THESIS

for

Ph. D.

CARDIOVASCULAR DISEASE IN FREELIVING WILD ANIMALS WITH PARTICULAR REFERENCE TO THE AFRICAN ELEPHANT (*Loxodonta africana*)

by

Sylvia K. Sikes

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VOL. I

ABSTRACT

CARDIOVASCULAR DISEASE IN FREELIVING WILD ANIMALS WITH PARTICULAR REFERENCE TO THE AFRICAN ELEPHANT (*Loxodonta africana*)

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(Thesis: Ph.D. Zoology)

A field survey to investigate the ecology of cardiovascular disease in freeliving wild animals is described. Its aim was i) to assess the susceptibility of such animals to arteriosclerosis, and particularly to atherosclerosis; ii) to examine in greater detail the ecology of cardiovascular disease in a single, naturally-susceptible species in relation to dietary change and stress in naturally occurring situations.

A total of 201 specimens, representing ~~46~~ 43 species of mammals and 25 of birds, was examined: 37 species of mammals had uncomplicated lipid deposits in the arterial intima, thought to represent a normal physiological occurrence; 13 had atheroma-like lesions of the intima; 20 species of birds showed positive lipidosis. These findings, compared with those reported in taxonomically equivalent groups of captive animals, are discussed.

The African elephant was selected for special study, The ecology of its cardiovascular disease patterns was studied in three different habitat types: one 'natural' (the 'control'), and two degenerate ('stressed'). Atherosclerosis and medial sclerosis were found not to occur in the 'natural' habitat type, but to be directly correlated

with habitat degeneration in the other two 'stressed' ranges, where 'stress' factors included excessive exposure to sunlight, dietary changes, frustration of the migratory habit, disrupted calving patterns, and over-population. Neither disease was found to be directly related to age, and each had a distinct intra-arterial development pattern: the aetiology of each is therefore thought to be basically independent, although in advanced cases interaction may occur.

Incidental results of the survey include: i) observations on the importance of relating the functional anatomy of the arterial supportive thickenings at ostia, bifurcation and regions of mechanical strain to the normal intra-aortic distribution of uncomplicated intimal lipid deposits; ii) observations on a valve-like structure in the aorta of the klipspringer; and iii) the formulation of a new field technique for assessing relative age in the African elephant.

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INTRODUCTION

This thesis constitutes an account of the investigations and results of a pilot survey, carried out under the auspices of the Pathology Department, Nuffield Institute of Comparative Medicine, The Zoological Society of London, and sponsored by the British Heart Foundation, as a contributory part of a much wider research programme on human atheroma. The generous financial support and encouragement given by the British Heart Foundation are gratefully acknowledged.

Background to the survey

Interest in the occurrence of atherosclerosis in wild animals captive in zoological gardens was aroused by the publications of Fox (1933; 1939) and Ratcliffe & Cronin (1958). Comparable occurrences of arterial disease were observed by the Pathologist at the Gardens of the Zoological Society of London and described in his annual reports to the Society (Fiennes 1959/1964).

The co-operation of members of the medical profession in extending these investigations on a comparative basis was therefore invited. The material examined consisted almost exclusively of routine autopsy cases passing through the Department of Pathology, Zoological Society of London. The findings of these extended studies have been fully described (Rigg, Finlayson et al. 1960; Symons & Fiennes 1962; Finlayson 1965; Fiennes 1965).

The classification and enumeration of the arterial lesions found, and elucidation of their pathogenesis, in relation to factors operating in conditions prevailing in Zoos and experimental laboratories alone was, however, seen to be inadequate. The need for a field 'control' survey, primarily ecological in character, was recognised, and the British Heart Foundation agreed to sponsor and finance it. I had the privilege of being appointed to carry out this field survey over the period from 1963 to 1966 (subsequently extended to 1967)*.

It has not been possible in the time available to complete detailed investigations on all the aspects of the material collected (e.g. other pathological findings; nutritional factors; blood serum analyses), for which the collaboration of specialists in other fields is necessary.

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*(I am indebted to the British Heart Foundation, and Royal Holloway College, University of London, who have kindly permitted me to make this survey the subject of this thesis.)

Provision has, however, been made by the Sponsors of the project to ensure the early completion of these investigations.

The field survey was thus launched in October 1963. I made the following 4 hypotheses the working basis of my study. The soundness of this decision is discussed further in Vol.II, pp 555 - 572.

i) Hypothesis

Since it appears that only a few genera of the vertebrates so far examined in captivity are susceptible to true atheroma, while some are resistant to it in conditions other than experimental, and in others the susceptibility line cuts through the group, susceptibility may be dependent upon some factor operating within the species.

Field test required:

To what extent and in what conditions in nature does arteriosclerosis, and in particularly atheroma, occur in freeliving wild animals, and is it confined to the same groups of susceptible animals as in captivity?

ii) Hypothesis

In view of i) above, while it appears that some naturally frugivorous or omnivorous groups (e.g. Psittacidae, Suidae) are resistant to atheroma, other members of these groups, naturally graminivorous or (experimentally) secondarily fed a ~~graminivorous~~ diet of seed or grain, are atheroma-susceptible.

Field test required:

Can a naturally-occurring situation be found where a freeliving wild species, normally omnivorous or frugivorous, has become secondarily graminivorous and if so, can any nutritional relationship be found between the occurrence of arteriosclerotic lesions and the change of dietary habit?

iii) Hypothesis

It appears that:

a) animals susceptible to atheroma are those which under natural conditions would have an especially large intake of vitamin C in fruits or shoots, but are secondarily deprived of it;

b) all those (Man and the sub-human Primates, guinea-pig, poultry), known to be unable to synthesise vitamin C, are among the susceptible groups;

c) none of the resistant species is known to require vitamin C in the diet;

d) the development of atherosclerosis is associated with hypercholesterolaemia, and blood cholesterol levels can be lowered by the addition of certain of the unsaturated fatty acids to the diet;

e) the organ responsible for the metabolism of the unsaturated fatty acids is the adrenal, and that this gland requires vitamin C for the purpose (Ratcliffe & Cronin 1958);

f) the increasing popularity of the empirical feeding of sprouted grains for captive and experimental rodents and some species of birds is due to its beneficial properties, supposedly deriving from the vitamin contents which are high in germinating seeds;

g) the vitamin C requirements of different groups of mammals and birds need re-appraisal, the essential fatty acid/ascorbutic properties of a diet being <u>per se</u> an insufficient criterion; the progress of the physiological condition of 'fatty streaking' to a pathological condition may reasonably be supposed to be associated with a change from a high vitamin diet (fruit, roots, shoots) to one of seeds or grains low in these nutritional components, and possibly antagonistic to them.

Field test required:

Can any naturally-occurring ecological situation be found, suggesting a possible vitamin-arteriosclerosis relationship?

iv) Hypothesis

When wild animals are over-crowded in an abnormally restricted territory and subjected to conditions inducing disrupted inter- and intra-specific behaviour responses, they show signs of stress having the effect of limiting the population and reducing longevity (Ratcliffe & Cronin 1958; Fiennes 1963).

Field test required:

Can any naturally-occurring situation be found where a stressed population of a single species can be compared with a non-stressed population? If so, is any relationship indicated there between stress factors and the occurrence of arteriosclerosis?

After briefing in specialised techniques at the Department of Pathology of the Zoological Society of London, University College Hospital Medical School, London, and the Royal Veterinary College, London,* I went to East Africa for the first stage of the programme.

In this phase, I was to collect cardiovascular material from elderly specimens, of known ecological status, of as wide a range of avian and mammalian species as possible. While doing so, I was to try to find a suitable species occurring in suitably contrasted habitats, which, with due regard to existing law and practice relative to conservation principles, could subsequently become the subject of more intensive study. My abridged report, read on my return from the first phase of the survey at the Meeting of the Nuffield Institute Cardiovascular Research Committee, on 7th October 1964, is appended (Appendix 2).

The survey then moved into its second phase, with the Cardiovascular Committee's extended authorisation and finance, as follows:-

A. to obtain additional aged specimens of species shown previously in Zoos to be atheroma-prone;

*(the help given by members of each of these departments is gratefully acknowledged).

B. to obtain more material from large mammals, especially buffalo and hippopotamus, in which other workers had recently claimed to have demonstrated atherosclerosis of the same type as occurs so commonly in Man; and

C. to pursue the comparative study of elephant arteries from good and bad habitats. A more detailed minute recorded by the Committee on this subject, and quoted here by permission, was as follows:

"Arterial Disease of Elephants. Miss Sikes' negative findings were of great value to the study in hand. Her most exciting positive finding was the arterial lesions in the aortae of elephants in the Murchison Park area, whereas a single aged specimen taken in the Aberdare Mountains was negative. The elephants in the Murchison area are overpopulated; their natural food (tree products) no longer exists there, and they subsist on grass and are in poor condition. Though protected from hunting, their migration and escape routes are largely blocked, and the whole population is overcrowded and stressed. In the Aberdare mountains, though hunted, the elephants have a wide choice of natural diets, are not overcrowded, and their migration routes are still open to them.

The further comparative study of arteries in elephants in good and bad habitats was considered to be urgently necessary."

The African elephant was thus selected as the species for more intensive ecological investigation in relation to its cardiovascular pathology.

A. Procedures

Within the limits of time and finance available, these extended terms of reference were met during the second phase of the survey, November 1964 - August 1965, the period from September 1965 to the present (1967) having been spent on laboratory investigations and analyses of the data and material collected in East Africa.

The evaluation procedures followed during this project fall naturally into two parts and are as follows:-

PART I: GENERAL SURVEY OF CARDIOVASCULAR DISEASE IN FREELIVING WILD EAST AFRICAN MAMMALS AND BIRDS

1. Rough estimation of relative age (dentition, size, appearance, status, etc.)
2. Macroscopic examination of hearts and aortae.

Sudan IV for aortae.

3. Frozen and paraffin sections of arterial lesions, and identification.

4. Identification of internal parasites.

5. Serum analysis.

6. Other traumatic, congenital and pathological conditions and relevance to cardiovascular disease found.

PART II: THE ECOLOGY OF CARDIOVASCULAR DISEASE IN FREELIVING WILD ELEPHANTS IN EAST AFRICA

A. Field studies and collection of data

The living elephant and its ecological background	Post-mortem studies
1. Normal appearance in life	— body measurements
2. Age estimation in life	--- ageing: dentition and eye-lens weights
3. Signs of disease in life	--- pathological conditions found
4. Nutrition: photos and identification of food plants	--- contents of stomach, caecum and rectum
5. Injuries	--- traumatic conditions found
6. Parasites	--- identification
7. Migrations and social structure of elephant communities	--- sexual status
8. Possible stress factors: confinement to Parks, over-population, food shortage, over-exposure to sunlight, altitude changes etc.	--search for any factors which might be correlated with cardiovascular disease

B. <u>Laboratory assessment of materials</u>

1. Ageing

2. Macro-examination of aortae
   i) Sudan IV + photography: lipid distribution
   ii) X-ray photography: Calcium distribution

3. Micro-examination
   i) Paraffin sections
   ii) Frozen sections: heart, arteries and other tissues

4. Normal and abnormal development and structure of heart and aorta

5. Environmental factors

6. Attempted assessment of effects of relevant factors: nutrition, stress etc.

Since this survey is primarily a pilot study on the <u>ecology</u> of atherosclerosis in nature, it is appropriate, even in the case of the African elephant, to regard the more detailed elucidation of the arterial histochemistry and histopathology as the prerogative of specialists in the disciplines of biochemistry and pathology. Frozen material, in quantities adequate also for statistical treatment, will no doubt shortly become readily available for this type of investigation, as well as for electron microscopy, from the extensive 'game cropping' schemes, which came into operation in East Africa in the latter part of 1965.

Valuable as such work will be, however, the National Parks, where these 'game cropping' schemes are operated, cannot be regarded as normal 'wild' habitats but rather as 'semi-artificial' (McDiarmid 1962). Consequently, material collected from them is likely to approximate more closely to that of captive animals rather than of genuinely 'wild' animals, freeliving in an unchanged truly natural habitat.

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PART I

GENERAL SURVEY OF CARDIOVASCULAR DISEASE IN FREELIVING WILD EAST AFRICAN MAMMALS AND BIRDS

Chapter 1

Definitions, and review of comparative studies in cardiovascular disease

The rapidly increasing volume of research into all aspects of human atherosclerosis has resulted in the production of vast amounts of information and literature on the subject. This is often derived from diverse and highly specialised associated disciplines. The Veterinary Public Health Unit of the World Health Organisation provides an up-to-date bibliography of comparative atherosclerosis research, and relevant comprehensive bibliographies are available in recent monographs (Branwood 1963; Jones 1963; Sandler and Bourne 1963; Chalmers and Gresham 1964; Finlayson 1965; Roberts and Strauss 1965), while current research publications with full bibliographies specifically concerned with atherosclerosis and related subjects are available in the Journal of Atherosclerosis Research, Amsterdam. Since the present study, however, is primarily ecological in character, focus has been restricted to directly relevant literature and definitions.

Although the terms of reference in this survey were primarily intended for an investigation of the occurrence of atherosclerosis in freeliving wild animals, the use of this term is by no means uniform among all investigators.

Finlayson (1965), writing from the viewpoint of human medical pathology, stated inter alia: "The terminology of arterial disorders is both confusing and confused. The term 'arteriosclerosis' which customarily includes atherosclerosis, medial calcification and other morphological lesions, conveniently envelops our ignorance of aetiology and pathogenesis.... A number of vascular lesions in animals defy ready classification, but until more is known about their aetiology, it would seen inadvisable either to fashion new names or to cast them into the lumber-room of arteriosclerosis." Dahme (1962) wrote: "The arterioscleroses which occur spontaneously in various animals are not uniform, either in nature, intensity or distribution in the arteries. They show moreover within a single animal species characteristic variations and are only partially comparable with human arteriosclerosis."

In the most comprehensive and authoritative recent work on comparative atherosclerosis, to which 56 authors currently engaged in research on atheroscleroses contributed, MacMillan (1965) summed up the difficulty as follows:" The term 'atherosclerosis' is commonly used to connote lesions that contain lipid in easily identifiable amount. Most of the lesions that have been described here are arteriosclerotic, some medial, some intimal, and some correctly subclassified as atherosclerotic. It must be emphasised forcefully that our definitions of 'arteriosclerosis' are still descriptive. While we may regret that we have not advanced beyond the descriptive definitions offered by the American Society for the Study of Arteriosclerosis, or the World Health Organisation, nevertheless we have not."

French (1964) regarded 'arteriosclerosis' as a 'generic' term and included within it three main types of sclerotic arterial disease clearly distinguished in Man:

(i) diffuse hyperplastic sclerosis of the small arteries ('arteriosclerosis' in American medical terminology, Anon.);

(ii) medial or Mönkeberg's sclerosis of the muscular arteries,

(iii) atherosclerosis, a disease affecting the intima of the aorta and larger distributing arteries, and taking the form of focal thickenings or plaques of fibrous and fatty material. The word 'atheroma' refers to an advanced atherosclerotic lesion in which the fatty element predominates.

The definition of atherosclerosis internationally accepted is that of the World Health Organization (1958), a definition also adopted by the Journal of Atherosclerosis Research to define its basis and scope, when it was founded in 1961 (Anon.1961):-

"Atherosclerosis is a variable combination of changes of the intima of arteries (as distinct from arterioles) consisting of the focal accumulation of lipids, complex carbohydrates, blood and blood products, fibrous tissue and Calcium deposits, and associated with medial changes".

Since such a clear distinction is made between at least three distinct types of arteriosclerotic disease in Man, and these again are rigidly distinguished from arteritides caused by infective and inflammatory agents, it is most surprising to find Lindsay & Chaikoff (1963) and Finlayson(1965) concluding that they should use the terms 'arterio-sclerosis' and 'atherosclerosis' synonymously.

In this thesis, the terminology, summarised above, defined by French (1964) with the definition of the World Health Organization (1958), will be followed, the term 'arteriosclerosis' being used in a 'generic' sense, and 'atherosclerosis' specifically, a distinction being drawn between the occurrences in wild animals which resemble this human disease, and the other types of lesions found. This seems to the author to be the only possible approach to fundamental research in comparative atherosclerosis, if it is to make any real and meaningful contribution to the ultimate elucidation of the pathogenesis of human athero-sclerosis.

Many investigators agree that there is good warrant for regarding certain types of lesion occurring in sub-human vertebrates as 'similar' or even 'identical' to atheromatous lesions in Man. For example, Lindsay & Chaikoff (1963) declared boldly that "the basic pathogenesis of naturally occurring arteriosclerosis (sic) in various mammalian orders is identical with that of the disease in the human being. In the human coronary artery (Moon &

Rinehart 1952) and aorta (Taylor 1953) elastic degeneration, mucoid deposition, and fibrosis appear to antedate lipid deposition. In animal species, degenerative lesions and fibrosis also predominate, and lipid accumulation is clearly a secondary phenomenon. It seems highly unlikely that the pathogenesis of arteriosclerosis in the human being should differ significantly from that in other species .... in avian species, the two forms of arteriosclerosis, the primary lipid lesion, and the primary fibrous lesion, have not always been clearly differentiated.... The fibrous lesion in birds, occurring in the abdominal aorta, does, however, clearly resemble the human lesion, particularly when the former is complicated by lipid deposition resulting from cholesterol feeding and diethylstilbestrol injections."

Dahme (1962) wrote: "The typical development in the human arterial wall of atheromatosis and atherosclerosis accompanied by cholesterol deposition plays a subordinate role in other mammals, whereas the arterial alterations in many birds resemble fairly closely the known phenomenon in Man. A number of factors are to be taken into account in connection with the occurrence of the sclerotic changes, e.g. age, disturbances of lipid and electrolyte metabolism, alimentary, genetic and hormonal influences, and, not least, strains on the circulatory system caused by increase in blood pressure."

Gresham & Howard (1963) commented: "The early atherosclerotic lesion of man is described and compared with that seen in naturally occurring disease in animals and in the experimental animal. A prototype lesion composed of collagen, elastin, mucopolysaccharide and some lipid is common to all and suggests that the early atherosclerotic lesion in man and animals begins as a repair to injury the cause of which is unknown."

Throughout this project, although its immediate objective was to make field investigations on the basis of the hypotheses listed (see Introduction, pp 7 - 10), its underlying raison d'être within the wider programme sponsored by the British Heart Foundation was constantly kept in mind, namely its relevance to the aetiology and pathogenesis of human atherosclerosis.

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Chapter 2

Materials and Methods

Search for suitable survey areas

It was determined by the sponsors of the survey that field activity should take place in East Africa, but that I should be free to search for suitable areas and seize available opportunities. My own previous experience of African large-mammal ecology and big-game hunting in East Africa would serve as the basis of this exercise.

Equipment

Although the project was generously financed, fieldwork and equipment would have to be limited accordingly. Enquiries and calculations made in East Africa on arrival led to the decision to purchase rather than to borrow or hire all basic equipment (landrover, tents, guns etc.).

Assistants

I also decided to employ and train a nucleus of two or three African Field Assistants on 'safari contract' terms, rather than finding temporary helpers on secondment from government departments. After a preliminary period of about three months with temporary employees, I was able to engage men previously known to me to form the nucleus of a reliable and loyal team.

In the second phase of the survey, when concentrating on elephant, buffalo and hippopotamus, the regular team consisted of eight members, of whom Charai Kamara (base-camp foreman) of the Agikuyu tribe, and Mutarimbo Ndete (gun bearer and field foreman) of the Wandorobo tribe were outstanding. Additional local 'hands' were engaged when required. I was also fortunate in having the temporary, voluntary general assistance, in the second phase of the fieldwork, of Miss E.V. Bernuth, whose knowledge and experience of hunting, combined with secretarial and hospital training, were invaluable.

It was also necessary in the latter phase to purchase a second landrover and tent, in order to accommodate and transport the additional field personnel, as well as the bulky autopsy material from the elephants. The British Heart Foundation generously gave an additional grant for the capital outlay and the running of this second vehicle; and the additional expenses resulting from employment of a larger field team were partly offset by the proceeds from the sale of ivory, kindly permitted latterly by the Game Department of Kenya.

Field procedure (animals other than elephant)

Two brief pilot safaris were run within two weeks of my arrival in Kenya, to test the adequacy of the equipment, to establish a routine procedure, and to train the assistants. The first of these dealt with four mammals only, and the second with seven birds. As a result of these two test trips, I was able to improve on my original design of special fittings in the land-rover, obtain essential equipment previously overlooked, and test the guns and the effect of different types of bullets and their positioning in the animal's body. (see ch. 5).

The field procedure established (varied slightly on future occasions, according to any peculiar circumstances) was as follows:-

1. Collection of specimens

On arrival in the area, contact was first established with local chiefs and native hunters, to ensure good relations and to select a suitable base-camp site. Then, immediately following the setting up of the camp (including preparation of the formol-saline storage drums), I drove around the area with the gun-bearer and a native hunter to ascertain the availability and accessibility of the specimens we expected to collect.

Every subsequent morning, the field team rose before daybreak and, accompanied by one local hunter, we drove to the previously selected part of the area, arriving there at dawn. It was frequently possible to obtain between one and three large specimens in time to complete the autopsies by late afternoon. If later on, another animal was available of a desired species, for which a permit was held, and time permitted completion of a further autopsy before nightfall when scavengers might interfere with the carcass, the additional animal was shot and routine autopsy performed. Very small specimens were usually taken back to the base-camp where, even at night, autopsy was possible by the light of a pressure lamp or a vehicle inspection lamp.

I refrained from shooting any animal on which we could not guarantee to perform a comprehensive autopsy in the time available before decomposition of the arterial intima would begin, or which was in such a position that I could not be reasonably sure of making a non-wounding, killing shot. The reasons for this were both practical (as it was important not to put the animal under the stress of wounding if the survey was to be carried out according to the terms of reference) and humanitarian (as it is my personal conviction that the method of collecting wild animals for any purpose should be humane).

2. Large specimens: mammals

i) The carcass was photographed.

ii) An attempt was made to collect serum (see ch. 5), and blood ~~serum was~~ smears were taken.

iii) One or both eye lenses were removed as follows: the eyeball was released from the socket, a short incision made along ~~the~~ its equator, penetrating the vitreous body, and the lens squeezed out (by applying gentle pressure on the opposite side of the eyeball) through the incision, into a specimen tube containing Richardson's Fluid. (Richardson, 1960).

iv) The following measurements were taken:

a) total length, measured by means of a steel tape measure pulled taut between two sticks or pipes placed vertically at the anterior tip of the ~~head~~ muzzle (extended forward) and the extreme end of the tail dock extended backward;

b) Girth: measured directly behind the elbows by means of a steel tape. Although some other workers were observed to measure the 'belly' of large mammals, I was unable to see any value in this, owing to its very rapid distension in the tropical heat.

c) Withers, or shoulder: this was measured as the straight length of a steel tape stretched from a pipe or rod, placed vertically against the withers as the carcass lay on its side (with the foreleg absolutely straight) to the outer edge of the hoof or paw held in its natural standing position. This measurement was chosen as being comparable to that used for living, captive animals.

d) Head length was measured along the curves from the tip of the snout along the sagittal line to the most posterior point of the head (usually the occipital bone); neck and back were always measured together by running the steel tape along the curves from the most posterior point of the head dorsally to the base of the tail dock.

e) Tail length: from the base of the dock (where the first caudal vertebra could be identified by moving the tail dorso-ventrally) to the end of the dock.

f) Foreleg: elbow to outer edge of hoof or paw, held in the natural, standing position.

g) Hindleg : stifle to edge of sole, with the hoof or paw held in the standing position.

h) Head width: the greatest width of the head (excluding horns and tusks) as found by using two flat boards placed against each side of the head, and measuring the distance between them.

i) Ear: length from tip to ~~intertragic notch.~~ tragus.

j) Horns: the measurements used were those described in Rowland Ward's Records of Big Game (Ward 1962).

v) Samples of ectoparasites were collected, and notes made of scars, injuries and external abnormalities.

vi) The carcass was weighed. In all cases, except buffalo, rhino, hippo, giraffe and large eland, the carcass was weighed intact. The tripod and scale used for weighing are described elsewhere (Sikes 1966 , appendix No. 6).

vii) The carcass was skinned. In certain cases, e.g. lion, oryx, zebra, the skins were required by the Game Department as a quid pro quo for the scientific collecting licence. In these cases the skins were salted down in accordance with hunting practice. Due to the abundance of ecto-parasites it was advantageous to remove the skin first, whenever possible, except in the case of hippo and warthog where skinning is tedious and difficult.

viii) Autopsy was performed with the carcass lying on its right side.

a) A portion of the carotid artery and the thyroid were removed from the neck and temporarily placed in water or saline. The head was removed and the mandible disarticulated. The tongue, nostrils, teeth, and anterior portions of the oesophagus and trachea were examined. The skull and mandible were cleared of flesh, and the skull sawn open for removal of the brain and pituitary, labelled and stored for subsequent maceration.

b) The entire left wall of the thorax and abdomen was removed, each rib being neatly severed near the vertebral column with an axe or machete.

c) All the viscera were eased away from the aorta, which could now be fully exposed <u>in situ</u> from the heart to the bifurcation. It was then freed from the carcass, severed from the heart at a point just near the scar of the <u>ductus arteriosus</u> and removed with attached portions of the coeliac, and ~~superior~~ anterior mesenteric arteries; one renal artery complete with kidney attached; and portions of the spermatic/ovarian, common iliac, and caudal arteries.

Particular care was taken never to stretch or squeeze the aorta, or in fact any portions of arteries, either during excision or during subsequent treatment. The aorta was gently placed in a bucket of clean water or saline. The pericardium was examined and then cleared away, and the heart removed from the carcass. It was cleared of extraneous tissue, rinsed free of clotted blood with water, internally and externally, photographed, weighed and kept in water or saline for further treatment.

The following organs were then examined, removed, weighed and either preserved intact, or else discarded after removing slips of tissue for histology:

lung; liver; spleen; kidney; adrenal gland; ovary/testis; mammary gland, uterus, foetus, placenta; pancreas; baculum; brain, pituitary, thyroid (previously extracted from head and neck).

About a handful each, taken at random, of stomach, caecal and rectal contents was collected and preserved in formalin in polythene bags.

d) Portions of the brachial and femoral arteries were removed and placed in water or saline.

e) The aorta was cleared of extraneous connective tissue, rinsed, and slit open along the mid-ventral line. If longer than 10 inches, it was then cut into convenient portions, each 8 - 10 inches long. Each portion was mounted, tunica intima upwards, on a polythene board, 12 x 9 inches in size, by means of staples. The whole was rinsed, examined and photographed. Slips of tissue, about 3 mm thick, were cut from portions suspected of being atheromatous and preserved in Richardson's Fluid for subsequent histological examination. The mounts were labelled, and each board put into a protective perforated polythene bag, and the whole dropped into a plastic bucket of 10% formol-saline. The portions of all other arteries collected were treated in the same way.

f) The heart was then examined. A single continuous incision was made, running through the right atrium, tricuspid valve, right ventricle, and pulmonary arch, and a similar direct one through the left atrium, mitral valve, left ventricle, and aortic valve and arch. Coronary arteries were exposed and slit longitudinally for *in situ* examination, and samples removed for mounting as described above. In a number of cases, only the portion of the heart containing the aortic valve, openings of the coronary arteries, and the aortic arch, was preserved.

g) If not too distant from the base camp, the carcass was revisited later to examine it, after the vultures had cleaned it, for bone abnormalities - a procedure well rewarded in the cases of two lions, M.39 and M.57 (see ch.7).

ix) After the return to camp:

a) The mounted arteries were stacked (standing on one edge)in one large bin of formol-saline, the hearts in another, and other organs in a third.

b) Blood serum was frozen down with dry ice, prepared by means of the 'carboneige' attachment to the Carbon dioxide siphon-fitted cylinder.

c) Skulls and mandibles were boiled in net bags over the open camp fire.

d) The full histology tissue bottles were stored, and replaced in the processing box by fresh ones.

e) Guns, processing boxes, cameras and vehicles were cleaned, checked and re-stocked for the following day.

f) Data sheets were checked, and the log written.

3. Small specimens: mammals

Procedure was identical with that of large mammals, except that:

i) generally the carcass could be transported (after measurement and serum collection) in the landrover until several had been collected, and then the autopsies could all be performed at one convenient site; and

ii) in the case of primates, autopsy was usually ~~done~~ performed with the carcass lying on its back.

4. Birds

A number of birds was usually collected in a group and transported to a convenient site. Ostriches, which had first to be skinned out and autopsy performed at the site of killing, were the only exception. Autopsy on birds was always performed from the ventral aspect and differed little in general procedure from that followed for primates.

5. Field data

All field data were recorded during the autopsy on printed field sheets (Appendix 1).

6. Laboratory procedure

i) Serum (see ch. 5).

ii) Lenses (Sikes 1966 b, p.292 & Table I).

iii) Parasites (see ch. 4).

iv) Arteries (including coronary arteries):

a) Gross staining with Sudan IV (Holman's method).

b) Radiography of mounted portions of aortae (very large mammals only) (see ch. 8).

c) Paraffin sections.

d) Frozen sections.

e) Micrography.

v) Hearts:

a) Gross staining with Sudan IV (Holman's method).

b) Histology of coronary arteries and portions of the myocardium.

vi) Other tissues and organs.

All the tissue slips collected for histological examination have been either paraffin-embedded and sectioned, one of each stained with haematoxylin and eosin, and another with Verhoeff and van Gieson's stain, or frozen and sectioned. In cases of special lesions (e.g. mineral deposits, parasites) other specialised stains have been applied, such as Von Kossa's, Giemsa, Gurr's, N.R.G., Alcian blue and Masson's trichrome.

These slides form a reference collection from which to assess the general health and normality of the animal and, in cases where arterial abnormality was found, to see if any connection could be found between the arterial condition and any other traumatic, congenital, or pathological condition.

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PLATE I

(a)

(b)

(c)

Chapter 3

Ecological Background: Age and Status

Ecological background

The animals (other than elephants) examined in this survey, were collected from a variety of habitat types and localities. FIG.I shows the whole area covered. The habitat types and localities are indicated on the map by arrows and include the following:-

I. Low* Uganda grasslands: (or degenerate savannah woodland) well watered and dominated nowadays by Hyparrhenia grasses, but actually representing degenerat woodland, containing only a few relict trees and very small forest stands, indicative of a former heavily wooded area, dominated by the genera Vitex, Terminalia, Combretum, Ficus etc.; altitude 2,000 - 5,000 feet. Mean annual rainfall 100 - 125 cm.

i) Environs of Lolim, Northern Uganda, in the game reserve known as 'the Elephant Sanctuary', which is adjacent to the Murchison Falls National Park. Game partially protected from hunting.

ii) Murchison Falls National Park, south of the Nile.

iii) Semliki plains, just south of Lake Albert.

* 'Low'; 'High' refer in ch. 3 and ch. 9 to altitude of terrain, not height of vegetational cover when used to describe habitat type. (Davidson, 1964)

iv) Queen Elizabeth National Park, lowland areas.

v) Chambura controlled hunting zone: a transitional area adjacent to montane forests.

II. Low* scrubland, Kenya: (degenerate arid savannah woodland)

predominantly degenerate Commiphora-Acacia mixed scrubland, overlying a Precambrian Basement Complex occurring in the Eastern Drainage zone of Kenya (Sikes 1934). Erratic rainfall, and surface water scarce and localised. Altitude 500 to 5,000 feet. Mean annual rainfall between 25 and 75 cm only.

i) Tsavo National Park (East) and environs, Kenya.

III. High* scrubland, Kenya:

this habitat type has a richer vegetational cover than the low scrubland, which derives directly from the different type of soil, in this case the weathered plateau lavas within, and flanking, the Rift Valley. The area contains a greater proportion of all-season springs, seepages and streams than the low scrubland, and the mean annual rainfall lies between 45 and 100 cm. Altitude 5,000 to 9,000 feet. These areas are grazed irregularly by large herds of Masai and cross-bred cattle, donkeys, goats and sheep (Malloiy and Heady, 1965)

i) Kajiado District, Kenya

ii) Kedong Valley, Kenya.

IV. High* ranchland:

these areas resemble those of III. (above), but lie in the areas formerly known as the 'White Highlands' of Kenya and are characteristically fenced and grazed by imported and cross-bred live-stock, operated on European-type management systems, i.e. with regular dipping or spraying, culling, pasture management, and the installation of watering troughs with piped water. In most of these ranchlands, game culling has been rigorously applied, and wild animals nowadays occur in comparatively small numbers. Rainfall and altitude as in III. (above).

i) Naivasha District: Osirian and Ndabibi Ranches.

ii) Naivasha District: Lake Naivasha (birds only).

V. Montane:

montane massifs, lying above 5,000 feet altitude, and in some cases rising to 10,000 feet, carrying thick, indigenous, mixed forest, bamboo forest and montane moorlands. Mean annual rainfall exceeds 150 cm.

i) Slopes of Ruwenzori Mountains, Uganda.

ii) Slopes of Mts. Kenya, Kinangop and Satima, Kenya.

iii) Slopes and foothills of Mt. Kilimanjaro (northern) Kenya.

VI. <u>Montane/Grassland</u>:

(transitional), valley forests of foothills of montane massifs.

i) Ruwenzori - Semliki.

ii) Kigezi Reserve, Maramagambo Forest, south-east of Queen Elizabeth Park, Uganda.

In this choice of habitat types, factors which might be expected to be important are: available surface water and its chemical composition at different seasons; available sources of mineral in licks and vegetation; vegetational cover and its value as fodder for herbivorous animals, shade, cover during breeding seasons; security from predators and freedom for migration; parasite populations; presence or absence of domestic stock and the type of management followed (relative to transmissible diseases, parasites and competitive demands on the pasture); degree of disturbance by man.

In general, however, inadequate numbers of specimens representative of each species (with the exception of the elephants) were collected to evaluate any of the above factors, except for the parasites, the importance of which in this context is indicated in ch. 4.

Age and status

The actual number of animals of each species allowed in the permits, generously granted by the game departments of Kenya and Uganda, was somewhat limited, and therefore mature elderly animals of both sexes were preferred when selecting for examination. It was supposed that the incidence of arterial disorders in wild animals would probably be greater in older and more mature specimens than in younger animals, if the species were susceptible at all.

The question of how to assess the age of a given wild animal on the hoof, of any of the wide range of species likely to be encountered, posed special problems, not least of which was the paucity of reliable field-recognition criteria. Among the many ageing criteria discussed by Cowdry (1939) the following may be relevant as visual citeria applicable to wild mammals: loss of elasticity and the withdrawal of fat produces recognisable skin wrinkling; the atrophy of hair papillae may produce hair colour changes, especially greying; epidermal atrophy may produce hoof, claw or nail distrophy; changes in the endocrine system may result in hyperpigmentation, and hyperplasia of the epidermis may cause senile keratosis.

Among criteria used by other workers, one may include for example horn growth as described by Brooks (1961) in Thomson's Gazelle and by Hediger (1966) in chamois, skin colour change in beavers (Patrick & Webb, 1960). Size is clearly an important feature especially during the developmental period. Unfortunately, few scientific workers have described reliable,visual age criteria for live animals, most having concentrated on those applicable post mortem, such as tooth eruption patterns, baculum length, eye-lens weight, and the development of epiphyses. After consideration of available literature, I was forced to the conclusion that too little reliable data was available to guide the collector visually in the field, and one's own experience would have to provide the only available criteria.

As a beginning, I compiled a list of maximum known life-spans in captive animals. (Anon. 1960; Flower 1931; Anon. 1961) and then carefully studied each ~~known-age~~ animal of known age at the gardens of the Zoological Society of London at Regent's Park and Whipsnade, in order to develop visual experience of as many captive animals of known age as possible, of those families and genera likely to be encountered in the course of the field work planned for East Africa.

Previous personal experience in field ecology, hunting and photography in East and West Africa was also valuable and appropriate, as was also experience of the show and market evaluation of farm and blood-stock on the hoof. It was clear, that a combination of this experience, plus a little intuition, would have to form the basis of selection for the study animals. Thus the criteria would include size, stance and conformation; skin colour, wrinkling and quality; condition of ears, muzzle and tail; presence and type of scars; social status (e.g. herd leader, lone male, cow with young); and finally size and wear of horns if present. (Anon. 1937; Hitchcock 1948; Codrington 1955; Miller & Robertson 1959; Williamson & Payne 1959; Saubidet 1943)

The differentiation of sex in the field is usually quite simple (except in smaller carnivores, and primates in thick forest), as most mature East African mammals possess dorsal secondary sex characters easily recognisable even in long grass. The relationship of the animal to other members of its group would also be a reliable criterion, as 'leaders' and 'rear-guard' animals in herds are generally larger and older members, and lone male animals of gregarious species are frequently found to be elderly.

At autopsy, it would be possible to make a more accurate estimate after measuring the carcass, examining the teeth (stage in eruption and wear) and assessing the sexual status.

In practice, the method of selection used was generally satisfactory, but, apart from the elephants for which more exact data were available (ch.10), it has not been possible to place the mammals collected into more than four rather arbitrary age groups, namely: foetus, juvenile (i.e. sexually immature); mature; and elderly or 'old, lone'.

The sexual and social status of the animal was important in assessing its relative age and physical fitness and activity. For example, specimen M.13 was a very elderly and rather inactive, lone buffalo and was seen at autopsy to differ considerably in size and condition from M.15, which was a very active, senior bull in a large herd of over 200 animals, sub-divided into groups of 30 - 40. M.43 was a greying, lone male reedbuck, which had adopted the protective company of a herd of kob, a habit frequently noticed also in the case of very elderly wildebeest, which will seek the protective company of a friendly herd of zebra rather than have to fend for themselves. M.64 was a very elderly bull eland, large and heavy in size, with heavy dewlap, and well-developed, but very worn horns, whose skin was the deep blue colour characteristic of elderly male eland. He associated with two other similar male elands. At autopsy, the teeth of all the above-mentioned specimens showed advanced molar wear, and there were tortuous, dark-coloured veins on heart and testes, as well as worn hooves and horns, and torn ears, all features commonly associated with advanced age.

In several cases, a pathological condition was associated with what appeared to be signs of premature old age. Examples of this were M. 31 (buffalo, see ch.7), M. 51 (oryx, see ch. 6) and M.124 (giraffe, see ch. 6).

No attempt has been made to assess the age of the birds collected, beyond noting if they were juvenile or mature.

Full details of all the animals collected (including elephants) with sex, age group assessment (based on a combination of visual assessment, social and sex status, and autopsy examination), habitat type, locality and date of collection are given in Tables 1 and 2 (Specimen Reference Lists) and Tables 3 and 4 (Species Lists).

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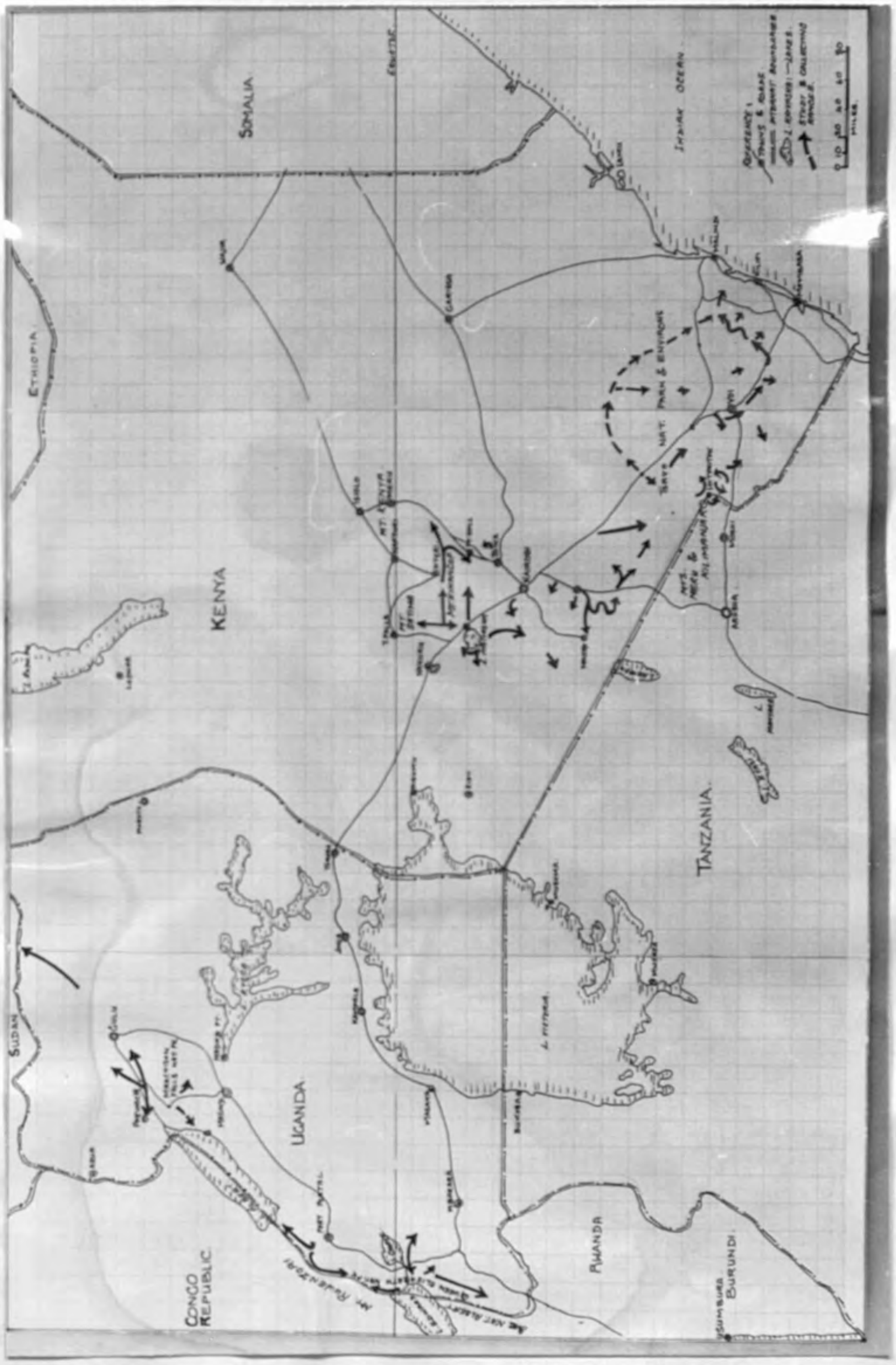
FIG 1



SKETCH MAP OF EAST AFRICA INDICATING COLLECTING & STUDY AREAS.

TABLE 1.

SPECIMEN REFERENCE LIST NO. 1: MAMMALS

No.	Species	Sex	Age	Locality	Date	Remarks
					1964	
M. 1	Impala	m	mat.	Kajiado	9.3.	
M. 2	Gazelle, Grant's	m	mat.	- do -	9.3.	
M. 3	Hartebeest, Coke's	m	mat.	- do -	10.3.	
M. 4	Zebra	m	mat.	- do -	10.3.	
M. 5*	Warthog	m	mat.	Q.E.Park	23.3.	
M. 6*	- do -	m	mat.	- do -	23.3.	
M. 7*	- do -	f	mat.	- do -	23.3.	
M. 8*	- do -	m	mat.	- do -	23.3.	
M. 9*	- do -	m	mat.	- do -	23.3.	
M.10*	- do -	f	mat.	- do -	23.3.	
M.11	Colobus	m	mat.	Lututuru	28.3.	
M.12	Bushbuck	m	mat.	- do -	28.3.	old
M.13	Buffalo	m	mat.	Lolim	2.4.	very old
M.14	Bushbuck	f	mat.	- do -	2.4.	
M.15	Buffalo	m	mat.	- do -	3.4.	
M.16	Oribi	f	mat.	- do -	4.4.	(ref. M.155)
M.17	Hartebeest, Jackson's	m	mat.	- do -	4.4.	
M.18*	Elephant	m	mat.	Murchison	14.4.	
M.19*	- do -	m	mat.	- do -	14.4.	
M.20	Civet	f	juv.	- do -	14.4.	
M.21*	Elephant	f	mat.	- do -	16.4.	
M.22*	- do -	f	mat.	- do -	16.4.	

TABLE 1 (cont.)

No.	Species	Sex	Age	Locality	Date	Remarks
					1964	
M.23*	Elephant	f	mat.	Murchison	16.4.	
M.24*	- do -	f	mat.	- do -	17.4.	
M.25*	- do -	f	mat.	- do -	17.4.	
M.26*	Hippo	f	mat.	Q.E.Park	24.4.	
M.27*	- do -	m	mat.	- do -	24.4.	
M.28*	- do -	f	mat.	- do -	24.4.	
M.29*	- do -	f	foet.	- do -	24.4.	
M.30	Buffalo	f	mat.	- do -	25.4.	
M.31	- do -	f	mat.	- do -	27.4.	
M.32	Kob	m	mat.	Semliki	2.5.	
M.33	Warthog	m	mat.	- do -	2.5.	
M.34	Kob	m	mat.	- do -	2.5.	
M.35	Kob	m	mat.	- do -	2.5.	
M.36	- do -	m	juv.	- do -	4.5.	
M.37	Hartebeest, Jackson's	f	mat.	- do -	5.5.	
M.38	- do -	f	mat.	- do -	5.5.	
M.39	Lion	m	juv.	- do -	7.5.	
M.40*	Hippo	m	mat.	Q.E.Park	8.5.	
M.41	Hyena,spotted	f	mat.	Semliki	11.5.	
M.42	- do -	m	mat.	- do -	11.5.	
M.43	Reedbuck	m	mat.	- do -	11.5.	
M.44	Vervet monkey	m	mat.	- do -	12.5.	
M.45	- do -	f	mat.	- do -	12.5.	
M.46	- do -	m	mat.	- do -	12.5.	
M.47	- do -	m	juv.	- do -	12.5.	

TABLE 1 (cont).

No.	Species	Sex	Age	Locality	Date	Remarks
					1964	
M.48	Jackal	f	mat.	Kajiado	11.6.	
M.49	Dikdik	m	mat.	- do -	12.6.	
M.50	Zebra	m	mat.	- do -	13.6.	
M.51	Oryx, Beisa	f	mat.	- do -	14.6.	
M.52	Jackal	f	mat.	- do -	14.6.	
M.53	Gerenuk	m	mat.	- do -	15.6.	
M.54	Giraffe	f	mat.	Dandora	17.6.	
M.55	Zebra	m	mat.	Kajiado	19.6.	
M.56	Lion	m	mat.	- do -	20.6.	
M.57	Lion	f	mat.	- do -	20.6.	v.old
M.58	Fox, bat-eared	m	mat.	- do -	23.6.	
M.59	Gazelle, Grants	m	mat.	- do -	24.6.	
M.60	Gerenuk	f	mat.	- do -	24.6.	
M.61	- do -	f	mat.	- do -	24.6.	
M.62	Jackal	m	mat.	- do -	25.6.	
M.63	Zebra	m	mat.	- do -	26.6.	v.old
M.64	Eland	m	mat.	- do -	28.6.	old
M.65	Serval	m	mat.	- do -	28.6.	
M.66	Oryx	m	mat.	- do -	29.6.	
M.67	Zebra	f	mat.	- do -	30.6.	
M.68	Genet	m	mat.	Ngong	4.7.	
M.69	Steinbok	m	mat.	Kedong	20.7.	
M.70	Zebra	f	mat.	- do -	20.7.	
M.71	Steinbok	m	mat.	Osirian	31.7.	
M.72	Hare	f	mat.	Ndabibi	31.7.	
M.73	Hyrax, Rock	m	mat.	- do -	1.8.	
M.74	- do -	f	mat.	- do -	1.8.	
M.75	- do -	m	mat.	- do -	1.8.	

TABLE 1 (cont.)

No.	Species	Sex	Age	Locality	Date	Remarks
					1964	
M.76	Spring hare	m	mat.	Ndabibi	3.8.	
M.77	Klipspringer	m	mat.	- do -	3.8.	
M.78	Reedbuck	f	mat.	Osirian	3.8.	
M.79	Serval	m	mat.	Ndabibi	4.8.	
M.80	Mongoose, whitetailed	f	mat.	- do -	4.8.	
M.81	Rodent mole	m	mat.	Osirian	4.8.	
M.82	Hyena, spotted	f	mat.	Senya	4.9.	v.old
M.83	Elephant	m	mat.	Kiambere	8.12.	
M.84	- do -	m	mat.	Lolim	24.12.	
M.85	- do -	m	mat.	- do -	24.12.	
M.86	- do -	m	mat.	- do -	28.12.	lopear
M.87	- do -	m	mat.	- do -	28.12.	truncated
					1965	
M.88	Elephant	f	mat.	Chambura	8.1.	gall-stones
M.89	Hippo	m	mat.	Kigezi Reserve	9.1.	
M.90	- do -	f	mat.	- do -	9.1.	
M.91	- do -	f	mat.	- do -	9.1.	
M.92	- do -	f	mat.	- do -	9.1.	
M.93	Elephant	m	mat.	- do -	12.1.	
M.94	Buffalo	m	mat.	- do -	14.1.	
M.95	- do -	m	mat.	- do -	14.1.	
M.96	- do -	m	mat.	- do -	14.1.	
M.97	- do -	m	mat.	- do -	15.1.	
M.98	Chimpanzee	m	mat.	- do -	16.1.	

TABLE 1. (cont.)

No.	Species	Sex	Age	Locality	Date	Remarks
					1965	
M.99	Elephant	m	mat.	Nyama-gasani	20.1.	
M.100	- do -	f	mat.	- do -	20.1.	
M.101	Colobus	m	mat.	Kigezi Reserve	23.1.	
M.102	Chimpanzee	f	mat.	- do -	24.1.	
M.103	Elephant	m	juv.	Kamae-Kyeni	11.2.	
M.104	Gazelle, Thomson's	m	mat.	Suswa	24.2.	
M.105	Jackal	f	mat.	- do -	25.2.	
M.106	Eland	f	mat.	- do -	25.2.	
M.107	Elephant	f	mat.	Coast Province	23.3.	senile
M.108	- do -	m	mat.	- do -	24.3.	
M.109	Wild dog	m	mat.	- do -	26.3.	
M.110	Elephant	m	mat.	- do -	1.4.	
M.111	Gerenuk	m	mat.	- do -	1.4.	
M.112	Elephant	f	mat.	- do -	2.4.	
M.113	- do -	m	juv.	- do -	2.4.	
M.114	- do -	f	calf	- do -	2.4	
M.115	Kudu	m	mat.	- do -	3.4.	
M.116	Elephant	m	mat.	- do -	6.4.	
M.117	- do -	m	mat.	- do -	6.4.	
M.118	- do -	m	mat.	- do -	9.4.	
M.119	- do -	m	mat.	- do -	9.4.	
M.120	- do -	m	mat.	- do -	12.4.	
M.121	- do -	m	mat.	- do -	12.4.	

TABLE 1 (cont)

No.	Species	Sex	Age	Locality	Date	Remarks
					1965	
M.122	Elephant	f	mat.	Coast Province	16.4.	
M.123	Wild Cat	m	mat.	- do -	24.4.	
M.124	Giraffe	f	mat.	Mbarasha	18.5.	
M.125	- do -	m	foet.	- do -	18.5.	
M.126	- do -	m	mat.	Kajiado	21.5.	
M.127	Elephant	f	mat.	Coast Province	5.6.	(ref. M.154)
M.128	Rhino	m	mat.	- do -	5.6.	
M.129	Eland	f	mat.	- do -	6.6.	
M.130	Fox, bat-eared	m	mat.	- do -	6.6.	
M.131	Elephant	f	mat.	- do -	6.6.	
M.132	- do -	m	mat.	Ol'Turesh	13.6.	
M.133	- do -	f	juv.	- do -	13.6.	
M.134	- do -	m	mat.	- do -	13.6.	
M.135	- do -	f	calf	- do -	13.6.	
M.136	Lion	f	mat.	- do -	17.6.	
M.137	- do -	f	mat.	- do -	17.6.	
M.138	- do -	m	mat.	- do -	18.6.	
M.139	Sykes monkey	f	mat.	Ngong	3.7.	
M.140	- do -	m	mat.	Ol'Turesh	14.7.	
M.141	Vervet monkey	f	mat.	- do -	14.7.	
M.142	Sykes monkey	m	mat.	- do -	14.7.	
M.143	Wild cat	m	mat.	- do -	14.7.	
M.144	Galago	f	mat.	- do -	14.7.	
M.145	Impala	m	mat.	- do -	14.7.	
M.146	Vervet monkey	m	mat.	- do -	18.7.	

TABLE 1 (cont.)

No.	Species	Sex	Age	Locality	Date	Remarks
					1965	
M.147	Lion	f	juv.	Makindu	20.7.	killed by a car
M.148	Hyena, striped	f	mat.	Ndi	23.7.	- do -
M.149	Elephant	m	mat.	Ndi	29.7.	
M.150	- do -	m	mat.	- do -	29.7.	
M.151	Aardwolf	f	mat.	- do -	2.8.	killed by a car
M.152	Elephant	m	mat.	Kinare	17.8. 1964	(original no. H.1)
M.153*	Rhino	m	mat.	---	1964	
M.154	Elephant	m	foet.	Coast Province	5.6. '65	(M.127A)
M.155	Oribi	m	foet.	Lolim	4.4. '64	(M.16A)

*(collected from cropping schemes or by other research teams; full supporting data not always available and basis of measurements sometimes differs)

TABLE 2.

SPECIMEN REFERENCE LIST NO. 2: BIRDS

No.	Species	Sex	Age	Locality	Date	Remarks
					1964	
B. 1	Pelican, white	f	mat.	Naivasha	29.2.	
B. 2	Cormorant, long-tailed	f	mat.	- do -	29.2	
B. 3	Heron, purple	m	mat.	- do -	29.2.	
B. 4	Cormorant, long-tailed	m	mat.	- do -	29.2.	
B. 5	Darter		mat.	- do -	29.2.	
B. 6	Buzzard, augur		mat.	- do -	1.3.	
B. 7	Eagle, tawny	f	mat.	Kajiado	9.3.	
B. 8	Vulture, hooded	f	mat.	Lolim	3.4.	
B. 9	Cormorant, white-necked	f	mat.	Semliki	4.5.	
B.10	Ibis, Hadeda	m	mat.	- do -	4.5.	
B.11	Cormorant, white-necked	f	mat.	- do -	4.5.	
B.12	- do -	f	mat.	- do -	4.5.	
B.13	Heron, purple	f	mat.	- do -	4.5.	
B.14	Heron, Squacco	f	mat.	- do -	4.5.	
B.15	Eagle, fish	f	mat.	- do -	4.5.	
B.16	Pelican	f	mat.	- do -	4.5.	
B.17	Darter	f	mat.	- do -	4.5.	
B.18	Vulture, white-backed	m	mat.	- do -	5.5.	
B.19	Vulture, hooded	m	mat.	- do -	5.5.	
B.20	Stork, saddlebill	f	mat.	- do -	11.5.	
B.21	Stork, woolly-necked	m	mat.	- do -	12.5.	
B.22	Hornbill, ground	m	mat.	- do -	13.5.	

TABLE 2. (cont)

No.	Species	Sex	Age	Locality	Date	Remarks
					1964	
B.23	Bustard, Kori	f	mat.	Kajiado	11.6.	(K.1)
B.24	Hornbill, red-billed	m	mat.	- do -	12.6.	(K.2)
B.25	Ostrich	m	mat.	- do -	15.6.	(K.3)
B.29	- do -	f	mat.	- do -	27.6.	
B.26	Bustard, Kori	m	mat.	Loita	14.12.	(K.4)
					1965	
B.27	Bustard, Kori	f	mat.	Suswa	23.2.	
B.28	Secretary Bird	f	mat.	- do -	24.2.	
B.30	Vulture, white	f	mat.	- do -	24.2.	
B.31	Bustard, Kori	f	mat.	- do -	24.2	
B.32	- do -	f	mat.	- do -	24.2.	
B.33	Parrot, red-headed	f	mat.	Kamae	2.3.	
B.34	- do -	m	mat.	- do -	2.3.	
B.35	Touraco, Hartlaub's	m	mat.	- do -	2.3.	
B.36	Vulture, white-headed	f	mat.	Coast Province	22.4.	
B.37	- do -	m	mat.	- do -	22.4.	
B.38	Vulture, hooded	m	mat.	- do -	22.4.	
B.39	- do -	m	mat.	- do -	22.4.	
B.40	Hornbill, ground	m	mat.	Ol'Turesh	16.7.	
B.41	- do -	m	mat.	- do -	16.7.	
B.42	Vulture, brown		mat.	- do -	16.7.	
B.43	Eagle, Bâteleur	m	mat.	- do -	16.7.	
B.44	Hornbill, ground	f	mat.	- do -	17.7.	
B.45	Guineafowl, helmeted	m	mat.	- do -	17.7.	
B.46	- do -	m	mat.	- do -	17.7.	

SPECIES LIST : TABLE 3.

Order and Species (alphabetically arranged)	Ref. No. m	Ref. No. f	Age group	Habitat type *	Degree of range-sharing w. villages & domestic stock **			Number collected m	Number collected f	Number collected Total
ARTIODACTYLA										
Buffalo, Cape										
Syncerus caffer caffer (Sparrman)	13	-	old, lone	G	-	-	-			
- do -	15	-	- do -	G	-	-	-			
- do -	-	30	mature	G	-	-	-			
- do -	-	31	- do -	G	-	-	-	6	2	8
- do -	94	-	old, lone	G	-	-	-			
- do -	95	-	- do -	G	-	-	-			
- do -	96	-	- do -	G	-	-	-			
- do -	97	-	- do -	G	-	-	-			
Bushbuck										
Tragelaphus scriptus (Pocock)	12	-	old, lone	M	-	-	-	1	1	2
- do -	-	14	mature	G	-	-	-			
Dikdik										
Rhynchotragus kirkii (Thomas)	49	-	mature	HS	V	-	U	1	-	1
Eland										
Taurotragus oryx (Lydekker)	64	-	old	HS	V	-	U			
- do -	-	106	mature	HS	V	T	U	1	2	3
- do -	-	129	- do -	S	-	-	-			
Gerenuk										
Litocranius walleri (Brooke)	53	-	mature	HS	V	-	U			
- do -	-	60	- do -	HS	V	-	U	2	2	4
- do -	-	61	- do -	HS	V	-	U			
- do -	111	-	- do -	S	-	O	-			
Gazelle, Grant's										
Gazella granti (Heller)	2	-	mature	HS	V	-	U			
- do -	59	-	- do -	HS	V	-	U	2	-	2
Gazelle, Thomson's										
Gazella thomsoni (Guenther)	104	-	mature	HS	V	T	U	1	-	1

SPECIES LIST: TABLE 3 (cont)

Order and Species (alphabetically arranged)	Ref. No. m	Ref. No. f	Age group	Habitat type *	Degree of range-sharing w. villages & domestic stock			Numbers collected m	f	Total
ARTIODACTYLA (cont)										
Giraffe, Masai										
Giraffa camelopardalis (Matschie)	-	54	mature	HR	V	T	-			
- do -	-	124	- do -	HS	V	-	U	1	3	4
- do -	-	125	foetus	HS	V	-	U			
- do -	126	-	mature	HS	V	-	U			
Hartebeest										
Alcelaphus buselaphus var. cokei (Guenther)	3	-	mature	HS	V	-	U			
- do - var. jacksoni (Thomas)	17	-	- do -	G	-	-	-	2	2	4
- do - - do -	-	37	- do -	G	-	-	-			
- do - - do -	-	38	- do -	G	-	-	-			
Hippo										
Hippopotamus amphibius (Heller)	-	26	mature	G	-	-	-			
- do -	27	-	- do -	G	-	-	-			
- do -	-	28	- do -	G	-	-	-			
- do -	-	29	foetus	G	-	-	-			
- do -	40	-	mature	G	-	-	-	3	6	9
- do -	89	-	- do -	G	V	-	-			
- do -	-	90	- do -	G	V	-	-			
- do -	-	91	- do -	G	V	-	-			
- do -	-	92	- do -	G	V	-	-			
Impala - Aepyceros melampus (Matschie)	1	-	mature	HS	V	-	U	2	-	2
- do -	145	-	- do -	M	V	-	U			
Klipspringer										
Oreotragus oreotragus (Neumann)	77	-	mature	HR	V	T	-	1	-	1

SPECIES LIST · TABLE 3 (cont.)

Order and Species (alphabetically arranged)	Ref. No. m	Ref. No. f	Age group	Habitat type*	Degree of range-sharing w. villages & domestic stock**			Numbers collected m	Numbers collected f	Numbers collected Total
ARTIODACTYLA (cont)										
Kob, Uganda										
Kobus kob	32	-	mature	G	-	-	-			
- do -	34	-	- do -	G	-	-	-	4	-	4
- do -	35	-	- do -	G	-	-	-			
- do -	36	-	juvenile	G	-	-	-			
Kudu, lesser										
Tragelaphus imberbis (Heller)	115	-	mature	S	V	-	U	1	-	1
Oribi - Ourebia ourebi	-	16	mature	G	-	-	-	1	-	1
- do -	155	-	foetus	G	-	-	-			
Oryx, fringe-eared										
Oryx beisa callotis (Thomas)	-	51	mature	HS	V	-	U	1	1	2
- do -	66	-	- do -	HS	V	-	U			
Reedbuck (Ward's) Bohor										
Redunca redunca wardi (Thomas)	43	-	old	G	-	-	-	1	1	2
—do—	-	78	mature	HR	V	T	-			
Steinbok										
Raphicerus campestris (~~DeWinter~~ Matschie)	69	-	mature	HS	V	-	U	2	-	2
- do -	71	-	- do -	HR	V	T	-			
Warthog										
Phacochoerus aethiopicus (Cretzschmar)	5	-	mature	G	-	-	-			
- do -	6	-	- do -	G	-	-	-			
- do -	-	7	- do -	G	-	-	-			
- do -	8	-	- do -	G	-	-	-	5	2	7
- do -	9	-	- do -	G	-	-	-			
- do -	-	10	- do -	G	-	-	-			
- do -	33	-	- do -	G	-	-	-			

SPECIES LIST : TABLE 3 (cont)

Order and Species (alphabetically arranged)	Ref. m	No. f	Age group	Habitat type*	Degree of range-sharing w. villages & domestic stock**			Numbers collected m	f	Total
CARNIVORA										
Aardwolf *Proteles cristatus* (Sparrman)	-	151	mature	S	V	-	U	-	1	1
Cat, Taita wild *Felis lybica taitae* (Heller)	123	-	mature	S	-	-	-	2	-	2
- do -	143	-	- do -	M	V	-	U			
Civet - *Civettictis civetta* (Cabrera)	-	20	juvenile	G	-	-	-	-	1	1
Dog, Cape hunting *Lycaon pictus* (Thomas)	109	-	mature	S	-	-	-	1	-	1
Fox, bat-eared *Otocyon megalotis* (Desmarest)	58	-	mature	HS	-	-	U	2	-	2
- do -	130	-	- do -	S	-	-	-			
Genet, *Genetta genetta* (Matschie)	68	-	mature	M	V	T	U	1	-	1
Hyaena, spotted *Crocuta crocuta* (Erxleben)	-	41	mature	G	-	-	-			
- do -	42	-	juvenile	G	-	-	-	1	2	3
- do -	-	82	old	HS	V	-	U			
Hyaena, striped *Hyaena hyaena* (Meyer)	-	148	mature	S	V	-	U	-	1	1
Jackal, black-backed *Canis mesomelas*	-	48	mature	HS	V	-	U			
- do -	-	52	- do -	HS	V	-	U	1	3	4
- do -	62	-	- do -	HS	V	-	U			
- do -		105	- do -	HS	V	T	U			
Lion - *Panthera leo* (Neumann)	39	-	juvenile	G	-	-	-			
- do -	56	-	mature	HS	V	-	U			
- do -	-	57	old	HS	V	-	U			
- do -	-	136	mature	M	V	-	U	3	4	7
- do -	-	137	- do -	M	V	-	U			
- do -	138	-	- do -	M	V	-	U			
- do -	-	147	juvenile	S	V	-	U			

SPECIES LIST: TABLE 3 (cont.)

Order and Species (alphabetically arranged)	Ref. m	No. f	Age group	Habitat type *	Degree of range-sharing w. villages & domestic stock**			Numbers collected m	f	Total
CARNIVORA (cont)										
Mongoose, white-tailed <u>Ichneumia</u> <u>albicauda</u> (Thomas)	-	80	mature	HR	V	T	-	-	1	1
Serval <u>Felis</u> <u>serval</u> (Wroughton)	65	-	mature	S	V	-	U	2	-	2
- do -	79	-	- do -	HR	V	T	-			
HYRACOIDEA										
Rock hyrax - <u>Procavia</u> <u>capensis</u>	73	-	mature	HR	V	T	-			
- do -	-	74	mature	HR	V	T	-	2	1	3
- do -	75		mature	HR	V	T	-			
LAGOMORPHA										
Hare, African <u>Lepus</u> <u>capensis</u> (De Winton)	-	72	mature	HR	V	T	-	-	1	1
PERISSODACTYLA										
Rhino, black <u>Diceros</u> <u>bicornis</u> (Linnaeus)	128	-	mature	S	V	T	U	2	-	2
- do -	153	-	- do -	?	?	?	?			
Zebra, Burchell's <u>Equus</u> <u>burchelli</u> (Lydekker)	4	-	mature	HS	V	-	U			
- do -	50	-	- do -	HS	V	-	U			
- do -	55	-	- do -	HS	V	-	U	4	2	6
- do -	63	-	- do -	HS	V	-	U			
- do -	-	67	- do -	HS	V	-	U			
- do -	-	70	- do -	HS	V	T	U			
PRIMATES										
Chimpanzee - <u>Pan</u> <u>troglodytes</u>	98	-	old	M/G	V	-	-	1	1	2
- do -	-	102	mature	M/G	V	-	-			
Colobus, black and white <u>Colobus</u> <u>polykomos</u>	11	-	old	M	-	-	-	2	-	2
- do -	101	-	mature	M/G	V	-	-			

SPECIES LIST : TABLE 3. (cont)

Order and Species (alphabetically arranged)	Ref. No. m	Ref. No. f	Age group	Habitat type *	Degree of range-sharing w. villages & domestic stock**			Numbers collected m	Numbers collected f	Numbers collected Total
PRIMATES (cont)										
Galago, Senegal Galago senegalensis	-	144	mature	M	V	-	U	-	1	1
Monkey, Blue (Sykes) Cercopithecus mitis	-	139	mature	M	V	T	-			
- do -	140	-	mature	M	V	-	U	2	1	3
- do -	142	-	- do -	M	V	-	U			
Monkey, Vervet Cercopithecus aethiops	44	-	mature	G	-	-	-			
- do -	-	45	- do -	G	-	-	-			
- do -	46	-	- do -	G	-	-	-	4	2	6
- do -	47	-	juvenile	G	-	-	-			
- do -	-	141	mature	M	V	-	U			
- do -	146	-	- do -	M	V	-	U			
PROBOSCIDEA										
Elephant, African savannah	154	-	foetus	S	V	T	U			
Loxodonta africana africana (Blumenbach)	-	135	calf	M	V	-	U			
- do - (listed in relative age order)	-	114	calf	S	V	T	U			
- do -	113	-	juvenile	S	V	T	U			
- do -	-	133	- do -	M	V	-	U			
- do -	103	-	- do -	M	V	T	U			
- do -	134	-	sub-adult	M	V	-	U			
- do -	110	-	- do -	S	V	T	U			
- do -	-	23	- do -	G	-	-	-			
- do -	-	100	- do -	M	V	-	U			
- do -	-	25	- do -	G	-	-	-			
- do -	83	-	- do -	M	V	-	U			

SPECIES LIST : TABLE 3 (cont)

Order and Species (alphabetically arranged)	Ref. No. m	f	Age group	Habitat type*	Degree of range-sharing w. villages & domestic stock**			Numbers collected m	f	Total
PROBOSCIDEA (cont)										
Elephant, African savannah (cont) (listed in relative age order)	99	-	prime adult	M	V	-	U			
- do -	132	-	- do -	M	V	-	U			
- do -	-	112	- do -	S	V	T	U			
- do -	85	-	- do -	G	V	-	-			
- do -	87	-	- do -	G	V	-	-			
- do -	149	-	- do -	S	V	T	U			
- do -	150	-	- do -	S	V	T	U			
- do -	118	-	- do -	S	V	T	U			
- do -	-	22	- do -	G	-	-	-			
- do -	-	24	- do -	G	-	-	-			
- do -	19	-	- do -	G	-	-	-			
- do -	-	88	- do -	G	V	-	-			
- do -	152	-	- do -	M	V	T	U			
- do -	-	131	- do -	S	V	T	U	25	15	40
- do -	-	127	- do -	S	V	T	U			
- do -	84	-	- do -	G	V	-	-			
- do -	93	-	senior adult	G	V	-	-			
- do -	119	-	- do -	S	V	T	U			
- do -	120	-	- do -	S	V	T	U			
- do -	108	-	- do -	S	V	T	U			
- do -	-	21	- do -	G	-	-	-			
- do -	18	-	- do -	G	-	-	-			
- do -	116	-	- do -	S	V	T	U			
- do -	117	-	- do -	S	V	T	U			

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SPECIES LIST: TABLE 3 (cont)

Order and Species (alphabetically arranged)	Ref. No. m	Ref. No. f	Age group	Habitat type *	Degree of range-sharing w. villages & domestic stock **			Numbers collected m	f	Total
PROBOSCIDEA (cont)										
Elephant, African savannah (cont) (listed in relative age order)	86	-	senior adult	G	V	-	-			
- do -	121	-	- do -	S	V	T	U			
- do -	-	122	- do -	S	V	T	U			
- do -	-	107	senile, lone	S	V	T	U			
RODENTIA										
Spring hare *Pedetes surdaster* (Hollister)	76	-	mature	HR	V	T	-	1	-	1
Rodent mole *Cryptomys sp.*	81	-	mature	HR	V	T	-	1	-	1

MAMMALS: Total number of orders represented: 8
Total number of species represented: 43
Total number of specimens collected, males 95 } 155
females 60 }

(Key: *Habitat type:
M = montane
G = Uganda grassland, or degenerated forest with permanent lakes and rivers
S = Scrubland
HS = High-altitude scrubland (non-fenced native ranching)
HR = High-altitude ranchland (fenced)

**Degree of range sharing w. villages and domestic stock:
V = villages and settlements
T = domestic stock, regularly treated against endo- and ecto-parasites
U = domestic stock, untreated (or irregularly treated) against endo- and ecto-parasites.

SPECIES LIST (BIRDS): TABLE 4

Order and Species (alphabetically arranged)	Ref. No. B. m	f	Age Grp.	Habitat Type
CICONIIFORMES				
Heron, purple Ardea purpurea*	B. 3	-	mat.	HR7
- do -	-	B.13	-do-	G7
Heron, Squacco Ardeola ralloides	-	B.14	-do-	G7
Ibis, Hadada Hagedashia hagedash	B.10	-	-do-	G
Stork, Saddlebill Ephippiorhynchus senegalensis	-	B.20	-do-	G
Stork, woolly-necked Dissoura episcopus	B.21	-	-do-	G
CORACIIFORMES				
Hornbill, ground Bucorvus sp.	B.22	-	-do-	G
- do -	B.40	-	-do-	M
- do -	B.41	-	-do-	M
- do -	-	B.44	-do-	M
Hornbill, red-billed Tockus camurus	B.24	-	-do-	HS
CUCULIFORMES				
Turaco, Hartlaub's Tauraco hartlaubi	B.35	-	-do-	M

*(after A.L. Thomson and/or J.G. Williams)

7(Littoral)

SPECIES LIST (BIRDS): TABLE 4 (cont.)

Order and Species (alphabetically arranged)	Ref.No. m	f	Age Grp.	Habitat Type
FALCONIFORMES				
Buzzard, Augur *Buteo rufofuscus*	B. 6	?	mat.	HR
Eagle, Bateleur *Terathopius ecaudatus*	B.43	-	mat.	M
Eagle, fish *Haliaetus vocifer*	-	B.15	-do-	G7
Eagle, tawny *Aquila rapax*	-	B. 7	-do-	HS
Secretary bird *Sagittarius serpentarius*	-	B.28	-do-	HS
Vulture, Egyptian *Neophron percnopterus*	-	B.30	-do-	HS
Vulture, hooded	-	B. 8	-do-	G
- do - *Necrosyrtes monachus*	B.19	-	-do-	G
- do -	B.38	-	-do-	S
- do -	B.39	-	-do-	S
- do -	B.42	?	-do-	M
Vulture, white-backed *Pseudogyps africanus*	B.18	-	-do-	G
- do -	-	B.36	-do-	S
Vulture, white-headed *Trigonoceps occipitalis*	B.37	-	-do-	S
GALLIFORMES				
Guinea-fowl, helmeted *Numida mitrata*	B.45	-	-do-	M
- do -	B.46	-	-do-	M

SPECIES LIST (BIRDS): TABLE 4 (cont.)

Order and Species (alphabetically arranged)	Ref. No. m	Ref. No. f	Age Grp.	Habitat Type
GRUIFORMES				
Bustard, Kori *Ardeotis kori*	-	B.23	mat.	HS
- do -	B.26	-	-do-	HS
- do -	-	B.27	-do-	HS
- do -	-	B.31	-do-	HS
- do -	-	B.32	-do-	HS
PELECANIFORMES				
Cormorant, long-tailed *Phalacrocorax africanus*	-	B. 2	mat.	HR7
- do -	B. 4	-	-do-	HR7
Cormorant, white-necked *Phalacrocorax carbo lucidus*	-	B. 9	-do-	G7
- do -	-	B.11	-do-	G7
- do -	-	B.12	-do-	G7
Darter *Anhinga rufa*	B.5	?	-do-	HR7
- do -	-	B.17	-do-	G7
Pelican, white *Pelecanus onocrotalus*	-	B. 1	-do-	HR7
- do -	-	B.16	-do-	G7
PSITTACIFORMES				
Parrot, red-headed *Poicephalus gulielmi*	-	B.33	-do-	M
- do -	B.34	-	-do-	M
STRUTHIONIFORMES				
Ostrich, *Struthio camelus*	B.25	-	-do-	HS
- do -	-	B.29	-do-	HS

7(Littoral)

TABLE 4 (cont.)

BIRDS: Total numbers

Orders represented:	9
Species represented:	25
Specimens collected:	46

PLATE II

(a) High Ranchland.

(b) Herd of eland on high scrubland.

PLATE II

(a)

(b)

PLATE III

Ageing criteria:

(a) Horn growth: elderly male bushbuck.

(b) Tooth wear: lower incisors, elderly female oryx.

(c) Horn and ear wear, size and stance: elderly male buffalo.

(d) Skin colour: elderly male eland.

PLATE III

(a)

(b)

(c)

(d)

Chapter 4

Identification and Relevance of Parasites

Collection of parasites

Endo- and ecto-parasites have been collected for identification from every specimen in which they could be located during autopsy, as these may play a significant role in the aetiology of cardiovascular disease in free-living wild animals. Although parasitic infestations occur in acclimatised and treated animals in zoos and experimental laboratories, they are comparatively unimportant in relation to cardiovascular disease (Fiennes 1967).

In the field, parasites were sought in the normally favoured parts of the body of each mammal and bird as part of the autopsy routine, and samples collected for identification. If parasites, or suspected parasites, were noticed in unusual locations, these were also collected. The following were routine inspection sites:-

A. Ectoparasites - ears, eyes, nostrils, buccal cavity, axilla, anus, external genitalia, tail.

B. Endoparasites - oesophagus, skin, trachea, lungs, liver, kidneys, heart and pericardium, intestinal walls, stomach, caecal and rectal contents, and blood smears.

Urine was not collected or examined.

Ectoparasites have been sent to Miss Jane B. Walker, M.Sc., Onderstepoort, South Africa, for identification, but this work is as yet incomplete.

Endoparasites have been identified by Dr.M.Clarkson, School of Tropical Medicine, Liverpool, and Mr.R.N.T-W-Fiennes, Pathologist, Zoological Society of London. The assistance of these workers is gratefully acknowledged.

Relevance of the parasites collected to cardiovascular disease

A. Ectoparasites must be regarded as having little or no significance in relation to the study of cardiovascular disease, except insofar as they may act as intermediate vectors for endoparasites (Protozoa, Leptospira and Helminths) liable to affect the blood-vascular system of the host.. In connection with this possibility, it was noted during this project that ectoparasites were remarkably scarce, or even totally absent, in wild animals collected in the high ranchlands, where domestic stock received regular internal and external treatment against parasites. This situation contrasted strongly with that obtaining in all other habitats.

B. Endoparasites

i) Helminths were positively located, and identified as the causal agents of aortic, cardiac and pericardial lesions in all of the eight buffaloes collected. These were identified as Onchocerca armillata (Railliet and Henry 1912) and Elaeophora poeli (Vryburg 1879).

The tortuous burrows ramifying through the arterial intima and media, aortic ulcers and aneurysms, and other characteristic lesions caused by these parasites, were not seen in elephant at all, although in one or two cases lesions did occur, which recalled the appearance of old calcified parasitic lesions (Bernard & Bauche 1912; Railliet & Henry 1912; Sandground 1932, 1938; Yamaguti 1961; Clarkson 1964). (Chodnik 1957,1958).

In certain Carnivora (spotted hyaena M.82; striped hyaena M.148 and Taita wild cat M.143) a type of lesion, similar to that resulting from the burrowing activities of Elaeophora and Onchocerca in buffaloes, was found. The burrows, however, were much smaller, and in many cases surrounding areas of early necrosis contained large numbers of very minute cells, which stained deeply with Giemsa and Gurr's NRG stains (Gurr 1963). It seems possible that the burrows may have been caused by a parasitic worm, perhaps <u>Spirocerca</u> sp. (Lapage 1962); (Babero 1965), and that a secondary tissue reaction followed.

<u>Spirocerca lupi</u> Rudolphi 1809 has been recorded from a cheetah in Kenya (Murray, Campbell & Jarrett 1964). These authors described "linear and oval raised plaques with superimposed thrombi ... along the entire length of the thoracic and the initial few cms of the abdominal aorta. There was a linear thrombus in the terminal 1 cm of the aorta and the thrombus bifurcated along both iliac arteries for 3 - 4 cm. Thrombi were found in both branches of the pulmonary artery. Histological examination revealed <u>Spirocerca lupi</u> worms tracking along the aortic media surrounded by areas of necrosis. The tracking had caused disruption of the elastic fibres and damage to the endothelial lining of the aorta with resultant thrombosis... Iliac thrombosis is a recognised cause of severe illness in the domestic cat... It is impossible to be sure whether the spirocercosis was the final cause of death, or whether this acted in conjunction with anaemia." In their comments on the presence of wedge-shaped renal infarcts in this cheetah, they also mention the possibility of pulmonary or renal embolism as the final cause of death.

This case is of particular interest, as records of naturally occurring thrombi in wild animals are rare. It should however be noted that this cheetah was one of a pair which had been subjected to excessive and unnatural stress during their capture near Wajir and subsequent transport to Nairobi, thus perhaps causing a previously 'silent' parasite to cause severe disease (Fiennes 1963). The other member of the pair responded to treatment and recovered. There appears to be no available evidence as to whether an adequate host-parasite tolerance is achieved in nature to enable wild carnivores to survive naturally occurring stresses.

The specimens of carnivores collected by the author do not show any evidence of potential foci for thrombus formation other than the scarification of the arterial intima. It is, however, of note that both in these carnivores and in buffalo with parasitic lesions of the aorta, strands of fibrinous material, staining pinkish-red with van Gieson's stain, were found to emanate from the aortic intima and trail into the aortic lumen. It is possible that in very advanced cases accompanied by the formation of intimal fibrinous tags, these might, under excessive stress, form foci for the formation of thrombi if the blood of the particular species is in fact capable of forming thrombi.

There seems to be sufficient evidence from domestic and captive animals to indicate that the blood of carnivores does, in exceptional circumstances, form thrombi (Palumbo & Hubbard 1966). A thrombic embolus was observed at autopsy in the carotid sinus of a tigress which died in the Gardens of the Zoological Society of London in 1965 (specimen DB/570). A further thrombus was seen in the left atrium, as were calcified lesions, although no lesions were found in the aorta itself. It is not improbable that this thrombus might have been the cause of terminal cerebral insufficiency.

ii) Leptospira - Agglutination tests for Leptospira antibodies in the sera of animals collected in this project were positive in the cases of giraffe (M.124), eland (M.106), Thomson's gazelle (M.104) and elephants M.150, 108 and 114. (Twigg 1966). The possible presence of Leptospira in arterial tissue cannot therefore be overlooked, and is presently under investigation by Dr. G.I. Twigg of Royal Holloway College, University of London.

iii) Other parasites - Identification of many of the parasites collected during the present project is still pending, as in many cases it relates more directly to the discipline of Parasitology itself than to comparative cardiovascular studies. For example, the occurrence of Setaria (Artionema) sp. (Clarkson 1966) in the aortic fascia of gerenuk (specimens M.60 and M.61) is, from the point of view of this project, an interesting but incidental autopsy finding, whereas its significance as a parasitological finding is that it appears to be a new host and a new site record for the genus.

A list of parasites collected during this project follows below.

LIST OF PARASITES : TABLE 5.

MAMMALS

Host	Parasites Ecto-	Parasites Endo- **	Notes
ARTIODACTYLA			
Buffalo, Cape (6 m, 2 f)	Ticks*	ARTHROPODS	
		? *Linguatula* sp.	in brain tissue (Garnham 1966)
		HELMINTHS	
		a) *Paramphistomum philllerouxi*	in stomach and liver
		b) *Thelazia rhodesii*	on conjunctiva
		c) *Onchocerca armillata*	in aortic wall and fascia, pericardium and epicardium
		d) *Elaeophora poeli*	in aortic arch (see Plates IV-VIII)
		e) Microfilaria, other (unidentified) perhaps *Setaria cervi*	in blood clot from right ventricle, fixed in 10% formalin, later stained Giemsa
		PROTOZOA	
		a) large schizonts, perhaps *Theileria parva*	in blood smears, stained Giemsa (Fiennes 1966)
		b) Parasitic organisms, ? other Protozoa	in smears from tail swellings, M.15 and M.97
Eland (1 m, 2 f)	Ticks*	HELMINTHS	
		Tapeworm (unidentified)	from liver
Gerenuk (2 m, 2 f)	Ticks*	HELMINTHS	
		a) Cestode cyst (unidentified)	on liver

*(sent to Miss J.B. Walker, Onderstepoort, South Africa, for identification)

**(Halloran 1955; Lapage 1956,1962) (Cheng 1964)

LIST OF PARASITES : TABLE 5(cont.)

Host	Parasites Ecto-	Parasites Endo-	Notes
Gerenuk (cont.)		b) Setaria(Artionema) sp.	3 females only resemble S. scalprum (see M.69) fibrinous tags also noted on lungs,stomach and spleen (Yeh 1959; Yorke & Maplestone 1926)
Gazelle, Grant's(2 m)	ticks*	HELMINTHS a) Thelazia sp.	on conjunctiva
		b) Cestode(unident.)	Cysts in connective tissues,thorac. & abdom.cavities, liver, & on heart
		c) Setaria sp.	Pericard.part. adherent to heart, with some fibrinous tags
Gazelle,(1 m) Thomson's	ticks*	HELMINTHS ?Cestode(unident.)	cysts in connective tissues
Giraffe, Masai (2 m,3f)	ticks*	HELMINTHS ? Cestodes(Unident.)	very large parasitic ~~hydatid~~ cysts (see Plate IX) white cysts in kidney & fibr. tags on various organs.
		PROTOZOA Babesia	in blood smear stained Giemsa, Eosinophilia,-?ass.w.indirect parasitism

LIST OF PARASITES : TABLE 5 (cont.)

Host	Parasites Ecto-	Endo-	Notes
Hartebeest (2 m, 2 f)	Ticks*	ARTHROPODS Oestrus variolusus	in nasal cavities & brain
		HELMINTHS a) Amphistoma sp.	in stomach
		b) Gedoelstia cristata	in carotid fascia
		c)? Cestode cysts	on heart, leg muscles, etc.
Hippo (3 m, 6 f)	Ticks* mites leeches	(Parasites identified by N.U.T.A.E. and E.A.V.R.O., Kenya) HELMINTHS Oculotrema hippopotami Fasciola nyanzae Nilocotyle wagandi N. minutum N. sellsi Gigantocotyle duplicitestorum 3 unident. schistosome sppecimens Moniezia sp. Ascaris hippopotami Cobboldina vivipara Leiperiatus hopkeni	Endoparasites not collected by author, as N.U.T.A.E. were carrying out detailed survey. (Dinnik et al. 1963; Thurston & Laws 1965)
Kob (4 m)	Ticks*	HELMINTHS Amphistoma sp.	stomach
		Setaria (Artionema) pillersi	2 specimens found in fascia of renal artery
Oribi (1m, 1f)	Ticks*	HELMINTHS Setaria (Artionema) scalprum	

LIST OF PARASITES: TABLE 5 (cont).

H o s t	P a r a s i t e s Ecto-	 Endo-	N o t e s
Oryx (1 m, 1 f)	Ticks*	HELMINTHS	
		Taenia hydatigena (larval stage)	
		Setaria sp.	Aortic fascia. ~~few lesions, shows some similarity to those of O. armillata in the buffalo~~
Reedbuck, Bohor (1 m, 1f)	Ticks*	HELMINTHS	
		Amphistoma sp.	stomach
		Nematode (unident.)	abdominal cavity
Steinbok (2 m.)	Ticks*	HELMINTHS	
		Setaria(Artionema) scalprum	
		Amphistoma sp.	stomach contents
		? Cestode (unident.)	cysts on liver & heart
Warthog (5 m, 2 f)	Ticks* Fleas*	Murshidia sp.	
		Setaria (Artionema) congolensis	intestine white areas, ? cysts on liver
CARNIVORA			
Cat, Taita wild (2 m)		HELMINTHS	
	Ticks*	?Spirocerca sp.	burrows in aorta
Fox, bat-eared (2 m)	Ticks*	HELMINTHS	
		Dipylidium otocyonis	in intestine
Hyena, spotted (1 m, 2 f)	Ticks*	HELMINTHS	
		Taenia hyenae	in intestine
		? Spirocerca sp.	burrows in aorta

LIST OF PARASITES: TABLE 5 (cont.)

Host	Parasites Ecto-	Parasites Endo-	Notes
Hyæna, striped (1 f)	Ticks*	HELMINTHS ?Spirocerca sp.	 in aorta-burrows
Jackal, black-backed (1 m, 3 f)	Ticks*	HELMINTHS Taenia hydatigena	 in intestine
Lion (3 m, 4 f)	Ticks* Fleas* Flies*	ARTHROPODS Linguatula serrata HELMINTHS Taenia gonyamai Nematodes(unident.) ? Cestodes	 in nostril of M.39 in intestine in body cavity white spots on liver,? cysts
Mongoose, white-tailed (1 f)	Ticks*	---	
Serval (2 m)	---	PROTOZOA Babesia sp.	in blood smear: Giemsa (Fiennes 1965)
HYRACOIDEA			
Hyrax, rock (2 m, 1 f)	---	HELMINTHS Inermicapsifer prionodes I. hyracis Nouvelnema cyclophoron Crossophorus collaris	(Petter 1959)
LAGOMORPHA			
Hare, African (1 f)	Ticks*	HELMINTHS ? Cestode? cyst	 one only seen on liver
PERISSODACTYLA			
Rhine, black (1 m)	Ticks*	no endoparasites seen or collected	

LIST OF PARASITES : TABLE 5 (cont.)

Host	Parasites Ecto-	Parasites Endo-	Notes
Zebra, Burchell's (4 m, 2 f)	Ticks*	ARTHROPODS	
		Gastrophilus pecorum	
		HELMINTHS	
		Anoplocephala rhodesiensis	(Spassky 1951)
		Probstmayria vivipara	
		Setaria equina	
PRIMATES			
Chimpanzee (1 m, 1 f)	Ticks*	HELMINTHS	
		Cestode	in intestine
Monkey, Vervet (4 m, 2 f)	none seen	Bertiella studeri	
		Subulura distans	
PROBOSCIDEA			
Elephant, African (25 m, 15 f)	Ticks*	ARTHROPODS	
		Oestridae, ? sp.	ear (Austen 1936)
		Platycobboldia loxodontis (larvae)	in buccal cavity, oesophagus, stomach
		Pharyngobolus africanus (larvae)	throat (Zumpt 1965)
		HELMINTHS	
		Mammomonogamus loxodontis	in lungs and trachea
		Murshidia sp. & M. linstowi	in stomach contents
		Toxascaris elephantis	in fascia of aorta and limb muscle
		Loxodontofilaria sp.	aorta (Berghe 1939)
		Quilonia sp. (? africana)	caecum
		Q. apiensis	stomach
		Grammocephalus clathratus	liver, bile ducts (Westhuysen 1938)
		Unidentified sp.	large cysts, (kidney, muscles); small cysts (endocard., left ventricle)

LIST OF PARASITES : TABLE 5 (cont.)

B I R D S

Host	Parasites Ecto-	Parasites Endo-	Notes
GRUIFORMES			
Bustard, Kori (1 m, 4 f)	---	HELMINTHS Raillietina sp.	in intestine
STRUTHIONIFORMES			
Ostrich (1m, 1 f)	---	HELMINTHS Ascaridia struthionis	in intestine

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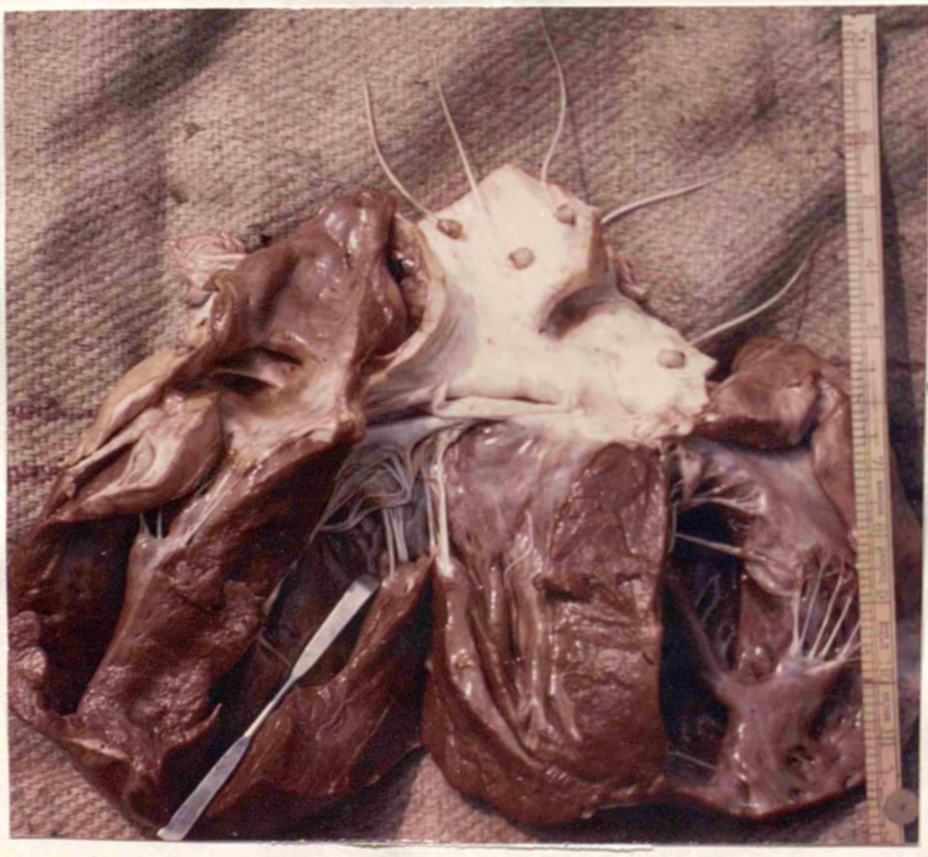
PLATE IV

(a) Elaeophora poeli in anterior part of aorta (portion I) of buffalo.

(b) E. poeli in aortic arch of buffalo.

PLATE IV

(a)



(b)

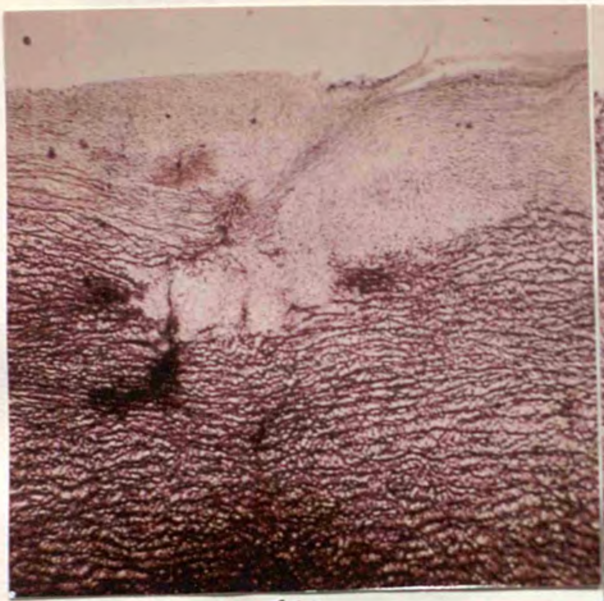
PLATE V

(a) TS aorta (portion I) of buffalo, showing small deposit of sudanophilic lipid, internal thickening and degeneration of the elastica of both intima and media associated with the activity of Onchocerca armillata (Sudan IV and haemalum, x 50).

(b) As above: x 100.

(c) Onchocerca armillata: microfilariae in the aortic fascia of a buffalo (Haemalum, x 100).

PLATE V



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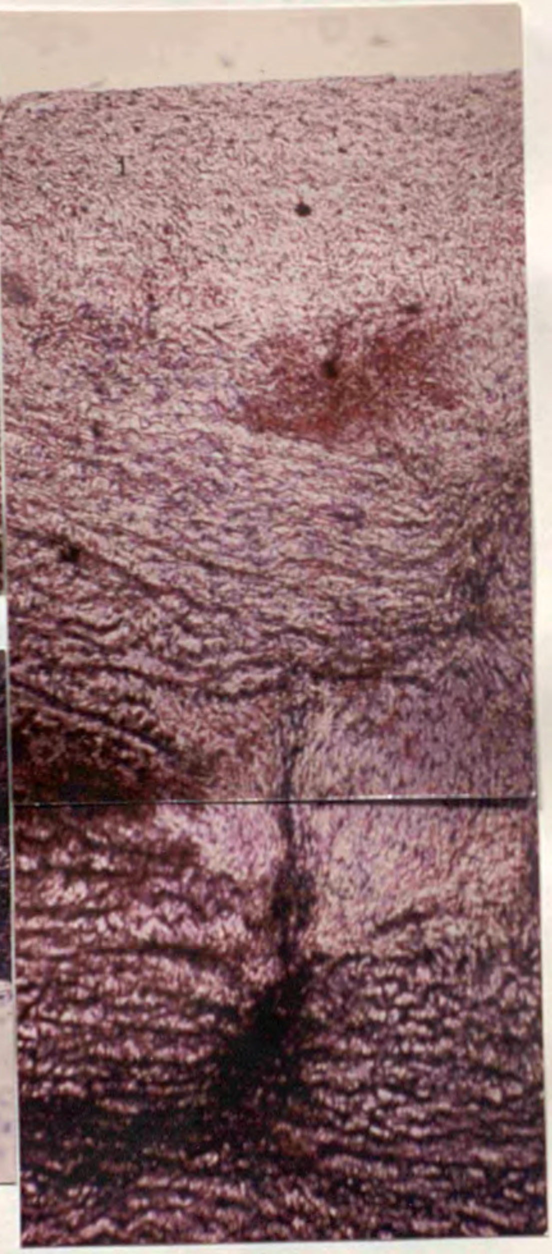

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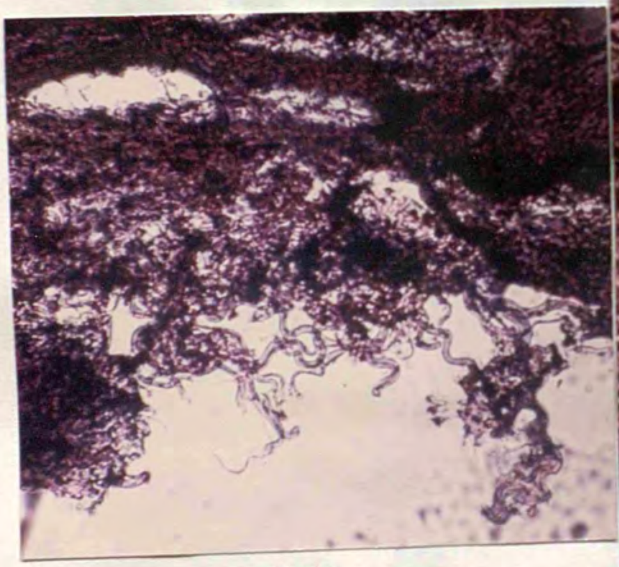


(c)

PLATE VI

(a) *Onchocerca armillata*: adult worms seen in section *in situ* in the aorta of a buffalo. (Verhoeff and Van Gieson stain, x 50).

(b) As above: portion (i) x 100.

(c) As above: portion (ii) x 100.

PLATE VI

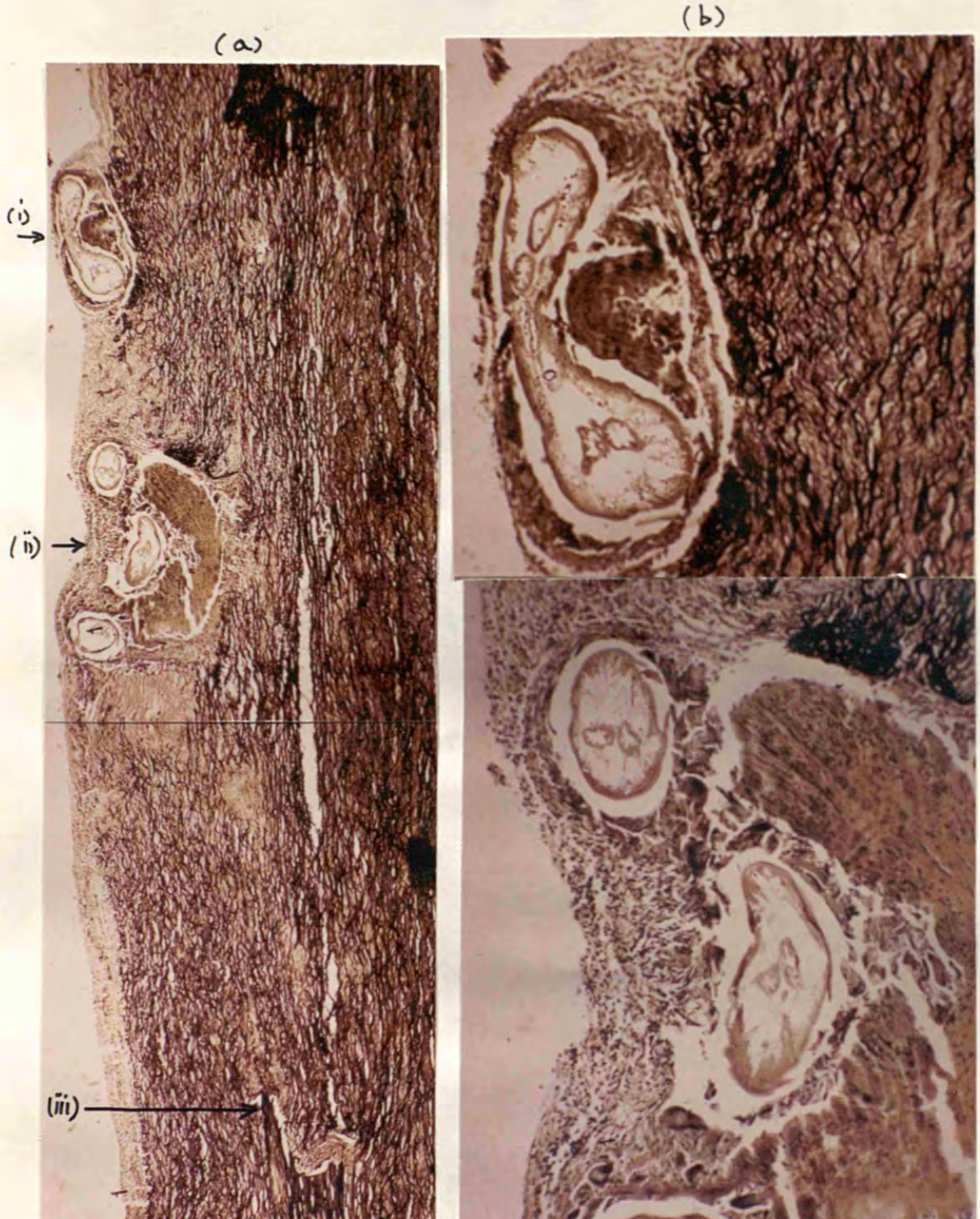


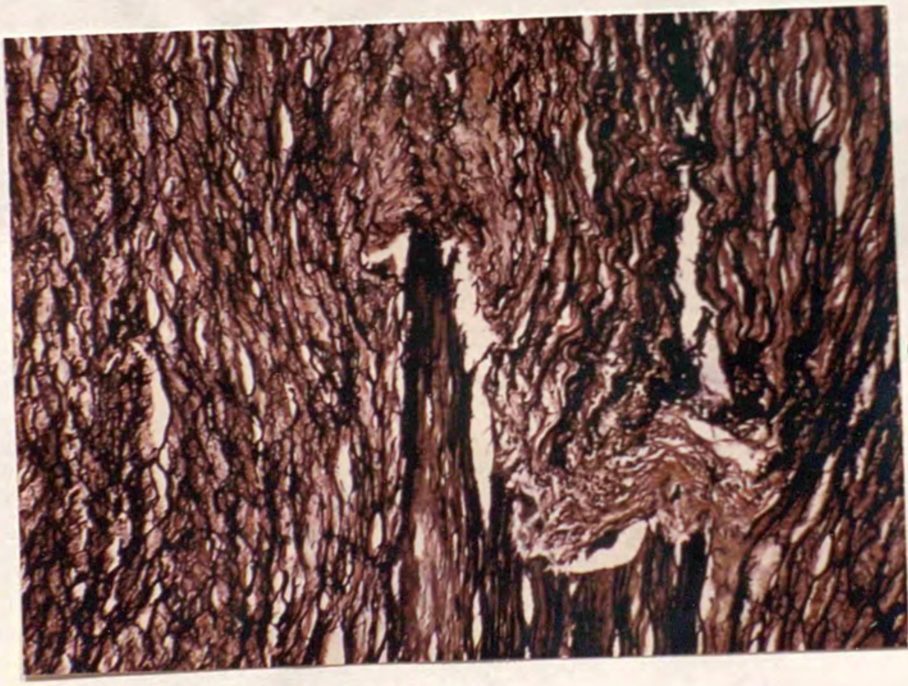
PLATE VII

(a) TS buffalo aorta: focal degeneration of the media associated with the activity of Onchocerca armillata (Verhoeff and Van Gieson stain, x 100).

(b) As above: showing mineralisation of part of the medial elastica (See Plate VI, iii) (Verhoeff and Van Gieson stain, x 100).

PLATE VII

(a)



(b)

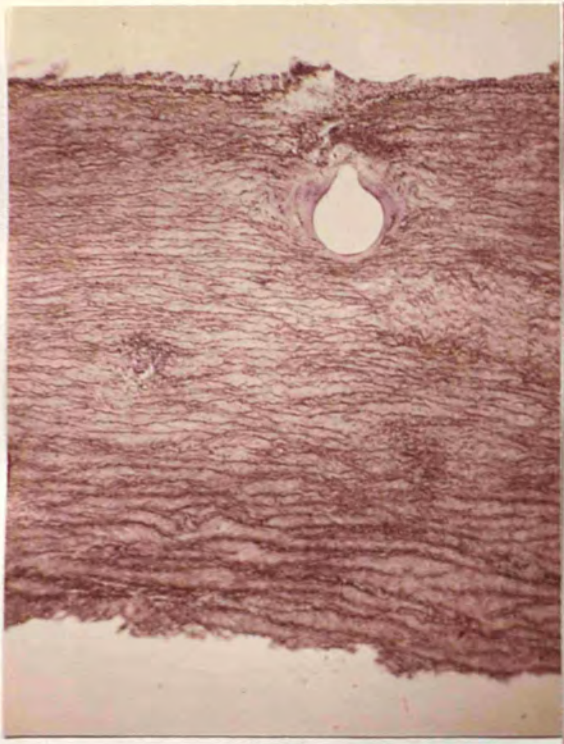
PLATE VIII

(a) *Onchocerca armillata*: TS *in situ* in abdominal aorta of buffalo (Verhoeff and Van Gieson stain, x 50)

(b) Parasitic Arthropod (unidentified specifically: Garnham 1967) in brain tissue of buffalo (H. & E., x 50).

(c) TS aorta of spotted hyaena, specimen M.82, showing areas of degeneration of the elastica, granular tissue, and a proliferation of macrophages. Extensive irregular deposits of sudanophilic lipid occurred in both the intima and media (Haemalum, x 100).

PLATE VIII



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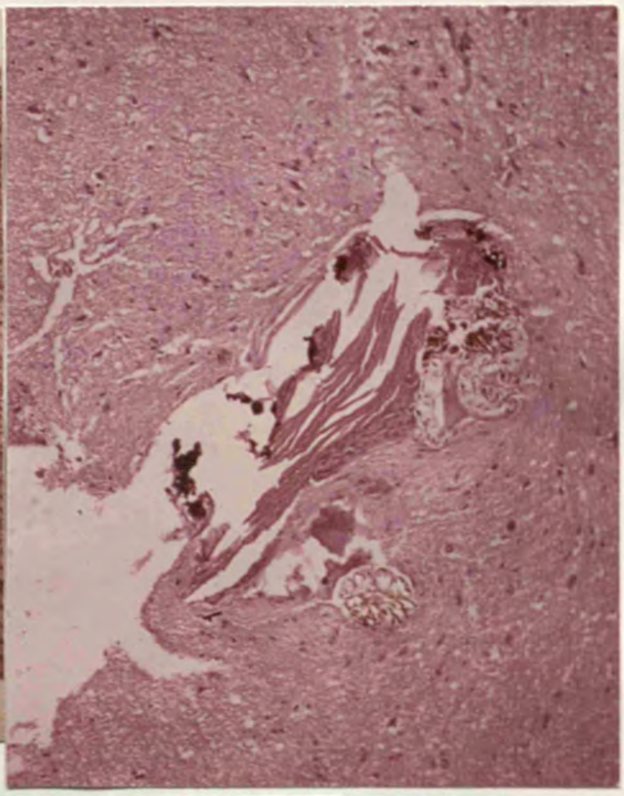

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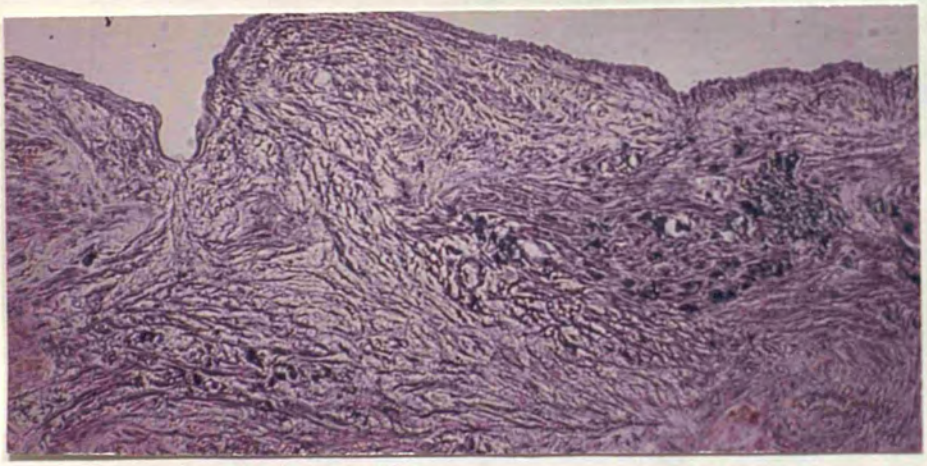


(c)

PLATE IX

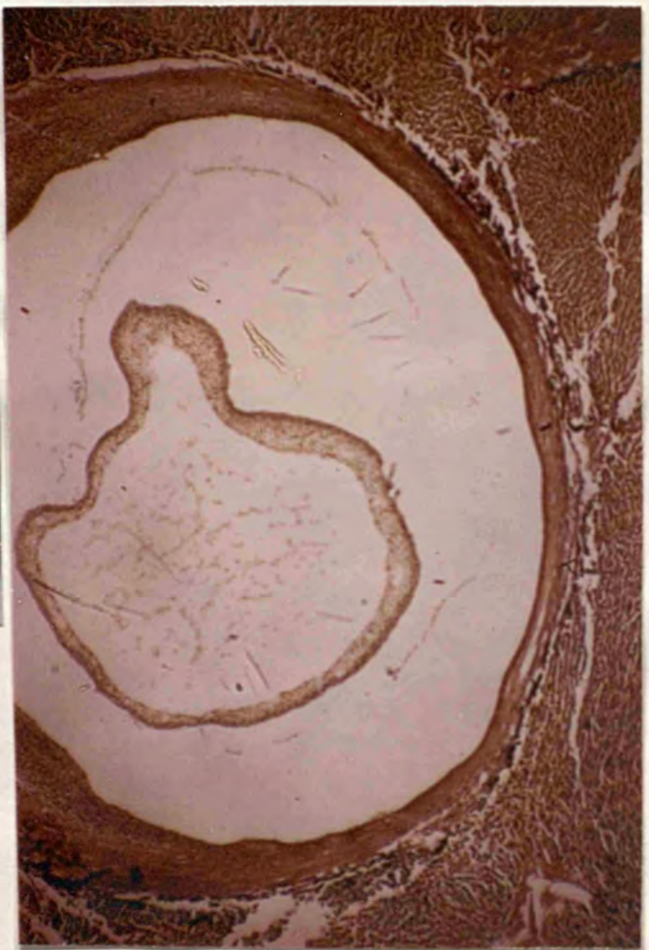
(a) Cystic liver: giraffe M.124.

(b) As above; TS. Verhoeff and Van Gieson stain, x 100.

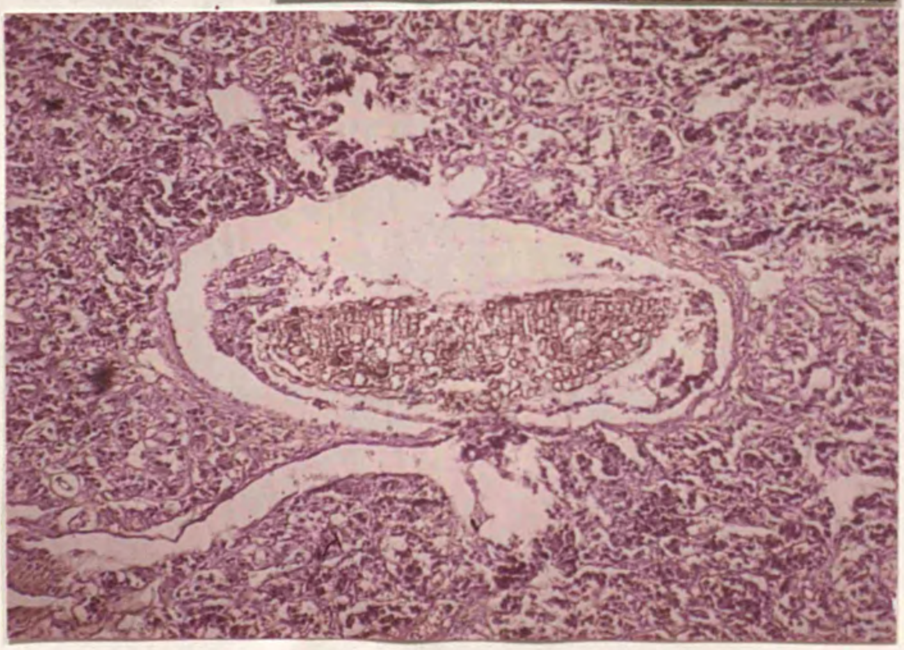
(c) Parasitic Arthropod(unidentified specifically: Clarkson 1966) in adrenal gland of giraffe, specimen M.54 (H. & E., x 100).

PLATE IX

(a)



b)



c)

Chapter 5
BLOOD SERUM ANALYSIS

The collection and analysis of blood serum was considered to be an essential adjunct of studies on arterial disease. Electrophoretic and routine clinical analyses had been carried out by Dr.W.G.Dangerfield at the North Middlesex Hospital, London, on serum samples collected from autopsy cases from a large number of species of exotic mammals, birds and reptiles at the Pathology Department of the Zoological Society of London. It was hoped that a comparison could be drawn between the results of these analyses and those of free-living wild mammals and birds.

Blood serum was therefore collected from as many specimens as possible during the present project. Unfortunately, the collection of high-quality samples was not always successful, and, in addition, one batch of good samples collected in Uganda was entirely spoilt due to a failure in refrigeration at the storage centre in Fort Portal, Uganda, where it was temporarily deposited for safe keeping. Nevertheless, 62 successful samples altogether were collected, representing 27 species.

Recommended technique

It had been decided at the outset of the project that serum, in preference to plasma or whole blood, should be collected in order to meet the requirements of the biochemists who were originally expected to carry out the analyses.

The following technique was outlined and demonstrated by Dr. L.G. Goodwin, Director of the Nuffield Institute of Comparative Medicine, and Dr. W.G. Dangerfield of the North Middlesex Hospital, and its application was proposed for use in the field: blood to be withdrawn from the heart, jugular vein, or femoral artery by means of either a disposable steriseal syringe fitted with a blood needle, or a vacuum venule, immediately after death; serum to be separated in a dual-speed hand-operated centrifuge, and drawn off into sterile specimen tubes containing Sodium azide; these to be frozen down with 'dry ice' and transported frozen to the United Kingdom.

The equipment required for this procedure was flown ready-prepared to East Africa. A portable, mains/battery vehicle refrigerator of $\frac{3}{4}$ cu.ft capacity was also obtained, and siphon-fitted cylinders, each containing 24 lb pressurised Carbon dioxide and weighing a total of 150 lb, together with a small detachable 'carboneige' machine, were ~~obtained~~ purchased locally in Nairobi, Kenya. These cylinders were not at the time available anywhere else in Kenya or Uganda and, due to transport delays, together with their great bulk and weight, were always difficult to handle and replenish. In the latter part of the expedition, when field work was centred in Kenya, it was possible to replace them by much smaller, and more convenient, specially adapted cylinders containing only 7 lb and 10 lb gas each.

During the preparatory week of collecting (see p 29) each of the four test mammals was killed by means of a soft-nosed rifle bullet penetrating the blood-vascular system. The test birds were killed either with a .22 rifle bullet or No.4, AAA, or SSG 12-bore shot.

Details of these are as follows:-

Specimen	Type of bullet	Position of shot
M.1 Impala, m	.375 magnum soft-nosed	through left flank to inferior vena cava
M.2 Gazelle, Grant's, m.	- do -	through right base of neck to carotids
M.3 Hartebeest, Coke's, m.	- do -	through chest, anterior, to heart
M.4 Zebra, Burchell's, m.	- do -	through left flank to inferior vena cava
B.1 Pelican, white, f.	12-bore AAA shot	head and neck
B.2 Cormorant, long-tailed, f.	12-bore No.4 shot	neck and abdomen
B.3 Heron, purple, m.	- do -	neck and head
B.4 Cormorant, long-tailed, m.	- do -	head and abdomen
B.5 Darter,	caught under-water in fishing net	- - - -
B.6 Buzzard, Augur	12-bore SGG shot	head
B.7 Eagle, tawny, f.	.22 bullet	frontals

In each of these specimens serum collection was a failure either because clotting occurred rapidly within the blood vessels, or because, on withdrawal of the blood, haemolysis was found to have occurred already, and serum failed to separate either by cell sedimentation or centrifugal rotation. In specimens M.1 - M.4 a traumatic wrinkling of the aorta occurred, resembling that of a female dik-dik, collected in Africa, and examined and illustrated by Finlayson (1965, Plate XXIII). The explanation of the published illustration states: "Dik-dik; free-living. Segment of descending thoracic aorta to show the normal granular appearance of the fixed intimal surface." My observation is that this kind of "granular appearance" is neither normal, nor is it an artifact due to fixation, but a traumatic reaction of the elastic blood vessels, and especially the aorta, when an animal is killed by the impact of a large object which penetrates and lacerates the large blood vessels and does not kill instantaneously, e.g. as by a soft-nosed, expanding bullet, a spear, arrow or knife. It is to be distinguished from the intimal wrinkling in the aorta found in certain healthy, elderly mammals (e.g. the African elephant).

I have not observed any similar effects when using a solid bullet, fired into any part of the central nervous system where death was instantaneous; or in specimens killed by means of tranquilliser techniques. In all specimens collected later in the present project where special circumstances (such as the need for an emergency shot) required the use of a soft-nosed bullet (e.g. lion M.138), the same traumatic wrinkling of the aorta occurred, and the collection of serum was a failure.

In contrast, specimens M.5 - M.10 (warthog) were all killed by the Park Warden in the Queen Elizabeth National Park cropping scheme by means of a solid rifle bullet in the brain. Blood was successfully withdrawn from the heart by means of the steriseal hypodermic syringes brought for the purpose, but the vacuum venules were a failure, due to the fact that the vacuum had been lost during their transportation by air to East Africa. The serum was successfully separated by means of an electric centrifuge available at the field laboratories of the Nuffield Unit of Tropical Animal Ecology, Mweya, Uganda.

It was soon apparent that the kind of bullet used and its position of impact and penetration were important. In the next series, M.11 - M.47, therefore, further experimentation with each stage of the technique was carried out, and a procedure was developed which was effective within the limitations of the available collecting and freezing equipment. The simplified technique obviated the need for transportation to the carcass of both the bulky cylinders and the vehicle refrigerator, and allowed for local variations in the accessibility of reliable, temporary storage facilities for the frozen material.

Serum collection was not attempted in cases where the specimen was collected after accidental death on the roads (e.g. M.20 civet; M.68 genet; M.148 striped hyæna; M.151 aardwolf; M.147 lion); where blood collection could not be completed within 15 minutes of death (e.g. elephants M.85, M.132-135, M.99) or where any laceration of the large blood vessels had occurred due to the type of bullet used (M.138 lion; M.144 Galago).

Modified technique

The procedure, finally adopted in all cases where conditions permitted serum collection, was as follows:-

i) All serum apparatus was sterilised at base, prior to each safari, and sealed in individual polythene bags, which could be slit open at the carcass.

ii) Killing:-

a) for elephants: an angled, solid rifle bullet (cal. .375 or .450) was used, penetrating the brain via the temporal fossa, the orbital cavity, or the external acoustic meatus;

b) for buffalo, giraffe and ostrich: an angled, solid rifle bullet (cal. .375) was used, penetrating ~~laterally~~ through the withers to the spinal cord;

c) for other, soft-skinned mammals and birds: an angled, solid rifle bullet (cal. .375 or ~~and~~ .22) was used, penetrating the brain; and

d) for small mammals (dik-dik, galago etc) and birds: SSG, AAA, or No. 4 shot, in the head was used.

iii) Blood was allowed to spurt direct from an incision in the exposed jugular or femoral veins into 10 ml polythene specimen bottles (shoulderless, with hinged lid), or was canulated into the bottles through flexible polythene tubing. Steriseal syringes were used in the case of small mammals.

The blood bottles were then placed in the coolest and most secure place available. This was usually among grass or herbs near the trunk of a shady bush or tree, rather than in the vehicles where agitation and disturbance of the blood might occur.

When adequate serum had separated, it was drawn off into sterile polystyrene specimen tubes (containing no Sodium azide or other preservative) and placed immediately into the centre compartment of a 3-tier flask, containing ice blocks, brought from the base camp, in its upper and lower compartments. The separated serum of certain large mammals (e.g. zebra, giraffe, elephant) was found to clot, and it was necessary to keep a constant check on the progress of separation, so that the serum could be drawn off prior to clotting.

Failures in the collection of serum in the tropics may occur at any of a number of points in the procedure, and for this reason several attempts to collect serum samples were unsuccessful. The samples collected and frozen successfully, and subsequently dispatched to various laboratories, and details of the analysts' findings are indicated in Table 6 pp 129–132.

In one case where an apparently unusual order of result occurred, the analysis of serum from a comparable species of captive animal has also been included (i.e. urea m./Eq.l in jackal).

Since none of the wild animals used in the present study was examined alive, using dart tranquillisation techniques, and facilities in the field were inadequate either for the preservation of whole blood or for the performance of clinical procedures, no blood counts, haemoglobin tests etc. were done. Data from four captive elephants have therefore been appended as having relevance to the field data obtained for serum.

Analyses

Analyses already performed on the serum samples are as follows:-

a) Electrophoretic analyses on serum cholesterol and lipid fractions: Dr. W.G. Dangerfield, North Middlesex Hospital, London.

b) Standard clinical autoanalysis of serum contents: Dr. I.D.P. Wootton, Postgraduate Medical School of London, London, W.12. (Wootton 1964)

c) Standard clinical analysis of serum contents: Mrs. Von Vignau, by courtesy of Dr. A.M. Harthoorn, Physiology Department, Pre-clinical Veterinary School, Chiromo, Nairobi, Kenya. (Anon. 1964)

d) Detailed analysis of amino-acids in elephant serum: Dr. M.A. Crawford and Mr. J. Paterson, Department of Biochemistry, Nuffield Institute of Comparative Medicine, The Zoological Society of London, London. (Harper 1965; Varley 1965; Wootton 1964)

e) Detailed analysis of lipids in elephant serum: Dr. J.H. Moore, The National Institute for Research in Dairying, Shinfield, Reading.* An analysis of the lipids in the adrenal gland of one African elephant was also performed by Dr. Moore, for

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*Present address: The Hannah Dairy Research Institute, Ayr, Scotland.

comparison with the serum lipids(Moore & Sikes, 1966).

f) <u>Clinical examination of blood collected from living, captive elephants:</u>

i) collected by the author from "Sheila", Indian elephant, Belvue Zoological Garden, Belfast, by courtesy of the Director;

ii) collected from three elephants (two African and one Indian) ~~elephants~~ at the Gardens of the Zoological Society, London: Miss S. Hook, Nuffield Institute of Comparative Medicine, The Zoological Society of London.

("Sheila", f.,20 yrs. old; "Diksie, f. African, 27 yrs. old; "Toto", f. African, 5 yrs. old; "Laksmi" f. Indian, 12½ yrs. old).

In every case, the workers concerned expressed satisfaction with the quality of the serum delivered to them, although in some cases the quantity was inadequate for the complete range of analyses to be performed.

It is not appropriate for the author to discuss either the techniques used at the different laboratories, nor to discuss the findings in any detail, other than just to note the high serum urea levels in arid-adapted artiodactyles (eland, oryx, gerenuk and steinbok) and scavengers (hyena and jackal).

The analysis of essential and non-essential amino-acids in elephant serum by Dr. M.A. Crawford and Mr. J. Paterson, although as yet completed for only six of the available serum samples from the African elephants collected in this project, has indicated that the essential amino-acids probably of primary importance in this species are:-

Tryptophan
Phenylalanine
Lysine
Threonine
Valine
Methionine
Leucine
and Isoleucine.

Essential amino-acids probably of secondary importance may be:-

Arginine
Histidine
and Cystine.

On most of the Technicon auto-amino-acid analyser tracings four unidentified peaks occurred before the Aspartic Acid peak in females, and five in males, and another after Alanine in both sexes. No Proline was found in the samples examined from three African cow elephants, but it was present in that of the Asiatic cow elephant "Sheila".

Since it is not yet clear as to exactly which of the amino-acids are truly 'essential' to the normal nutritional requirements of the African elephant, it is not considered possible at present to attempt any interpretation of the rations of essential to non-essential amino-acids (see Table 7). It seems possible that Proline and Arginine may be essential in male, but not in female African elephants (Crawford 1966). An estimation of total amino-acids, in μ molecules/ml of serum, does however show a direct relationship to the nutritional status of the individual animal as observed alive and subsequently at autopsy.

For comparative purposes, an estimation of the amino-acid content of the blood serum of "Sheila", the Indian elephant destroyed in February 1966 at the Belvue Zoological Gardens, Belfast, was also performed, and it is apparent that, although the ratio of supposed essential to non-essential amino-acids indicated a balanced dietary intake, the total serum amino-acids in μ molecules/ml were extremely low, a finding consistant with other conclusions drawn at autopsy on the nutritional status of this elephant (Appendix 3).

In the case of the very elderly cow, specimen No.107, all the amino-acids represented were present in unusually low concentrations, a finding consistent with those on "Sheila". It is of note here that both "Sheila" and specimen No.107 were suffering from starvation rather than malnutrition, due to failure to masticate fodder adequately. In "Sheila's" case this was due to malocclusion resulting from a molar tumour; in the case of M.107 it was due to the completion, in extreme old age, of the normal course of molar eruption, resorption and fragmentation, so that the remaining molar surfaces were inadequate for effective mastication, and the quantity of food actually swallowed in a digestible state was severely limited.

The particularly interesting finding by Dr. J.H. Moore of appreciable concentrations of $\Delta^{8,11,14}$ eicosatrienoic acid in the serum cholesterol esters and phospholipid fractions of African elephant serum and adrenal gland, is fully discussed in the joint paper, now in press, of which the ms is appended (Appendix 5).

It is intended that in due course the remaining samples of elephant serum available in this collection should also be fully investigated, with the object of searching for any indications of a relationship to habitat type and naturally available nutrients.

Arrangements are already in hand (see ch.4,p.87) also to test all serum samples still available for Leptospira antibodies.

These tests are being undertaken by Dr.G.I. Twigg of Royal Holloway College, University of London, whose assistance and interest is greatly appreciated.

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Key to Serum Analysis Tables

i) Age groups

Juvenile)
Mature) all Orders except Proboscidea
Old)

Calf)
Juvenile)
Sub-adult) Proboscidea only
Prime adult)
Senior adult)
Senile)

ii) Habitat type

G - Uganda grassland. Queen Elizabeth National Park and environs; Semliki Plains, Murchison Falls National Park and environs.

S - Scrubland, low (under 5,000 ft altitude) Kenya

HS - Scrubland, high (above 5,000 ft altitude) Kenya

M - Montane - forested (above 5,000 ft altitude) Ruwenzori Mountains, Uganda; Kinangop, Satima, Kenya, Kilimanjaro Mountains, Kenya.

G/M - Grassland, montane. Transitional, Uganda

iii) Serum analyses

Groups (a) to (e) - see pp. 129-135

iv) Captive Zoo animals. (f). p. 136.

TABLE 6

ORDER AND SPECIES	Spec. Ref. No. m	f	Age Grp.	Habit. Type	Serum Coll.	Serum Analysis completed	Notes
ARTIODACTYLA							
Buffalo, cape	-	30	mat.	G	+	(b)	Tuberculosis
- do -	-	31	mat.	G	+	(b)	Tuberculosis
- do -	94	-	mat.	G	+	(a),(b)	Elaeophora poeli in aorta
- do -	97	-	old	G	+	(a),(b)	E. poeli in aorta
Eland	64	-	old	HS	+	(c)	-
- do -	-	106	mat.	HS	+	-	-
Gazelle, Thomson's	-	104	mat.	HS	+	-	-
Gerenuk	53	-	mat.	HS	+	(c)	-
Giraffe, Masai	-	54	mat.	HB	+	(b)	lactating
- do -	-	124	mat.	HS	+	-	preg.full-term
- do -	126	-	mat.	HS	+	-	-
Hartebeest, Jackson's	-	37	mat.	G	+	(b)	lactating
Hippo	-	26	mat.	G	+	(b)	-
- do -	27	-	mat.	G	+	(b)	-
Klipspringer	77	-	mat.	HR	+	-	
Oryx, fringe-eared	-	51	mat.	HS	+	(c)	lactating, parasites
- do -	66	-	mat.	HS	+	(c)	aortic plaques
Reedbuck	-	78	mat.	HR	+	-	pregnant
Steinbok	69	-	mat.	HS	+	-	-
Warthog	5	-	mat.	G	+	(b)	-
- do -	6	-	mat.	G	+	(b)	-
- do -	-	7	mat.	G	+	(a),(b)	-

ORDER AND SPECIES	Analyses: Group (a) LIPID T	α	β	CHOLESTEROL T	α	β	Analyses: Group (b) Cholesterol mg/100 ml	Na m.Eq/1	K m.Eq/1
ARTIODACTYLA									
Buffalo, cape	-	-	-	-	-	-	50	-	-
- do -	-	-	-	-	-	-	25	> 160	7
- do -	270	90	150	60	30	30	90	138	>7
- do -	520	140	390	31	8	25	100	141	56
Eland	-	-	-	-	-	-	25	161	6.6
- do -	-	-	-	-	-	-	-	-	-
Gazelle, Thomson's	-	-	-	-	-	-	-	-	-
Gerenuk	-	-	-	-	-	-	-	-	-
Giraffe, Masai	-	-	-	-	-	-	20	115	4.2
- do -	-	-	-	-	-	-	-	-	-
- do -	-	-	-	-	-	-	-	-	-
Hartebeest, Jackson's	180	60	110	55	31	24	70	>160	>7
Hippo	100	90	0	13	9	2	20	>160	>7
- do -	-	-	-	-	-	-	-	-	-
Klipspringer	- -	-	-	-	-	-	-	-	-
Oryx, fringe-eared	-	-	-	-	-	-	-	-	-
- do -	-	-	-	-	-	-	53	-	-
Reedbuck	-	-	-	-	-	-	-	-	-
Steinbok	-	-	-	-	-	-	-	-	-
Warthog	-	-	-	-	-	-	-	>160	> 7
- do -	-	-	-	-	-	-	-	>160	> 7
- do -	180	45	90	42	13	27	50	-	-

ORDER AND SPECIES	and (c) Cl. m.Eq/1	Urea mg/100ml.	Ca m.Eq/1	Mg m.Eq/1	PO_4 m.Eq/1	Total Protein g/100 ml	Alk. Phosph. K.A.	Bili-rub. mg%	SGOT SF	SGPT SF	A/G
ARTIODACTYLA											
Buffalo, cape	-	< 10	2.3	1.5	2.8	4.9	8	-	-	-	-
- do -	> 122	< 10	4.5	1.7	3.9	11.2	5	-	-	-	-
- do -	100	< 10	4.6	2.8	2.9	8.6	7	-	-	-	-
- do -	99	8	4.7	3.4	3.0	10	12	-	-	-	-
Eland	111	40	10.5	2.6	10.2	7.8	5	0.1	137	10	0.6
- do -	-	-	-	-	-	-	-	-	-	-	-
Gazelle, Thomson's	-	-	-	-	-	-	-	-	-	-	-
Gerenuk	-	63	-	-	-	-	-	-	-	-	-
Giraffe, Masai	> 122	< 10	7.0	2.2	2.6	13.0	15	0.1	74	15	0.5
- do -	-	-	-	-	-	-	-	-	-	-	-
- do -	-	-	-	-	-	-	-	-	-	-	-
Hartebeest, Jackson's	> 122	< 10	3.4	1.3	3.2	7.1	8	-	-	-	-
Hippo	> 138	< 10	5.1	2.7	5.7	10.2	5	-	-	-	-
- do -		< 10	7.0	2.3	5.7	11.4	10	-	-	-	-
Klipspringer	-	-	-	-	-	-	-	-	-	-	-
Oryx, fringe-eared	-	35	-	-	-	-	-	-	-	-	-
- do -	-	28	-	-	-	6.1	-	-	110	35	-
Reedbuck	-	-	-	-	-	-	-	-	-	-	-
Steinbok	128	47	10	-	6.7	5.1	10.6	-	57.5	37	-
Warthog	> 138	< 10	4.9	15	5.9	8.8	5	-	-	-	-
- do -	> 138	< 10	5.9	1.7	6.7	7.7	4	-	-	-	-
- do -	-	< 10	4.4	1.2	4.3	6.4	4	-	-	-	-

TABLE 6 (cont)

ORDER AND SPECIES	Spec. Ref. No. m	f	Age Grp. (i)*	Habit. Type (ii)*	Serum Coll.	Serum Analysis completed (iii)*	Notes	Analyses: Group (a) LIPID T	α	β	CHOLESTEROL T	α	β	Analyses: Group (b) and (c) Cholesterol mg/100 ml	Na m.Eq/1	K m.Eq/1	Cl m.Eq/1	Urea mg/100ml	Ca m.Eq/1	Mg m.Eq/1	PO_4 m.Eq/1	Total Protein g/100 ml	Alk. Phosph. K.A.	Bili-rubin mg %	SGOT SF	SGPT SF	A/G
Warthog	9	-	mat.	G	+	(a),(b)	-	180	60	120	50	18	33	25	-	-	-	<10	5.2	2.0	6.2	7.6	8	-	-	-	-
- do -	-	10	mat.	G	+	(b)	-	-	-	-	-	-	-	-	>160	>7	>138	<10	7.2	2.2	9.6	10.6	7	-	-	-	-
- do -	33	-	old	G	+	(b)	-	-	-	-	-	-	-	-	145	5.6	>138	<10	6.1	1.7	2.6	10	22	-	-	-	-
CARNIVORA																											
Fox, bat-eared	58	-	mat.	HS	+	(c)	-	-	-	-	-	-	-	-	-	-	-	-	-	2.6	-	5.4	-	-	-	-	0.6
Hyena, spotted	-	82	old	HS	+	(a), (b)		- 420	- 250	- 150	- 85	- 55	- 30	120 140	133 139	7.7 6.8	120 122	98 80	11.4 5.2	3.2 2.1	- 3.9	5.7 6.5	4 2	<01 -	100	98	0.4
Jackal, common	-	52	mat.	HS	+	(c)	-	-	-	-	-	-	-	-	-	-	-	30	-	-	-	-	-	-	-	-	-
(- do - (iv)*)	-	-	-	Zoo	-	(b)	-	-	-	-	-	-	-	290	151	5.0	119	27	5.0	1.8	2.3	6.8	2	-	-	-	-
Lion	39	-	Juv.	G	+	(a),(b)	bone abnormalities	310	120	160	110	40	60	70	>160	>7	>122	<10	4.7	1.6	3.7	10.6	1	-	-	-	-
- do -	56	-	mat.	HS	+	(b),(c)	-	-	-	-	-	-	-	95 90	240 >160	8.5 6.8	196 - >138	40 27 <10	9.4 9.6 4.8	2.0 1.9 1.7	8.5 8.1 3.9	6.6 6.5 6.9	4 3 2	<0.1 <0.1 -	17 22 -	2 18 -	0.4 0.5 -
- do -	-	57	old	HS	+	(c)	bone abnormals.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.6	-	-	-	-	0.5
Serval	65	-	mat.	HS	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	79	-	mat.	HR	+	(c)	-	-	-	-	-	-	-	15	194	8.6	-	140	-	-	-	5.5	5	-	115	63	-
HYRACOIDEA																											
Rock Hyrax	-	74	mat.	HR	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LAGOMORPHA																											
Hare	-	72	mat.	HR	+	-	found dying	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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TABLE 6 (cont.)

ORDER AND SPECIES	Spec.Ref. No. m	Spec.Ref. No. f	Age Grp. (i)*	Habit. Type (ii)*	Serum Coll.	Serum Analysis completed (iii)*	Notes	Analyses: Group (a) LIPID T	LIPID α	LIPID β	CHOLESTEROL T	CHOLESTEROL α	CHOLESTEROL β
PERISSODACTYLA													
Rhinocerus, black	128	-	mat.	HS	+	-	-	-	-	-	-	-	-
- do - , white	(iv)*	-	mat.	Zoo	-	(b)	-	-	-	-	-	-	-
Zebra	50	-	mat.	HS	+	(c)	-	-	-	-	-	-	-
- do -	-	67	mat.	HS	+	(a)(b)(c)	pregnant	-	-	-	-	-	-
								210	120	90	46	25	13
PRIMATES													
Chimpanzee	98	-	old	G/N	+	-	Atheroma	-	-	-	-	-	-
- do -	-	102	juv.	G/N	+	-	-	-	-	-	-	-	-
PROBOSCIDEA (***)													
RODENTIA													
Spring Hare	76	-	mat.	H/E	+	-	-	-	-	-	-	-	-
BIRDS													
Bustard, greater	-	B.23	mat.	HS	+	(c)	-	-	-	-	-	-	-
Ostrich	B.25	-	mat.	HS	+	(c)	-	-	-	-	-	-	-
Stork, saddlebill	-	B.20	mat.	G	+	(a),(b)	-	160	60	90	80	50	30

ORDER AND SPECIES	Analyses: Group (b) and (c) Cholesterol mg/100 ml	Na m.Eq/l	K m.Eq/l	Cl m.Eq/l	Urea mg/100 ml	Ca m.Eq/l	Mg m.Eq/l	PO_4 m.Eq/l	Total Protein g/100 ml	Alk. Phosph. K.A.	Bili-rubin mg %	SGOT SF	SGPT SF	A/G
PERISSODACTYLA														
Rhinocerus, black	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do - , white	80	134	-	93	32	-	-	-	11.0	4	-	-	-	-
Zebra	-	-	-	-	25	-	-	-	6.8	15	<0.1	195	18	0.4
- do -	104	187	8.0	98	25	11.8	2.3	7.8	7.4	12	<0.5	240	17	-
	150	135	5.0	108	16	6.2	2.8	2.2	8.1	15	-	-	-	
PRIMATES														
Chimpanzee	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PROBOSCIDEA (***)														
RODENTIA														
Spring Hare	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BIRDS														
Bustard, greater	-	-	-	-	24	-	-	-	-	-	-	-	-	-
Ostrich	-	-	-	-	10	-	-	-	-	-	-	-	-	-
Stork, saddlebill	100	167	>7	>138	<10	5.1	2.3	5.5	10	11	-	-	-	-

(*) see Key List
(***) see separate list

TABLE 6

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ORDER AND SPECIES PROBOSCIDEA	Spec.Ref. No. m	f	Age Grp. (i)*	Hab. Type (ii)*	Serum coll. (iii)*	Anal. compl.	Notes	Analyses: Group (a) LIPID T	α	β	CHOLESTEROL T	α	β	Analyses: Group (b) and (c) Cholesterol mg./100 ml	Na m./Eq/1	K m./Eq/1	Cl m./Eq/1	Urea mg/100 ml	Ca m./Eq/1	Mg m.Eq/1	PO_4 m./Eq.1	Total Protein g/100 ml	Alk. Phosph. K.A.	Bilirubin mg %	SGOT SF	SGPT SF	A/G
Elephant, African savannah	-	114	Calf	S	+	(d)	-	=	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	113	-	juvenile	S	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	-	100	sub-adult	M	+	(b)	lactating	-	-	-	-	-	-	90	113	6.6	<82	25	5.5	4.9	2.7	12.6	6	-	-	-	-
- do -	83	-	sub-adult	M	+	(a,b,e)	-	200	30	160	31	8	23	60	115	4.5	82	32	6.9	2.1	1.7	8.5	6	-	-	-	-
- do -	-	112	pr.adult	S	+	-	lactating	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	87	-	pr.adult	G	+	-	aortic Calcium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	149	-	pr.adult	S	+	(e)	septic tusk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	150	-	pr.adult	S	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	-	88	pr.adult	G	+	(b),(e)	lactating; aortic Ca. ~~aortic Calcium~~	=	=	=	=	=	=	100 37	125 137	7 7.0	82 107	33	5.5 12.9	3.5 3.4	3.5 6.6	10.8 7.1	6 8	- -	- 40	- 10	- -
- do -	152	-	pr.adult	M	+	(b,c,d,e)	-	-	-	-	-	-	-	170	126	6.6	93	35	5.9	2.9	2.9	7.6	7.2	-	-	-	-
- do -	93	-	snr. ad.	G	+	(a,b,e)	advanced aortic Calcium	110	36	80	11	6	4	40	-	2.4	-	<10	1.8	0.7	0.9	3.4	2	-	-	-	-
- do -	120	-	snr. ad.	S	+	(d)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	108	-	snr. ad.	S	+	(d)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	116	-	snr. ad.	S	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	86	-	snr. ad.	G	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	121	-	snr. ad.	S	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	-	122	snr. ad.	S	+	(d)	lactating	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do -	-	107	senile	S	+	—	—	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elephant, "Dikzie" (African) (iv)*	-	f	pr.adult	(Zoo)	+	(f)	nephritis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
- do - , "Toto"	(iv)*	f	juvenile	(Zoo)	+	(f)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elephant, "Lakzmi" (Indian)	(iv)*	f	adult	(Zoo)	+	(f)	-	-	-	-	-	-	-	75	133	-	96	29	6.1	1.8	-	8.2	12	-	-	-	-
- do - "Sheila"	(iv)*	f	pr.adult	(Zoo)	+	(f)	malocclusion; malnutrition	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(*) see Key List

TABLE 7.

GROUP (d): ANALYSIS OF AMINO-ACID COMPOSITION: ELEPHANT SERUM

AMINO-ACID µmole/ml	SPECIMEN NUMBER: Females				Males		
	114	122	107	"Sheila" (iv)*	152	108	120
Cysteic		–	–	–	–	–	–
Urea		–	–	–	–	–	–
Aspartic		+	–	0.06	0.16	0.08	0.10
Threonine (E)**		0.19	0.04	0.29	0.30	0.11	0.12
Serine		+	0.02	–	0.07	0.29	0.40
Homoserine		–	–	+	–	+	–
Glutamic		0.10	0.08	0.03	0.35	0.07	0.15
Proline	–	–	–	0.11	0.26	0.49	0.45
Citrulline	–	+	–	+	–	–	+
Glycine	0.23	0.26	0.14	0.16	0.43	0.24	0.26
Alanine	0.13	0.21	0.07	0.15	0.30	0.24	0.27
αNH_2Butyric	–	–	–	–	–	–	–
Valine (E)	0.14	0.25	0.09	0.14	0.27	0.17	0.17
Cystine	–	+	–	–	+	–	–
Methionine (E)	–	+	–	–	+	–	–
Isoleucine (E)	–	0.08	–	0.06	0.07	0.06	0.02
Leucine (E)	0.84	0.17	0.03	0.11	0.15	0.09	0.06
Norleucine	–	–	–	–	–	–	–
Tyrosine	0.04	0.08	0.02	0.04	0.12	0.06	0.06
Phenylalanine (E)	0.05	0.10	0.04	0.07	0.09	0.07	0.12
γNH_2Butyric	–	–	–	–	–	–	–
Ethanolamine	–	–	–	–	–	–	–
Ammonia	–	+	–	–	–	–	–
Ornithine	+	0.2	+	+	+	+	+
Lysine (E)	0.10	0.11	0.04	0.08	0.12	0.09	0.13
Tryptophan (E)	+	+	+	–	+	–	+
Histidine	0.01	0.06	0.03	0.04	0.07	0.06	0.06
Arginine	+	–	–	0.12	0.06	0.02	0.06
Total amino-acids	–	1.81	0.60	1.46	2.82	2.14	2.43
Tot.essent. amino-ac. (excl. Proline) (E)	–	0.90	0.24	0.75	1.00	0.59	0.62
Tot.non-essent.am-ac. (incl. Proline)	–	0.91	0.36	0.71	1.82	1.55	1.81
Ratio	–	1.0	0.7	1.1	0.5	0.4	0.3
Tot.essent.amino-ac. (incl. Proline): bulls only (E)	–	–	–	–	1.26	1.08	1.07
Tot.non-essent.am-ac. (excl. Proline) bulls only	–	–	–	–	1.56	1.06	1.36
Ratio	–	–	–	–	0.8	1.0	0.8
Tot.essent.amino-ac. (incl. Proline, Histidine, Arginine): bulls only (E)	–	–	–	–	1.39	1.16	1.19
Tot.non-essent.am.-ac. (excl. Proline, Histidine, Arginine): bulls only	–	–	–	–	1.43	0.98	1.24
Ratio	–	–	–	–	1.0	1.2	1.0

NOTES: Females: 4 unknown peaks on tracings
Males: 5 - do -
Specimen (f)114: analysis incomplete
+ trace present
**(E): Essential Amino-acid (H. sapiens)

TABLE 8

GROUP (e): ANALYSIS OF LIPIDS IN ELEPHANT SERUM AND ADRENAL GLAND

(I) Plasma Lipids (% of total plasma lipid)	Specimen Ref. Nos. females M.100 (L)*	M.88 (L)*	males M.83	M.152	M.93
Cholesterol	8.5	8.0	8.7	6.9	8.7
Cholesterol ester	38.0	36.9	39.4	36.0	40.3
Triglyceride	13.9	13.7	10.2	16.7	11.7
Phospholipid	34.8	36.6	37.0	35.6	34.6
Unesterified fatty acid	4.8	4.7	4.8	4.8	4.7
(II) Plasma Lipids (mg/100 ml plasma)					
Total lipid	208	210	177	280	225
Total cholesterol	64.6	62.8	56.8	79.1	73.4
Esterified cholest.	46.9	46.0	41.4	59.8	53.8
Free cholesterol	17.7	16.8	15.4	19.3	19.6
Triglyceride	28.9	28.8	18.1	46.8	26.3
Phospholipid	72.4	76.9	65.5	99.7	77.9
Unesterified	10.0	9.9	8.5	13.4	10.6

*(L) Lactating

TABLE 8 (cont)

GROUP (e): ANALYSIS OF LIPIDS IN ELEPHANT SERUM AND ADRENAL GLAND

(III) Adrenal Lipids (% of total lipid)	Specimen Ref. No. male M.149
Free cholesterol	4.3
Cholesterol ester	47.7
Triglyceride	4.7
Phospholipid	43.3

(IV) Adrenal Lipids (g/100 g dry tissue)	
Total lipid	63.1
Total cholesterol	20.6
Esterified cholesterol	17.9
Free cholesterol	2.71
Triglyceride	2.96
Phospholipid	27.3

TABLE 9.

GROUP (f) : CLINICAL EXAMINATION OF WHOLE BLOOD OF LIVE CAPTIVE ELEPHANTS

	African elephants		Asiatic elephants	
	"Diksie"	"Toto"	"Sheila"	"Laksmi"
R.B.C.(million/cmm)	3.8	3.0	3.2	2.9
W.B.C.(1000/cmm)	9.6	12.7	12.9	9.9
Hb.(%)	114	82	98.5	80
P.C.V. (%)	51	36	43	38
Platelets (1000/cmm)	453	597	329	-
M.C.V. (μ^3)	133	117	136	130
M.C.H.(μug)	44	40	46	41
M.C.H.C. (%)	33	34	33	31
Reticulocytes (%)	0.1	0.6	0.2	-
DIFFERENTIAL				
Neutrophils(%)	35	39	39	39
Lymphocytes(%)	50	44	46	55
Monocytes(%)	13	14	16	5
Eosinophils(%)	2	3	0	1
Basophils(%)	0	0	0	0
E.S.R.(wintrobes) (mm in one hour)	9	45	31	-
Blood Sugar(mg/100ml)	40-65	65-130	90-130	-
M.C.D. (μ)	-	9.6	8.5	9.27
M.C.F.	-	-	-	-
Illness or Injury	nephritis	anaemia	malocclusion	—

Chapter 6

Examination of Cardiovascular Material

This chapter contains the results of the examination of the cardiovascular material and data collected during the project from all species other than elephant.

Section A (pp 137 - 139):

Difficulties encountered over the use of the word 'susceptible' (p. 7) in relation to freeliving wild animals in their natural environment arose early in the course of the field work. Other difficulties were encountered over the terminology for describing the detailed internal arterial anatomy of so wide a range of wild animal species, due to the paucity of published accounts on this type of comparative study. To meet this need, it has been necessary to coin some new descriptive termes.

Section B (pp 140 - 144):

A general note on the naturally occurring supportive thickenings encountered in the arterial wall.

Section C (pp 144 - 218): follows the same order of species as used in Tables 3 and 4 (pp 66 - 77) and gives details of the cardiovascular findings, species by species.

Section D (Table 10, pp 219 - 222): summarises the 'susceptibility' of the wild animals examined, compared as nearly as possible with captive animals in taxonomically equivalent groups.

Section E (pp 226 (a) and (b): highlights the more significant observations, but since this chapter and the cardiovascular findings in elephant (Vol.II, ch.11) are interdependent, the combined results are reviewed in the Discussion, Vol.II, pp 555 - 575 and in the Summary, Vol.II, pp 576 - 582.

Chapter 6

Examination of Cardiovascular Material

A Technique for mounting, measuring and describing the aortae

In ch. 2, Materials and Methods, pp 27 – 42 the routine autopsy procedure adopted for the dissection and on-site treatment of cardiovascular material was described, and it was emphasised that in the case of mammals, the aorta was severed from the heart while still in situ in the carcass (p.35 (c), followed by the removal of aorta and heart separately.

There were two main reasons for adopting this procedure: first, it considerably reduced the risk of over-stretching the aorta during its removal from the carcass and subsequent washing; secondly, it was thought better to have a uniform technique for dissecting, mounting, measuring and describing the aorta in all species studied, rather than adopting one method for elephant and rhinoceros, and another for all other species. In the case of adult elephant it is not usually practicable or advisable to extract the heart with the whole aorta attached owing to the bulk and weight of the heart, and the consequent risk of damage to the aorta.

Moreover, in the elephant, the aortic arch resembles a primitive truncus arteriosus and is so large and elastic that it is inconvenient to mount it on polythene boards in the same way as the aorta proper.

In all mammals, therefore, the aortic arch was left attached to the heart, (care being taken to deter assistants from lifting it by putting the fingers or a hook of the weighing scale into the cut end of the aortic arch and brachiocephalic trunks) and preserved with it intact, after making the exploratory incisions described in ch. 2 p 37 (f). The aorta was mounted by means of staples on polythene boards, with the internal surface uppermost, as described in ch.2,p 36-37 (e), and preserved in plastic tanks or bins in 10% formol-saline.

At the laboratory, all the fixed aortae were soaked in tap water for about 30 minutes and then immersed on their mounting boards first in 70% alcohol for 20 minutes; and then in Sudan IV stain (20 mins), and finally differentiated in 80% alcohol. Large rectangular glass tanks were used at each stage in this procedure.

A scale drawing of the stained, mounted aorta was then made on squared paper by means of a mechanical drawing arm, and the areas stained red by the Sudan IV indicated on the drawing. The drawing of the aorta was then marked off into five equal successive portions from the proximal (anterior) end - i.e. at the line of severance from the aortic arch running through the scar of the ductus arteriosus - to the bifurcation, described as portions I - V respectively. Each portion was then marked off longitudinally into four equal portions, namely the 'dorsal', 'right lateral', 'left lateral' and the two halves of the 'ventral'. The area containing lipid or other lesions could thus be measured and described according to a standard formula. In practice, in this project, the technique was only fully developed in the case of the elephant aortae, where quantitative area counts were made to estimate separately the intra-aortic distribution of lipid and Calcium deposits in the aortic wall.

The method is of somewhat limited value in the case of very small aortae (e.g. the mole-rat, M.81), but even in these its extended use by enlarging the scale of the drawings could be valuable for a comparative analysis of normal internal aortic anatomy in different species, as well as of intraspecific variations.

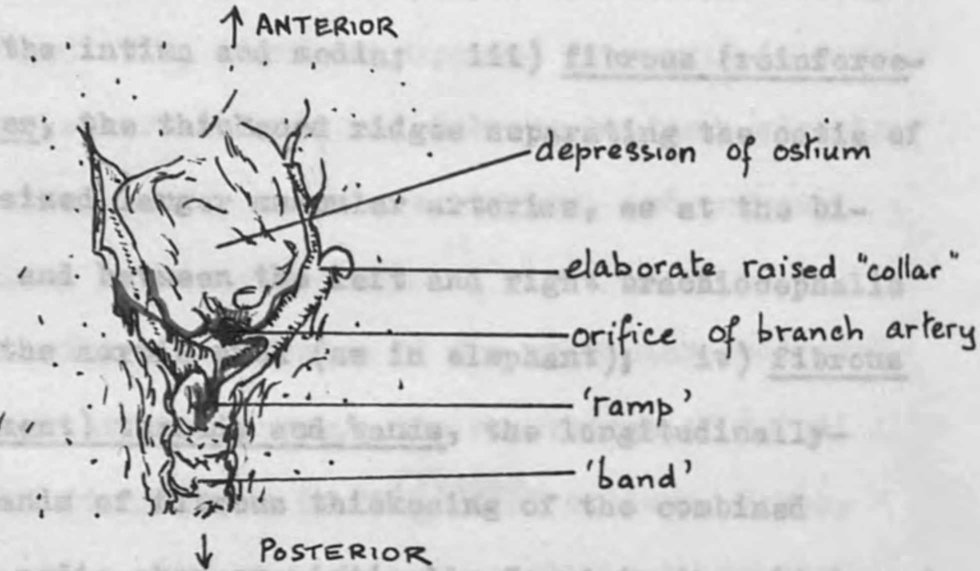
B. Naturally occurring, anatomical thickening of the arterial wall

As the presence of small amounts of lipid in the intima of the arterial wall surrounding the ostia, both large and small, of branch arteries of both the aorta and the muscular arteries was found to be almost universal, a search was made for published descriptions of the anatomy of the ostia. Such descriptions are remarkably few.

Luginbühl, Jones & Detweiler (1965) referred to these and stated that :"The fibrous and fibro-elastic tissue was often arranged in a laminated manner in the intimal caps at the sites of vascular orifices". Conti (1953) referred to them as "cushions". Finlayson (1965) stated *inter alia*: "Some of these thickenings are closely related to vessel ostia and branchings; others, not so related, appear to be so regularly sited that it is difficult to escape the conclusion that they are basically anatomical.... Histologically, these intimal thickenings usually include collagen and elastic fibres, smooth muscle cells and mucopolysaccharide ground substance. The underlying internal elastic may or may not appear fragmented....The primary function of such thickenings may be largely supportive and mechanical."

This conclusion accords with the findings of the present field survey, in which the anatomy of the internal surface of the normal aorta has been examined on a comparative basis in a wide range of species.

As will be shown, it has become evident during this survey that: i) such supportive thickenings of the aortic wall apparently occur at the ostia of all branch arteries of the aorta and muscular arteries; ii) that the actual structure and possible mode of functioning of these ostial thickenings is characteristic for each species; iii) that the position and number of ostia, and the degree of sharing of ostia by neighbouring branch arteries, has a basic, characteristic arrangement in each species, although there is considerable room for intraspecific variation as to detail; iv) that a distinctive pattern of fibro-muscular and fibro-elastic threads and bands occurs in the combined intima and media of the walls of the aorta and muscular arteries, which is characteristic for each species; and v) that the ostial thickenings and fibrous ridge patterns may be functionally adapted to the peculiar haemodynamics of animals with highly specialised habits, of which the hippopotamus and the klipspringer are more extreme examples.



Elaborate ostium of an intercostal artery originating in Portion I of a hippo aorta (sudanophilic lipid shown in red) — internal aspect of aorta.

In a recent paper (Appendix 4 ; Sikes, in press) I referred to the ostial thickenings of elephant as "reinforcement plaques". This term was subsequently found, however, to be inadequate to describe the different types of normal supportive thickening which may be encountered in a single aorta, and in this chapter the following terms have been used to allow greater descriptive scope for differentiating between them: i) ostial collars, namely the thickened part of the ostium partially or wholly enclosing the ostial cavity; ii) ostial ramps, the distal slope of the ostial collar, usually tapering away gradually to merge imperceptibly with the normal fibrous tissue of the intima and media; iii) fibrous (reinforcement) ridges, the thickened ridges separating the ostia of two equal-sized larger muscular arteries, as at the bifurcation, and between the left and right brachiocephalic trunks in the aortic arch (as in elephant); iv) fibrous (reinforcement) threads and bands, the longitudinally-oriented bands of fibrous thickening of the combined intima and media characteristically found in the mid-dorsal line, but also recognisable and sometimes very prominent and specific as a general surface pattern in the anterior portion (portion I) of the thoracic aorta. In all the species studied, these normal collrs, ramps, ridges, bands and threads tend to become less regular and more prominent in old age, a condition perhaps associated with senile loss of elasticity.

Finlayson (1965) pointed out that foci of hyperplasia based on normal supportive anatomical thickenings of the aortic wall may be induced by excessive mechanical forces such as a build-up of fluid pressures within the vessel lumen, or a weight increase of tissues attached to the outside of the vessel. Such persistent hyperplasia and degenerative changes accompanied by lipid infiltration and accumulation, and reparative processes adding to the bulk of the damaged area, might be expected to result in the formation of abnormal fatty and fibrous buttons, streaks, plaques, haemorrhagic lesions, aneurysms, and osseous metaplasia.

In describing the aortae of the specimens collected in the course of this survey, the occurrence of normal amounts of intimal lipid in the fibrous ostial collars, ramps, and ridges, is regarded as in no way abnormal, as its occurrence in these sites was almost universal. The absence of any lipid from these sites appears to be the exception rather than the rule.

The order of species used in this chapter follows that of the Species Lists, pp 66 - 77

C. ARTIODACTYLA

Buffalo

Eight buffaloes, 6 males and 2 females, all obtained in Uganda, were examined. Of these, two males were collected in the environs of the Murchison Falls National

Park, two females in the Queen Elizabeth National Park, and four males in the Kigezi Reserve bordering the Ishasha area of the Queen Elizabeth National Park.

In mature, full-grown bulls (body wight 600 - 700 kg, height at withers >140 cm) the aorta was 75 cm long and 9.5 to 6.0 cm wide (mean fixed size). Mean heart weight was 3.25 kg in mature males and 2.85 kg in mature females (fresh weight). The only two females collected were both very emaciated, a condition associated with chronic pulmonary disease, resembling that described by Thurlbeck _et al_. (1965).

All eight specimens were infected with the Filariid worms _Elaeophora poeli_ and/or _Onchocerca armillata_, of which the former had settled in the intima of the aorta and the latter burrowed into the arterial walls via the tunica adventitia. The latter was found in the eight specimens examined, in varying concentration in all parts of the aorta, iliac arteries, femoral arteries, and brachial, carotid and coronary arteries. It is thus impossible to provide a description of the normal aorta, based on the specimens collected in the present study. The same is true of the hearts, as not one of these was parasite-free, and in the case of M.30 the heart was also very large,pale and flaccid.

The aorta is shown in FIG. 2 p 151 and it is of note that the general proportions show more resemblance to that of the elephant than the hippopotamus; in general it resembles that of most of the savannah antelope studied. As in the other species examined, individual variations occurred in the detailed arrangement of the ostia of the branch arteries, and of the arteries originating at or near the bifurcation. The bold, raised pattern of fibro-muscular ridges characteristic of the internal surface of the hippo aorta is lacking in buffalo, but faint longitudinal strands and depressions can be seen in older animals. The scar of the ductus arteriosus is smaller in proportion than in the hippopotamus.

The infestation with the Filariid worms mentioned above, and described in ch. 4, p 84 , renders any attempt to distinguish spontaneous lesions quite impossible. Where Elaeophora poeli is present, ulceration of the intima occurs, penetrating deep into the media. Microfilariae escape into the surrounding tissues and make their way back to the aortic lumen or into the vasa vasorum. The elastic fibres and other tissues of the aortic media degenerate, and in some cases ulcers progress to form ~~an~~ aneurysms. In others, calcification of the medial tissues occurs, while the intimal epithelium proliferates to form an irregular covering plaque about 0.5 to 1.5 cm diameter.

An advanced aneurysm was found just proximal to the level of the scar of the duct.art. in specimens M.15 and M.96, and just distal to it in M.30.

It was noted that specimens M.96 and M.97, which had four and five settled females of E. poeli respectively in the aortic arch, also possessed the heaviest hearts (3.95 and 3.5 kg respectively) of the 8 buffaloes examined.

The presence of Onchocerca armillata had caused degeneration of the elastic lamellae of the tunica media of the arteries. This is illustrated in Plates V and VII , pp 102 and 106 . The outlines of the tortuous burrows on the intimal surface of the aorta were clearly visible to the naked eye and quite distinct from the normal wavy, fibro-muscular bands described in older elephant and buffalo aortae (see Plate XIV p.240)

Mineral deposition, and the eventual extensive calcification of the media, usually on or adjacent to, the internal elastic lamella, is frequently seen. In specimen M.13 (apparently a very elderly animal), about 7.5 cm of the right external iliac artery was brittle with a 'honeycomb' of calcified plaques, resembling those seen in some elephants (see Plate XXII p 254). The lumen of this vessel was considerably reduced. This buffalo had been noted as being lame before it was collected. The partial occlusion described here was possibly the cause of the lameness; in the internal iliac a raised, grey, ulcerating plaque, about 0.6 to 1.8 cm wide, was also found, but no other lesions were seen in the right hind leg.

Sudanophilic material was present in all areas containing worms or their burrows, in both the aorta and the muscular arteries, including the coronary arteries. In no case were worms or burrows found to have pentrated the coronary arteries beyond a distance of 4 cm from the coronary opening in the aortic sinus.

In M.94 the aortic sinuses were riddled with burrows extending into both coronary arteries, both of which had somewhat constricted openings; there was a ridge of nodules and burrows just above the opening of the left coronary artery. The author is not aware of any existing descriptions of the death of buffalo in Uganda which was shown at autopsy to have been due to cardiac failure, but it seems reasonable to suppose that a heavy parasite burden within the coronaries could in due course result in infarction and terminal cardiac failure.

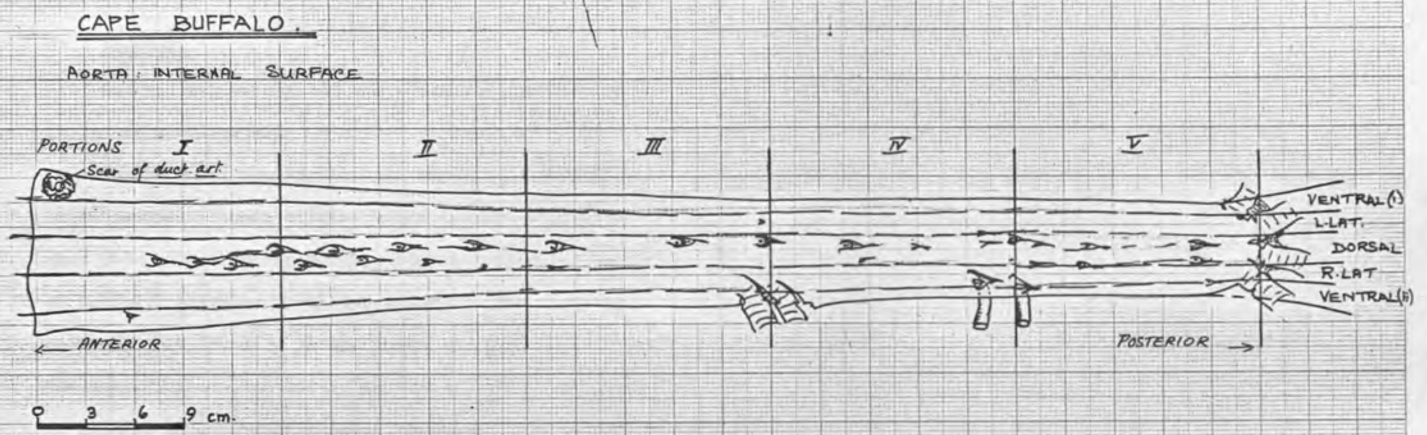
Another characteristic feature of aortae heavily infested with O. armillata was damage to the intima. The worms apparently fray this from time to time, and it was comparatively common to find collagen fibres extruding freely through the aortic intima into the lumen. These were only clearly visible using optical magnification greater than 100. Fibrinous tags on the epicardium and pericardium appeared to be associated with the Filariid infestations, being more abundant in the animals with a heavier parasite burden (Lapage 1962). These fibrinous tags appear as pink, characteristic masses at autopsy (see Plates X and XI pp 230 and 232).

Field data

Spec.No.	Sex	Body wt. kg	Length* cm	Height** cm	Heart wt. g	Notes
M.97	m	700	295	153	3,500	5 E.poeli units in aortic arch
M.95	m	622	300	150	3,400	1 scar of E. poeli
M.96	m	–	292	150	3,950	4 E.poeli units in aortic arch
M.15	m	–	310	145	2,940	heart riddled w. parasites & parasitic lesions
M.94	m	575	282	140	2,920	
M.13	m	–	295	130	2,800	heart shaggy
M.30	f	396	292	145	2,920	heart enlarged; pale; flaccid
M.31	f	360	278	145	2,780	heart shaggy; valves thickened

* Straight measurement: nose-tip to tip of tail dock [p. 31(a)]
** Straight measurement to withers. [p. 32(c)].

FIG. 2.


CAPE BUFFALO.
AORTA: INTERNAL SURFACE
PORTIONS
I
II
III
IV
V
Scar of duct. art.
VENTRAL (i)
L.LAT.
DORSAL
R.LAT
VENTRAL (ii)
ANTERIOR
POSTERIOR
0
3
6
9 cm.

Bushbuck

One elderly male(M.12) and one young pregnant female (M.14) were collected.

In the male, the coeliac and anterior mesenteric arteries had a common origin, but no other abnormalities were seen either in the aortae, hearts, or other samples of muscular arteries in either animal. Both had small intimal lipid deposits in the ostial collars and ridges. The superficial veins of the male were dark and knotty as in all the elderly male animals examined.

Field data

Spec. No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.12	m	90	162	84	380	
M.14	f	-	130	74	-	pregn.

Dikdik

Only one dikdik was examined, a mature male, M.49. It showed no unusual cardiovascular features, possessing normal lipid deposits around the ostia of branch arteries, and showed no ~~other~~ abnormalities.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.49	m	5	66	38	49	

Eland

Three specimens were collected: one elderly bull (M.64), one mature cow (M.129) and one well-grown, but sexually immature cow (M.106).

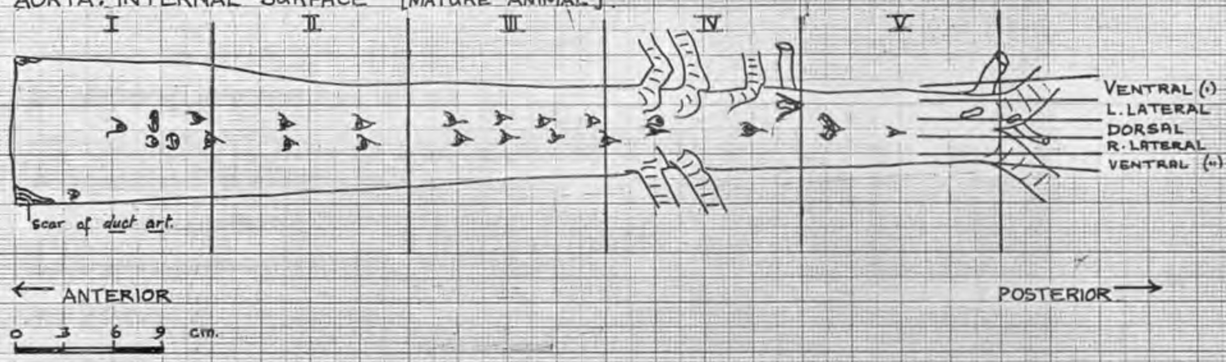
The aorta is illustrated in FIG. 3 p 154. No structural peculiarities were noted, and in general the heart and aorta resemble those of the buffalo. The ostial collars and reinforcement ramps are not large or prominent, although clearly recognisable, and there is no evident patterning of the intimal surface. In all these specimens, sudanophilic material was present in the customary position in the ostial collars and ramps of the aorta and coronary arteries. The scar of the duct.art. was lozenge-shaped, its longer axis lying in the longitudinal axis of the aorta.

No abnormalities were seen in any of the hearts of the

FIG. 3.

ELAND.

AORTA: INTERNAL SURFACE [MATURE ANIMAL].



NOTES:
1. THICKNESS: 7·80 — 1·0 mm.; WIDTH: 9·0 — 4·0 cm.; LENGTH: 55—60 cm. [AS MOUNTED, FIXED IN 10% FORMALIN].
2. PATTERN: NO PROMINENT PATTERN
3. OSTIA: ROUNDED; COLLARS & REINFORCEMENT PLAQUES PRESENT, BUT INCONSPICUOUS.
4. COELIAC, ANT. MESENTERIC, & RENAL ARTERIES ALL ORIGINATE IN PORTION IV.
5. SUDANOPHILIC MATERIAL: PRESENT IN INTIMA WITHIN OSTIA & ON OSTIAL COLLARS OF ALL SPECIMENS COLLECTED; ARRANGEMENT REGULAR.

three eland. In the aorta of the elderly male, M.64, however, a single, long fatty streak 5 cm x 0.5 cm in size was noted in the ventral line of the aorta, just anterior to the coeliac artery (see Plate XV(b) p 242). The micrograph shows that the intima was thickened, and contained lipid deposits. A similar plaque on the abdominal aorta of a Malayan tapir was described and illustrated by Chaikoff & Lindsay (1963). No other cardiovascular abnormalities were seen in these three specimens.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.64	m	710	320	160	3850	
M.129	f	-	-	-	1700	
M.106	f	190	230	140	1200	immature

Gerenuk

Four gerenuk were collected, two males (M.53 and 111) and two females (M.60 and 61). The male M.53 was elderly.

The typical aorta is illustrated in FIG. 6 p 176 and has features which may best be understood by comparison with that of the steinbok and the klipspringer, both of which typically inhabit rocky hill sides and, like the gerenuk, frequently assume a vertical posture. This habit is least marked in the steinbok and most marked in the klipspringer. The gerenuk, although associated with a certain type of vegetation essentially belonging to rocky terrain in arid and semi-arid habitats, is not necessarily a hillside dweller. It does, however, customarily assume a goat-like, bipedal vertical stance when browsing off high branches, and even in its normal quadrupedal stance its head is held high, the back sloping towards the withers. The chamois-like stance and habits of the klipspringer are discussed on pp. 174-177.

In all three species, the anterior dorsal ostia are clearly paired, shaped like narrow slits and slanted diagonally across the longitudinal axis of the aorta. In the gerenuk, this shape and position characterises the paired ostia of all the intercostal arteries, while in the steinbok only the first two pairs are affected. In the klipspringer, all the paired ostia of the intercostal arteries are narrow and slanted, and in addition are reduced in number. In all the gerenuk collected, the renal arteries had a common origin in the aorta, while in the klipspringer the coeliac and the anterior mesenteric arteries also had a common origin. In both steinbok collected, these four arteries had separate origins in the aorta.

The ostia of all the branch arteries of the aorta of the gerenuk were characterised by the exaggerated cup-like shape of the ostial collars, although in this species the ramps were indistinct. The extreme development of this arrangement seen in the klipspringer is illustrated in FIG. 6 p 176 and discussed on p 177

Only traces of normal lipid deposits could be detected in the ostial collars of the three younger gerenuk (M.111, M.60 and M.61), but in the elderly male they were more extensive and very distinct at the origins of the coeliac and anterior mesenteric arteries, and on the ridges of the bifurcation. An area of some 2 cm x 1.5 cm between the common origin of the renal arteries and the second pair of dorsal collateral arteries contained lipid deposits in the slightly thickened intima. Traces of sudanophilic material also occurred in the intima of the ostial collars and ramps of the coronary arteries and at the carotid bifurcation. The heart, like that of the giraffe, showed high muscle tonus and had a very pointed apex.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.53	m	41	182	93	311.6	
M.111	m	-	-	-	-	
M.60	f	28	180	84	-	
M.61	f	28	180	79	247.7	

Gazelle, Grant's

Two males, M.2 and M.59, were collected, of which the latter was elderly, having very large, heavily ringed horns and a grey face and muzzle, and knotty varicose veins on the heart, testes and alimentary canal. The hearts and aortas showed no unusual features and contained intimal lipid in the normal position in the ostial collars.

The right ventricle of M.59 was unusually pale in colour, but no necrotic tissue could be located suggesting infarction, and no occlusive plaques were located in the right coronary arteries. The usual lipid distribution in the ostial collars and ridges was noted, but no sclerotic areas or undue thickening was seen. Parasitic worms, collected from the mediastinum and pericardium, were identified as Setaria sp. (see ch. 4, p 90) Fibrous shaggy tags on the pericardium in both specimens and on the epicardium of M.2 are supposedly associated with the presence of Setaria sp. (Lapage 1962).

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.2	m	78.5	166	93	-	
M.59	m	72	163	83	680	

Gazelle, Thomson's

Only one male Thomson's gazelle was collected for study, M.104. It was apparently healthy and normal in all respects and contained intimal lipid deposits in the usual sites in the ostial collars and ridges of the aorta, coronaries and other muscular arteries.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.104	m	23	114	61	175.5	

Giraffe

Four specimens were examined: one was an elderly, senior herd bull which carried scars of a previous encounter with lion (M.126); one a lactating cow, whose calf was not found in the vicinity (M.54); and one a cow carrying a full-term foetus (M.124). It was noted that this cow was under considerable stress at the time it was first seen, and moved very slowly, lagging far behind the herd of 29 giraffe to which it belonged. The foetus was the fourth specimen examined (M.125).

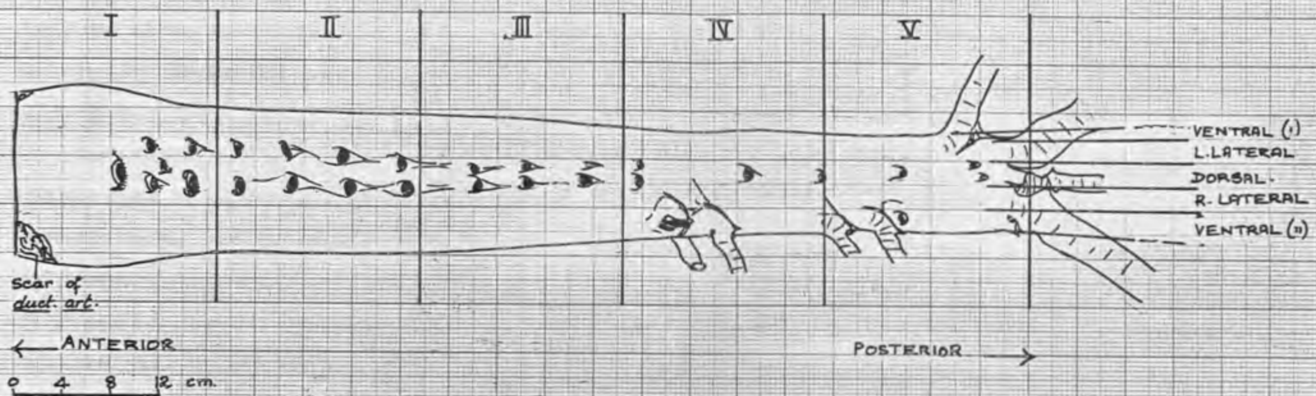
The aorta is illustrated in FIG. 4 p 161, and the heart in Plate X p 230. The normal heart, as seen in this illustration, is very firm and has an unusually pointed apex. The ostia of the branch arteries of the aorta are rather wide, 'mouth-like' and neat, and collars and reinforcement ramps are distinct but not prominent. No prominent intimal surface patterning was seen. The ostial collars were very clearly demarcated in the foetal aorta.

Sudanophilic material was present in the ostial ramps of all specimens, except in the foetus M.125, in the aorta and coronary arteries, and traces were seen

FIG. 4

GIRAFFE.

AORTA: INTERNAL VIEW. [MATURE ANIMAL]



NOTES:

1: THICKNESS: 12·0 mm — 1·55 mm; WIDTH: 13·5 — 8·0 cm; LENGTH: 85—90 cm [AS MOUNTED, FIXED 10% FORMALIN]

2: PATTERN: IRREGULAR, INDISTINCT LONGITUDINAL PATTERN OF SPARSE DEPRESSIONS.

3: OSTIA: WIDE; COLLARS & REINFORCEMENT PLAQUES NOT PROMINENT ALTHOUGH CLEARLY RECOGNISABLE.

4: COELIAC & ANT. MESENTERIC ARTERIES IN PORTION IV; RENAL ARTERIES IN PORTION V.

5: SUDANOPHILIC MATERIAL: PRESENT IN OSTIAL COLLARS of ALL SPECIMENS COLLECTED, [EXCEPT FOETUS].

in the ostial collars of carotid, iliac and brachial arteries. A particularly intricate, fibrous arrangement was noted at the carotid bifurcation in all specimens. This was well loaded with sudanophilic material in every case. (FIG. XXI p 252).

Intimal sudanophilic material was widespread throughout the aorta of M.124, the pregnant cow. These areas were not clearly distinguishable as 'streaks' or 'plaques' but resembled the sudanophilic 'smudge' seen in the aortae of pregnant and lactating elephants (see ch.11, p 382 and Appendix 4 , p 606; Sikes, in press). To a lesser extent, there was a similar widespread occurrence of intimal lipid in the aorta of the lactating cow M.54.

Calcium deposits occurred in a very small area (1.2 x 0.4 cm) in portion III of the aorta of the bull M.126. The surface appearance of this lesion resembled the outline of a coiled nematode worm, but it was not possible to identify it with certainty beyond the fact that an irregular calcific deposit was present in the media.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart g	Notes
M.126	m	1,310	487	335	7300	
M.124	f	807.5	460	300	5100	pregn.
M.54	f	755	450	280	4650	lact.
M.125	f	45	-	-	452	foetus, full-term

Hartebeest

Four hartebeest were collected, two males M.3 and M.17, and two females M.37 and M.38. In these, ~~the structure of~~ the heart and aorta showed no deviation from the usual structure typical of savannah antelope, and all contained lipid deposits in the ostial collars, ramps and ridges of the aorta and the larger muscular arteries. These deposits stained a little more heavily in the two females (both lactating) and included a diagonal 'smudge' between the scar of the duct.art. and the anterior dorsal ostia of the aorta in the same pattern noted in lactating elephant, hippo, giraffe etc.

A cyst, thought to be parasitic, was located near the apex of the heart in M.37 (Plate XI p 234) and fibrous, pericardial 'tags' were seen in M.3, M.37 and M.38. These, as in Grant's gazelle, may be associated with the presence of parasites (Lapage 1962).

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt.g	Notes
M.3	m	-	200	122	-	
M.17	m	-	230	136	-	
M.37	f	133	208	120	1000	lact.
M.38	f	137	210	120	900	lact.

Hippopotamus

Nine hippos, three males and six females, were examined, of which one female (M.29) was a full-term foetus ~~(Plate p)~~. All were collected in the Queen Elizabeth National Park, Uganda, and environs.

In mature, full-grown animals (total body length over 325 cm) the fixed aorta was 85 - 90 cm in length (from the scar of the duct. art. to the bifurcation); internal circumference (measured as total intimal surface width after mounting open on polythene boards) was 13 - 14 cm at the anterior end and 4.0 - 5.0 cm in the portion between the origins of the anterior mesenteric and right renal arteries, average ratio 3.0. Thickness of intima and media combined ranges from 7 mm at the anterior to 2.0 mm at the posterior end, average ratio 3.5. The longitudinal measurement for fixed hippo aortae is about 65% of the fresh length. The percentage change in transverse measurements was not investigated.

Heart weight appeared to be greater in females than in males of comparable body length. Body weight was only obtained for one specimen (M.40): it weighed 1,305 kg, and the heart weight was 4.85 kg., or .37 g heart weight/ 100 g. body weight.

A scale drawing of the intimal surface of the aorta of an adult hippo is shown in FIG. 5 p 172. It is of note that the proportions indicated in this drawing differ remarkably little from those found in the aorta of the full-term foetus M.29. It is also of note that the coeliac, anterior mesenteric renal and lumbar arteries all lie in the posterior fifth of the aorta, whereas in buffalo and elephant they are contained in the posterior two-fifths, the coeliac and renal ostia lying at the junction of portion III and IV, and the renals at the junction of portions IV and V.

The structure ~~of the tissue~~ of each ostium differs recognisably from that of elephant and buffalo, and the fibro-elastic collars and reinforcement ramps are very pronounced. In older animals, they unite in the dorsal line to form a characteristic, longitudinal band of raised and sometimes roughened tissue. A great deal of variation in number and arrangement of the ostia was noticed and, in both the thoracic and abdominal portions, may be either distinctly paired or apparently single. Close examination of the fibrous collars of the single ostia suggests an early (perhaps intra-uterine) fusion of the pair to form a common orifice.

In one specimen, M.89, whose aorta is shown in FIG. 5 p172, partial fusion of the anterior dorsal ostia seems to have occurred. In two other specimens (M.90 and M.26) the coeliac and anterior mesenteric arteries had a common origin in the aorta, while in the other seven they had separate and distinct ostia. Variations were also noted in the details of the arrangement, at the bifurcation, of the origins of the external and internal iliac arteries.

Other features, which seem to be characteristic of the normal hippo aorta, are: i) the unusually large proportion of smooth muscle in the tunica media throughout the aorta; ii) the organisation of this to form numerous thin longitudinal fibro-muscular bands and threads, lying in the thoracic aorta just below the internal elastic lamella, and fanning from a focus in the dorsal aspect of the aortic arch, at the level of the duct.art., in a general posterior direction. These are particularly clearly defined in the thoracic aorta of the full-term foetus and in all specimens give the intimal surface a distinctive, longitudinal patterning.

In the two oldest specimens (M.26, f, and M.89 m) this patterning was also wavy and rough and recalls (although not so advanced) the condition seen in an elderly male elephant (Plate I (2), Appendix 4 p 652.

In the abdominal portion of the aorta of an elderly hippo, the pattern appeared to be predominantly transverse in direction, fanning from the origins of the larger branch arteries and bifurcation.

Sudanophilic material was present, as in elephants, (see Appendix 4 p 606 ; Sikes, in press) in the normal fibrous reinforcement ramps posterior to each ostium, and within the orifice (Plate XX p 250).

This characteristic arrangement of unusually elaborate and prominent fibro-muscular collars, ramps, ridges and bands, associated with all branch-artery ostia, and in particular those of the dorsal line, would seem to suggest a particular adaptation to the natural habits and environment of the hippo. Perhaps the ostial 'collars' are able to exert some control over the size of the ostium. It would seem also that the hippo aorta is not only exceptionally elastic, but also contains an unusually high proportion of smooth muscle, and one must ask if perhaps the aorta itself is developed to an unusual extent as a self-adjusting blood-pressure control mechanism adapted to periods of prolonged or deep submersion under water. Little is as yet known about the physiology of the circulatory system of the hippo during the periods of submersion, which are said to average anything from 20 seconds to 4-5 minutes, but may well be longer (Frechkop 1955).

Abnormalities were few and seemed to be generally of a minor character. In a recent publication, Thurlbeck's (1965) observations on hippopotami were illustrated. Unfortunately, in referring to the dorsal supportive fibrous bands, he used the terms "intimal fibrosis" and "these lesions", suggesting their occurrence and development with increasing age as a pathogenetic process, a description which does not accord with the findings of the present survey on these structures in this and other species. Similarly, the statement "Intimal lesions at the distal margin of the intercostal vessels were present in all animals" does not seem acceptable as the description of a normal anatomical development found almost universally in the wild Artiodactyles studied.

The only cardiovascular abnormalities seen in the nine hippos examined by the author during this project were the following: i) irregular areas of rough,'gritty' or granular vegetations on the intima of the pulmonary arch and within the right aortic sinus of M.89, and on the endocardium of the right ventricle of M.26 (Plate XVI p 244). Minute foreign bodies, perhaps associated with the presence of parasites, were seen in the lung tissues of this animal, but have not been conclusively identified, and one is uncertain as to whether these are associated with the vegetations seen in the right side of the heart.

ii) A few small, diffuse, grey plaques, not containing sudanophilic material, were found in the intima of portion IV of the aorta and external iliac artery of M.26; bodies found in the media in the same region may be parasites but have not yet been identified conclusively; iii) Calcified discs were found in the media of the aortic arch (M.26) but their location did not necessarily coincide with any thickening of the intima, but rather appeared to be due to the activity or presence of a parasite, and a cystic 'button',apparently on the intima,is illustrated in Plate XVII p 246. iv) A few tiny scattered, intimal fibrous 'buttons', about 1.0 - 2.1 mm long and 0.2 - 0.4 mm wide, were noted in portion I of the aorta of M.91 and in the right external iliac artery of M.40. No lipid material was found in these 'buttons', generally characterised entirely by fibrous hyperplasia, but in M.91 a small calcified lump was found in the media just below such a 'button' (see FIG. XVII p246).

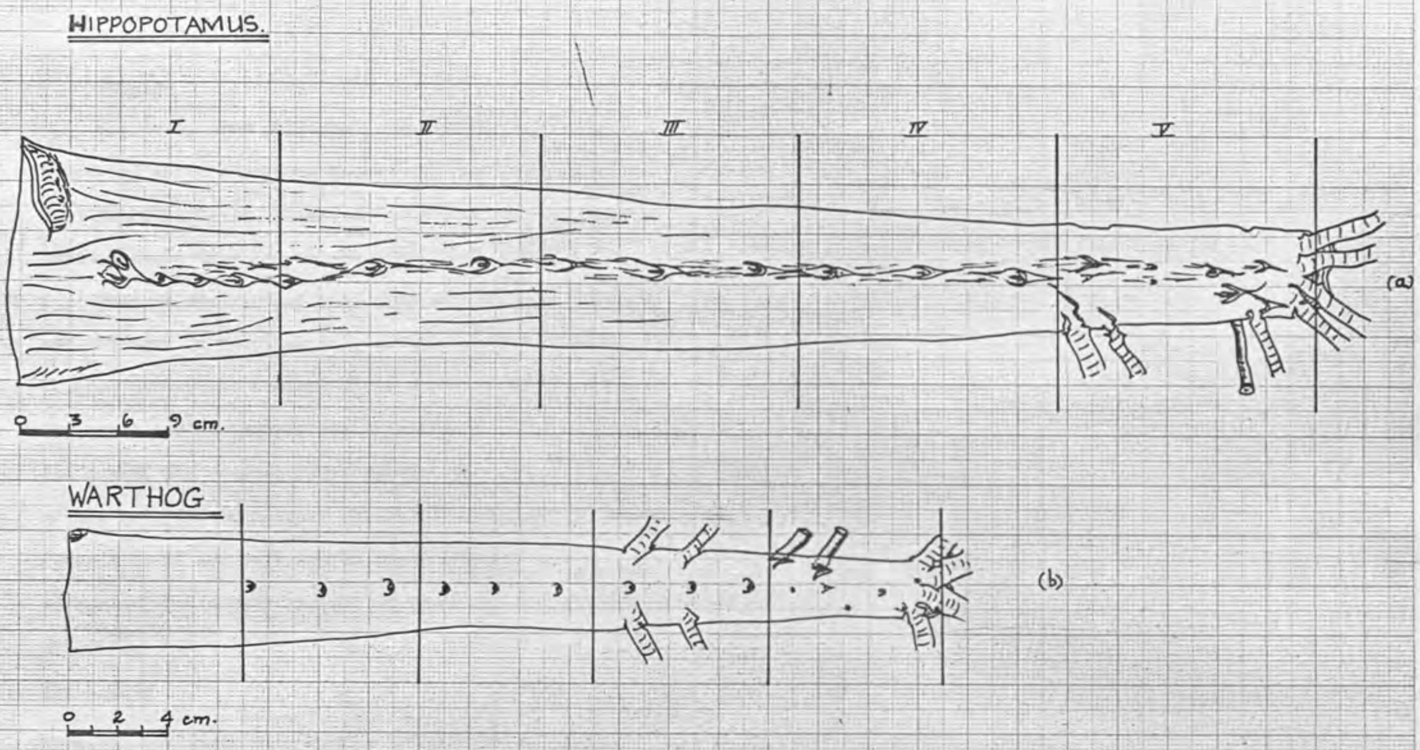
It is of note that the author found no abnormalities in the coronary arteries of hippo, and no fatty plaques could be found other than small amounts of sudanophilic material located within the normal reinforcement structures of the younger specimens (with the exception of the foetus) and M.28. As in elephant, the author supposes this to be a normal condition (Appendix 4 p 606 Sikes, in press). Specimen M.28 was in advanced pregnancy, and sudanophilic material was found extending into certain areas of the intima, outside the reinforcement ramps, collars and bands. It was nowhere dense and recalls the same occurrence in elephant, as mentioned above.

One gains the impression that the normal hippo aorta possesses some specialised adaptations to its amphibious habit which would reward further study. Some of the features described by previous workers as degenerative changes (Thurlbeck 1965) would appear, when examined in comparison with the normal arterial supportive structures seen in other large mammals, such as elephant and buffalo, to be in fact similar normal structures, exhibiting an exceptional degree of prominence associated with their adaptive specialisation.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.89	m	-	350	-	4500	
M.40	m	1305	305	-	4850	
M.27	m	-	304	-	5000	
M.26	f	-	350	-	6450	
M.91	f	-	350	-	5200	
M.90	f	-	332	-	5000	
M.28	f	-	330	-	-	pregn.
M.92	f	-	310	-	3140	
M.29	f	-	120	-	-	foetus

Fig. 5



Impala

Two males were collected, M.1 and M.145. The heart and aorta showed no anatomical deviation from that characteristic of savannah antelope, and the usual intimal lipid deposits at the ostia were noted.

Fibrous pericardial tags were particularly abundant and 'shaggy' in specimen M.1; and in M.145 some thickened plaques containing intimal lipid deposits extraneous to the usual ostial occurrences were found. These lay in the dorsal and ventral lines between the level of the ostia of the anterior mesenteric and renal arteries, and in the first 2 cm of the left common iliac artery. No endoparasites at all were located in the body of the latter specimen.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt.g	Notes.
M.1	m	73.5	173	97	540	
M.145	m	-	-	-	-	

Klipspringer

Specimen M.77, a mature male in excellent condition, was unfortunately the only klipspringer collected. The most unusual internal structure observed in the aorta is presumed to be normal and characteristic of the species. A regular, and very clearly defined, arrangement of parallel fibrous ridges pass diagonally from a dorsal, longitudinal ridge, to the left and anteriorly, around the lumen of the aorta, across the ventral line, to peter out just before reaching the dorsal line again. The whole structure appears to be either a valve or possibly a means of canalising a substantial part of the aortic blood by setting up an anti-clockwise vortex in the region of the main aortic visceral branches. The apparatus lies in the portion of the aorta containing the common origins of the coeliac and anterior mesenteric arteries and the two renal arteries. (Fig. 6 p. 176)

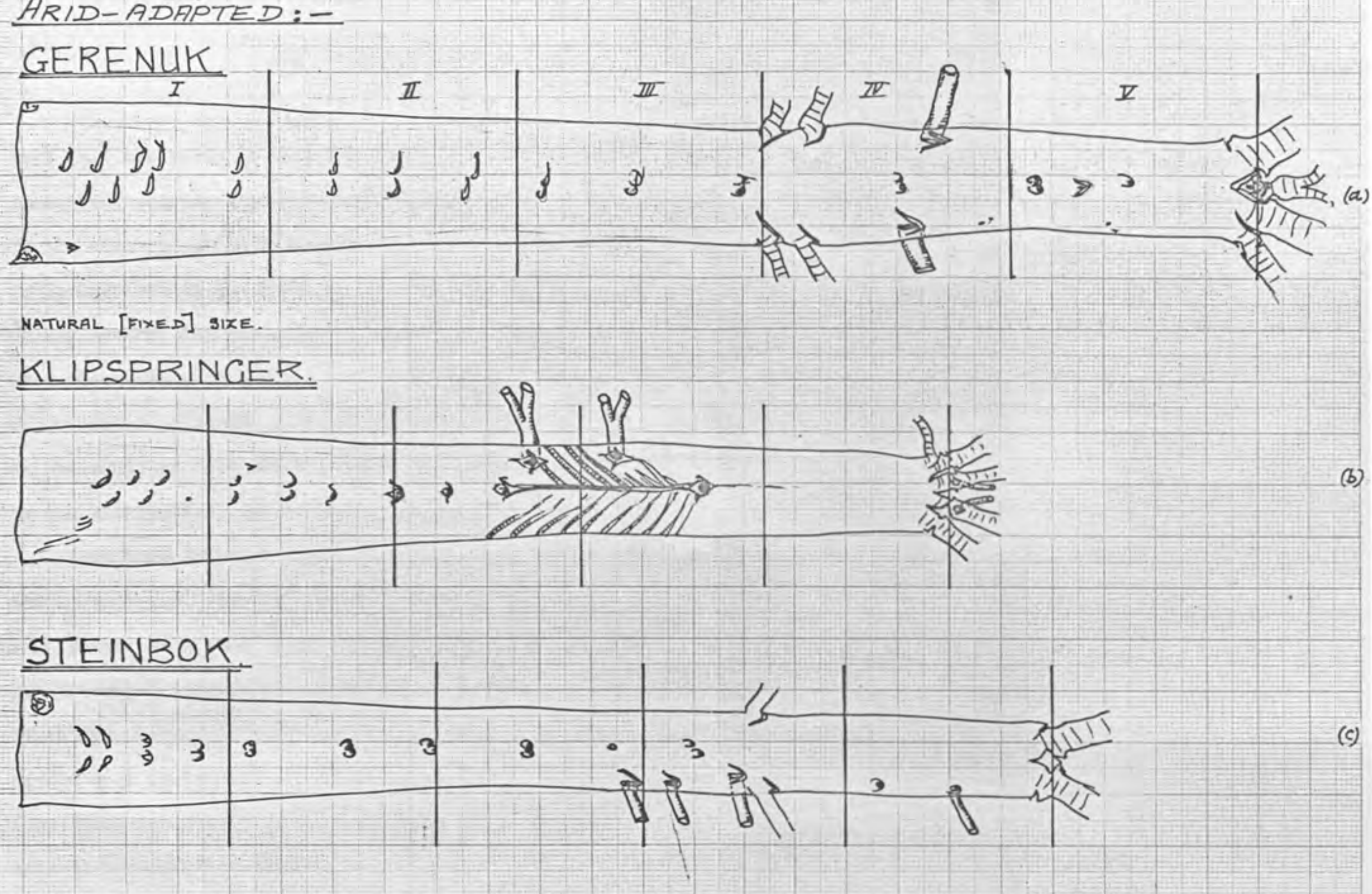
Other striking deviations from the usual anatomy of the aortae of savannah antelope and gazelle are the total absence of ostia of branch arteries in the abdominal aorta between the renal arteries and the bifurcation; the diagonally slanted, paired ostia of the thoracic branches, and the round, cup-like 'lip' of the ostial collars of all the branch arteries. The inter-ostial reinforcement ridges at the bifurcation are also very prominent.

The peculiar anatomy of this aorta may have a functional explanation in terms of the habits of this species. It is a chamois-like rock dweller (Frechkop 1955), frequently reported at altitudes of up to 9,000 ft in East Africa, and occurring throughout the mountainous regions of Africa south of the Sahara, although nowadays apparently it is nowhere common.

It makes vast leaps from rock to rock and frequently adopts a vertical posture when feeding. Frechkop(1955) wrote: "It can clearly be distinguished from all other antelopes by the way it stands only on the anterior rim of its hooves, and by the entirely different character of its pelage, and must therefore at present be regarded as belonging to a distinct sub-family, the Oreotraginae Pocock 1910". Grassé, in his "Traité de Zoologie" (1955) in fact provisionally assigned it to this sub-family.

No reference to the aortic valve-like apparatus described above could be located in the literature. It is thus only possible at this stage to suggest the hypothesis

FIG. 6


ARID-ADAPTED:-
GERENUK
I
II
III
IV
V
(a)
NATURAL [FIXED] SIZE.
KLIPSPRINGER.
(b)
STEINBOK.
(c)

that this apparatus in fact functions as a blood-control mechanism, whereby a greater proportion of blood is passed to the viscera during undisturbed periods of browsing or rest, and less to the hind limbs, but, when fear and the sudden demands for the physical activity of rapid escape over the rocks occur, the aorta is dilated (or perhaps the valve ridges relaxed), allowing the main volume of blood in the aorta to pass uninterrupted to the posterior vessels at the bifurcation, and thence to the hind limbs.

Much more detailed study of the flow of blood within the aorta and of the distribution of nerves to this aortic valve-like apparatus would be necessary for the unequivocal confirmation of this hypothesis. Nevertheless, it is not unreasonable to suppose that such a peculiar and specialised anatomical arrangement within the aorta has a functional relationship to the specialised habitat and mode of life of the species.

No intimal lipid deposits were detected in the ostial collars, ramps or ridges of the aorta, or the muscular arteries of specimen M.77.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.77	m	9.8	86.5	53.5	65	

Kob

No females of the species were collected. Four males (M.32, 34, 35, 36) of various ages were examined.

The anatomy of the heart and aorta showed no significant deviation from that of other savannah antelope and contained the usual deposits of sudanophilic material.

In specimen M.34, a raised band 5.5 x 0.6 cm lay anterior to the ostium of the coeliac artery in the ventral line and contained lipid deposits and slight medial mineralisation. Intimal lipid deposits occurring at the bifurcation in this specimen extended beyond their usual location in the ostial ridges, ramps and collars, notably in the first cm of the common iliac arteries. Fibrous, pericardial tags occurred in specimens M.35 and 34, and as in hartebeest, etc., are supposed to be associated with the presence of the parasite Setaria sp.(Lapage 1962).

Fatty plaques just above the aortic sinuses of M.32 and lipid-containing patches were associated with the orifices of both coronary arteries. A white fibrous patch (1 x 0.75 cm) occurred in the right ventricle just below the pulmonary valve, and unusually prominent nodules were noted on the chordae tendinae of the mitral valve.

Kob: Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.34	m	91	173	96	680	
M.35	m	89	168	91.5	590	
M.36	m	83.5	-	-	-	
M.32	m	81.5	175	91.5	-	

Kudu, Lesser

Specimen M.115 was an elderly bull, accompanied by three cows. Regrettably, no measurements were taken on site due to the author's involvement in a slight accident connected with the collecting of this specimen.

The aorta was however mounted and examined and found to conform anatomically to those of other typical savannah antelope, containing small deposits of intimal lipid in the usual sites, associated with the ostia of branch arteries. Lipid also occurred in the aortic sinuses and on the ridges of the origin of the brachio-cephalic trunks.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.115	m	-	-	-	-	

Oribi

A pregnant female oribi (M.16) with a full-term female foetus (M.155),which was examined as a separate specimen, was collected.

No unusual features of the cardiovascular system was noted. Traces of lipid were present in the ostial collars of the dam but not of the foetus.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.116	f	17.5	109	68.5	230	pregn.
M.155	f	1.0	40	23	-	foetus

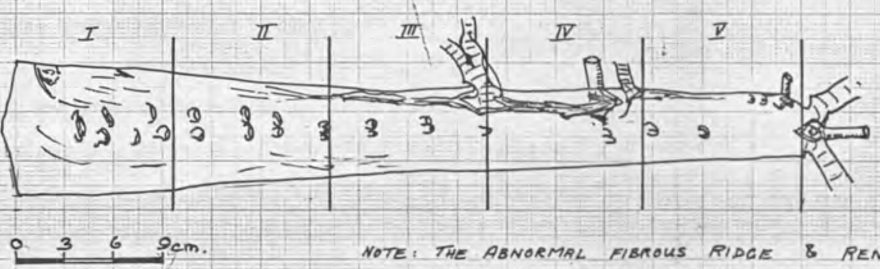
Oryx, Fringe-eared

Specimens M.66 (mature male) and M.51 (female) were collected. The very elderly cow, M.51, was lactating (with a very well-grown calf at foot, which escaped with the rest of the herd and was later seen sharing another nursing cow with its calf) and had an early pregnancy. It had a heavy infestation of parasite worms (see ch.4,p 92), and its teeth were worn down to mere stumps (Plate III p 81).

The heart and aorta of the male (M.66) conformed to

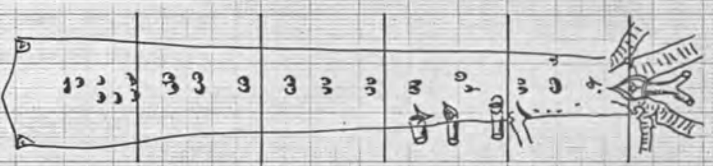
FIG. 7

ORYX



NOTE: THE ABNORMAL FIBROUS RIDGE & RENAL ARTERIES WITH A COMMON ORIGIN ARE SHOWN HERE AS SEEN IN M.51. A MALE ORYX, M.66., DID NOT HAVE THESE, & ITS AORTA RESEMBLED THAT OF THE HARTEBEEST [See below].

HARTEBEEST.



KOB.

AORTA RESEMBLES THAT OF HARTEBEEST, IMPALA, GRANT'S & THOMSON'S GAZELLES, KUDU, DIKDIK & ORIBI IN ITS GENERAL PROPORTIONS & ARRANGEMENT OF BRANCHES.

REEDBUCK

AORTA IS MORE SLENDER IN PROPORTION TO LENGTH THAN IN HARTEBEEST.

the normal type characteristic of savannah antelope (see eland above) and contained small deposits of intimal lipids in all the usual sites, including the muscular arteries.

In the aorta of the cow (M.51), however, a tough fibrous raised band, forming an anterior and posterior extension of the ostial collar and ramp of a single large ostium shared by the coeliac and anterior mesenteric arteries, was found. A few irregular and very minor deposits of lipid were detected in the intima of the anterior portion of this band. At its anterior end it petered out as threads, indistinguishable from the slight wrinkling typically seen in the anterior portions of the aortae of very elderly ungulates.

Rather heavy intimal lipid deposits occurred at the bifurcation, especially on the crescentic fibrous ridge frequently noted in the dorsal line linking the reinforcement ridges at the origins of the two common iliac vessels. Some lipid also extended into the first 2 cm of the iliac arteries and was not confined to the intima of the ridges. Calcific nodules were noted in the mitral valve of this specimen, and in the reinforcement ridges at the bifurcation, and ~~were~~ are supposed to be associated with its old age. The right coronary artery had a double orifice in the right aortic sinus.

The fibrous band contained some calcific deposits in addition to the ~~and~~ small amounts of extraneous arterial lipid, but these did not appear to be in any way excessive for a lactating and pregnant female, which was apparently also very elderly.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.66	m	192	200	125	1390	
M.51	f	160	221	121	-	pregn.& lactatg.

Reedbuck

A very elderly male (M.43) and a pregnant female (M.78) were collected. No unusual structural features of the hearts, aortae or muscular arteries were noted.

In M.43 all superficial veins had the varicose, 'knotty' appearance typical of old age in ungulates, and the animal itself was rather lean. The intimal surface of the aorta was somewhat wrinkled. No lipid could be detected in the aorta and muscular arteries even at the usual sites, although it was present in these sites in the aorta and coronary arteries of the female (M.78). Lipid was detected in the aortic sinuses of M.43, however.

No abnormalities of the heart or arteries were seen.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.43	m	41.2	145	76	500	—
M.78	f	-	-	-	-	pregn.

Steinbok

Two male steinbok were collected. Reference has already been made to the structure of the normal aorta of this species (see above: gerenuk and klipspringer, and FIG. 6 p 176).

Intimal lipid deposits were noted at the usual sites in the aorta and muscular arteries. A large cyst, supposedly parasitic, was noted near the apex of the heart of M.69, and a hard calcified lump was noted on the left renal artery and is thought to be a calcified parasite, although it was too heavily calcified to be positively identified as such. It apparently did not cause any occlusion of the artery concerned. No abnormalities of heart or aorta were observed in specimen M.71.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.69	m	9.4	81	46	-	
M.71	m	9.0	79	48	-	

Warthogs

Specimens M.5, 6, 8, 9, and 33 were males, and M.7 and M.10 females. Unfortunately, specimens M.5-10 were collected under some pressure during a Park 'cropping' programme, in which the carcasses were shared between several workers. It was thus neither possible to dissect the aortae undamaged from the carcasses, nor to ensure their proper subsequent care and preparation with Sudan IV stain for the macroscopic examination of lipid distribution.

Traces of lipid were found, however, in the aortic arch, attached to the heart of every specimen, around the reinforcement ridges between the brachio-cephalic trunks and cusps of the aortic valve, as well as in the ostial collars and ramps of the coronary arteries.

Small lipid deposits occurred in the usual sites in the complete aorta and muscular arteries of M.33, the only specimen which was individually collected and examined, independently of the Queen Elizabeth National Park cropping scheme.

No abnormalities were seen in the hearts and aortic arches of specimens M.5-10, but in the intact aorta of M.33 five isolated white 'buttons' were located in portion I of the aorta, which resembled those found in hippo (Plate XVII p 246).

The internal surfaces of the carotid arteries were rather wrinkled, presumably associated with the apparently old age of M.33.

The measurements given below (M.5 - 10) are as taken by the NUTAE team. The preparation of the hearts for weighing differed from the technique used by the author for all other specimens individually collected during the present study.

/Field data

Field data: Warthog

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.33	m	92.5	175	84	350	
M.6	m	101.5	190	84	470	
M.9	m	96.2	190	84	681 (?)	
M.5	m	80.5	170	76	-	
M.8	m	64	170	73.5	300	
M.7	f	44	150	96	-	
M.10	f	42.5	148	-	200	

CARNIVORA

Aardwolf

One specimen only was obtained. This had been killed on the Nairobi - Mombasa road by a passing vehicle. The posterior part of the abdominal aorta was damaged, as were the abdominal viscera and the head and neck. The heart and thoracic aorta, however, were intact, but unfortunately some decomposition had occurred. No abnormalities were macroscopically visible in the fresh aorta, and no lipid deposits were indicated by Sudan IV stain.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.151	f	7.3	86.5	46	-	

<u>Cat, Taita Wild</u>

Two male Taita wild cats were obtained, M.143 and M.123. No abnormality was seen in one of these, M.123, collected in the Tsavo National Park environs in an area totally devoid of domestic stock, and no unusual features of the normal aorta were seen.

In the other specimen, however, (M.143) the same type of aortic lesions as in the spotted hyaena M.82 and the striped hyaena M.148 was seen. These lesions are apparently caused by the burrows of parasites through the intima and media. A similar occurrence in a jackal aorta was noted by Finlayson (1965).

An accumulation of lipid deposits in the damaged tissues characterised this lesion, similar to that in the tissues damaged in buffalo aortae by the activities of <u>Onchocerca armillata</u>. In this particular case, an aneurysm ~~(Plate p)~~ and haemorrhagic lesions were seen, while the formation of small thrombi had occurred in some of the worst frayed parts of the intima. The distribution of the lesions is indicated in FIG. 8 p.196.

The parasites causing this lesion are thought to be <u>Spirocerca</u> sp., but as no record of the occurrence of these parasites in the Taita Wild Cat and the two species of hyaena described below could be located, further investigation is necessary before they can be identified conclusively.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.143	m	4.6	97	35	19.8	
M.123	m	4.1	94	35	13.0	

Civet

Only one civet was collected, an immature female, M.20, which was found dying in a small patch of relict gallery forest within the Murchison Falls National Park. The cause of death was not established, and histopathological examination of the preserved tissues is pending. However, no abnormality of the heart or aorta was seen. No measurements were taken.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.20	f	-	-	-	-	

Dog, Cape Hunting

One mature male of this species was collected, M.109. The heart and aorta appeared to be normal. Only the faintest trace of intimal lipid could be detected in the anterior portion of the aorta. Otherwise it was not seen even in the ostial collars or ramps.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.109	m	24.5	138	66	239	

Fox, Bat-eared

Two mature males were collected, M.58 and M.130. The heart and aorta of M.130 appeared to be normal, and traces of lipid were detected on the reinforcement ridges at the bifurcation. In M.58, however, raised yellowish plaques were noted in the aorta, and the heart was somewhat flaccid, as compared with that of M.130. The yellowish plaques resembled a similar lesion seen in the aorta of jackal M.48 and seemed to be mainly fibrous with irregular traces of lipid. They covered a much more limited area of the aortic intima and differed completely in macroscopic appearance from the parasitic lesions described here in cat and hyaena.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.58	m	3.7	81	28	19.6	
M.130	m	3.2	76	28	-	

Genet

Only one genet was collected, an old male, M.68, which had been killed by a vehicle on the Nairobi - Ngong road. No lesions of the heart or aorta were seen, and no lipid deposits were detected by Sudan IV stain.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.68	m	2	77.5	24	-	

Hyaena, Spotted

Three spotted hyaena were collected, one young male (M.42), one pregnant female M.41, and one very elderly, lactating female M.82.

No abnormalities of the hearts and aortae of M.42 and M.41 were noted, and only the faintest indication of the presence of intimal lipid near the scar of the duct.art.and on the bifurcation ridges could be detected. It was, however, observed that the ostial collars and ramps appeared to be fairly sharply defined, and a faint wavy fibrous pattern could be detected on the intimal surface in portion I.

The thoracic aorta of specimen M.82, however, was pitted and ulcerated with haemorrhagic lesions and burrows. Lipid deposits occurred throughout the damaged tissues of the intima and media, and the elastica was generally distorted and disrupted. These lesions are thought to be parasitic in origin and are discussed above (see Taita wild cat) and in ch.4, pp 85 - 87 . The distribution of these lesions is indicated in FIG. 8 p 196, and a section of the aorta in Plate VIII p 108 . Unfortunately, this animal was not observed long enough, prior to its collection for study, to see whether its activity appeared to be impaired as a result of the presence of these very advanced aortic lesions. The general condition of the animal was very poor indeed, as judged by the low body weight, the patchy, staring condition of the coat, and the very bad teeth.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt:g	Notes
M.42	m	52.5	130	90	330	
M.82	f	49	145	90	360	lact.
M.41	f	67	151	100	594	pregn.

Hyaena, Striped

Specimen M.148 was the only striped hyaena obtained. It had been killed by a vehicle on the Nairobi - Mombasa road, Kenya. The heart, as well as the posterior portion of the aorta, was damaged, but portions I - IV of the aorta were intact and contained widespread lesions, similar to those described in M.130 (Taita wild cat) and M.82 (spotted hyaena), described above, (see also ch.4, pp 85-87). Lipid deposits occurred not only in the damaged tissues of the aortic intima and media, but also in the ostial collars of the brachial and carotid arteries.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.148	f	-	126	71	-	

Jackal, Black-backed

Four mature specimens were obtained: M.62, male; and M.48, 52, 105 female; M.48 was pregnant.

The normal heart and aorta possess no unusual features, except that it is of note that the ostial collars and ramps are very sharply defined. Sudan IV stain indicated only minute traces of intimal lipid near the duct.art. and the ridges of the bifurcation.

In specimen M.48, the pregnant female, a very small yellowish fibrous plaque was noted just anterior to the ostium of the coeliac artery. It contained no lipid deposits and seemed to be a simple intimal, fibrous, hyperplastic extension of the ostial collar of the coeliac artery.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.62	m	7.9	97	48	45.5	
M.105	f	8.3	-	-	62.0	
M.48	f	7.2	99	43	-	pregn.
M.52	f	7.5	97	43	-	

Lion

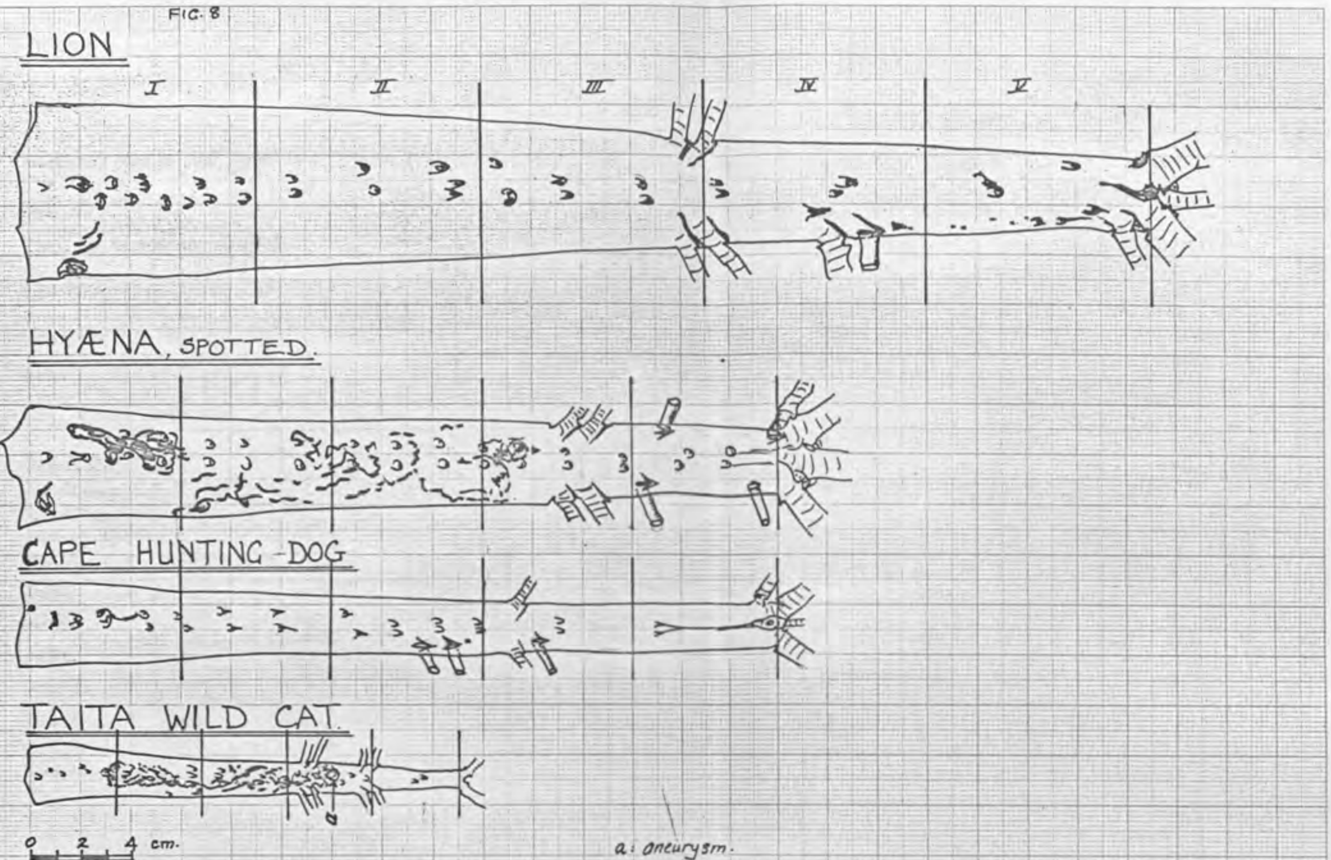
Seven lion, three male and four female, were obtained. These specimens were collected in four widely separated localities and included a well-grown cub of each sex (M.39 m, M.147 f), a mature adult male (M.56), an elderly male (M.138), a lactating female (M.136), a pregnant female (M.137) and a very elderly female (M.57).

It is of note that three of these were obtained fortuitously:- the male cub, M.39, which had a severely injured hind leg and was not thriving, was destroyed; the female cub, M.147, was killed by a vehicle on the Nairobi - Mombasa road; and the elderly female, M.57, attacked the author and assistants during the post-mortem examination of specimen M.56 and had to be detroyed as an emergency measure.

Of these seven lion, only the lactating female (M.136) showed any ~~abnormality~~ peculiarity of the aorta and iliac arteries, and this was merely a slight excess of the usual lipid deposits occurring at the aortic bifurcation. Only in this specimen was any abnormality of the heart noted, namely a small cyst in the left ventricle.

In every specimen, lipid was found in all the ostial

FIG. 8


LION
I
II
III
IV
V
HYÆNA, SPOTTED.
CAPE HUNTING-DOG
TAITA WILD CAT.
0 2 4 cm.
a: aneurysm.

collars, ramps and normal ridges, and around the duct. art. of the aorta, as well as in the coronary arteries. This is therefore supposed to be normal in wild lion. In M.138, the branches of the cardiac veins were dark and knotty in appearance, as were those of the testes, as typically seen in elderly animals.

Cases M.39 and M.57 are further described in ch.7, pp 261, 262.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.138	m	185	252	108	790	
M.56	m	148	262	99	700	
M.39	m	86.3	230	82	324	
M.57	f	103	232	86.5	565	
M.137	f	135	240	92	675	pregn.
M.136	f	117	232	81	565	lact.
M.147	f	60	200	73.5	370	

Mongoose, White-tailed

One specimen only, a pregnant female (M.80) was collected. The heart and aorta showed no abnormalities, but the aorta was characterised by the completely circular ostia of the dorsal branches, and the wide separation from each other of the ostia of each thoracic pair. No lipid was detected in the aorta.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.80	f	4.3	99	30	28.5	pregn.

Serval

Two specimens, both male, were collected. M.79 was a very fine mature male; specimen M.65 was also mature but in poor general condition.

No abnormalities of the heart and aorta of either were detected, and only traces of aortic lipid deposits near the duct. art. and the ridges of the bifurcation.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.79	m	10	110	54.5	51.5	
M.65	m	8	98	44	38.2	

HYRACOIDEA

Rock Hyrax

Three specimens, two male and one female, were collected (M.75, 73 m; M.74 f). These were all in excellent coat and were active and normal in appearance and behaviour, but were heavily infested with parasites (see ch.4, p. 93 *). No unusual features of the heart and aorta were noted, and traces of lipid were detected at some of the ostia in specimen M.73.

It is perhaps of particular interest here to note that a young, mature male Tree Hyrax, "Mimbi", which had been kept as a pet since it was found abandoned while still very young, was brought to England by air in 1966 and died within a week of its arrival. Its brother, caught at the same time and in similar conditions, is still alive at the time of writing (Jan. 1967) having been flown back to East Africa again. Both animals were generally given the freedom of the house and gardens, but received a mixed 'household' diet in addition to locally collected natural vegetable fodder.

When examined post mortem, the aortic arch of "Mimbi" was found to be packed with occlusive, lipid-filled atheroma-like intimal plaques*. Other, similar, plaques were found throughout the aorta ~~(FIG. p)~~, as well as excessive lipidosis of the intima at the bifurcation and in the coronary arteries.

These tame hyraxes lived in only partial captivity within their own home range, but had access to unusual additions to their diet, and to unusual protective care. It is possible that the stress induced by the temporary total confinement, combined with the operation of fear stresses, during the flight to England precipitated the terminal cardiac failure, from which "Mimbi" probably finally died. The presence of fatty, partially occlusive, aortic and coronary plaques would undoubtedly have predisposed the animal to a terminal cardiac crisis due to any form of excessive stress.

Field data (rock hyrax)

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.75	m	2.25	48	23	9.4	
M.73	m	1.04	34	–	2.6	
M.74	f	2.5	46	23	8.1	pregn.

*(I am indebted to Mr. and Mrs. John Savidge of the Ruaha National Park, Tanzania, who kindly provided the information on these 2 tree hyraxes and gave me "Mimbi"s carcass for cardiovascular investigation)

LAGOMORPHA

Hare, African

Only one hare was collected, and this was found lying on the ground on a highland ranch, with hind limbs partially paralysed. The animal died about an hour after its capture. All the viscera were congested and had a 'cyanosed' appearance, and the heart was large and flaccid, but exceptionally dark in colour. The entire alimentary canal was congested and haemorrhagic. The internal surface of the aorta, however, showed no unusual features at all.

Samples of the tissues of this specimen were given to the Makerere College Veterinary School Clinic, Kabete, for examination, but the results were not disclosed, and up to the present no *post-mortem* report has been received.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.72	f	1.8	51	-	15	

PERISSODACTYLA

Rhinoceros, Black

Only one complete rhinoceros was collected and examined, M.128. This was a young, adult male, collected in the neighbourhood of Tsavo National Park (East) Kenya.

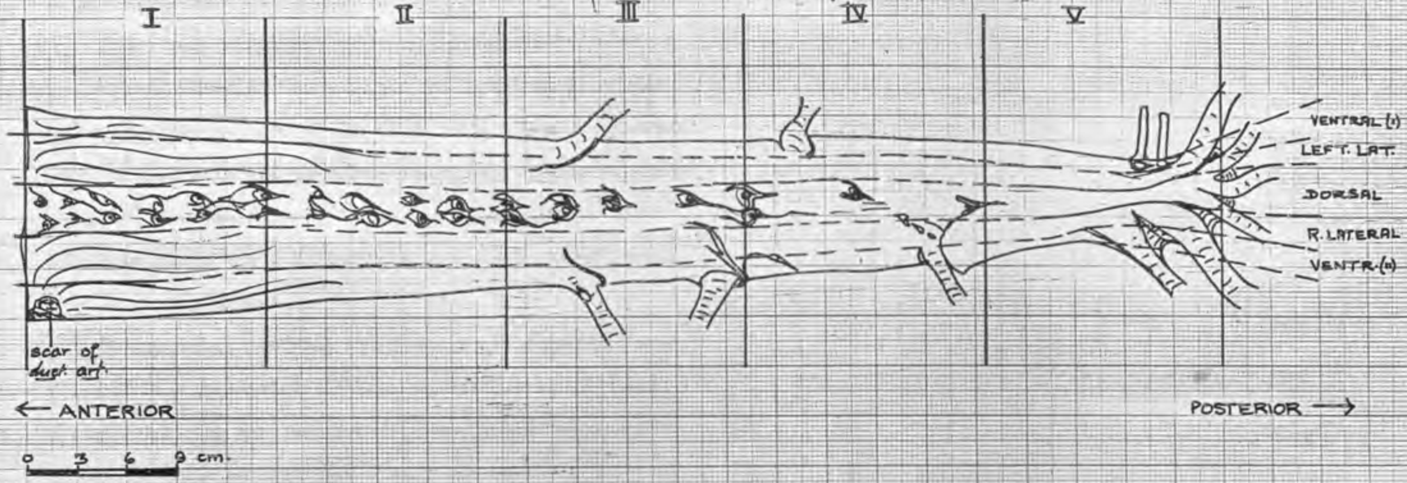
In addition, a piece of arterial tissue, 5 cm square, said to have been taken from the aorta of a rhinoceros, was given to the author by a senior research worker in Kenya. This piece was accepted and labelled M.153. Since no data as to sex, age, etc. were supplied and it was not known from which part of the aorta it was cut, it has not been useful in this project. Perhaps its real value here is to emphasise how essential it is, in comparative cardiovascular studies of this type, to obtain whole aortae, (rather than pieces), adequately prepared and annotated, for examination.

The dissected aorta of M.128 is illustrated in FIG. 9 p 203. As this was the only specimen examined, it is not possible to state whether it is a truly representative normal aorta, but compared with the aortae of other species, it appeared to have no unusual features. The arrangement of coeliac, anterior mesenteric, renal and posterior branch arteries, differed slightly from those of other species, but no lesions

FIG. 9

RHINOCEROS.

AORTA, INTERNAL SURFACE. [YOUNG ADULT ANIMAL].



NOTES: 1. THICKNESS: 11.0 — 1.1 mm ; WIDTH: 13 — 5 cm; LENGTH: 72 cm. [AS MOUNTED, FIXED IN 10% FORMALIN]

2. PATTERN: LONGITUDINAL FOLDS [DEPRESSIONS] IN PORTION I.

3. OSTIAL COLLARS AND REINFORCEMENT PLAQUES VERY DISTINCT; PAIRS OFTEN TOTALLY OR PARTIALLY FUSED; OFTEN WITH SINGLE OPENING.

4. COELIAC, ANT. MESENTERIC, & RENAL ARTERIES ORIGINATE IN PORTIONS III & IV.

5. SUDANOPHILIC MATERIAL: REGULAR ARRANGEMENT; PRESENT IN INTIMA OF OSTIA AND COLLARS.

of any kind could be found.

There was a distinct pattern of longitudinal fibrous threads and bands in the anterior end (portion I) of the aorta, and the collars of the ostia of the branch arteries were particularly well defined with rather elongated posterior reinforcement ramps, clearly connecting with the following pair, but not forming a prominent raised dorsal band as in the hippo.

Sudanophilic material was present and distinct, confined within the ostial collars and reinforcement ramps of the aorta and was abundant in these positions as well as in the coronary arteries. None was located, however, outside these collars and normal ramps, and in the carotid, renal, iliac and femoral arteries very little was present at all. As in other mammals of this age group examined in this project, this distribution of internal lipid is thought to be normal.

No cardiac abnormalities were noted.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart g	Notes
M.128	m	1,005	335	142	6,900	
M.153	-	-	-	-	-	

Zebra, Burchell's

Four stallions, all older animals, were collected (M.63, 4, 50 and 55) in addition to two pregnant mares (M.67 and 70).

No unusual features were noticed about the heart, aorta and muscular arteries, which differ little in general characteristics from those of the horse. The ostial collars and ramps, however, are scarcely noticeable as such to the naked eye. Only in the two mares could any traces of lipid be detected in the aorta and other arteries, and these were only faintly noticeable in the aortic sinuses, on the cusps of the aortic valve and the neighbouring aortic intima, on the scar of the ductus arteriosus, and on the reinforcement ridges at the bifurcation.

One of the features characteristic of healthy wild zebra is the abundance of yellow, subcutaneous fat, especially on the nape of the neck, and on the dorsum and quarters. The heart also almost invariably contains large deposits of sub-epicardial fat. Comparable deposits of stored fat do not normally occur in other African savannah ungulates. It is thus of interest that in this species in the wild state lipids of the arterial intima were found to be almost non-existent. (Fig 10 p 207)

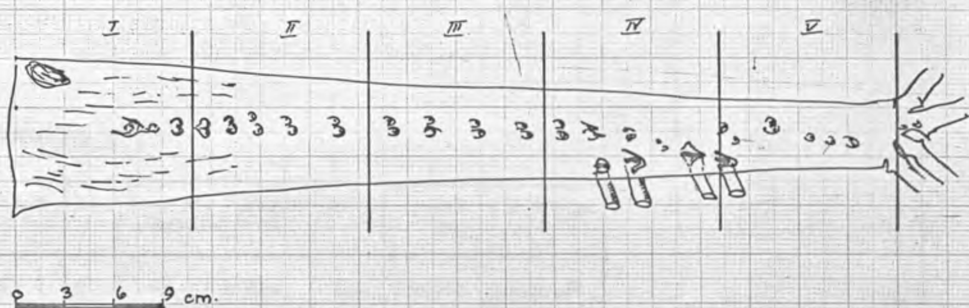
The only arterial abnormality noted was one small ridged patch, 1.2 x 1.5 cm in area, lying in the right lateral line between the levels of the 7th and 8th pairs of dorsal thoracic ostia in specimen M.50 (male), in which calcific plates lay in the media against the internal elastic lamella ~~(Plate p).~~ One must suppose that this ~~was~~ resulted from a tissue reaction consequent upon some localised traumatic occurrence in the aortic wall, as there was no indication of the presence of parasites in this tissue. M.50 was the senior stallion of is herd and was scarred from fighting; it seems possible that injury to the aortic wall might possibly have resulted from a fall. Apart from this single localised occurrence, no other Calcium deposits were detected micro- or macroscopically in zebra arteries.

Unlike the zebra examined, the only related wild species available in East Africa - the rhinoceros - was found to have very marked lipid deposits in the usual sites around the ostia on the intima of the aorta and the muscular arteries (see above).

/Field data

FIG. 10

ZEBRA



Field data (zebra)

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart g	N o t e s
M.63	m	-	250	120	2,000	'retired'
M.4	m	-	260	112	1,900	
M.50	m	335	268	123	1,900	
M.55	m	335	260	123	1,950	
M.67	f	330	253	120	1,950	pregn.
M.70	f	270	250	120	1,500	pregn.

PRIMATES

Chimpanzee

Special Permits were granted by courtesy of the Uganda Game Department for the collection of two adult chimpanzees for this study. These were collected in a marginal habitat in the Kigezi Game Reserve, where active encroachment by villages and tea plantations, and lumberjacks, had already made considerable inroads on the Maramagambo Forest, which still contains a comparatively large wild chimpanzee population. Nevertheless, this population is subject to disturbance of the forest habitat by the population overspill of elephant from the Queen Elizabeth National Park, in addition to the human encroachment mentioned above, on three sides of the forest.

This chimpanzee population must thus be regarded as subject to the abnormal conditions of a 'stressed' habitat - i.e. a habitat with the overall vegetational cover disturbed (by elephant and man); the area of which is constantly being reduced; and which is becoming (from the chimpanzee point of view) almost totally isolated from other extensive forests.

In view of the need for conserving the species by all possible means, it would have been out of the question to request permits to kill additional wild chimpanzees in a genuinely undisturbed , 'natural' habitat for comparative purposes. In describing the cardiovascular material collected, it is recognised that, although both specimens were genuinely wild animals, they came from this 'stressed' habitat, a fact which may have some bearing on the findings.

Specimen M.98 was an elderly male, greying around the face and on the scalp. His teeth were worn and broken, and his face wrinkled. His hands and feet were calloused and the nails pitted and rough. The other specimen, M.102, was a much younger animal, a female, which had irregularly pigmented skin, but whose coat was thick, black and silky.

The normal heart and aorta of the species, which closely resemble those of Man, are too well known to require description.

The elderly male, M.98, was the only mammalian specimen collected in the whole of this study project in which plaques were found, closely resembling those of true atheroma in Man, in the aorta, coronary and larger muscular arteries. Chaikoff and Lindsay (1966) in their study of 67 non-human Primates collected from jungle sources, generally without any prolonged interval in captivity, concluded that "only in chimpanzees, spider monkeys and several species of <u>Macaca</u> were well-developed distinctive atheromatous plaques with cholesterol deposits encountered". Regarding the overall situation in 67 specimens representing 17 species of non-human Primates they stated;" The development of arteriosclerotic lesions in coronary arteries and in the aorta in our study of 67 Primates is apparently similar, if not identical, to the development of fatty streaks, pearly plaques, and atherosclerotic plaques in the human being. However, the degree of lipid infiltration, including the amount of cholesterol deposited in the intimal lesions is generally less in Primates than is usually found in Man."

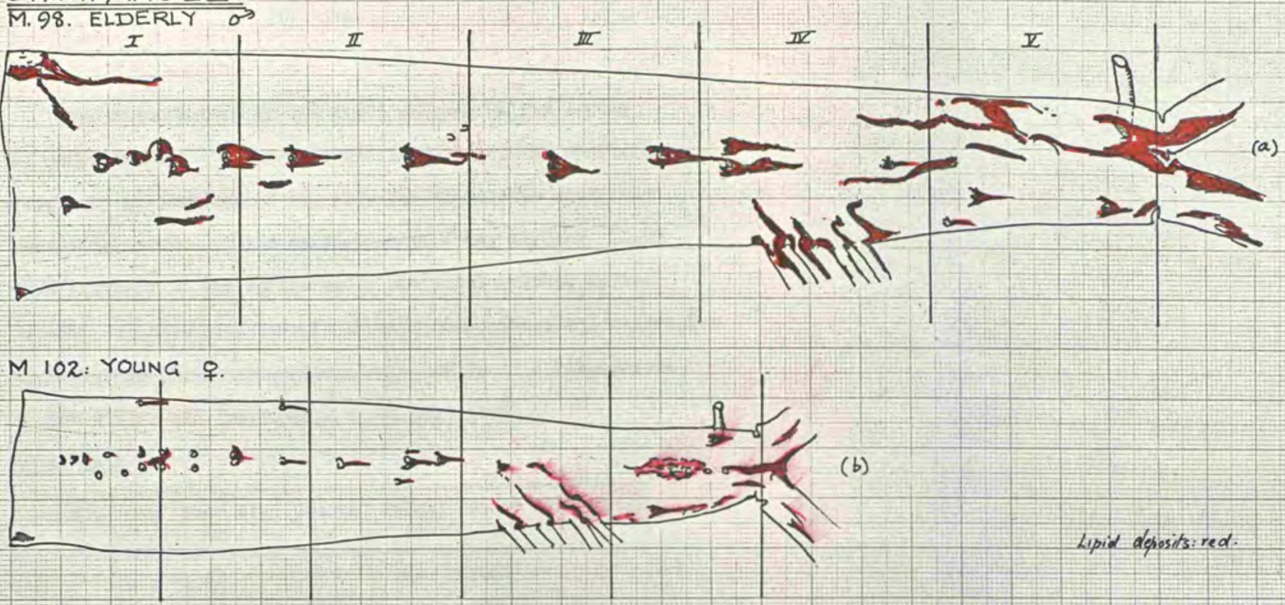
The occlusive lipid intimal plaques found in some of the scrubland elephants bore a close resemblance to those of Man (see Vol.II, pp443-451) in many details, but the appearance if examined in the perspective of the whole aorta would generally be distinguishable. The differences are probably basically related to the specific histology (for example the diameter, relative length and elasticity of the fibres, cells and layers of the arterial wall), the specific character of lipid metabolism, and possibly even the evolutionary and taxonomic differences of each species. It is of interest, nevertheless, that the African elephant and the chimpanzee, which naturally share the same habitat and eat the same type of natural diet (with the addition only of insects and perhaps some other small animals ~~matter~~ in the case of the chimpanzee) are the only two species in which, in the present survey, extensive, lipid-filled partially-occlusive intimal plaques of the aorta, coronary and other muscular arteries were found. (Fig 11 p.213)

In both species these findings were linked with stressed habitats, although, as mentioned above, no chimpanzees of comparable age could be examined from a truly natural 'control' habitat, as was possible with the elephant.

P. 213

FIG. 11

CHIMPANZEE



[Both drawings nat. (fixed) size].

The distribution of the lipid plaques in the aortae is shown in FIG. 11 p 213 and the large partially occlusive plaque in the orifice of the anterior mesenteric artery in Plate XXIII p 256. The occurrence of fatty streaks, lipid infiltrations of the aortic wall, and lipid patches in the carotid and iliac arteries in captive chimpanzees was reported by Finlayson (1965), Hamerton (1941) and in wild chimpanzees by Fox (1939) and Vastesaeger & Delcourt (1961).

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.98	m	48	82	82	202.6	
M.102	f	22	68.5	64	103.9	

Colobus, Black and White

Two males, M.11 and M.101, were collected, both in 'stressed' habitats as regards the disturbed character of the forest and its consequential isolation.

Intimal lipid deposits in the collars of the ostia of the aorta and on the ridges at the bifurcation were noted in M.11, but no streaks or plaques occurred otherwise. In M.101, however, which was an older animal, streaks were found in portions I, III and V of the aorta, in addition to heavy deposits around the ostia of the coeliac, anterior mesenteric and renal arteries, as well as in the coronary arteries near the ostial reinforcement ramps.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.101	m	7.0	125	39.0	34.8	
M.11	m	-	119	39.5	-	

Galago, Senegal

One galago, a mature female, (M.144) was collected, but the specimen was extensively damaged by the shot, and only a portion of the thoracic aorta was suitable for examination. Minute traces of lipid were detected in the collars of the ostia.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.144	f	0.213	40.5	9.0	-	

Monkey, Blue (Sykes')

Two males and one female were collected (M.142,140 and 139). No unusual features of the heart and aorta were noted, and traces of lipid confined to the ostial collars of the aorta were present in all specimens, being particularly distinct around the ostia of the coeliac and anterior mesenteric and renal arteries, and at the bifurcation in specimen M.142, a large male. No other lipid plaques or streaks were detected.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.142	m	8.5	140	-	47	
M.140	m	3.5	102	-	17	
M.139	f	2.5	94	29	10.6	

Monkey, Vervet

Of the Six specimens collected, only M.44, M.146 and M.45 had small intimal lipid streaks in the aorta, in addition to the normal lipid-containing sites in the ostial collars in the aorta, coronary, carotid and brachial arteries. In the two young males (M.46 and M.47) intimal lipid was only detected at the ostia of the coeliac and mesenteric arteries and the dorsal reinforcement ridge at the aortic bifurcation.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.44	m	5.5	99	28	12	
M.141	m	3.3	100	-	-	
M.146	m	2.8	94	-	13.4	
M.46	m	1.4	79	20.2	-	
M.47	m	1.4	79	24.0	-	
M.45	f	3.4	99	28	12	

PROBOSCIDEA: see Vol. II, pp

RODENTIA

Spring Hare

One mature male (M.76) was collected. No unusual features of the heart and aorta were noted, and minute specks of intimal sudanophilic deposits could be detected with a hand lens in the ostial collars of the aorta. These were not sectioned, and no other intimal lipid was detected in the aorta.

It is perhaps of general zoological interest to note that, [contrary to a statement made by Risley (1966) that no animal eats the East African sage bushes] the stomach of this specimen contained only the well-masticated leaves of the sage bush. The animal was fat and in excellent general condition; resident in high ranchland which had extensive sage bush cover, and a good population of spring hares.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.76	m	2.8	84	-	11.4	

Mole (rodent) - Cryptomys sp.

One male was collected. Intimal lipid was detected in the aorta only at the scar of the duct.art. and around the ostia of the coeliac and anterior mesenteric arteries.

Field data

Spec.No.	Sex	Body wt. kg	Length cm	Height cm	Heart wt. g	Notes
M.81	m	0.325	28	-	0.8	

Section D. TABLE 10

Susceptibility: Mammals

(i) Lipid occurrences confined to specific, anatomically constant, ostial collars, ramps and ridges, and intermediate 'bands' and 'threads', uncomplicated by disruption of the I.E.l.

(ii) Widespread 'smudges' and diffuse 'streaks' of intimal lipid, extraneous to the sites described above, and associated with pregnancy and/or lactation.

(iii) Reported 'fatty streaking' in taxonomically equivalent groups of captive animals.

(iv) Atheroma-like occurrences involving intimal proliferation and/or metaplasia; with or without the deposition of intra- or extra-cellular lipid, mineralisation, and vascularisation; and accompanied by disruption of the I.E.L.

(v) Reported cases of atheroma in taxonomically equivalent groups of captive animals.

(vi) Medial arteriosclerosis.

(vii) Arteritides affecting any or all layers of the arterial wall and known to be caused by infective or parasitic organisms.

(viii) Reported cases of medial sclerosis and arteritides in taxonomically equivalent groups of captive animals.

TABLE 10 (cont.)

Susceptibility: Mammals

Order, Family & species	i)	ii)	iii) *	iv)	v) *	vi)	vii)	viii) *
ARTIODACTYLA								
Hippopotamidae								
Hippo	+	+	?	+	?	+	−	?
Suidae								
Warthog	+	−	+	+	+	−	−	+
Giraffidae								
Giraffe	+	+	+	−	−	+	−	−
Bovidae								
Buffalo	?	?		?		+	+	
Bushbuck	+	+		−		−	−	
Dikdik	+	−		−		−	−	
Eland	+	−		+		+	−	
Gerenuk	+	−		+		−	−	
Gazelle, Grant's	+	−		−		−	−	
Gazelle, Thomson's	+	−		−		−	−	
Hartebeest	+	+	+	−	+	−	−	+
Impala	+	−		+		−	−	
Klipspringer	−	−		−		−	−	
Kob	+	−		+		−	−	
Kudu, Lesser	+	−		−		−	−	
Oribi	+	+		−		−	−	
Oryx	+	+		+		+	−	
Reedbuck	+	+		−		−	−	
Steinbok	+	−		−		+	−	

*(see over)

TABLE 10 (cont.)

Susceptibility: Mammals

Order, Family & species (cont)	i)	ii)	iii) *	iv)	v) *	vi)	vii)	viii) *
CARNIVORA								
Viverridae								
Civet	-	-		-		-	-	
Genet	-	-	+	-	-	-	-	+
Mongoose, white-tailed	-	-		-		-	-	
Hyaenidae								
Hyaena, spotted	+	+	?	-	?	-	+	?
Hyaena, striped	+	-		-		-	+	
Protelidae								
Aardwolf	-	-	?	-	?	-	-	?
Canidae								
Dog, Cape hunting	+	-		-		-	-	
Fox, Bat-eared	+	-	+	+	-	-	-	+
Jackal, black-backed	+	-		+		-	-	
Felidae								
Cat, Taita wild	+	-		-		-	+	
Lion	+	+	-	-	-	-	-	+
Serval	+	-		-		-	-	
HYRACOIDEA								
Procaviidae								
Hyrax, rock	+	-		-		-	-	
(Hyrax, tree)	+	-	+	+	-	-	-	-

*(see over)

TABLE 10 (cont.)

Susceptibility: Mammals

Order, Family & species (cont.)	i)	ii)	iii) *	iv)	v) *	vi)	vii)	viii) *
LAGOMORPHA								
Leporidae								
Hare, Cape	–	–	?	–	?	–	–	?
PERISSODACTYLA								
Rhinocerotidae								
Rhinoceros, black	+	–	?	–	?	–	–	?
Equiidae								
Zebra, Burchell's	+ ?	+	+ ?	–	–	+	–	+
PRIMATES								
Pongidae								
Chimpanzee	+	–	+	+	+	–	–	–
Cercopithecidae								
Colobus	+	–		+		–	–	
Blue monkey	+	–	+	–	+	–	–	+
Vervet	+	–		–		–	–	
Lemuridae								
Galago, Senegal	+	–	+	–	–	–	–	+
PROBOSCIDEA								
Elephantidae								
Elephant, African savannah	+	+	–	+	–	+	–	+
RODENTIA								
Pedetidae								
Spring hare	+	–		–		–	–	
Bathyergidae			+		+			–
Mole rat	+	–		–		–	–	

*(derived as consistently as possible from Finlayson (1965), Lindsay & Chaikoff (1963), Fiennes (1965), and Finlayson & Symons (1964).

B i r d s

A total of 25 species of birds, representing 9 Orders, was collected. The hearts of the first seven specimens collected (B.1 - B.7) were sent to Dr. R. Finlayson for examination and comment, but as yet the findings are not available. The results from the aortae only of specimens B.1–7, and hearts with aortae of specimens B.8 - B.46 are therefore only briefly summarised here, as it was felt that it would extend the scope of the study beyond one's own working capacity, and the limits of available time and equipment, to attempt to make the bird study in any way detailed or comprehensive.

It was, however, noted that early fatty streaking and distinct fatty plaques in the aortic intima,of the type described by Finlayson (1965) in captive wild birds, occurred in several of the specimens collected. These occurrences were most extensive in the two ostriches (M.25 and M. 29) and in the greater bustards (B.23, 26,31,27 and 32). In no case was any advanced plaque seen, which could have had even a partially occlusive effect on the vessel in which it was situated.

/TABLE

TABLE 11.

Susceptibility: Birds

Order & species (alphabet. arranged)	Spec. No.	Sex	Body wt. g	Intimal lipid streaks & plqus. in aorta	Susc. in capt-ivity
CICONIIFORMES					
Heron, purple	B.3	m	950	–	
- do -	B.13	f	1580	–	+
Heron, squacco	B.14	f	256	–	
Ibis, hadada	B.10	m	1125	–	+
Stork, saddlebill	B.20	f	5000	++	+
Stork, woolly-necked	B.21	m	2000	–	
CORACIIFORMES					
Hornbill, ground	B.22	m	3460	–	
- do -	B.40	m	3150	–	
- do -	B.41	m	3400	+	
- do -	B.44	f	3540	++	+
Hornbill, red-billed	B.24	m	217	–	
CUCULIFORMES					
Turaco, Hartlaub's	B.35	m	238.5	–	?
FALCONIFORMES					
Buzzard, augur	B.6	–	–	+	
Eagle, bateleur	B.43	m	2400	++	+
Eagle, fish	B.15	f	3050	+	
Eagle, tawny	B.7	f	2115	++	
Secretary bird	B.28	f	3000	+	

TABLE 11 (cont)

Susceptibility: Birds

Order & species (cont.)	Spec. No.	Sex	Body wt. g	Intimal lipid streaks & plques in aorta	Suscept. in captivity
Vulture, Egyptian	B.30	f	2115	–	+
Vulture, hooded	B.8	f	–	++	
- do -	B.19	m	2260	–	
- do -	B.38	m	2000	+	
- do -	B.39	m	2000	–	
- do -	B.42	–	2247	+++	
Vulture, white-backed	B.18	m	5100	–	
- do -	B.38	f	4500	+	
Vulture, white-headed	B.37	m	5100	+	
GALLIFORMES					
Guineafowl, helmeted	B.45	m	1800	–	+
- do -	B.46	m	1700	–	
GRUIFORMES					
Bustard, Kori	B.23	f	5300	+	?
- do -	B.26	m	10200	+++	
- do -	B.27	f	–	+	
- do -	B.31	f	5000	++	
- do -	B.32	f	7000	+++	

TABLE 11 (cont.)

Susceptibility: Birds

Order & Species (cont.)	Spec.No.	Sex	Body wt.	Intimal lipid streaks & plques. in aorta	Suscept. in captivity
PELECANIFORMES					
Cormorant, long-tailed	B.2	f	520	-	
- do -	B.4	m	500	-	+
Cormorant, white-necked	B.9	f	450	-	
- do -	B.11	f	500	-	
- do -	B.12	f	540	-	+
Darter	B.5	-	-	-	
- do -	B.17	f	-	-	?
Pelican, white	B.1	f	4500	-	
- do -	B.16	f	6300	-	+
PSITTACIFORMES					
Parrot, red-headed	B.33	f	241	-	
- do -	B.34	m	254	-	+
STRUTHIONIFORMES					
Ostrich	B.25	m	136,400	++++	
- do -	B.29	f	131,000	++++	+

E. Chapter summary

1. The technique adopted for mounting, measuring, and describing all the aortae was the same as that used for elephant aortae, which required a slightly specialised technique, due to their large size (ch.11,pp 383 - 384).

Section A (pp.137 - 139)

2. Thickenings of the arterial wall frequently noted by other workers to be associated with the formation of atheromatous plaques, but suggested by some (notably French & Jennings, 1965; Finlayson 1965) actually to be normal anatomical supportive structures, were closely examined in different species in this project. They were found to vary somewhat in structure in different species, the major variations apparently being related to the natural mode of life of the species. It was found necessary to coin the following new terms in order to provide adequate scope for description: 'ostial collars', 'ramps', and 'ridges'; and 'supportive bands' and 'threads'.

Section B (pp.140 - 144)

3. The cardiovascular findings in 42 mammalian and 25 avian species have been described, species by species, in alphabetical sequence (English nomenclature) within each order, the orders themselves also being arranged in alphabetical sequence. Scale drawings, based on the mean measurements of the aortae of adult specimens representative of the main species are given in FIGS 2 (p 151), 3 (p 154), 4 (p 161), 5 (p 172), 6 (p 176), 7 (p 181), 8 (p 196), 9 (p 203), 10 (p 207) and 11 (p 213).

The presence of variable amounts of lipid in the ostial collars, ramps and ridges, and supportive bands and threads, was found to be almost universal in mammals, the only exception being very small-sized specimens (in these cases the techniques used may have been insufficiently sensitive to detect very minute lipid deposits) and zebra. In the latter species, only traces of lipid were detected in the aortae of males, and diffuse intimal 'smudges' in two pregnant females.

In birds, no aortic lipid was detected in the aortae in the orders Cuculiformes, Galliformes, Pelecaniformes and Psittaciformes, but in examining the birds it was not possible in the time available to make any detailed study of the normal internal anatomy of the aorta, and it may be that microscopic deposits of lipid have been overlooked.

Intimal lipid deposits apparently increase normally in lactating and/or pregnant female mammals in natural conditions.

Particularly interesting, specific characteristics of the arterial supporting structures were noted in the hippopotamus (p 142 and pp 164 - 172), the rhinoceros, and three arid-adapted species, the steinbok, gerenuk and klipspringer. In the latter, the supportive thickenings in the region of the origin of the coeliac and anterior mesenteric arteries were structurally modified and were thought to function as a valve, controlling blood flow within the aorta. Modification in the arrangement and number of branch arteries originating in the aorta also support this view.

Medial calcification of the abdominal or muscular portion of the aorta and other muscular arteries was common in the Ungulates, but seemed to be unimportant in other groups. Sections C & D, (pp 144 - 226a)

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PLATE X

(a) Buffalo heart: left lateral aspect.

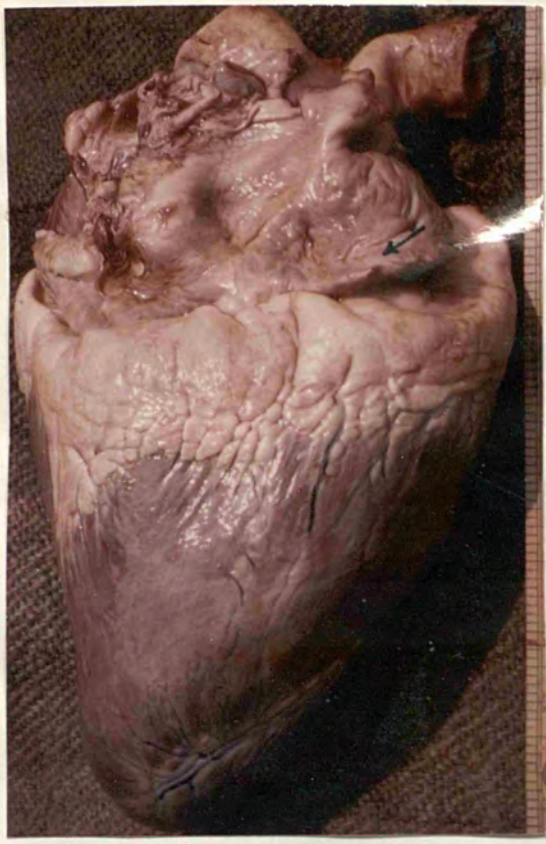
(b) As above: ventral view. Fibrous, epicardial tags are indicated by arrows.

(c) Heart of giraffe: M.54 (young, adult female).

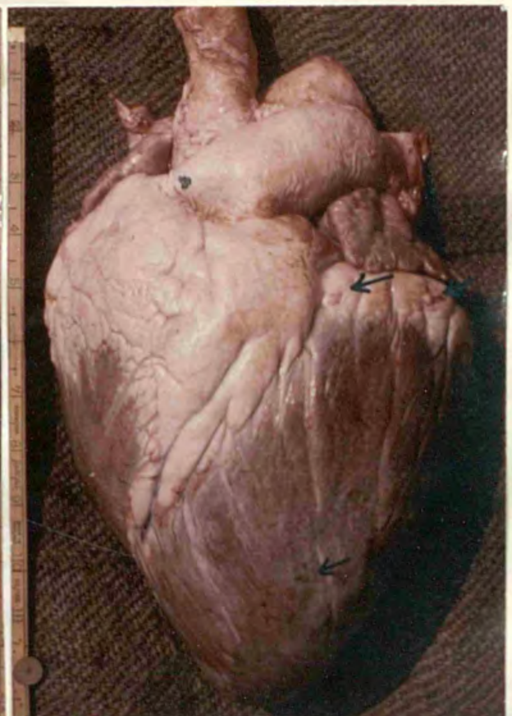
(d) Heart of giraffe: M.126 (elderly male).

PLATE X

(a)



(b)



(c)

(d)

PLATE XI

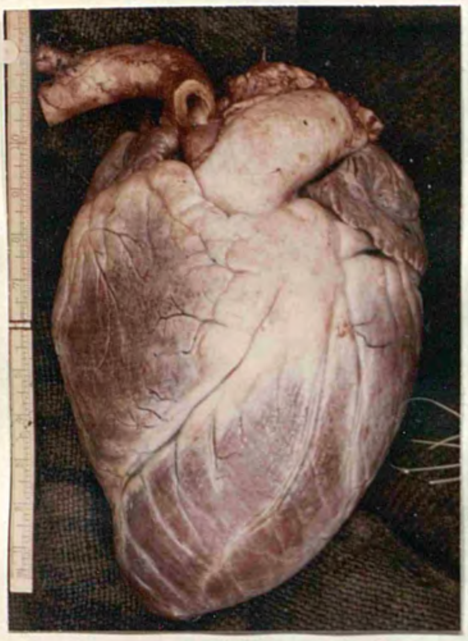
(a) Heart of eland, M.64 (elderly male) ventral view.

(b) As above, dorsal view.

(c) Heart, aorta and kidneys of gerenuk, M.53.

(d) Heart (with pericardium attached) and aorta of kob M.34, showing fibrous pericardial and epicardial 'tags'.

PLATE XI



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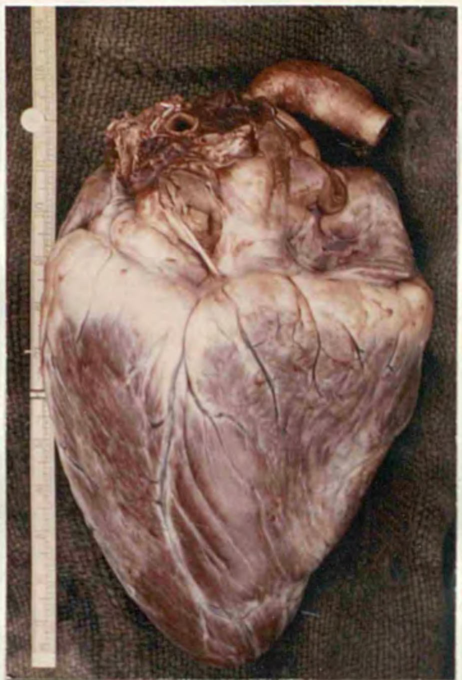


(b)

(c)

(d)

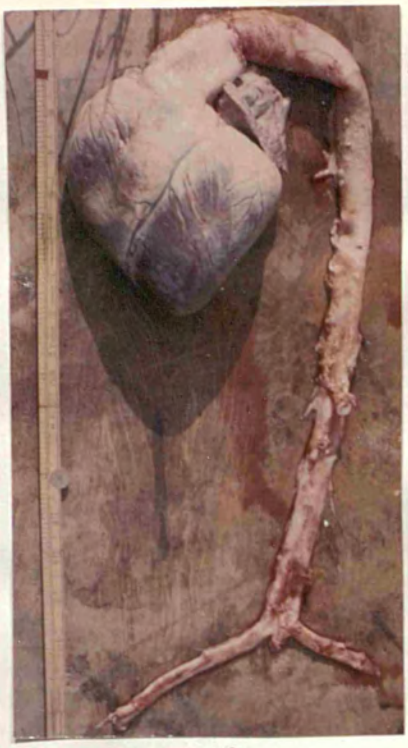
PLATE XII

(a) Heart and aorta of oryx, M.51.

(b) Internal surface of aorta (unstained) of oryx M.51, showing position of thickened fibrous band (see p 182).

(c) Ventral view of heart of hartebeest M.37, with sub-epicardial parasitic cyst near apex of left ventricle.

PLATE XII



(a)

(b)

(c)

PLATE XIII

(a) Heart, aorta and kidneys of lion, M.39.

(b) Heart, aorta and kidneys of lion, M.57.

(c) Heart of lioness, M.56 (very elderly), ventral view.

(d) As above: dorsal view.

(e) Heart and aorta of jackal M.52.

PLATE XIII

(a)

(b)

(c)

(d)

(e)

PLATE XIV

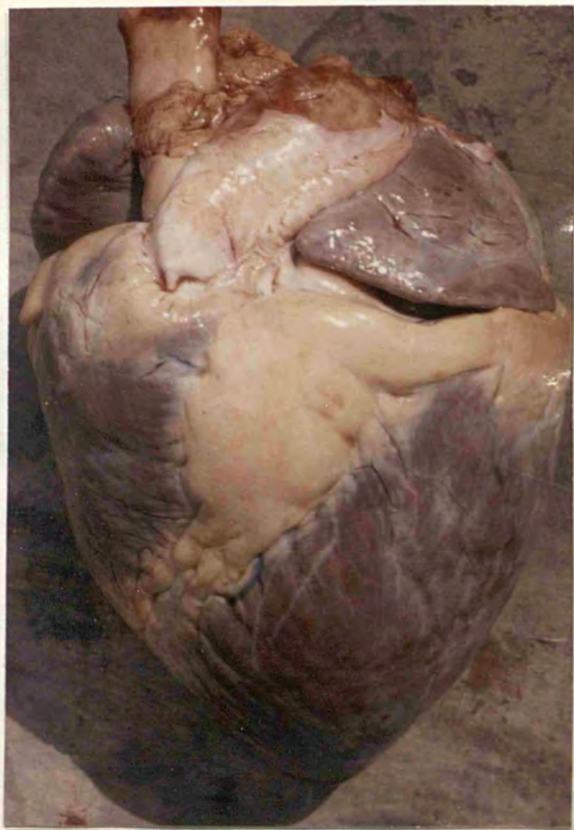
(a) Heart of zebra M.50 (ventral aspect).

(b) Heart of zebra M.63 (ventral aspect).

(c) Heart of rhinoceros M.128 (dorsal view).

(d) As above: ventral view.

PLATE XIV



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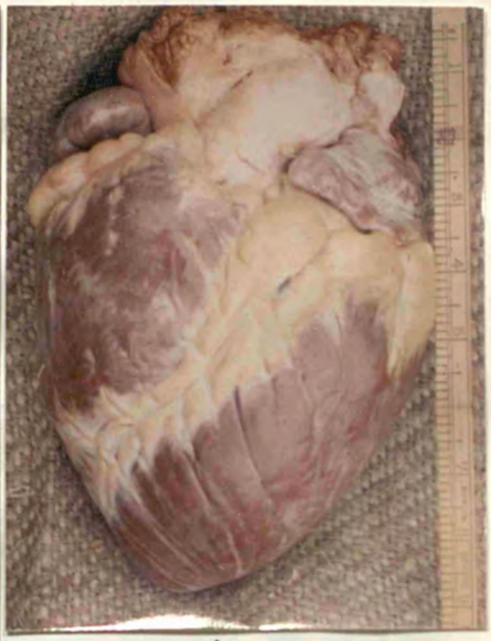


(b)

(c)

(d)

PLATE XV

(a) Buffalo, M.15,: sagittal section of aneurysm at anterior end (Portion I) of aorta, associated with the presence of Elaeophora poeli. (Sudan IV stain).

(b) Tracks of Onchocerca armillata in aorta (Portion I) of buffalo. (Sudan IV stain).

(c) Internal surface of aorta of eland (M.64), showing normal ostial supportive structures.

(d) Internal surface of aorta of hippo, showing normal ostial supportive structures, seen here to be more prominent than, for example, those of eland (c).

PLATE XV

(a)

(b)

(c)

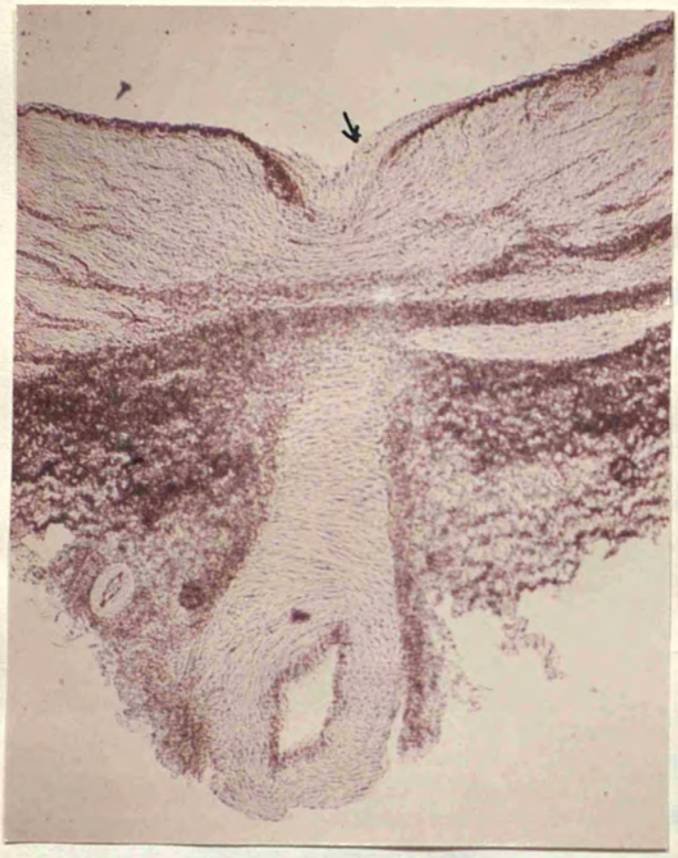
(d)

PLATE XVI

(a) TS. of right ~~coronary~~ carotid artery of rhinoceros, M.128, at the ostium of a minor branch, showing the slight thickening of the intima of the ostial 'collar' (Haemalum, x 50).

(b) TS of a fatty plaque, in aorta of eland M.64, unassociated with normal supportive structures (Sudan IV and haemalum, x 50). Arrows indicate small subendothelial deposits of sudanophilic lipid. Slight disruption of the internal elastic lamella had occurred.

PLATE XVI



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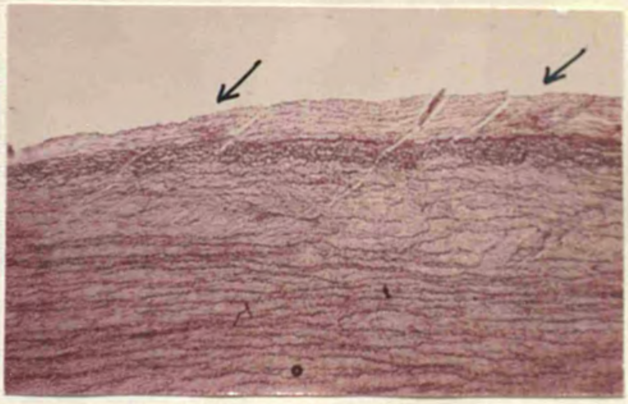


(b)

PLATE XVII

(a) LS. pulmonary arch of hippo, M.89, showing vegetations(haemalum).

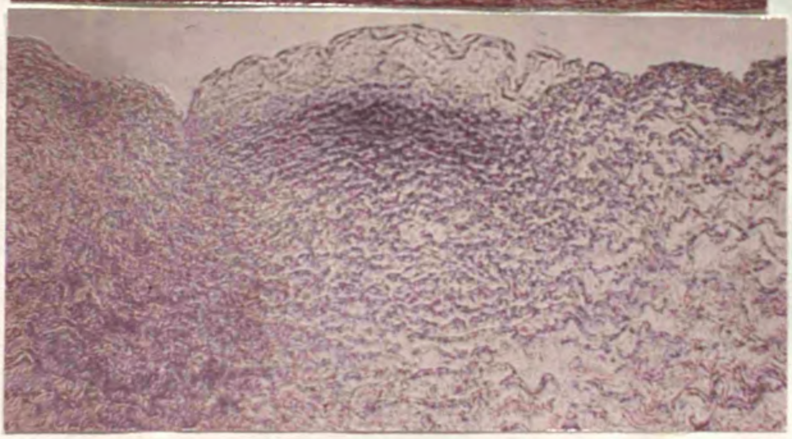
(b) LS. endocardium of right ventricle of hippo, M.89, showing vegetations (haemalum).

(c) LS. right aortic sinus near orifice of coronary artery, showing intimal irregularity macroscopically visible as 'roughness' (haemalum).

PLATE XVII

(a)

(b)



(c)

PLATE XVIII

(a) Cyst, supposedly parasitic, protruding into the lumen of the aorta of hippo, M.26. Diffuse sudanophilic deposits occur in the media. The I.E.L. is disrupted. (Sudan IV and haemalum).

(b) Subendothelial lipid deposits in the thickened intima of a small plaque in Portion I of the aorta of a ~~buffalo~~ hippo (Sudan IV and haemalum).

(c) A circular intimal 'button', overlying a small calcific medial deposit in Portion I of the aorta of a hippo. The elastica is disrupted, but the thickened intima contains no lipid deposits.

(d) (e) A tiny, fibrous intimal 'button', devoid of lipid deposits, but with re-duplicated I.E.L., and slight disruption of the underlying medial elastica, in the iliac artery ~~portion I of the aorta~~ of a hippo (Sudan IV and Haemalum).

PLATE XVIII

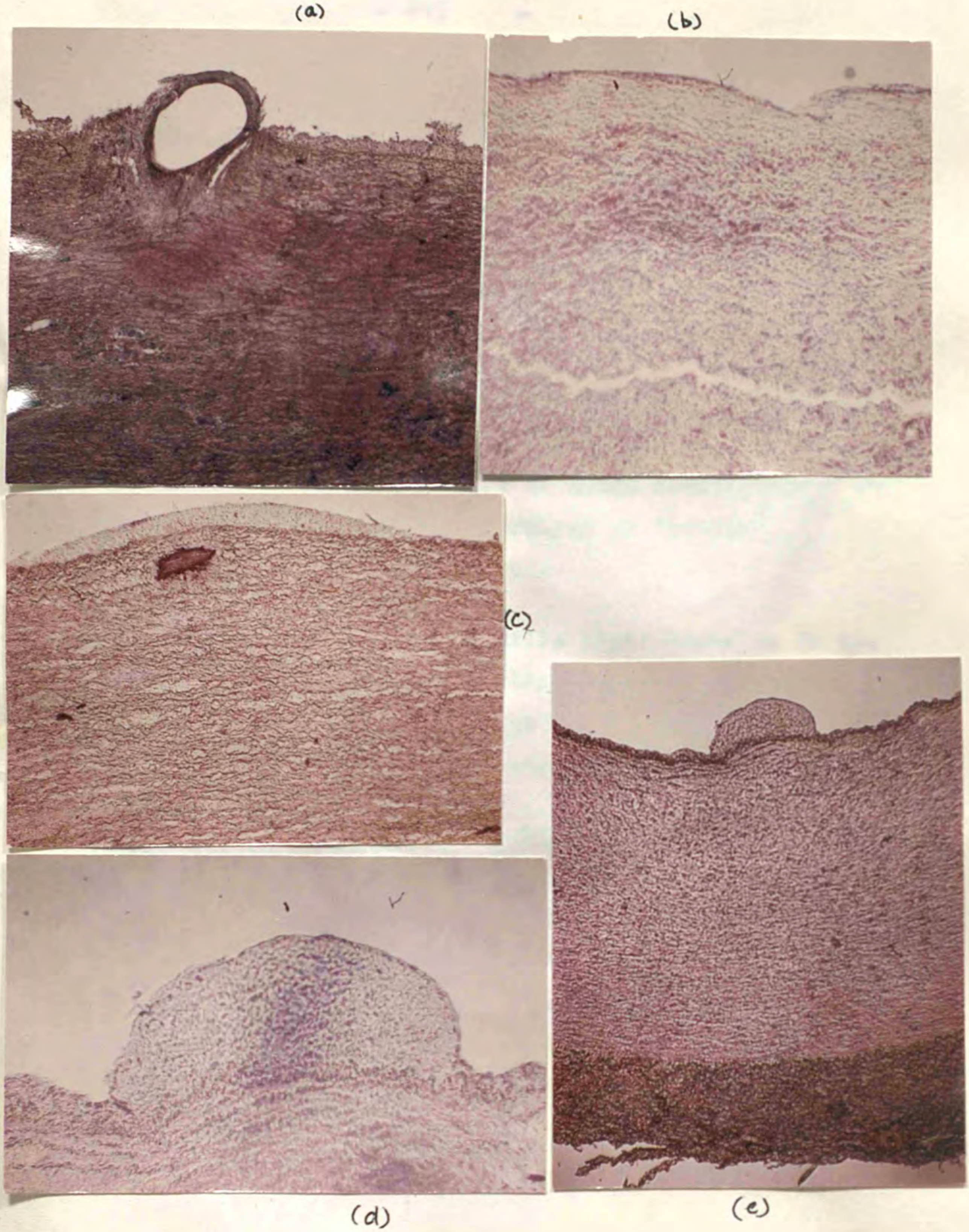


PLATE XIX

(a) M.54, giraffe. Extensive fibrous plaque in abdominal aorta, containing no lipid deposits, but some re-duplication of the I.E.L. and some disruption of the medial elastica (Verhoeff and Van Gieson stain).

(b) TS. of the ostium of a small branch of the coronary artery of M.124 showing the supportive thickening or 'collar' (V. & V.G. stain).

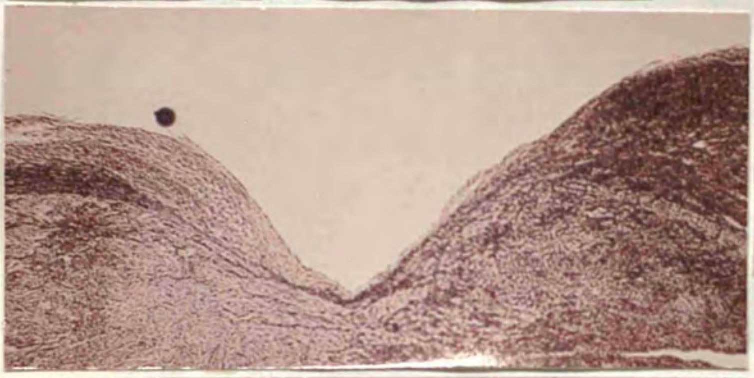
(c) Normal sudanophilic lipid deposits in the deep subendothelial tissue of the intima of the supportive 'ramp' of the ostium of a coronary branch. Giraffe M.124.

(d) Deep medial calcific deposit in the aorta of giraffe, M.126. The overlying intima is seen to be thickened and fibrous. The calcific lesion was localised and suggests a possible reaction to former parasitic activity.

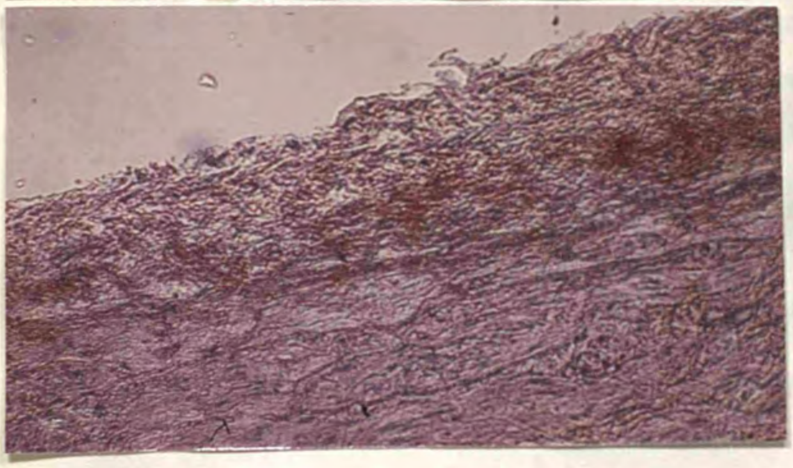
PLATE XIX

a)

d)



b)



c)

PLATE XX

LS. of the left dorsal 6th ostium of portion I of the aorta of a hippo:

(a) the centre of the ostial depression, showing a small deposit of lipid in the thickened intima. The I.E.L. peters out, as do the medial elastic lamellae, towards the centre of the ostial depression;

(b) the rim, or 'collar', of the same ostium showing a slightly thickened intima with a wavy I.E.L. (suggesting additional extensibility) overlying a thickened circular band consisting mainly of smooth muscle. The elastic lamellae of the media are here seen to terminate rather abruptly where they abutt on the collar of smooth muscle (E) In this particular section, lipid deposits were also found in the intima of the 'ramp', just beyond the edge of the photograph

PLATE XX

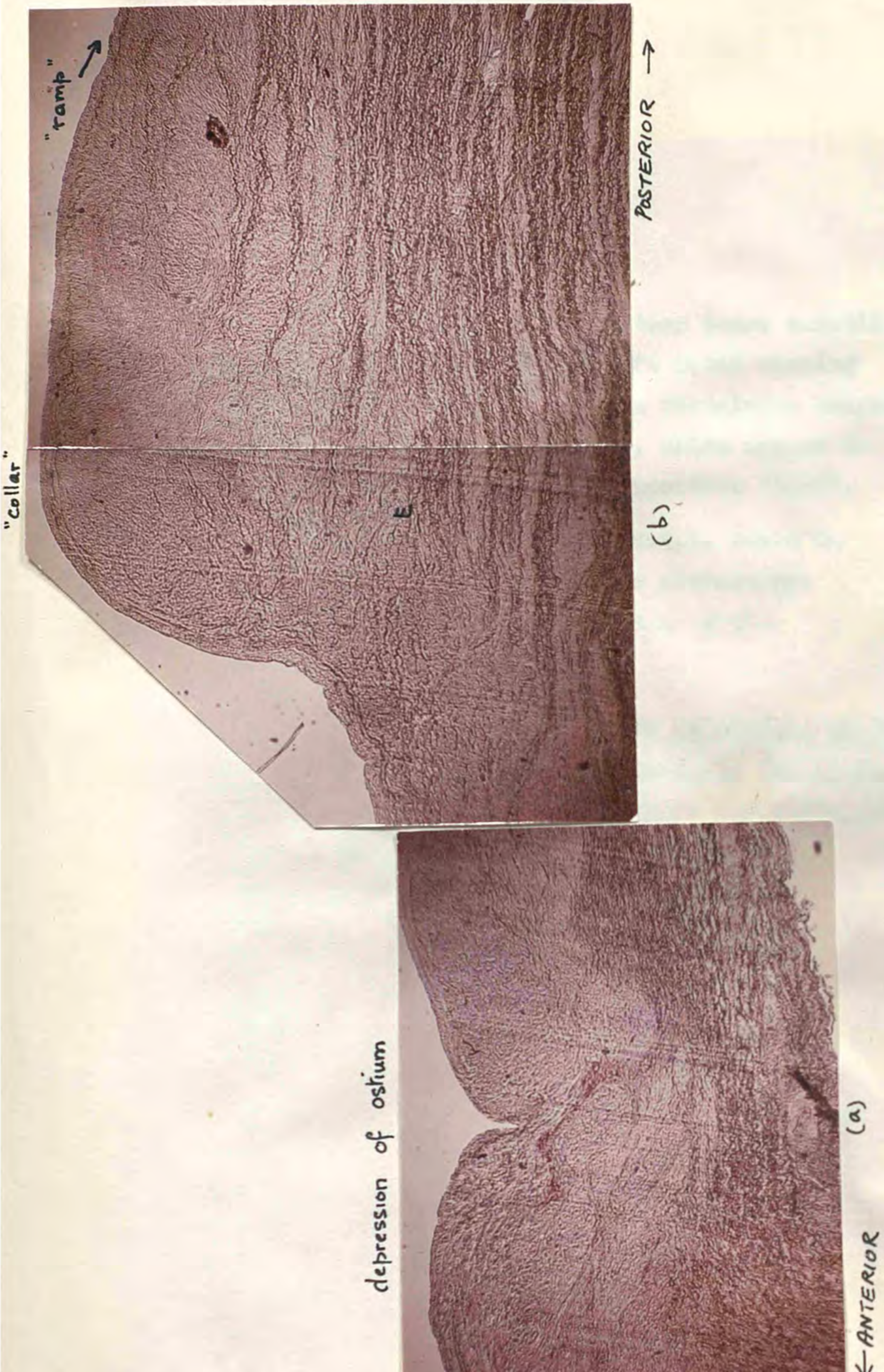


PLATE XXI

(a) TS. normal carotid artery (near carotid bifurcation) of giraffe M.126 showing ridged, fibrous intima containing sudanophilic lipid deposits, which appear to belong to a normal supportive 'band'.

No disruption of the I.E.L. could be detected by high-power microscopy. (Sudan IV and haemalum). x 50.

(b) TS. common iliac artery of buffalo (M.31) showing fibrous thickening of the intima, and (right) duplication of the I.E.L.(D) (V. & V.G. stain).

PLATE XXI

a)

(b)

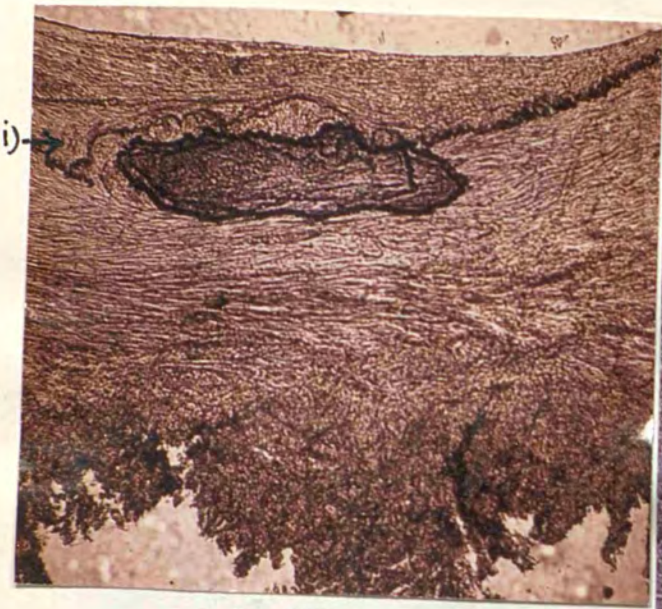
PLATE XXII

(a) Iliac artery of buffalo showing thickened intima, disruption of the I.E.L., and a heavy calcific deposition on what was probably the original I.E.L. (Haemalum, x 50).

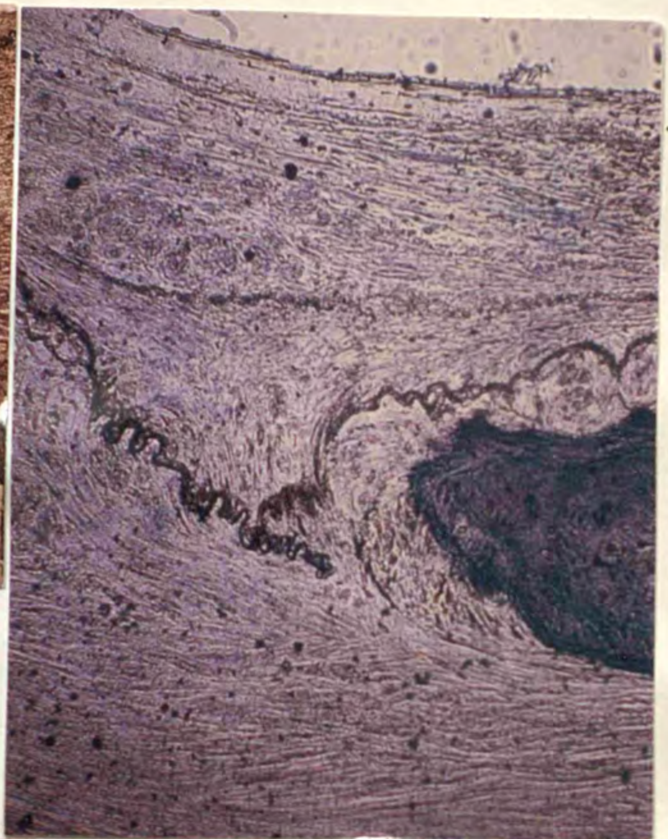
(b) Portion (i) of (a) above, ~~stained with Sudan IV and haematoxylin (x 100)~~. Replacement of the fragmented I.E.L. with active proliferation of macrophages and fibroblasts has occurred. Presumably this lesion is caused by a tissue reaction following the passage of Onchocerca armillata in the vicinity of, or even through, the I.E.L. (Gurr's NRG stain, x 100).

(c) Tissue reaction in the media of the aorta of a buffalo, where numerous burrows of O. armillata occurred (Gurr's NRG stain, x 400).

PLATE XXII



(a)



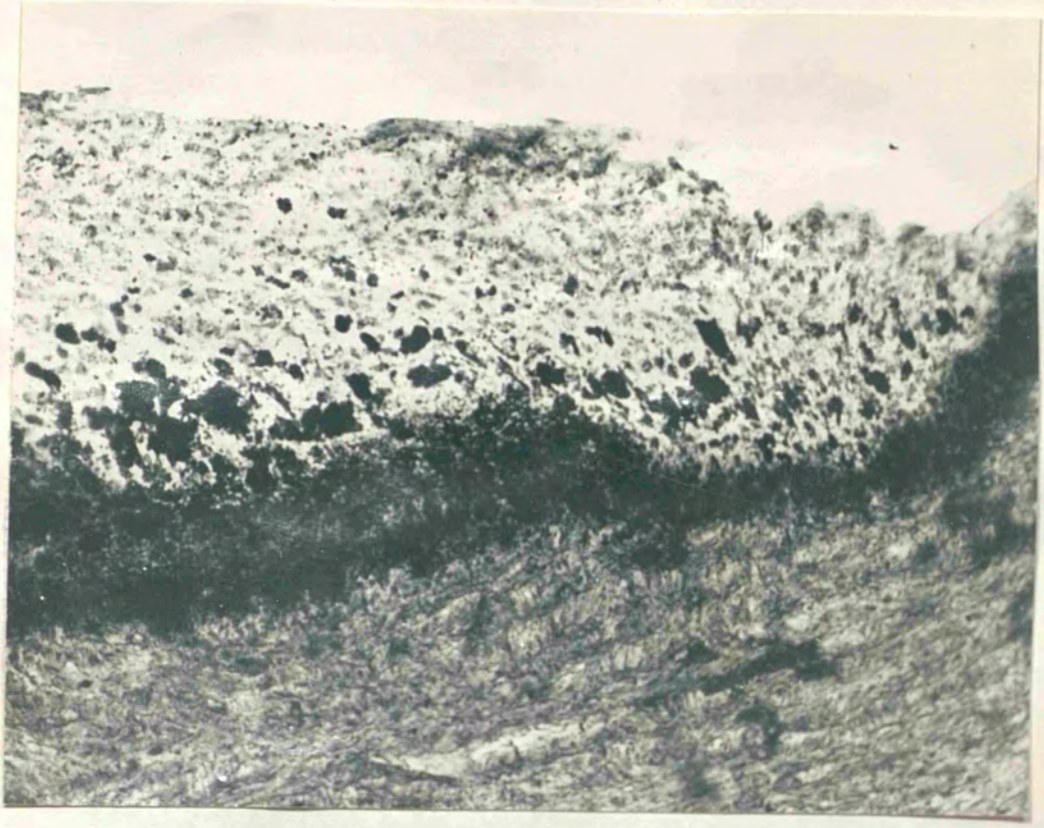
(b)

(c)

PLATE XXIII

(a) Atheromatous plaque in aorta of male chimpanzee, M.98 (Sudanophilic lipid shows dark).

PLATE XXIII



Chapter 7

Other Traumatic, Congenital and Pathological Conditions

In this chapter, attention is drawn to only a few selected cases which are relevant, insofar as they may have caused a situation stressful to the individual animal concerned, thus possibly affecting directly or indirectly the normal functioning of the cardiovascular system. It is also of interest to record selected cases of traumatic occurrences in the wild state in relation to individual survival capacity - e.g. the lioness (M.57) and the giraffe (M.126).

The systematic histo-pathological examination of the whole reference collection of slides made from tissue slips taken from the main body organs, as autopsy routine, is however pending. It is hoped that this may be completed as a separate study in the near future.

Cases with heavy parasitic infestations causing impaired general condition are described in ch. 4, pp 82-110

ARTIODACTYLA

Buffalo

(i) Scars due to fighting, wear of the underside of the horns of old animals due to the flicking of the ears, blindness and lameness are fairly common traumatic occurrences. Blindness may be caused either by injury or by the presence of the Nematode worms Thelazia rhodesii (see ch.4, pp 89).

(ii) In specimen M.30, an unidentified body about 5 cm in diameter, apparently a displaced ovary, or possibly an ectopic pregnancy, was located in the abdominal cavity, attached on one side by a twisted connective and vascular cord to the urinogenital organs, and adherent on the other to the diaphragm.

(iii) Chronic pulmonary disease resembling that described by Thurlbeck et al. (1965) and associated with an infestation of the cardiovascular system by Onchocerca armillata and Elaeophora poeli (see ch. 4, p 84; ch. 6 pp 144-151) was seen in specimens M.30 and M.31. These specimens were killed in the same locality as the five animals examined by these authors.

M.31 was very emaciated and extremely feeble. An aneurysm, 1.5 cm in diameter, caused by E. poeli, was found in her aorta, in addition to burrows typical of O. armillata (Plate IV p 240). It is not unreasonable to suppose that such aneurysms are liable to rupture eventually, an event which may partly explain the occurrence in the Queen Elizabeth National Park of the natural death of large numbers of buffalo each year. Equally, one may suppose that the debilitating effects of bovine tuberculosis and/or actinobacillosis (Thurlbeck 1965) in themselves, even without cardiovascular complications, may prove fatal to the Park buffaloes.

Giraffe

(i)Specimen M.126 was of considerable interest as regards the ability of the species to survive attack and injury. This was the senior bull of a mixed herd consisting of one younger, mature bull and nine cows. He was a very large giraffe (body weight 1,310 kg., height at withers 335 cm, total length nose-to-tail 487 cm) and carried on the withers the deep scars of a lion bite and long claw marks down the right flank. The third and fourth ribs on the off side had been fractured, but had healed naturally. The scar of a deep bite was clearly visible at the base of the tail, and two sets of claw marks ran down both quarters and hindlegs to the hocks.

It was evident that this animal had at some time been attacked simultaneously, probably by three lions, but had managed to kick them off, escape and recover (Plate XXVII p 272).

In seeking an explanation of the case of lioness M.57 (see p 261), it is apparent that lions are not always successful in hunting, and do not always escape injury themselves. Varaday (1966) for example described a case witnessed in southern Africa, where two buffalo killed and trampled a full-grown lion which attacked them. A successful kick from a bull giraffe could cause extensive injuries to any attacking predator.

(ii) Specimen M.124 was a cow carrying a full-term foetus (50 kg). It was noticed to lag badly behind a mixed herd of some 29 giraffe to which it belonged, and was found at autopsy to have a somewhat atrophied cystic and necrotic liver (Plate IX p 110). The adrenal glands, usually a yellowish colour in giraffe, were dark red, congested and heavier than those of either of the other two adult giraffe collected in this survey.

CARNIVORA

Civet

The case of the young civet found dying in the Murchison Falls National Park (ch.6, p 189)has not yet been investigated, nor the cause of the condition established. It is hoped to examine it further in the near future. A suspected possible cause is rabies, as the animal's convulsive behaviour when found resembled cases seen in Africa by the author in mongoose, and domestic dogs and cats, previously. The scientific Warden of the Park confirmed occasional occurrences of rabies in the area.

Lion

Specimen M.57 was a very elderly lioness, whose behaviour was unusually aggressive. She fled with the pride when the male lion M.56 was shot, and disappeared. The author and assistants began to take measurements and prepare the autopsy on the male lion, when the old lioness was seen stalking the party through the thorn bushes. The pride had been baited, with a wildebeest carcass suspended in a tree, and she first moved in, crouching under the bait, and then crouched tensely preparing to spring on the working party. She was shot at that moment.

Post-mortem examination showed her to be in poor condition, her coat patchy and dry, her weight very low for her height and length (see p. 197) and her teeth worn. An old scar across the back of both thighs suggested an old bullet wound. Hedgehog spines in her paws must have caused considerable discomfort, and the presence of the skin and tail of a rat in her stomach suggest that she was reduced to a starvation diet. This may have accounted for her jealous possessiveness of the bait, and perhaps even of the carcass of the male lion.

The skeleton was later examined and the findings are illustrated in Plate XXIV p 266 . The limb bones were normal (the tibia and fibula of lion, specimen M.39, with a naturally healing fracture are shown for comparison) but two ribs showed evidence of a previous fracture. The pelvis and thoracic vertebrae, however, were remarkable in their asymmetry, the proliferation of exostoses, and the atrophy of the intervertebral disc lying between two thoracic vertebrae. Dr. P.P. Scott (1966) expressed the opinion that the injury which must have caused the rib fracture, was not necessarily related to the condition of the pelvis and vertebrae; that the case did not resemble any caused primarily by nutritional deficiency in felines known to her; and that it was her view that it might be a case of osseous metastasis, a view to which the fact that (in the field) the ovaries were noted to be 'cystic' perhaps lends some support.

LAGOMORPHA

African Hare

The case of specimen M.72 has already been mentioned (ch.6, p 201). The clinical report is still awaited.

PERISSODACTYLA

Rhinoceros(M.128)

An extensive star-shaped scar on the flank seems indicative of an injury in calfhood (Plate XXVII p 272). It is an interesting point for speculation as to whether the sire or the dam of the species may on occasion inflict such an injury with its horn on a calf during disciplinary treatment, or whether this specimen had been the target of a poacher's spear or arrow.

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PLATE XXIV

(a) (b) Pelvis and two ribs of lioness, M.57. The ribs show naturally-healed fractures. Extensive exostoses may be seen on the pelvis, which also has a distinct asymmetry.

(c) Vertebrae of lioness, M.57, (sagittal section) showing atrophy of one inter-vertebral disc.

(d) Normal bones of hind limb of lioness M.57; cancellous bone at site of fractures to tibia and fibula of lion M.39.

PLATE XXIV

(a)

(b)

(c)

(d)

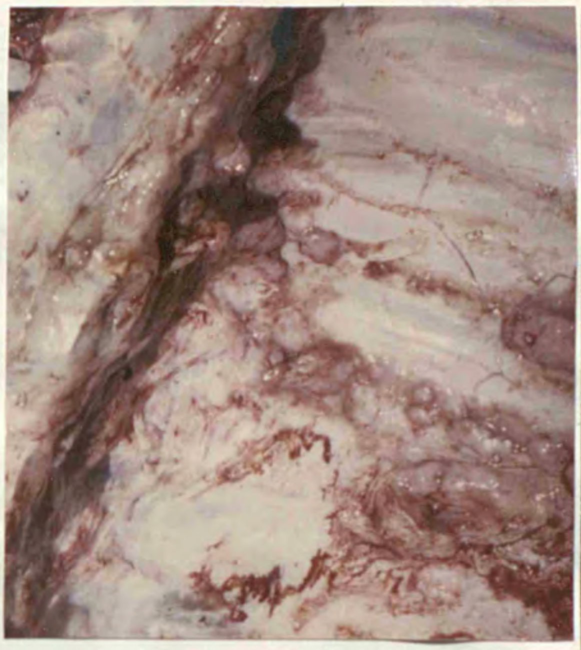
PLATE XXV

(a) Buffalo M.31. Tuberculous lesions, (supposedly of bovine tuberculosis, see p 258) in the pleural cavity.

(b) M.31. Tuberculous lesions in the liver.

(c) M.31. General emaciation.

PLATE XXV



(a)

(b)

(c)

PLATE XXVI

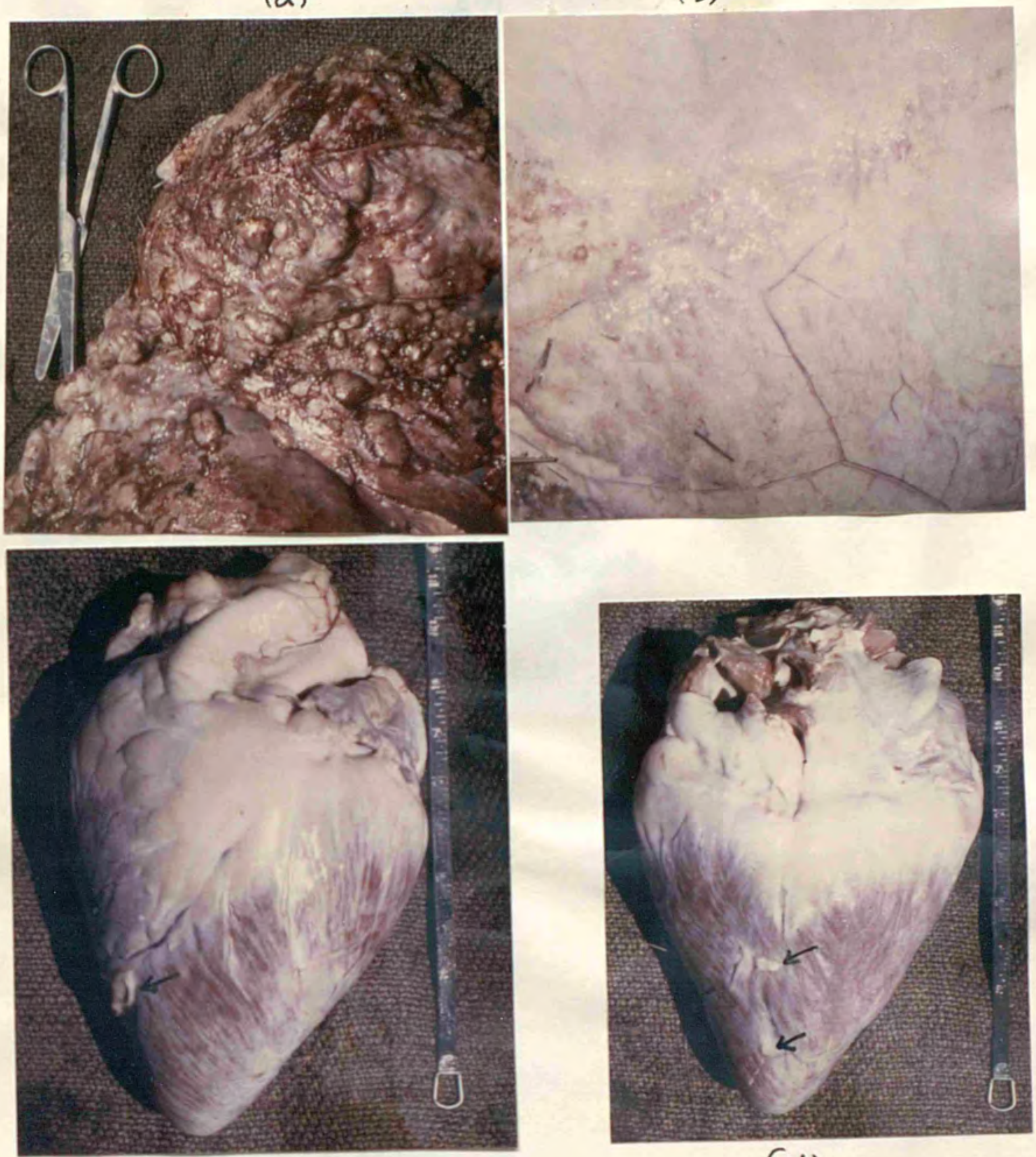
(a) M.31: Tuberculous lesions in the lung.

(b) M.31: Fibrous 'tags' on the peritoneum.

(c)(d) M.31: Tuberculous lesions on the epicardium.

PLATE XXVI

(a) (b)



(c) (d)

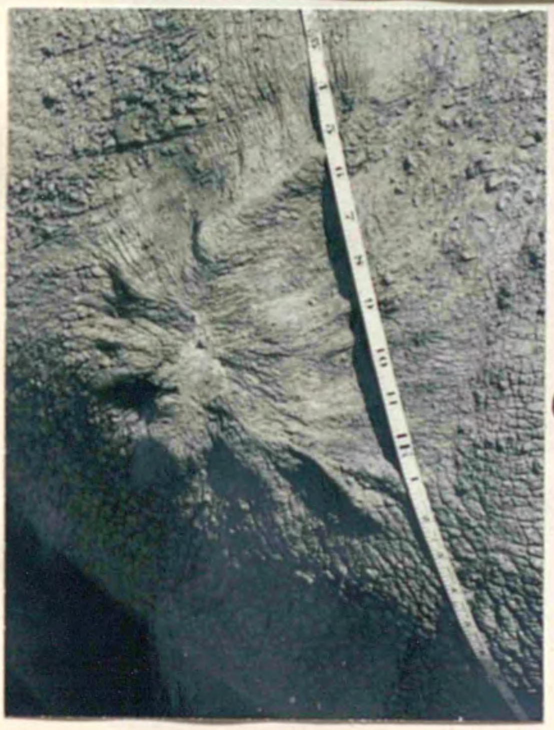
PLATE XXVII

(a) Scar of claw marks (probably lion) on quarters of giraffe M.126.

(b) Large scar of former injury on flank of rhinoceros M.128.

PLATE XXVII

(a)



(b)

PART II

THE ECOLOGY OF CARDIOVASCULAR DISEASE IN FREELIVING WILD ELEPHANTS IN EAST AFRICA

Chapter 8

Materials and Methods

On completion of the first phase of the field survey, the species selected for more detailed study was the African savannah elephant (Loxodonta africana africana Blumenbach), see Appendix 3, p. 598

Although certain species of Primates, as well as the ostrich (Struthio camelus), were considered for this purpose, neither was chosen. Already several species of Primates were the subject of cardiovascular field studies by other groups of workers; and in the case of the ostrich difficulties might arise in obtaining collecting permits, as well as in finding a simple technique for ageing individual birds.

At the time when the decision was reached to study the ecology of cardiovascular disease in the African elephant, no firm decision had been announced by either the Kenya or Uganda governments to proceed with large-scale elephant cropping programmes, although the subject had been under discussion for some time. A pilot cropping study scheme had however already been carried out in the Murchison Falls National Park, Uganda, and, by courtesy of Mr. J. Savidge, Scientific Park Warden, I was able to examine and collect material from seven elephants shot then. All seven specimens (M.18,19, 21-25) showed cardiovascular abnormalities. I was also able, on a private licence, to collect a middle-aged bull elephant in a montane habitat (M.152) as a 'Control' specimen. This animal showed no cardiovascular lesions.

It was on the basis of these findings that the British Heart Foundation agreed to authorise me to equip a fully independent mobile unit, with two vehicles, adequate for carrying out comprehensive autopsies on elephants selectively shot in contrasted habitat types in East Africa, in the second phase of the survey (see ch. 1 ,p12,13) The list of the equipment used is given in Appendix 1,pp 587-592. Altogether, a total of 40 elephants was thus examined.

Co-operation by Game and Parks Departments in Kenya and Uganda

The plan to collect elephant from selected, contrasted habitat types for detailed *post-mortem* examination was outlined to the Chief Game Wardens of Uganda and Kenya respectively, and in each case their co-operation, advice and assistance proved to be fundamental to the success of this study. They were able to advise as to suitable localities for which permits could be issued for me to select elephants of both sexes belonging to the required age groups. They also kindly co-ordinated my schedules to fit in with those already made by organised tourist-hunting parties in the hunting zones, in such a way as to minimise any overlap of activities.

The study of the background ecology of the habitat types chosen also necessitated a considerable amount of observation on live elephant within the National Parks adjacent to, or near, some of the hunting zones used for collecting. Permits, issued by courtesy of the Directors of National Parks of Kenya and Uganda respectively, enabled me to spend considerable periods watching, filming, and following recognisable herds moving in and out of the Parks. This was invaluable in enabling me to develop observational experience of making on-the-hoof age/weight/height estimates, as well as in recognising signs of disease and abnormality in living elephants. It was also during these observational activities that data were collected for the background study of the main ecosystems involved (see ch.9, pp 293-348 and appendices 4 and 7 pp. 606-653

A large part of the success of this study must be attributed to the co-operation accorded by these government departments in permitting me this freedom to explore the available habitats over such a wide territory, and thus to find a naturally unrestricted habitat type which could serve as a 'control'. This could be contrasted with the semi-restricted, degenerate habitat types associated with the Murchison Falls, Queen Elizabeth and Tsavo National Parks. The freedom to operate the vehicles and the team of African assistants as an independent unit in the field was also fundamental in enabling me to seize all the available opportunities to collect the required elephants in circumstances suitable for comprehensive autopsy.

Autopsy procedure

Selection, killing, and autopsy procedure in general followed that outlined in ch. 2, pp. 27-44 as described for large mammalian specimens, with slight modifications necessitated by the great weight and bulk of the carcass and its members, and the thickness of the skin.

The killing of the selected elephants in terrain suitable for autopsy also frequently involved long patient trailing of the herds until the positioning of both the elephant (or elephants) and the terrain was suitable. If possible two, three, or even four, elephants standing together were then shot in quick succession, using only the 'brain shot' at close range, a procedure adopted in emulation of the method demonstrated in the Murchison Falls National Park pilot cropping scheme by Mr. J. Savidge. The value of this procedure is discussed in Appendix 6 p 282 and ch.5, p 111 - 136. The method was not without a certain degree of risk, but for these cardiovascular studies proved in practice to be a very successful and satisfactory approach.

On occasions when three or four elephants were shot together, a bivouac camp was made beside the carcasses, and essential work continued on into the night by the light of vehicle headlamps, long-lead 60-watt inspection lamps and hurricane lamps, guarding against night scavengers by means of fires. In such cases, less urgent work such as the final chopping out of tusks, brain, and mandibles could be completed on site early next morning.

The ears, ivory, and tail hairs were of commercial value (see p 29), so these had to be removed and treated according to hunting and trade practice. In Uganda, all of these were handed in to the Game Department, whereas, latterly, the Game Department of Kenya took over all ears, but permitted the sale of the ivory on behalf of this cardiovascular project. Exceptions to this rule were made in the case of damaged or diseased tusks, of which I was allowed to retain the abnormal parts for further study (see ch. 12 p 516). The remains of the carcasses, after autopsy, were used for human consumption in areas where national legislation permitted, and in other areas if was left to the scavengers for 'cleaning', after which (usually a matter of 2 to 6 hours after our departure from the carcass) I would,if possible,return to examine the skeleton for bone abnormalities.

Details of the body measurements made and the preparation of the mandibles and eye lenses for ageing purposes are described in Appendix 6 ~~pp~~ (Sikes 1966b);

the extraction and preservation of cardiovascular material for further study in Appendix 4, p 606 (Sikes, in press); the collection of blood serum in ch. 5, pp 111-136, and parasites in ch. 4, pp 82-110.

Laboratory procedures

1. Macro-examination of aortae

i) Lipid distribution

a) Sudan IV gross staining (Holman et al. 1958) and photography.

All the aortae and samples of arteries were washed and then gross-stained (still stapled to their polythene boards as mounted in the field) in 20-litre glass tanks. When stained, each mount was photographed and the prints fitted together and mounted on squared paper to provide a composite photograph of each complete aorta.

In addition, each portion of aorta was drawn to scale on squared paper, and the stained areas drawn accurately on it. Each complete aorta, from the point of attachment of the ductus arteriosus to the bifurcation was divided transversely into five equal lengths, numbered I to V. Each portion was subdivided longitudinally into four portions: dorsal, right lateral, ventral and left lateral. The total area of each subdivision was then found by counting the total number of ½ cm squares contained (all parts of squares on the right edge of each portion being counted, and all parts of square on the left being ignored), and the area of each clearly demarcated button, streak, or plaque stained with Sudan IV was similarly counted.

The results were set out as tables, and are given in ch. 11 pp 400-419 . The intra-aortic distribution of intimal sudanophilic material is shown in histograms, FIGS: 21-27. The area of sudanophilic material in the whole aorta, calculated as a percentage of the whole area, for all forty elephants examined, is given in Appendix 4 FIG. 2 p 650.

It will be noted that the quantitative estimate of sudanophilic material refers only to the area distribution in the intima and ~~ix~~ not to volumetric or other quantitative tests made by the chemical extraction of the lipids. Such methods are under development by Dr. Crawford at the Nuffield Institute of Comparative Medicine; since they involve the destruction of the aorta itself, this approach would not have served the purpose of this project. With additional material, obtained from the current large-scale cropping schemes, ample opportunity should be available for detailed qualitative and quantitative biochemical analyses of intra-aortic lipids in elephants.

ii) Calcium distribution: radiography

Radiography was carried out by Miss P. Verity in the Radiology Department of the Nuffield Institute of Comparative Medicine, under the direction, and by courtesy, of Dr. G. du Boulay.

The procedure was as follows:

The aortae were submitted for radiography in pieces, each piece stapled on a stiff polythene backing 12 x 10 inches in size. A Watson Dental X-ray unit was used with a fixed rating of 60Vp and 20mA with a total aperture filtration equivalent to 2 mm aluminium. The diaphragm and cone were removed. Trials had been made on much more sophisticated apparatus with a high output generator and tubes with foci from .3 mm to 2.0 mm, but for this purpose the dental machine was found to give the best results.

Most of the pictures were made on Gevaert Industrial film, 'D4', at a focal film distance of 40" and an exposure of 20 - 24 seconds, depending on the thickness of the aorta.

A few Ilford Industrial 'F' films were used. These needed half the exposure and gave adequate but not as good definition as the Gevaert film. To prevent the tube from overheating only one exposure was made every half hour. For protection from radiation the exposure was made from outside the room.

The specimen was set up on its backing sheet, and lay on top of a special measuring grid. Beneath this lay the film enclosed in a 'plastic cassette', and beneath the cassette a brass sheet to prevent back-scatter. The whole "sandwich" was placed on the floor so as to obtain a maximum focal film distance. The special measuring grid, made by Mr. Tom Crichton of St. Bartholomew's Hospital, consisted of a 1 mm gauge perspex sheet, engraved with radio-opaque lines in two directions forming a pattern of 5-mm squares. The films were developed for 8 minutes at 68°F in Ilford 'Phenisol' developer.

Quantitative counts of the area of each portion of the aorta wall containing Calcium were made in the same way as for Lipid distribution, except that the need to make scale drawings was eliminated by the inclusion of the ½ cm scale grid in the radiographs. Direct counts on the viewer could therefore be made. The results of these counts are given in ch. 11 pp. 400-402 A graph showing the area of aortic wall containing Calcium as a percentage of the area of the whole aorta for each of the forty elephants examined is given in Appendix 4 , FIG. 3 p 651.

2. Microscopic examination

i) Histology tissue slips, collected from each of the main internal organs (see p. 36) including the heart, at the carcass, and preserved éther in Richardson's Fluid (Richardson 1960) or in standard 10% formol saline (Peacock 1955) (previously prepared at the laboratory with glass-distilled water and poured ready into 10 ml polythene collecting tubes), were all paraffin-embedded and sectioned at 4 µ or 5 µ. Two sections of each were stained with haematoxylin and eosin, and one of each with Verhoeff and van Gieson stains (Gurr 1963) in order to provide a basic set of reference tissues.

This procedure (during which a total of approximately 4,000 slides of stained sections were made), although somewhat time-consuming, has proved to be of very great value to the subsequent understanding of cardiovascular abnormalities found, especially in the case of parasitic lesions. It has also served as a guide in determining additional microscopy necessary for the elucidation of particular abnormalities. For example, where mineral deposits were found, von Kossa's stain (Clayden 1962) was applied; for Lipids Sudan IV and haemalum, using frozen sections; for suspected parasites Giemsa or Gurr's N.R.G. (Gurr 1963) stains, and for Leptospira sp. Warthin-Starry's silver impregnation method(Carleton 1962).

ii)Tissue slips cut transversely from the aorta and other arteries at autopsy were preserved as above. In particular, these slips were taken from portions which appeared, to the naked eye, to have buttons, plaques or other abnormalities of the intima. Each of these was then divided into two portions, one being paraffin-embedded, and the other sectioned by a freezing-microtome for staining with Sudan IV and haemalum, or Giemsa. The paraffin sections were stained with haematoxylin and eosin, and with Verhoeff and van Gieson's stains.

An additional standardised set of eight longitudinally cut slips was taken from each preserved aorta on return to the laboratory. These were taken just posterior to the scar of the ductus arteriosus, one in the mid-dorsal line, and one in the mid-ventral; a second pair just anterior to the origin of the coeliac and ~~superior~~ anterior mesenteric arteries, one dorsal and one ventral; a third pair at the level of the renal arteries; and a final pair from a point just anterior to the bifurcation, one dorsal and one ventral. Each of these was cut irrespective of the presence or absence of buttons, plaques or suspected abnormalities, and was stained with a) haematoxylin and eosin; b) Verhoeff and van Gieson; c) Alcian blue. These have been used as the basis for the description of the normal aorta (ch. 11 p.430-433)

As mentioned in ch. 2 p 41 , a wide range of fine histochemical stains has not been applied to this collection of material, as it is felt that these belong more properly to the specialised fields of biochemistry and histopathology, and are outside the scope of this, primarily ecological, survey.

3. <u>Normal and abnormal developments and structure of heart and aorta, and their relationship to age</u>

On the basis of the determination of the relative age of the 40 elephants examined in this survey (ch.10 and Appendix 6 (Sikes 1966b), an attempt has been made to compare the size, weight and shape of the hearts and aortae, and to determine the normal growth and ageing patterns for these organs. These are in turn related to changes due to any abnormalities seen. The results of this study are given in ch. 11 (~~24~~) pp. 388 - 438.

<u>Examination of data obtained relating to environmental factors which may be relevant to the cardiovascular material examined</u>

Details of the habitat types studied (ch. 3 and 9, and Appendix App 615 - 620 and Fig. 1 p. 649), parasites identified (ch. 4), traumatic, congenital and pathological conditions (other than cardiovascular) found (ch. 12) are given in the appropriate chapters.

These must be related to such important, and rapidly changing, factors as behaviour patterns, population dynamics and stress factors in the environment, the interpretation of which can at present be at best only tentative in the case of the African elephant. Insufficient statistical work has been achieved to date to warrant the formulation of any conclusive discussion on these factors, and in any case current research under game management research programmes is confined almost exclusively to the degenerate Park habitats. Practically, no extensive and reliable data are available regarding elephants in their natural habitats of indigenous forest on unrestricted ranges, linked by open long-distance migration routes.

The data I have managed to gather to contribute to the discussion on this subject have been gained from the few available reports on i) recent researches on elephant within the National Parks and their environs; ii) searches of ivory licence books and sales records in East Africa; iii) discussion with hunters; iv) searches in older books on hunting and African history; v) verbal accounts by older European, Asian and African residents in the areas studied; vi) verbal accounts by older members of African elephant-hunting tribes of tribal lore and custom with regard to the former vegetational cover, hunting rites etc. It will be appreciated that almost all these sources of information, with the exception of i) and ii), must be treated with great caution, but clear patterns do nevertheless emerge as to the former characteristic patterns of elephant behaviour, population density and migration. These are discussed in ch. 9, pp. 293-348 Appendix 7 (Sikes 1966c) p 269 — 271, and pp 570-572.

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PLATE XXVIII

(a) An early stage in autopsy: grassland elephant, specimen M.86.

(b) Weighing the carcass piecemeal: complete head with tusks of scrubland elephant, specimen M.116.

(c) Use of viscera hooks: montane elephant, specimen M.103.

PLATE XXVIII

(a)

(b)

(c)

PLATE XXIX

PLATE XXIX

The head is cleared of skin and flesh, prior to disarticulation of mandible, and removal of tusks and brain. Specimen 116.

PLATE XXIX

Chapter 9

Ecological Background: Elephant Communities Studied in Three Selected Habitat Types

Three distinct habitat types were selected as the background for a study of the ecology of cardiovascular disease in the African elephant. The object was to provide the necessary field tests in answer to the questions arising from hypotheses (ii), (iii) and (iv) listed in the Introduction (pp 5 -17).

The 'control' habitat type

One of these habitats should be as 'natural' as possible and serve as a 'control'. For the purpose of this study this would have to be a habitat still containing a large proportion of extensive indigenous vegetation over a wide and varied range known to have been used by elephant for at least a century, and preferably for longer. As it is most unlikely that the maximum life span of an African elephant exceeds a century, one may thus suppose that any elephants collected in such a habitat would have been subject only to the intrinsic stresses characteristic of such an ecosystem throughout its life-time, and would have enjoyed, without interruption, the environment to which it may be supposed to be best adapted by nature.

The very extensive ranges of three great montane massifs of East Africa suggest themselves as the obvious 'control' habitat type. They have been singularly free, until very recent years, of interference with the elephant ranges by encroachment, although irregular disturbance by hunters in the montane forest has undoubtedly occurred from time immemorial. Evidence of this is suggested by the long traditional use by the Wachagga, the Wanderobo and the Pygmies of ivory and elephant-hair bangles. The irregular hunting of elephant within these areas may thus be regarded as consistent with its character as the 'control' habitat type.

Degenerate habitat types

The other two habitat types chosen both lie in the East African lowlands* (i.e. altitudes less than 5,000 feet) and both represent degenerate habitats, characterised by what McDiarmid (1962) termed "semi-artificial" conditions in relation to the diseases of freeliving wild animals.

The first, Uganda grassland, is today typically degenerate woodland/savannah, associated with the formerly

* "high" and "low": these terms are used here, and in Vol. I, ch. 3, to refer to altitude of terrain, not height of vegetational cover, when describing habitat type (Davidson, 1964).

rigidly protected Queen Elizabeth and Murchison Falls National Parks and environs. Reasons for the degeneration of this habitat are described in Appendices 4 and 7. (Sikes 1966c). In each case, large elephant communities have become over-concentrated within these areas, over-browsing them, and exhibiting changed physique and behaviour patterns. These appear to be the result of frustration of the migratory habit; denial of access to forest refuges for calving, respite from direct sunlight, and variation of the diet; and possibly also of over-population stresses, affecting temperament and 'territory rights' (Kuehme 1962). Here, total protection from hunting has been imposed for some twelve years. Prior to this, severe ~~control~~ application of the hunting laws already afforded the animals very effective protection.

The Uganda grasslands, at the time when this field survey was carried out, must be regarded as an environment in an advanced state of degeneration, quite uncharacteristic <u>per se</u> as an elephant habitat. It is possible, however, that, if direct migratory access were still open to these elephant communities to reach extensive, undisturbed, indigenous forests, adequate to their dry-season needs, elephant might naturally visit the grassland areas from time to time. Recent elephant population studies in these areas by Buss & Savidge (1966) and Buechner et al. (1963) suggest that this frustrated natural tendency in Uganda elephant to migrate to forest refuges is evidenced by the seasonal movements of the herds along former migration routes.

The second lowland habitat chosen is that of the Tsavo National Park (East), Kenya, and environs. Previously, this was Commiphora-Acacia mixed savannah Woodland, thinning out to arid scrubland to the north. Today, however, it is a degenerate, low scrubland, the degeneration of which may be attributed to several factors similar to those influencing the Uganda grasslands. It differs signally, however, in its basic biomass-carrying capacity, due to its completely different geological and hydrographical background. These are discussed more fully in Appendix 7 (Sikes 1966c).

As in the Uganda grasslands, the Tsavo National Park and its environs is not, per se, an environment to which the African elephant is fully adapted naturally. Characteristically, the elephant was found here in the past only during the rainy seasons, or during its long-distance migratory treks, to and from its forest refuges. The denial of most of those forest refuges to it today has brought about the build-up of an excessive resident elephant population, subject to quite unnatural stresses, in a semi-restricted and degenerate environment.

It may readily be seen that the complex of surface water discharges/soil type/vegetational cover, characteristic of each of the three habitat types chosen, differs radically and may have the following effects in relation to the elephants:-

i) Physical activity: the mountainous and extensive high-altitude terrain of the montane habitat type offers longer, and more varied, routes for migration (Sheldrick 1965) and meandering and makes greater physical demands.

ii) Interest and play: studies of elephant behaviour whether in Zoos (Trumler 1959; Kuehme 1962), circuses or in natural conditions (Sikes 1966a) indicate that elephants tend to play vigorously and actively both with objects in their environment and with each other. The varied vegetation of the montane habitat offers the interest of selecting food from a wide choise of plants and the constant use of forefeet and trunk. The monotony of the grassland and scrubland vegetation and terrain offers little interest, and apparently boredom leads to wanton destructiveness to the habitat (Anon.1957).

iii) Nutrition: the montane diet is extremely varied. The forest soils are known to be high in Calcium and Phosphorus content, as situation undoubtedly reflected in the chemical content of the fodder, whereas these elements seem to constitute a very low percentage of the grassland and scrubland soils (Sheldrick 1965). The montane diet contains a high proportion of arboreal products, including various fruits (fleshy and woody), roots and tubers, as well as shoots and bark. Dry-season fodder in the lowland habitats is severely restricted and consists mainly of hay (Buss 1961). It is known that elephant will search diligently for fruits however small, of which they are particularly fond, such as those of the Borassus palm, wild ginger (Aframomum sp.), Vitex, Capparis and Warburgia. The latter would appear to be a tasty condiment, as it is very hot to the human taste, and the leaves are sometimes used in the preparation of curry by Indians. The fruit of the Tamarind tree and the Desert date are also eaten by elephant (Anon. 1962; Dale & Greenway 1961).

One supposes that the montane diet is richer in all nutrients including the main vitamins, minerals and trace elements. Differential chemical assay on the stomach, caecal and rectal contents, collected from the elephants used in this study is planned as a corollary to the present survey, to be carried out in due course.

iv) Calving: old-time hunters' descriptions of mating and calving in elephant always suggest that the natural tendency is to mate and calve in the cover of thick forest (Rushby 1965). In the denuded lowland habitats it is not uncommon nowadays to see elephants openly both mounting each other in play and in copula, and even to find newly born calves apparently dropped in the open grass or among thin bushes (Buss & Smith 1966; Nel 1963; Short 1966; Wright 1964).

~~or among thin bushes.~~ In the forests, young calves are rarely exposed to direct sunlight, whereas in degenerate lowland habitats they may be seen dragging themselves along beside, or beneath the dam through the mid-day heat to water holes or feeding grounds.

v) Exposure to direct sunlight: Experience of elephants in forest habitats convinces one that exposure to direct sunlight is enjoyed normally only for limited periods, and that shade, coolness and humidity are preferred to prolonged exposure to the tropical sun. Elephants observed in the degenerate lowland habitats are perforce subjected to prolonged periods of exposure to unmitigated sunlight, a factor which I have suggested as possibly being correlated with the occurrence of aortic calcification (ch 11 pp 252 - 253 and Appendix 4 (Sikes, in press).

vi) Parasite burden: It is possible that there is a greater parasite burden in elephants in over-crowded, semi-restricted habitats. Data are not available from this survey, however, on which

~~to~~ to base any discussion of this point.

vii) Genetic factors: Isolation of elephant communities in ~~contrasted~~ semi-restricted habitats might encourage the survival of those with advantageous genetic characteristics. Data are at present inadequate on which to base any positive discussion of this point.

Summary of the three habitat types

A. Montane (M)

m.1 Uganda-Congo: Mt. Ruwenzori

m.2 Kenya: Mts. Kenya, Kinangop and Satima

m.3 Kenya-Tanzania: Mt. Kilimanjaro

General characteristics:-

i) Altitude of elephant range: 5,000 - 10,000 ft.

ii) Mean annual rainfall: > 150 cm.

iii) Temperature range: < 10°C - < 26°C

iv) Surface water availability: always abundant in alpine moorland bog seepages, fresh springs and flowing streams.

v) Exposure of elephant to direct sunlight in glades and on moorland: usually only ~~at night,~~ in the early morning and evening; frequent cloud and mist cover reduces exposure.

vi) Disturbance: limited disturbance by hunting in higher altitudes. Considerable disturbance by hunting and 'game control' shooting at lower altitudes and foothills, where cultivation and forestry plantations occur. History indicates a considerable degree of native hunting in the past, and in the Mt. Kenya - Kinangop-Satima ranges there is verbal history of widespread interference with elephant, rhinoceros and buffalo by means of automatic military weapons during the Second World War.

It is also of note that very rapid encroachment by settlement in these areas is occurring at present and has greatly accelerated in the past three or four years, with extensive destruction of the forest belts from the foothills in an upward direction. On the Kenya- Kinangop - Satima ranges, an area known personally to the author for some 35 years, this interference has already been seen to affect water supplies to ranches on the plateau foothills. The existence of natural safeguards against a similar occurrence on Mt. Kilimanjaro were noted by Wood (1965).

Game Department 'control' activities have also included ditching between new native settlement schemes on what was, until recently, heavily forested land and the receding forest line. This 'control' scheme was being carried out by the Game Department during the course of the field work on the present project, and it was already clear that this mountain range will soon cease to have validity as a 'natural' habitat type and become a 'restricted' one from the point of view of elephant population and migration. A similar situation was also seen to be developing on Mt. Ruwenzori and, to a lesser extent, on certain slopes of Mt. Kilimanjaro. Nevertheless, elephant within these ranges still manage to migrate without restriction throughout the upper forested areas above the cultivation line.

vii) Vegetational cover: on all these three mountain ranges a dense montane gallery forest belt begins at about 7,000 ft. altitude. On the Kenya - Kinangop - Satima complex this is followed by a dense bamboo forest belt, succeeded by giant heath and tussock moorland, which leads up to the rock-belt and the snow-line. Towards the upper edges of the forest belts, glades occur and usually attract game. These often surround alpine seepage bogs, favoured as wallows or licks, and said to have a high Sodium and Magnesium content. The surrounding ground becomes compacted by the tendency of the game to 'stamp' and graze there.

Throughout the warmer periods of the day, elephant are usually hidden in the deeply shaded, humid, bamboo and gallery forests, digging in the soft soil and leaf mould for roots and tubers, and feeding on the rich variety of plant material available. The forest soils generally have a high Phosphorus and Calcium content (Wood 1965). As the author has frequently noted the presence of soil and stones in the stomach contents of most of the elephants studied, it seems probable that the animals also actually eat leaf-mould and soil in the forest habitats. Personal observation of elephants apparently doing this, and fragments of what appeared to be dead forest leaves found in the stomach contents of one montane specimen (M.103) would appear to confirm this.

Whether the habit of coprophagy ever occurs normally in wild elephants in a forest habitat, has not been described, although it is known to occur in captive elephants.

The stomach contents of the elephants from the montane habitats in general showed a high proportion of budding twigs, bamboo fibre, arboreal leaves and bark, and a variety of both soft and woody fruits. Comparatively little monocotyledonous leafy material other than bamboo was found. This shows a marked contrast to the 88% grass found by Buss (1961) in the stomach contents of Uganda grassland elephants, although insufficient material is as yet available on which to base a meaningful percentage estimate.

The vegetational cover of the montane habitats studied in this survey, and listed below, is basically similar in each area, with the exception of the presence or absence of a wide belt of mountain bamboo. Where (as on the Kenya - Kinangop - Satima ranges) this belt is extensive, bamboo forms an important part of the elephant diet.

/List

List of vegetational cover - montane habitats
(dominant species only)

1. Gallery forest belt

Trees:

Agauria salicifolia
Calodendrum capense
Casearia battiscombei
Cassipourea malosana*
Conopharingia usambarensis
Ficus spp.
Hagenia abyssinica
Ilex mitis
Macaranga kilimandscharica
Mitragyna rubrostipulata
Myrica salicifolia
Newtonia buchanani
Nuxia congesta
Olea africana
O. kilimandscharica
Juniperus procera
Phoenix spp.
Podocarpus spp.

Bamboo:

Arundinaria alpina

Climbers and orchids:

Begonia meyeri-johannis
Polystachya spp.
Schefflera volkensii

Shrubs:

Crassocephalum mannii
Hypericum revolutum
Hypericum spp.
Lobelia gibberoa
Rubus volkensii

Ground cover, including ferns, tree ferns and lichen:

Asplenium spp.
Cardamine africana
Cyathea sp.
Cyperus spp.
Drynaria volkensii
Elephantoglossum spp.
Hymenophyllum sp.
Impatiens spp.
Isoglossa laxa
Lycopodium spp.
Mimulopsis kilimandscharica
Selaginella kraussiana
Trichomanes sp.
Usnea spp.
Viola eminii
Vittaria spp.

*(dies spontaneously when exposed through forest destruction)

2. <u>Moorland</u>

Trees:

<u>Hagenia abyssinica</u>
<u>Nuxia congesta</u>
<u>Rapania rhododendroides</u>
<u>Senecio kilimanjarica</u>
<u>S. battiscombei</u>
<u>S. keniodendron</u>
<u>Senecio</u> spp.

Grasses:

<u>Agrostis producta</u>
<u>Andropogon amethystinus</u>
<u>Deschampsia flexuosa</u>
<u>Exotheca abyssinica</u>
<u>Festuca kilimanjarica</u>
<u>Koeleria gracilis</u>
<u>Pentaschistis borussica</u>
<u>P. minor</u>

Shrubs, heather, heath-like bushes & ground-cover:
(other than Graminae)

<u>Adenocarpus mannii</u>
<u>Anemone thomsonii</u>
<u>Anthospermum usambarensis</u>
<u>Arabis alpina</u>
<u>Artemisia afra</u>
<u>Blaeria</u> sp.
<u>Carduus steudneri</u>
<u>Dierama pendulum</u>
<u>Disa stairsii</u>
<u>Erica arborea</u>
<u>Euryops</u> sp.
<u>Gladiolus watsonioides</u>
<u>Helichrysum spp.</u>
<u>Hypericum revolutum</u>
<u>Kniphofia thomsonii</u>
<u>Kotschya recurviflora</u>
<u>Lobelia gibberoa</u>
<u>L. aberdarica</u>
<u>L. keniensis</u>
<u>L. sattimae</u>
<u>Mariscus kerstenii*</u>
<u>Myrica</u> sp.
<u>Myrsine africana</u>
<u>Philippia</u> spp.
<u>Protea kilimandscharica</u>
<u>Scabiosa columbaria</u>
<u>Selago johnstonii</u>
<u>Stoebe kilimandscharica</u>
<u>Trifolium burchellianum</u>
<u>T. cryptopodium</u>

*(has got long, conical fleshy stem-bases, which are much sought after by elephants)

3. *Alpine bogs*

Lobelia spp., particularly *L. deckenii* (Giant Lobelia)

Senecio spp., particularly *S. cottonii* (Giant Groundsel)

Alchemilla spp.

Carduus keniensis

Haplocarpa rueppellii

Luzula abyssinica

Ranunculus oreophytus

Swertia crassiuscula

Veronica glandulosa

Grasses and grass-like sedge:

Anthoxanthum spp.

Carex monostachya (bog sedge)

Koeleria gracilis

Poa schimperiana

The above list of plants represents only the common dominant species (Dale & Greenway 1961; Greenway 1965). Clearly this vegetational cover offers great variety and contrasts markedly not only with the limited plant-species range, but also the limited amount of physical cover, available in the low grassland and scrubland habitat types. One presumes that it offers the elephants not only a more interesting diet, but also one more likely to be sufficient in both balance and quantity to satisfy their needs.

The forest regions also offer shelter from continuous exposure to the sun, privacy for mating and calving, and safe feeding in the day-time, with opportunity to sleep at intervals during the night, a situation clearly preferred by elephant when available to them. Rushby (1965) confirms this observation, remarking that elephant are normally diurnal in habit in genuinely natural conditions.

B. Grassland (G) [or degenerate savannah woodland]

g.1 Queen Elizabeth National Park and environs.

g.2 Murchison Falls National Park and environs.

General characteristics

i) Altitude: approximately 2,000 - 5,000 ft.

ii) Mean annual rainfall: 100 - 125 cm.

iii) Approximate temperature range: 18° - 30°C.

Solar mid-day exposed dry soil temperature 45° - 50° C.

Solar mid-day exposed soil temperature under medium grass cover 24° - 26° C. (Field 1964).

iv) Surface water availability: abundant.

v) Soil: the soils characteristic of these areas are derived from relatively young lacustrine or volcanic deposits, the latter consisting of volcanic tuffs spread over the surrounding countryside and weathered to form soils of limited fertility. Overgrazing of these soils, where they overlie gravels,sands and clays of the original Rift Valley bed, readily produces sheet and gully erosion. Low drainage areas are occupied by black soils of low porosity.

g.1 Queen Elizabeth National Park and environs

This is a grassland area dominated by the grasses Themeda triandra, Sporobolus pyramidalis and Hyparrhenia spp. The eastern environs contain the Maramagambo Forest, formerly dense and extensive, rising on to the Kichwamba Plateau, but ~~not~~ now reduced by the encroachment of settlements and tea plantations. On the north-eastern and western flanks are explosion crater areas, and north and southwest are Lakes George and Edward (Unpubl.reports NUTAE 1962-66).

List of vegetational cover*

Maramagambo Forest

Trees:

Cynometra alexandri	Maesopsis eminii
Balanites wilsonia	Uapaca guineense
Celtis mildbraedii	Warburgia ugandensis
Elaeophora druifera	

*(Dominant species: Anon. 1962)

Maramagambo Forest (cont.)

Shrubs:

Argo muellera macrophylla
Lasiodiscus mildbraedii
Ritchiea duchesnii
Teclea nobilis

Riparian and swamp forest

Trees:

Acacia mildbraedii
A. sieberiana
Aeschynomene elaphroxylon
Cleistopholis patens
Croton macrostachyus
Khaya grandifoliola
Phoenix reclinata
Rauvolfia oxyphylla
Trichilia roka

Shrubs:

Mimosa pigra
Securinega virosa
Sesbania sesban

Sedges etc.:

Cyperus papyrus
Leersia hexandra
Pistia stratiotes
Typha australis

Thickets and isolated clumps

Trees:

Acacia spp.
Albizia coriaria
Balanites aegyptiaca*
Borassus aethiopicum
Celtis africana
Euphorbia candelabrum
E. dawei
Ficus gnaphalocarpa

Shrubs:

Allophyllus africanus
Cordia ovalis
Erythrococcus bongensis
Euclea latidens
Grewia similis
Olea africana
Pavetta albertina
Securinega virosa
Teclea nobilis

*(the fruits are said to be effective against bilharzia)

Thickets and isolated clumps (cont.)

Climbers:

Capparis erythrocarpus
C. tomentosa
Cissus quadrangularis

Grassland ~~savannah~~ Grasses:

Bothriochloa spp.	Hyparrhenia filipendula
Brachyaria decumbens	Imperata cylindrica
Cenchrus ciliaris	Microchloa
Cymbopogon afronardus	Ramphicarpa montana
Eragrostis tenuifolius	Sporobolus spp.
Heteropogon contortus	Themeda triandra

Trees: (scattered, round- or flat-topped thorn trees)

Acacia gerrardii — Albizia coriaria
A. hockii — and Ficus gnaphalocarpa (huge, widely scattered shade trees, common in the extreme south of the Park)
A. sieberiana

g.2 Murchison Falls National Park and environs

This park differs only slightly from the Queen Elizabeth National Park and is described in Appendix 7, pp 255 – 272 (Sikes 1966c) and Appendix 4 ~~pp~~ (Sikes, in press) ~~pp~~ 606 with bibliography. In a recent paper Buss (1966) showed how effectively restricted within the Murchison Falls National Park and its adjacent Elephant Sanctuary the elephant populations found there have become in recent years.

The list below gives some of the more abundant and conspicuous species found in the Park (Anon. 1962; Buechner & Dawkins 1961; Buechner, Buss et al.; Buss 1961; Buss & Savidge 1966).

List of vegetational cover

Rabongo Forest

Trees:	Shrubs:
Chlorophora excelsa	Acanthus pubescens
Cola gigantea	Argomuellera macrophylla
Cynometra alexandri	Rinorea ardisiae flora
Ficus spp.	R. ilicifolia
Holoptela grandis	R. poggei
Khaya grandifoliola	Rothmannia urcelliformis
Pterygota mildbraedii	Securinega virosa

Riparian and swamp forest, Wairingo

Trees:	Grasses:
Acacia spp.	Chloris gayana
Croton macrostachyus	Setaria setulosa
Khaya grandifoliola*	
Trichilia spp.	

*(Mahogany, often with the butts of the trees grotesquely swollen owing to repeated damage by elephant)

Thicket

Trees:	Shrubs:
Acacia sieberiana	Acacia senegal
Albizia coriaria	Canthium crassum
Cassia sieberiana	Combretum aculeatum
Euphorbia candelabrum	Dalbergia melanoxylon
Tamarindus indica	Erythroxylum fischeri
	Harrisonia abyssinica
	Teclea nobilis

Grassland (degenerate woodland and shrub savannah)

Trees:	Shrubs:
Acacia spp.	Combretum binderanum
Afzelia africana	Crateva adansonii
Balanites aegyptiaca	Lonchocarpus laxiflorus
Borassus aethiopicum*	Piliostigma thonningii
Combretum spp.	Pseudocedrela kotschyi
Ficus spp.	Securinega virosa
Euphorbia candelabrum	**Grasses:**
Kigelia aethiopum	Brachyaria sp.
Lannea stuhlmannii	Cymbopogon afronardus
Maerua angolensis	Hyparrhenia spp.**
Prosopis africana	Imperata cylindrica
Terminalia glaucescens	Loudetia arundinacea
	Panicum maximum
	Sporobolus sp.

*(the distribution of this palm has been attributed to elephant which are very fond of eating the fruits)

**(this grass now forms the bulk of the Park and is still extending)

C. Scrubland (S) (degenerate arid savannah woodland)

Tsavo National Park (East), Kenya, and environs.

General characteristics

i) Altitude: 500 - 5,000 feet

ii) Mean annual rainfall: 25 - 75 mm. only (Anon. 1962).

iii) Approximate temperature range: <18° - 32°C

iv) Climate: arid, with one or two rainy seasons annually, separated by longer dry seasons; very limited and widely separated surface water discharges.

v) Soil type: pre-Cambrian Basement Complex, with volcanic extrusions. Most of the area nowadays carries a vegetational cover of degenerate, mixed Commiphora-Acacia savannah, with few larger trees remaining in isolated clumps or near 'dongas' (wet-season river gulleys and sub-surface 'sand-rivers') within the National Park. Vegetational cover approximating more closely to that characteristic of the area some fifty years ago, still exists outside the Park boundaries.

Since fire is not effectively controlled within the Park, and elephant concentration has been excessive due to the installation of artificial watering points within the Park (Appendix 4 pp 606 ; Sikes, in press), the natural vegetation has at present little chance of recovery. Outside the Park, however, where fire is not controlled but early random burning is often effectively, if inadvertently, carried out by honey seekers, hunters and travellers, and the elephant do not concentrate in specific areas, the natural vegetation regenerates fairly successfully.

List of vegetational cover - dominant species*

Trees:

Acacia elatior
A. tortilis
and Acacia spp. (12+)
Adansonia digitata
Albizia anthelmintica**
Boscia sp.
Boswellia hildebrandtii
Cassia abbreviata
Commiphora baluensis
C. riparia
and Commiphora spp. (7+)
Delonix elata
Diospyros mespiliformis
Ficus spp.
Hyphaene coriacea
Lannea alata
Melia volkensii
Newtonia sp.
Phoenix reclinata
Platycelyphium voense
Sterculia spp.
Sylvetia peruviana
Tamarindus indica
Terminalia spp.

*(Bax & Sheldrick 1963; Dougall & Sheldrick 1964; Dale & Greenway 1961)

**(Infusion of the root-bark used by the Samburu as a vermifuge; bark and roots boiled to produce an emetic and laxative in malaria; bark used in brewing)

Shrubs:

Acalypha fruticosa
Bauhinia taitensis
Boscia coriacea
Cordia gharaf
Grewia bicolor
G. sulcata
Premna resinosa
Pyrenacantha malvifolia
Salvadora persica
Suaeda monoica*
Terminalia orbicularis

Ground cover:

Abutilon mauritianum
Aristida sp.
Asparagus sp.
Brachiaria spp.
Cenchrus spp.
Chloris spp.
Commelina benghalensis
Cyperus spp.
Digera alternifolia
Eragrostis sp.
Heliotropum sp.
Indigofera schimperi
Panicum spp.
Sansevieria ehrenbergii
Solanum incanum
S. renschii
Tephrosia spp.
Tetrapogon sp.

Dougall & Sheldrick (1964) and Bax & Sheldrick (1963) have listed some of these, as well as some less common species of plants known to be eaten by elephant in the Tsavo National Park. They differentiate between the use of fruits; bark; shoots, leaves, and twigs; and roots and tubers. They have also analysed many of these component

*(very high Na content, over 8.1%, found on the edge of salt pans (Dale & Greenway 1961)

parts of the diet. Unfortunately the analyses give little indication as to actual daily quantities - (except for the percentage of ash, Silica, Calcium, Phosphorus, crude protein and crude fibre in one day's diet of the single, tame elephant "Samson") - taken by elephant of different ages and at different seasons, especially since many of the herbs, creepers and some of the grasses are shortlived and would only be available during the rainy season; this work was still in its early stages.

These workers ~~have~~ made only a brief reference to the role of Sansivieria ehrenbergii (wild sisal), mentioning the "common belief that elephant can exist for indefinite periods without drinking, merely by chewing such plants as Sansevieria". In a preliminary experiment with Sansevieria leaves collected during the wet season, they extracted about 30% of 'free' water from the plants. This plant~~, however,~~ is greatly favoured by elephant particularly during the dry season. The leaves and rhizomes are succulent, and the elephants chew and bruise them, leaving only the fibre, which is spat out as a distinctive 'twizzle' or 'chew'.

Lock (1962) reported that cultivated sisal, Agave *sisalana*, which contains a precursor of Cortisone, and is comparatively rich in minerals, is also much sought after by elephant in the dry season. Archibald (1954) has recorded *Sansevieria thyrsiflora* as one of the plants contributing most to the diet of elephant in the Addo Elephant National Park in South Africa: here the rhizomes are uprooted and eaten. Although most researches on the sisal plant have concerned themselves with the quality and amount of fibre present, Davis (1904) tried to find a chemical basis for the common usage of the rhizomes in African medicine as a cure for haemorrhoids and as a vermifuge, but published no detailed analysis, apart from mentioning the occurrence of a glucoside, a globulin and an albumen. Although Watt & Breyer-Brandwijk (1962) ~~have~~ gathered more general information on medicinal and poisonous properties of plants in Southern and Eastern Africa, no detailed account of these plants' composition could be found.

Another plant, which appears to be of some importance in the diet of the Tsavo elephants, and which is much used during the dry season, the whole being dug up with tusks and feet and then broken into pieces and chewed, is the tuber Pyrenacanthia malvifolia. The taste of this tuber, which can reach a diameter of approximately 3 - 4 feet, is somewhat bitter and causes profuse salivation.

In other parts of the Park, the ripe fruits of the Doum Palm are eaten, the tree being shaken vigorously by the elephant until any fruits above the reach of the animal's trunk fall to the ground. In other areas of Africa, where the author has encountered elephant in Doum and Borassus palm habitats, it was noted that the fruits are especially favoured when fermentation of the pulp has begun. It is also recognised that elephant are important agents in the dispersal of these species, the seeds of which are not digested (Dale & Greenway 1961).

No systematic sampling appears to have been attempted to date of water and soil at water holes and licks for chemical analyses. Two samples of water from the Ithumbo Springs and from the well at Voi River Ndololo with a pH of 6.6 and 6.9 respectively, and both with ±60 hardness, do not appear to be significant for this present survey. The only results available on soil samples were derived from licks remote from the elephant study area used in this project.

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PLATE XXX

(a) Montane juniper forest, Kinangop Mountain, showing alpine moorland and peaks in background.

(b) Montane forest: northern shoulder, Mt. Ruwenzori.

PLATE XXX

(a)

(b)

PLATE XXXI

(a) Giant heath on alpine moorland.
Gura Falls on Mt. Kinangop.

(b) Alpine bog showing soil compacted by game and a distinct elephant trail leading out to the right. Red-hot pokers (Kniphofia thomsonii) seen on this bog are said by some to have been introduced, but have been well known on Mt. Kinangop since the turn of the century, and possibly longer.

(c) Lower limit of montane bamboo as seen in 1965. Many miles along the lower edge of this forest are currently being cut out to provide for expanding settlements.

PLATE XXXI

(a)

(b)

(c)

PLATE XXXII

(a) Elephant trail through montane bamboo forest, Mt. Kinangop, Kenya.

(b) Montane gallery forest, M. Kinangop.

(photographs taken in 1934; used here by courtesy of Mrs. E.P. Sikes).

PLATE XXXII

(a)

(b)

PLATE XXXIII

Dry season:

(a) view across scrubland in environs of Tsavo National Park, Kenya;

(b) view of scrubland within Tsavo National Park, showing combined damage caused by elephant and fire.

PLATE XXXIII

(a)

(b)

PLATE XXXIV

(a) Doum palm (Hyphaene coriacea) on banks of Tsavo River, Kenya.

(b) Recent volcanic cinder heap: Tsavo National Park, Kenya.

(c) Baobab (Adansonia digitata) showing damage to bark, caused by elephant. Tsavo environs, Kenya.

PLATE XXXIV

(a)

(c)

(b)

PLATE XXXV

(a) Undamaged baobab, with full, wet-season foliage, Mombasa, Kenya.

(b) Undamage baobab, leafless, as seen in transitional season.

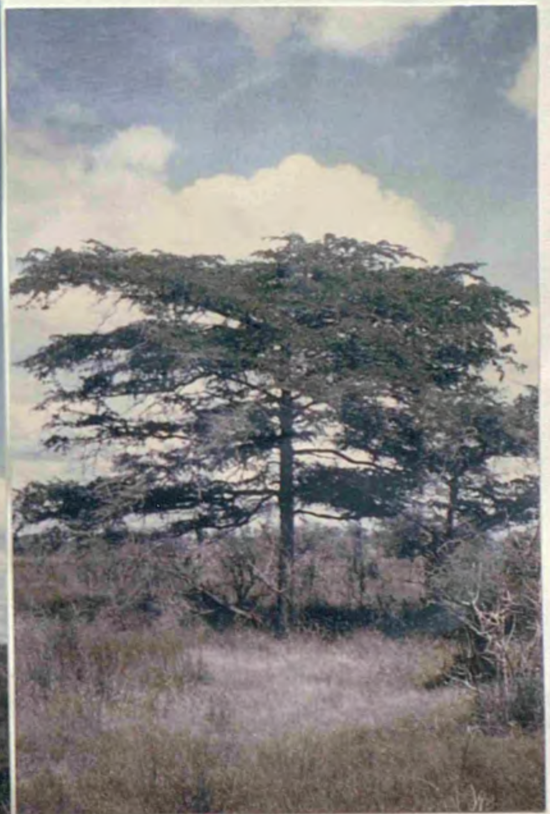
(c) (d) Typical, isolated, shady trees (Acacia spp.) used as resting-places by elephant in Tsavo and environs, (Kenya) during the midday heat.

PLATE XXXV

(a)

(b)

(c)



(d)

PLATE XXXVI

(a) Rainy season: a former fire-break, Tsavo National Park boundary.

(b) Foliage freshly browsed, and soil freshly ploughed by elephant, Tsavo environs, Kenya. Boscia coriacea, Pax.

(c) Grasses and herbs eaten by elephant in Tsavo and environs: Asparagus sp, and Cenchrus ciliaris, L.

PLATE XXXVI

(a)

(b) (c)

PLATE XXXVII

(a) Dry season: Pyrenacantha malvifolia Engl.

(b) Transitional season: Acacia elatior.

(c) Wet season: Effects of elephant pressure on thin vegetational scrubland cover. Acacia sp.

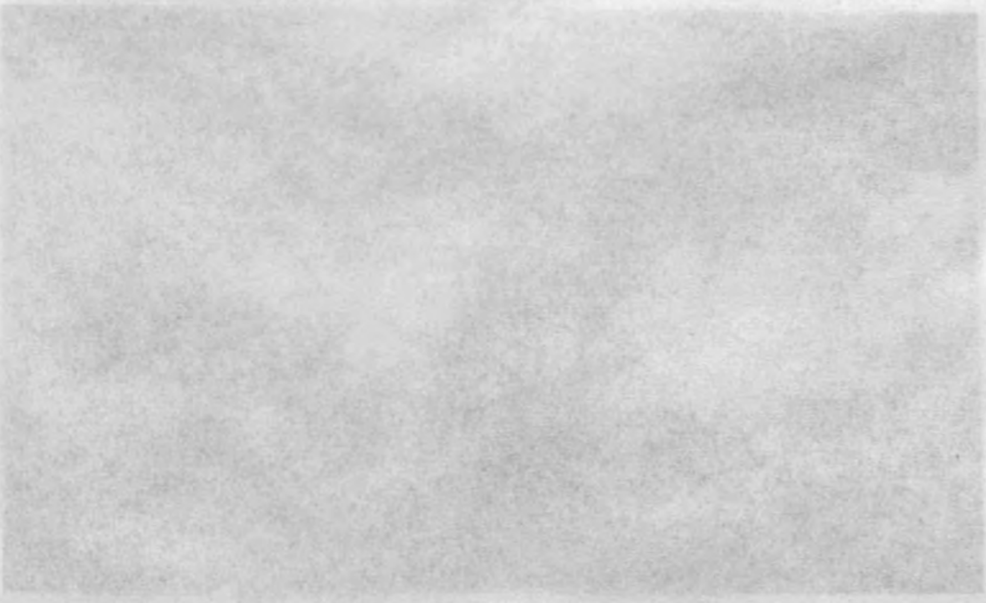


PLATE XXXVII

(a)

(b)

(c)

PLATE XXXVIII

(a) (b) Ipomoea mombassana, Vatke

(c) Brachiaria sp.

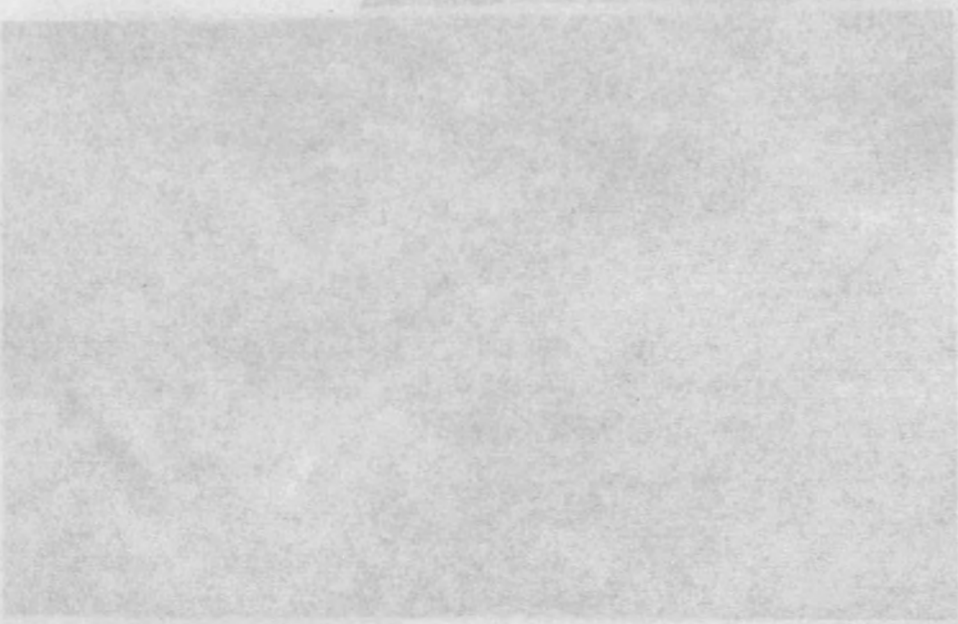


PLATE XXXVIII

(a)

(b)

(c)

PLATE XXXIX

(a) Encroachment on the coastal forest-lands near Malindi, Kenya. Formerly these coastal forests contained large elephant populations and constituted the main dry-season refuges and calving grounds.

(b) Devastation caused by elephant around the artificial water hole, Aruba Dam, situated within the Tsavo National Park (East). Dam and safari lodge were built in 1953

(c) A bull elephant vigorously shaking a doum palm in an effort to dislodge the fruit. In Tsavo National Park, Kenya, near western boundary.

PLATE XXXIX


(a)


(b)


(c)

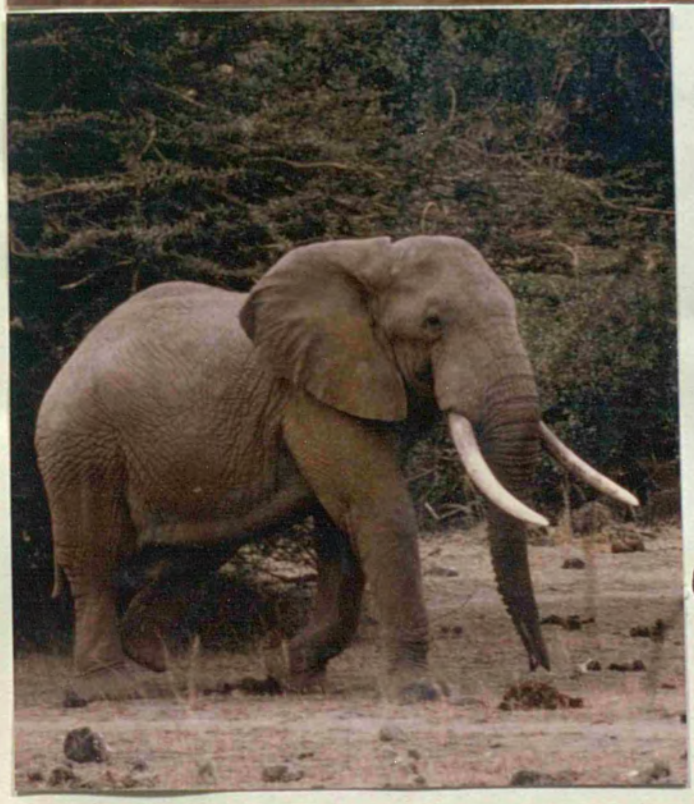
PLATE XL

(a) Unmitigated exposure to the midday sun in scrubland showing advanced degeneration

(b) A very fine senior bull (probably molar age group V) in a transitional montane/ scrubland habitat, Kenya.

PLATE XL

(a)



(b)

PLATE XLI

(a) Degenerate savannah woodland in the 'Elephant Sanctuary', N.W. Uganda.

(b) A herd of nursing cow elephant in the Murchison Falls National Park, Uganda. Their diet consists of 88% grass, and the elephant, including young calves, suffer unmitigated exposure to tropical sunlight and heat.

PLATE XLI

(a)

(b)

Chapter 10

Age and Status

Methods for the determination of relative age in the African elephant

The method used in the determination of the relative age of the forty African elephants examined in this project is fully described in Appendix 6 pp 279 - 295. (Sikes 1966b).

It had become apparent in discussion with other workers engaged in elephant research in Africa that existing methods for ageing the species on the basis of molar eruption were cumbersome and of limited reliability. Based upon the pattern and size of the ridges of the molar crowns, there was always the possibility that in elephant collected from different habitat types these methods might fail to allow for differences in rate of molar wear and crown development. Moreover, they did not provide a reliable method for identifying the molars currently in wear, or a reliable reference point in any given jaw, to which its own molar development could be related.

The physical bulk of the jaws and molars of an elephant pose an acute problem to the field worker, who may wish to age a given elephant in the field, but is not in a position to transport whole jaws to distant reference collections for appraisal.

The need for a much simpler and more direct method for use by field workers and hunters was evident, and the author therefore attempted an entirely new approach. Although this new method is based, as are previous ones, upon the unique type of molar eruption characteristic of the Proboscidea, it begins from a different premise: namely the character of the molar laminary progression itself. During the molar progression, a definite number of potential laminae characteristic for each molar develop within the alveoli, and progress anteriorly along the mandibular ramus, past the foramen mentale, where simultaneous root resorption and fragmentation of the crown occurs. Although not every lamina necessarily erupts into full wear on the crown, each can be recognised from the lateral aspect. Recognition of the particular lamina currently en passage past the foramen mentale, and assignment to it of a descriptive name or number, thus provides a sound basis for the determination of relative age. Since a total of 57 recognisable potential laminae progress along each mandibular ramus in the maximum potential life-span of a normal African elephant of either sex, this method also provides an absolute age-scale.

While this method may not appear academically as detailed as those suggested by other workers, it has considerable advantages for the field worker. First, it obviates the necessity to transport and store whole jaws for subsequent age determination by experts; secondly, it does not require the assignation to the specimen of an age based on annual increments which, at best, can be but arbitrary in the case of adult animals in view of the exceedingly limited data available at the present time; thirdly, it is based upon the natural progression of a definite, characteristic number of potential molar laminae of which the six molars, potentially available in each half-jaw, are comprised; fourthly, it allows for the individual specimen to be aged by a simple descriptive formula based upon a numbered physiological progression which appears to be independent of nutrition, health, tooth-wear or habitat type; fifthly, it applies equally to males and females; sixthly, it is unnecessary to spend time examining all four half-jaws in detail, and it will be seen that differences in wear relating to the anterior fragmenting portions or intermediate erosion points are irrelevant to this method; finally, it is sufficiently simple for any research worker, hunter, field assistant, or elephant guard to use in the course of his normal duties.

In the laminary progression, beginning at birth of the elephant, six molars made up of a total of 57 potential laminae, move progressively along each mandibular ramus in an anterior direction. The first lamina of the first lower molar of each mandible erupts just above the <u>foramen</u> <u>mentale</u> soon after birth. As each molar moves anteriorly past the <u>foramen</u> <u>mentale</u>, its roots appear to bend backward as 'fangs' and are resorbed, while the crown fragments irregularly, the broken portions being dropped from the mouth or swallowed.

When the last lamina of the sixth molar lies above the <u>foramen</u> <u>mentale</u>, mastication is no longer possible, and the elephant declines rapidly. An elderly elephant approaching this point is described in Appendix 6 p.290 and Plate V. Another was described by Perry (1954).

The normal molar progression along each mandibular ramus consists of the following: molar I: 5 potential laminae; II: 7 laminae; III: 10 laminae; IV: 10 laminae; V: 12 laminae; VI: 13 laminae. Care has been taken to describe these as 'potential' laminae, for, although the pulp possesses the number of transverse branches given above and all of these normally calcify, not all invariably grow to the level of the crown and come into wear. They may remain as low buttresses and pillars at the anterior and posterior ends of the molars, or they may come into wear asymmetrically. Abnormalities in number are readily recognisable.

Discussion of data and findings of Laws and Sikes

A recent publication by Laws (1966) is of very great value in that it provides a wealth of data, valuable in understanding the growth and identity of the individual molars in each half-jaw. It is, however, confusing that in ~~its~~ this publication, as in previous literature, observations on the number of laminae characteristic of each molar have not been considered in terms of the potential development of the pulp itself and calcification of its component 'buds'. Apparently the reason for this is that dried jaws were used for Laws' study, not all of which were opened either medially or buccally for examination of root development. In his publication, chronological ages derived from body growth curves have been arbitrarily assigned to thirty molar-age groups, dependent entirely on crown ridge patterns which include the anterior fragmenting portions.

The bulk of data refers to elephant collected within the low grassland habitats of Uganda, which, as shown in Appendix A p. 606 (Sikes, in press) represent degenerate habitats in which there is reason to think that potential longevity in the elephants is abnormally low. This is thought to be linked with the occurrence of cardiovascular disease patterns associated with the degeneration of the habitat. Abnormalities of the molars mentioned by Laws appear to be associated with the deranged Calcium metabolism I have described in the above Appendix (4), p. 606.

It is most gratifying that the sequence described for the large number of mandibles (385) examined by Laws coincided admirably with that described in my own paper (1966b) and in fact 'dove-tails' in such a way that many gaps in my jaw sequence are filled by Laws' data. One serious gap in both series relates to the second molar. Sufficient data are available, however, from the Basel Zoo elephants (Lang 1965) to fill in this gap also, and to indicate that little fragmentation of this tooth occurs while it is in the jaw. In this case the whole, or most of the, tooth is finally shed as a complete unit.

The lack of field material in this group of calves has three probable explanations:- i) the jaws of calves dying naturally in the wilds are usually completely demolished by scavengers and are rarely found; ii) hunters and research workers have tended to avoid the necessity of shooting young calves, which most people, however experienced they may be as hunters (Rushby 1965), find singularly distressing; iii) in cases where the dam has been shot, a young calf is usually immediately taken off by the herd and adopted by another nursing cow. The author has witnessed this occurrence several times, and it is also well authenticated by other research workers (Savidge 1964) and hunters (Rushby 1965; Bell 1960).

Nevertheless, although the relative age sequences harmonise without any discrepancies at all, Laws' 30 arbitrary "age groups" and "mean-age years" appear to be very irregular indeed when shown against the laminary age sequence, combining his, Lang's and my data (FIG. 12).

Clearly he himself recognised the risk of irregularities occurring if an arbitrary scale of this nature were proposed, for he wrote:- " The 30 age groups are a ranked series, and while we can be confident that they represent a series of increasing ages, the allocation of absolute ages presents difficulties ... Although faced with these difficulties, an attempt has nevertheless been made to allocate ages to the groups, because even crude estimates of absolute ages which can later be refined, are more useful than relative ages" (Laws 1966, p.16-17).

Examination of FIG. 12 p 370 shows that the allocation of year-ages based on captive elephants of known age harmonises reasonably with Laws' and my scales up to about the age of 25 - 30 years. Above this point, however, I am unable to accept his ageing sequence either in grouping or mean ages in years. A normal decline in growth-rate, both in the body as a whole and in individual organs, almost invariably characterises mammalian growth curves(Reeve & Huxley 1945). The growth curves for elephant given by Laws here are based upon a modification of Walford's method (1946) and show just such a levelling-off of body growth - i.e. at about 30 years in the elephant (Laws 1966, Fig.13). It would thus be most probable that the period occupied by the progression of laminae of the fifth and sixth molars would be longer, perhaps twice or three times as long as the period of rapid growth in the first 25-30 years.

As additional data become available, it seems increasingly probable that the belief of early writers that the development and life-span of the elephant are broadly similar to that of Man is right.

As Laws(1966) points out, there is some evidence available indicating a difference in growth rate of elephants from different areas, such as the Sudan, the Congo, and Uganda. Such habitat differences are undoubtedly also reflected in tusk density and growth character, features on which the ivory categories, used in the ivory trade in the African, Indian and Chinese markets, have been based for several centuries (Waljee, 1965,pers. communication; Pereira personal communication; Anon. 1886; Cust 1902; Dutt 1901, Maskell 1905).

In any case, it is quite clear that above 25 - 30 years of age, the allocation of year-ages can at present be at best only arbitrary. Laws stated, as regards the year-age allocations to his scale:- " A more or less arbitrary assessment of the time-scale was made... By reference to the estimated potential longevity, arbitrary time intervals were then allocated, as a first approximation." In view of the irregularity of his thirty age groups, when entered against the foramen-mentale line (FM line), his arbitrary allocation of a time scale is seen to be of somewhat ~~misleading.~~ doubtful value.

The FM scale suggested as a reliable, practical ageing system

One cannot escape the conclusion that the FM line provides a natural and reliable age-reference scale, which is greatly to be preferred to an arbitrarily allocated time scale, especially above the point of elephant maturity (25-30 years, or FM.V/2-5). Commenting on this new technique in a personal communication, Scott (1966) wrote:- "the fresh approach, in particular the use of the foramen mentale as a datum point, gets rid of the troublesome asymmetrical wear of the anterior end of the molars".

If adopted widely, the description of ~~laminary~~ relative age by the FM formula (or possibly by laminary number), would be applicable to elephants of either variety (africana or cyclotis)(Petter 1964), taken from any habitat, irrespective of local growth-rate differences. Moreover, this scale describes the natural norm to which the irregularities and abnormalities in tooth development seen occasionally in elephant jaws can be properly orientated.

The laminary-age reference chart, FIG. 12 p 370 shows also that both the degree of irregularity in fragmentation of the anterior molar 'shelf', and of erosion at the contact points at the anterior and posterior ends of the molars, is irrelevant in the assessment of laminary age.

The significance of bony progression waves in the mandibular ramus

A feature of the mandibular molar progression, which puzzled the author for some time, is indicated in FIG. 12 p 370 by line AB. If a line is ruled straight through the last lamina in wear of the posterior molar in use, in as many mandibles as possible, it is seen to lie parallel to the FM line, and at a constant distance of twelve laminae from it. If, however, the line is drawn so as to pass exactly through each of these points, it is seen to curve inward at each point where a molar junction occurs following a single complete worn molar, and prior to the emergence into wear of the leading lamina of the next molar (AB^2). Fig. 12 p. 370.

The significance of this line becomes evident when the empty dry jaws, from which the molars have been extracted, are examined. In Plate VI(b) in Appendix 6 (Sikes 1966b) one of these is illustrated. As suggested in that paper, the forward propulsion of the molars seems to be provided by a wave-like action of the structure of the bone of the mandibular ramus, whereby a dynamic growth pattern is produced.

This is not entirely surprising when one becomes familiar with the appearance of the bony alveolar capsules which form temporarily around the developing molars in the alveolar pockets, and with the rapid infiltration of bony trabeculae into the space left posterior to the final lamina of molar VI as it progresses forwards.

When these wavy ridges of 'spongy' bone are counted in any mandibular ramus, it is found that there are apparently always twelve in operation posterior to the foramen mentale. The number of waves appears unaffected by the deposition of the wider plugs of packing bone that are necessary between the anterior and the posterior laminary root groups in the larger molars, although the spacing between them seems to be variable and adaptable.

The question as to what happens to these twelve waves at the time when a new molar is just moving into wear, also puzzled the author greatly until a study was made of the mandibular and molar angles in the available specimens. One was at a loss to know how best to measure this. However, if scale-drawings of the jaw, with molars exposed medially in situ, are made, a single line may be ruled equidistant from crown to roots of ~~the centre of~~ the centre of the portion of each molar in wear, or coming into wear, and parallel to its crown. Another line is then drawn through the developing laminae in the alveolar pocket as nearly as possible equidistant between its potential crown and roots. The angle between these lines, the 'molar angle' may be measured, and is seen to decrease slightly in magnitude from calfhood to early adulthood, and then to increase again as old age is approached. This change in molar angle seems to be associated with the advance of the molar progression. The total number of bony progression waves anterior to the angle, however, as mentioned above, appears always to be twelve, even when a new molar is just coming into wear. See FIG. 13 p 371.

The practical use of the FM scale and formula, laminary number, and social-age group

In Appendix 4 p 606 (Sikes, in press) attention is drawn to three simple and useful methods, by which the age of African elephants may be described. The first of these is based on the social age/status groups, characteristic of unrestricted wild elephant in indigenous, unspoiled habitats, and is related to molar-laminary age. It could readily be used by field ecologists, hunters and control officers in the field, for describing living wild elephant. The second method is simply to describe the laminary number of a given elephant whose molars may be examined. This is merely a statement as to which out of the normal sequence of 57 potential laminae, is currently situated above the foramen mentale of the right (or left) mandible. The third is the FM formula: i.e. the number of the molar, with the number of its laminae (always numbered from the anterior to the posterior of the molar and jaw) currently situated above the foramen mentale. For example, an elephant of laminary age FM.V/9 has the ninth lamina of the fifth molar situated above the foramen mentale. One aged FM.IV/3-4 has the interval between the third and fourth laminae of the fourth molar situated above the foramen mentale. A general molar grouping based on this formula is also useful in the field for an elephant in which, for example, any lamina of the third molar lies over the foramen mentale: it may be said to be 'using its third molar'. Similarly, one in which any lamina of the fourth molar lay over the FM, would be said to be 'using its fourth molar' et seq.

A suggestion that the term 'laminary stage ' would be preferable to 'laminary age' (Morrison-Scott 1966) was considered, but in view of the already widespread use in Africa among elephant management and research workers of the term 'molar age', it seems more consistent merely to extend the existing field terminology and refer to 'laminary age'.

Summary of procedure for determining the laminary age of a given elephant whose mandibles may be examined

1. The right mandible is disarticulated from the skull and separated from the left mandibular ramus at the symphysis mandibulae with an axe. It is cleared of skin and flesh(PL.XXIX,p.292).

2. The bone on the medial side of the right (undried) mandible is carefully chipped away with a very sharp axe or machete to expose the complete series of molars, both those in wear and those in the alveolar pockets (PL. XLII, p.372).

3. The exact number of calcified laminae, situated above and posterior to the foramen mentale, is counted and their development noted: i.e. whether as a buttress or a pillar, whether in wear, or whether still developing within the alveolar capsule.

4. By comparison of these data with the laminary age diagram (FIG. 12 p 370), it should be possible to locate the exact stage reached in the laminary progression. Should there be any doubt, or any abnormality present, (e.g. supernumerary molars or laminae) it would be necessary to obtain additional data: i) from the other three half-jaws; ii) by measuring the length of the crown in wear (from FM line to posterior edge of crown in wear); iii) maximum width of crown in wear (outer edge of widest enamel loop posterior to foramen mentale); and iv) dry weight of molars in wear (Appendix 6 p 286 Sikes 1966b). Accuracy of the laminary age obtained may be checked by its general agreement with any available body measurements and field observations on the live animal's social age group and herd status. In cases of gross anomaly, some causal abnormality

may be evident upon further examination of the carcass.

Tusk growth and ageing

Laws (1965, unpublished reports) has suggested that tusk growth may be correlated with age in African elephants. He is currently collecting material to investigate this hypothesis, although probably few workers would regard this as a practical field technique for ageing elephant. Plates XLV ~~and~~ pp 375-379 illustrate some different ~~normal~~ tusk types and the effects of growth and wear upon them.

Tusk growth may, however, prove to have ecological significance relating to the nutritional characteristics of particular habitats, or be of statistical value in assessing genetic isolation factors (Irwin 1964).

From the viewpoint of the present study, the character of normal tusk growth in African elephants has no particular significance, except insofar as it may be relevant as the basis for recognition and interpretation of tusk abnormality. This is referred to in greater detail in ch. 12 p 516 . Plates XLIII, p. 373, and XLIV p. 374.

Social age groups and herd status

In the selection of elephant for examination in this project, recognition of the social status of individual animals in relation to the herd or group to which they belonged was of great importance. For this purpose, one's previous personal experience proved invaluable, while at the same time body measurements and examination of the genitalia at autopsy were of value in developing this experience into a more accurate assessment. (Perry 1953, 1964; Amoroso & Perry 1964). The detailed study of the ovaries, testicular material, and pituitary glands collected in this project, however, is still pending. A combination of the above criteria was used as the basis of the social-age-group assessment indicated in Appendix A pp and in ~~FIG.~~ TABLE II p 291 (Sikes 1966b).

Laws (in press) has described analytical work on herd structure currently in progress during the Tsavo National Park cropping scheme, begun in the latter part of 1965. Unfortunately, the findings of that particular study, in isolation, may themselves prove to be atypical insofar as they are likely to reflect the stresses and anomalies resulting from elephant overpopulation and habitat degeneration in that area.

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Waljee, Valimohamed Haji (1965). (Accredited Ivory Merchants Mombasa, Zanzibar and India). Personal Communication.

FIG 12

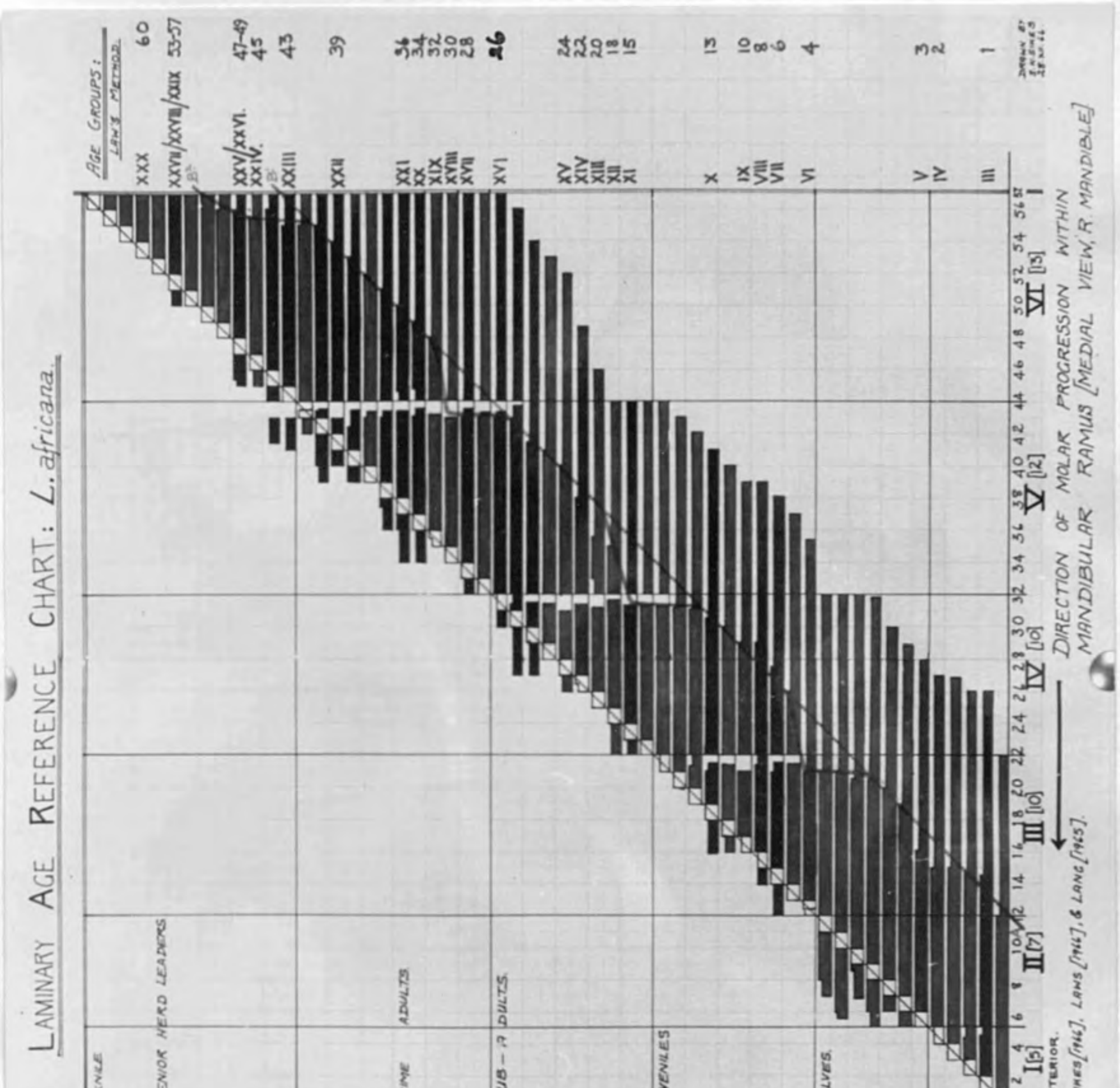
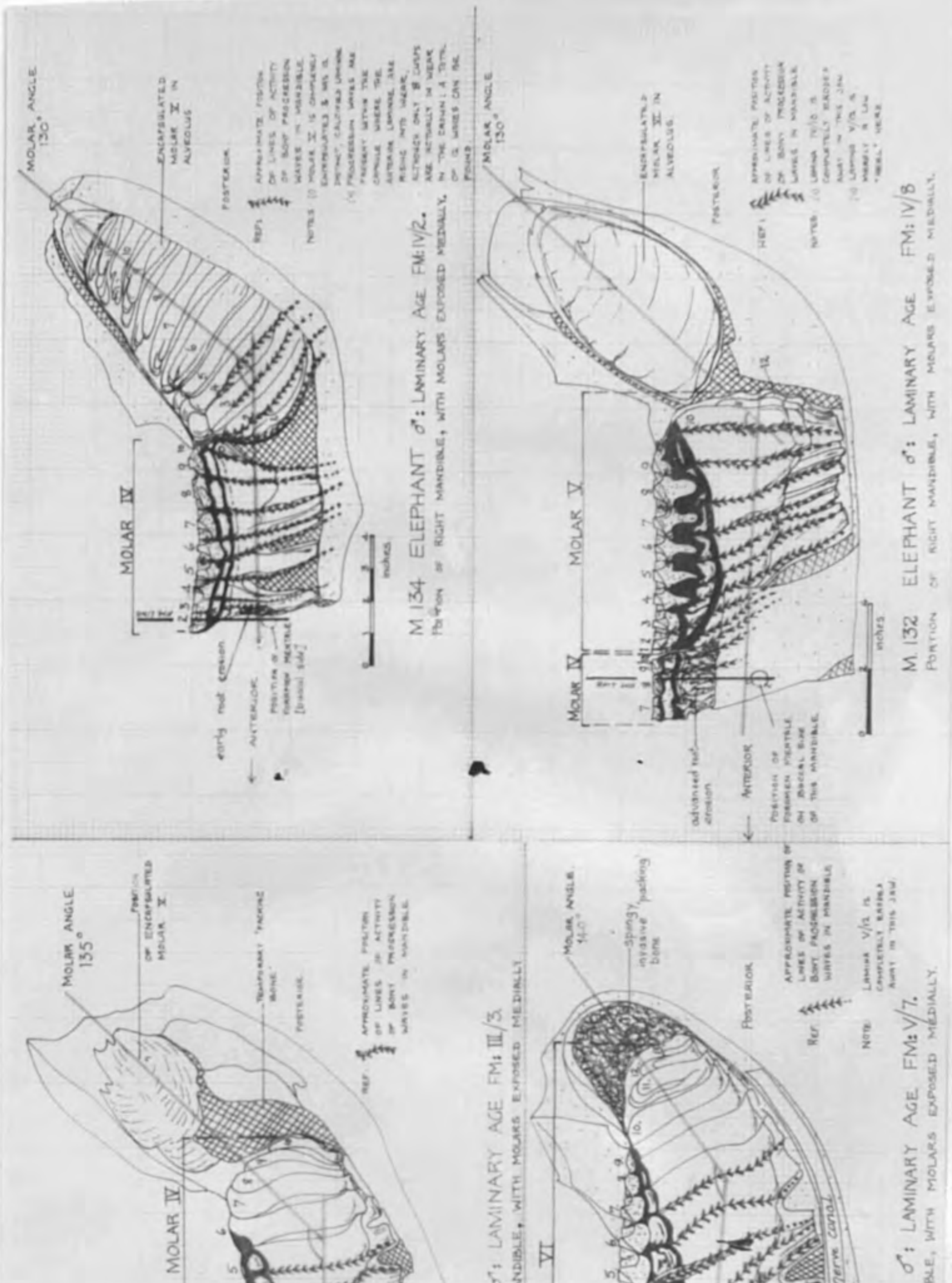

LAMINARY AGE REFERENCE CHART: L. africana.
DIRECTION OF MOLAR PROGRESSION WITHIN MANDIBULAR RAMUS [MEDIAL VIEW, R MANDIBLE]

FIG 13



M 134 ELEPHANT ♂: LAMINARY AGE FM: IV/2. PORTION OF RIGHT MANDIBLE, WITH MOLARS EXPOSED MEDIALLY.

M 132 ELEPHANT ♂: LAMINARY AGE FM: IV/8 PORTION OF RIGHT MANDIBLE, WITH MOLARS EXPOSED MEDIALLY.

M 113 ELEPHANT ♂: LAMINARY AGE FM: III/3. PORTION OF RIGHT MANDIBLE, WITH MOLARS EXPOSED MEDIALLY.

M 120 ELEPHANT ♂: LAMINARY AGE FM: V/7. PORTION OF RIGHT MANDIBLE, WITH MOLARS EXPOSED MEDIALLY.

PLATE XLII

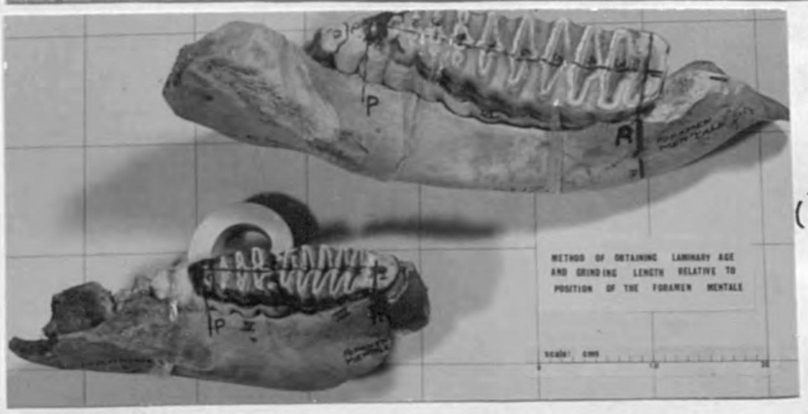
(a) Medial view of right mandible of an elephant, illustrating the method used for exposing the molar laminae (including those in the alveolar pocket) by means of a sharp machete or axe at the autopsy site.

(b) Measurement of 'grinding length' (see Sikes 1966b,pp286-287).
A = anterior; P = posterior.

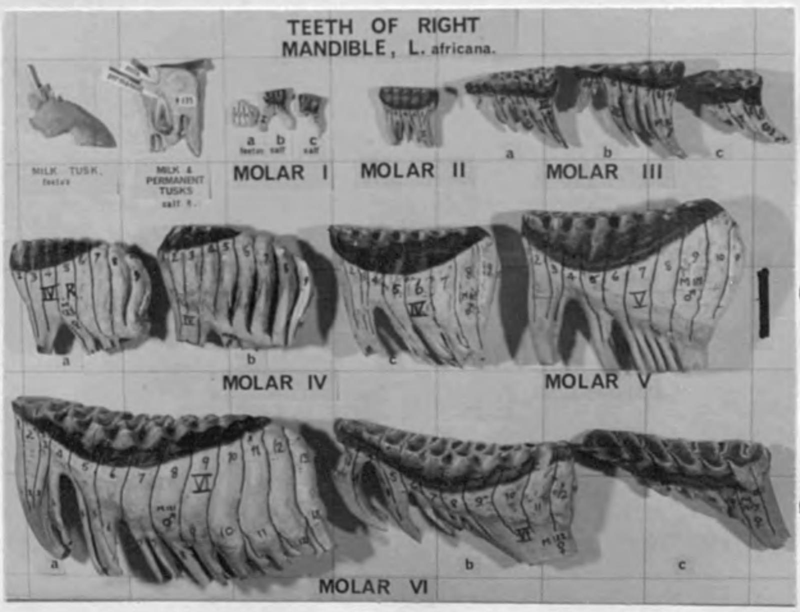
(c) The development of the teeth of the right mandible during the complete molar progression which occurs during the life-time of the African elephant.

PLATE XLII

(a)



(b)



Anterior

(C)

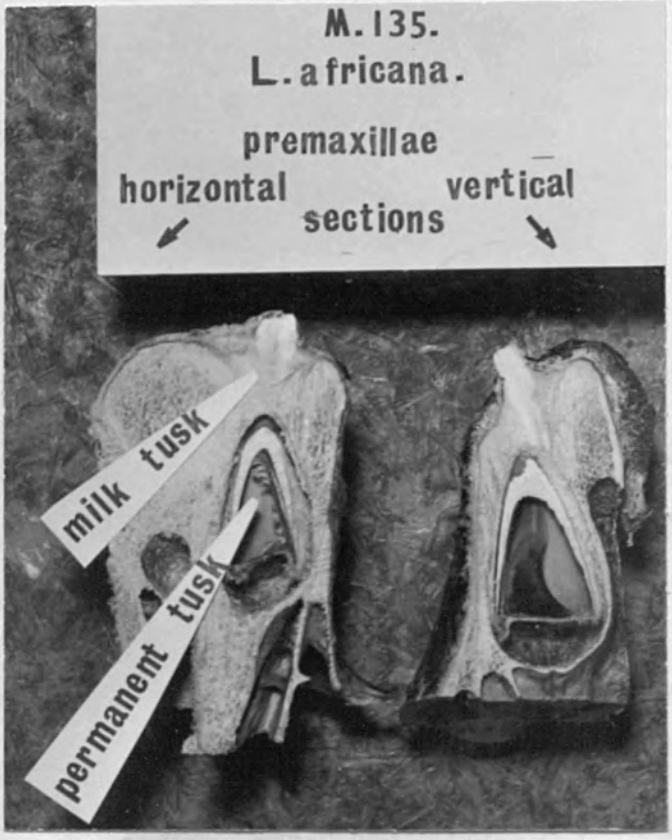
Posterior.

PLATE XLIII

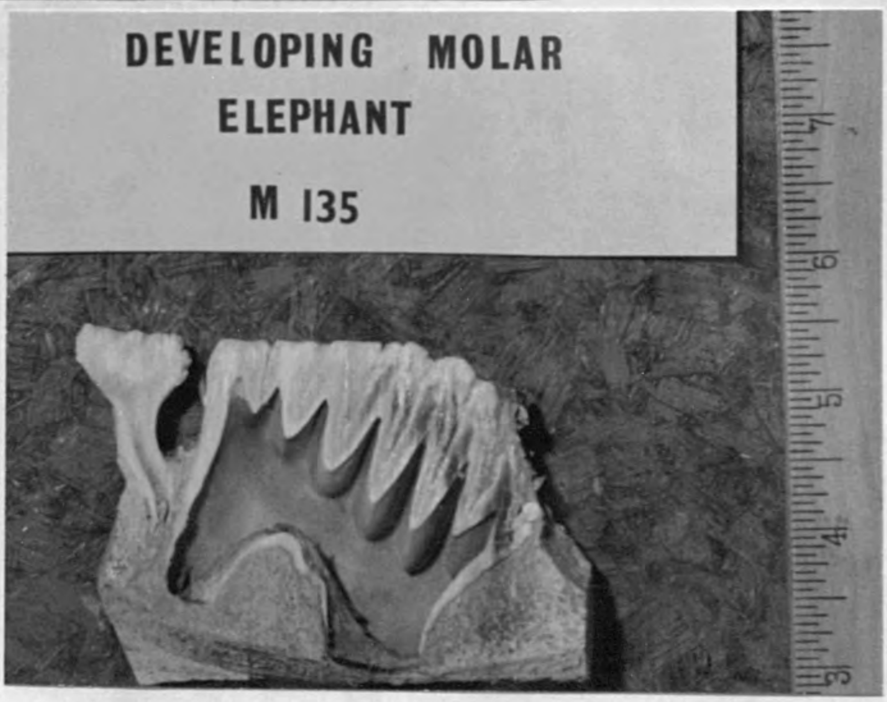
(a) Early tusk development in the African elephant. Young calf M.135.

(b) Early molar development (right molars I and II)in the African elephant. Calf M.135. (Sagittal section).

PLATE XLIII



(a)



(b)

PLATE XLIV

(a) Early tusk development in the African elephant. Yearling calf, M.114 (female). (Surface view and sagittal section).

(b) As above: juvenile male, M.113. (Sagittal section).

PLATE XLIV

(a)

(b)

PLATE XLV

Variations in tusk development in adult African elephant bulls:

(a) M.116. Very well-curved tusks, 205 and 200 cm long, weight 29.5 and 27 kg. Age FM/V/9-10. Tsavo environs.

(b) M.84. Short, sturdy tusks of dense ivory, with formerly broken tips now worn smooth again by wear. Length 190 and 170 cm. Weight 30.5 and 28.8 kg. Age FM/V/6. Uganda grassland.

(c) M.117. Very well-curved, long, wide tusks. Length 200 and 190 cm; weight 37.5 and 35 kg. Age FM/V/11. Tsavo environs.

(d) M.93. Very slender, sharp tusks, little worn and apparently little used. Length 170 and 160 cm; weight 10.5 kg each. Age FM/V/7. Uganda grassland. This middle-aged elephant had advanced aortic calcification.

PLATE XLV

a)

(b)

(c)

(d)

PLATE XLVI

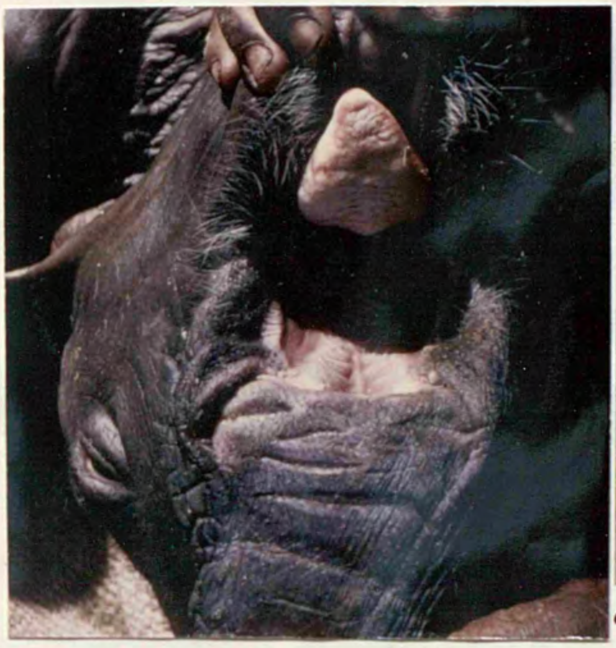
Foetus M.154

(a) View into open mouth: molars and tusks not yet erupted.

(b) Deciduous tusks: sagittal sections.

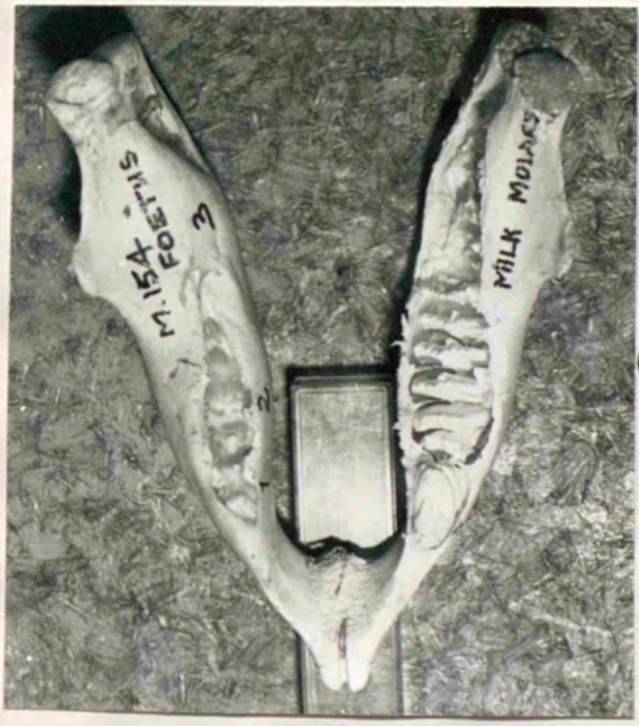
(c) Dried mandible: unerupted molars *in situ*.

PLATE XLVI



a)

(b)



(c)

Chapter 11

EXAMINATION OF CARDIOVASCULAR MATERIAL

(Elephants)

Chapter 11

Examination of Cardiovascular Material

Examination, measurement and description of the heart and aorta

The technique for the examination, measurement, and description of the heart and aorta of the mammals described in ch.6, pp 137 - 256 was based upon the technique designed primarily for the examination of the cardiovascular material collected from elephants. A consistent technique throughout is clearly advantageous, although it differs in some respects from that customarily used in human and veterinary autopsy procedure, where the usual study material is smaller in size.

It was also necessary to adopt a technique suited to the unusual character of the proboscidean heart and aorta, in which the heart is partially bifurcated at the apex, has two anterior venae cavae, and the aortic arch resembles a 'primitive' truncus arteriosus both anatomically and functionally. This is further discussed on pp 394-395

In all the following descriptions, the term 'aorta' refers only to the part severed from the aortic arch by a transverse incision passing through the <u>ductus arteriosus</u> and lying posterior to it. The aorta, slit longitudinally along the ventral line (i.e. running through the scar of the <u>ductus arteriosus</u>) and mounted flat with the intimal surface upward, is illustrated in the scale drawings FIG. 28 p.419 In practice it was necessary to mount the aorta in convenient lengths in linear order on separate polythene boards for fixation and storage.

Each aorta, prepared in this manner, was measured and divided ~~arbitrarily~~ into five geometrically equal lengths consistently referred to as 'Portion I', 'Portion II', ... 'Portion V', from anterior to posterior. Each portion was also divided arbitrarily into four longitudinal parts, 'dorsal', 'right lateral', 'ventral' and 'left lateral', the ventral part being linearly bisected by the actual longitudinal incision made for mounting.

<u>Estimation of lipid and Calcium deposits in the aorta</u>

Separate, direct area counts of lipid deposits, indicated by gross staining with Sudan IV by Holman's method, and of Calcium deposits by radiography, using in each case a $\frac{1}{2}$ cm grid (see ch.8, pp 281 - 283, and Appendix 4,p 606 were made and the rsulting figures processed. Probability tests confirmed the validity of the graphs shown in Appendix 4, pp 606 . These illustrate that i) there is a clear correlation between the presence and amount of aortic Calcium in elephant and the habitat type; ii) some sudanophilic lipid deposits occur in all elephants, but that the amount and distribution may be related to habitat type and/or breeding activity.

In the present study, this technique has been carried further, and a quantitative analysis of the intra-aortic distribution of Calcium and lipid deposits has been carried out. Although individual samples represent only a small number of elephants in each case, a distinct pattern has emerged showing the development pattern of these deposits in the major age groups of each sex in each of the three habitat types studied. In certain age groups, samples were inadequate to obtain a valid result, and histograms for these groups are not therefore available.

The results are represented (FIGS 21–27, pp. 412 to 418) by a series of histograms showing the mean percentage area of the aortic wall containing lipid deposits (black) and Calcium deposits (cross-hatched) found in each longitudinal quarter of each portion of the aorta for each of the main molar age groups.

Examination of these histograms indicates strongly the probability (i) that the main deposition of medial Calcium found in these elephants develops independently of the lipids; (ii) that neither the deposition of lipid nor of Calcium can be directly correlated with the ageing process; (iii) that the presence of lipid deposits within the ostial reinforcement 'collars', 'ramps' and 'ridges' of the aorta appears to occur universally in elephants, and that its distribution also appears to have a relationship to the haemodynamic flow pattern within the aorta; (iv) that the aortic lipid deposits in suckling calves and lactating and pregnant cows seem to be more extensive than in other elephants and in some cases occur as streaks, and 'smudges' outside the usual locations.

When the individual aortae were re-examined in the light of the quantitative analyses, it became apparent that abnormal extraneous lipid deposits could be distinguished in particular cases. These are described in more detail on pp 443 to 447 and in Appendix 4, p 606, (Sikes, in press). Nevertheless, as was already suggested in PART I of this survey (ch.6, pp 140 to 144), the occurrence of normal intimal lipid deposits and fibrous supportive thickenings in the aortae of wild mammals is extremely common (French and Jennings, 1965). It would seem therefore that unqualified reports referring to these as pathological lesions should be accepted with some diffidence.

It appears that it is necessary in the case of free-living wild animals to possess adequate ecological field data on the specimen in question and knowledge of the complete aorta, before classifying an intimal and/or medial thickening showing discontinuity of the elastica (see p 219 and Plate LXII), intimal lipid deposits (Plate LV and p. 439), mineralisation of the internal elastic lamella, or fibrous thickenings, as pathological.

The following descriptions of the normal heart, aorta, and muscular arteries of the African elephant are based upon the indications as to the probable nature of the true 'norm', derived from the quantitative analyses described above.

The 'normal' specimens described are those taken from the montane (natural) habitat type or those older animals collected in the scrubland habitat type, which appeared not to have suffered the effects of stress due to the progressive degeneration of the habitat which has occurred over the last twenty five years, at the onset of which they were already mature, fully grown animals.

A. The heart

The cardiac anatomy of the Asiatic elephant has been described in some detail by Hill (1938); and of a foetal African elephant by Eales (1929). Hill described material obtained both from an adult and a foetus in Colombo and also reviewed the existing relevant literature. A very brief description, including a photograph of the heart of an African elephant, is also provided by Frade (1955); and in 1963, Jayasinghe et al. published electrocardiograms of two adult female Asiatic elephants.

Generally speaking, published accounts of cardiovascular studies on the African elephant are extraordinarily scarce. For this reason, a considerable number of field photographs of African elephant hearts have been included in this chapter, as they serve to illustrate some of the differences which may be observed in hearts taken from elephants of different age groups and general body condition, and collected in different habitat types.

It is not the purpose of this thesis to describe minutely the anatomy of the heart and vascular system, but judging from the paucity of detail in the literature on the subject, it would appear that detailed investigation of the circulatory system of the adult African elephant has been somewhat neglected up to the present and would repay detailed study.

The anatomical investigations carried out in the course of the present project have been confined to those immediately concerned with ~~differentiating between~~ describing the normal structure of the heart and walls of the major arteries in relation to their pathology. It is, however, evident that very considerable variations as to the details of the cardiovascular structure occur between individual elephants. In some cases there are important differences in the circulatory system between elephants living in montane habitats and those living in degenerate lowland areas. The shape and proportions of the heart, and the degree of tonus, provide an example of this type of difference.

The cardiac anatomy is, in general, similar to that described in Asiatic elephants by Hill (1938). A few points have arisen, however, during the examination of the hearts of the 40 wild African elephants collected, which call for comment:-

i) In no case was an os cordis found.

ii) The arrangement at the origin of the brachiocephalic trunks on the anterior curve of the aortic arch is very variable indeed. Usually the right and left brachiocephalic trunks have separate origins in the aortic arch, but in one case both had a common origin; and in another ~~trunk~~, the right brachiocephalic trunk, left common carotid, and left brachial arteries all had separate origins in the aortic arch.

iii) The degree of bifurcation of the right and left ventricles varies according to the environmental background and associated physical condition of the individual animals (Cf. Plate LI , p 429)

iv) The position of the origin of the infundibular branch of the right coronary artery and the bifurcation of the left coronary artery vary slightly in different individuals.

v) The relative dimensions of the heart differ in different individuals.

vi) The amount of fat in the fatty mantle, and the tone of the cardiac muscle is consistently greater in montane than in lowland elephants. In the young montane male elephant M.83 (Plate L (b), p427) and M.103 the subepicardial fat was so abundant that it almost entirely covered the ventricles, masking the bifurcation. The main coronary vessels lie embedded in the subepicardial fat and the position of the coronary arteries is not detectable externally in the case of animals in good condition.

vii) The cusps of the aortic valve normally enclose the origins of the two coronary vessels within the aortic sinuses, as described by Vulpian & Philipeaux (1856). This was questioned by Hill (1938).

No attempt was made to investigate the details of the cardiac veins and sinuses, but the course of the larger ones was noted to be generally consistent with the description by Hill (1938) for the Asiatic elephant. In older animals, the superficial cardiac veins and branches were prominent, dark-coloured and 'knotty' in appearance.

The presence of two anterior Venae cavae and one posterior Vena cava in the specimens examined was observed to conform with previous descriptions for the Asiatic elephant.

Heart size and weight relative to body weight

In Tables 12-14 pp 397-399, relevant data obtained from the forty elephants examined here are listed. The data in Table 16 p 403 are listed by courtesy of Dr. I.O. Buss, Department of Wildlife, Washington State University. These latter were obtained by him during the study of elephant in Uganda. Ageing data on these are not available, and it is not clear whether all the elephants were collected only from grassland habitats.

The relationship between heart weight and body weight using the combined data is given in FIG. 14 p 404. Calculation of the average value of g.heart/100 g.body weight on Buss' data is 0.51 and on my own data 0.49, an overall average of 0.50. This is considerably greater than 0.39, the figure published by Spector (1961).

The slight discrepancy between the results of Buss and my own may be due i) to differences in the techniques used for the estimation of fluid loss at the time of weighing the carcass, and hence to slight differences in the body weight obtained; ii) to differences in treatment of the heart itself prior to weighing. His elephants were usually killed by means of a solid rifle bullet fired into the heart, whereas mine were killed with the brain shot. There may also have been slight variations in the amount of tissue removed from the heart in each case, since my technique was standardised with the prior purpose of subsequent examination of the heart for cardiovascular lesions; whereas this was not Buss' primary objective. It is gratifying, however, that the ~~agreement~~ difference between these results is ~~close~~ small enough to be negligible, and it is possible to state confidently that the index 0.5 provides a sound basis for field estimates of the total carcass weight of African elephant based on heart weight alone.

It is of interest that, based on the limited data available from my own collection, a recognisable distinction is evident in the heart weight index (g/100 g body weight) of grassland (0.47), scrubland (0.49 and montane (0.52) elephants. This differentiation is consistent with the results obtained from the quantitative examination of aortic lesions relative to habitat, described in Appendix 4, p~~p~~ 606 (Sikes, in press). Moreover, the actual shape of the heart, found by measuring length and width (see Tables 12 to 14, pp 397 to 399, and Plates L and LI, pp 427 to 429) is seen to reflect the ecological background. The hearts of the montane elephants not only had a thicker and more extensive fatty mantle, greater myocardial tone and a less conspicuous shorter, right apex, but were also measurably greater in length than in width (Plate L).

The Aortic Arch

Plate XLVIII, p 423 shows the position of the heart and aorta in situ, viewed from the right side, of a full-grown bull elephant. The character of the aortic arch is seen here to recall the primitive truncus arteriosus of lower vertebrates rather than the typical mammalian aortic arch. It consists of a highly elastic, cone-shaped chamber, the walls of which (excluding the tissue of the tunica adventitia) may be as much as 22 mm in thickness in a large bull elephant. Owing to its very large size and elastic character, it has proved extremely difficult to achieve a true measurement of its 'length', as the discrepancy is very great between the measurement along the dorsal line of the arch, to the scar of the ductus arteriosus (which thence becomes the ventral line of the aorta) and that along the ventral and anterior curve of the arch (which thence continues as the dorsal line of the aorta). The mean of these two measurements taken as consistently as could be achieved, is described here (Table 15, pp 400 to 402) as the "length of the aortic arch".

The unsatisfactory character of this measurement is fully recognised, and, as mentioned above, in all descriptions and measurements here the elephant aorta is treated separately from the aortic arch.

In view of the unique character of the proboscidean heart and aorta (commonly said to be evolutionary 'primitive'; Young 1957), the use of a specialised technique for the measurement and description of the aortic arch and aorta in a detailed study of this type seems to be justified. The decision to use this same technique for the study of the aortae of the other mammalian species also, in order to ensure consistency of description throughout this project as a whole, has been discussed in ch. 6, pp 137 - 139.

The Aortic Valve and Sinuses

In a healthy elderly bull elephant, each cusp of the aortic valve was found to be 11 cm wide by 5.5 cm deep, to contain no fenestration, and to be capable of covering the coronary orifices effectively during ventricular systole. The normal intima of the aortic sinuses is thin and smooth but is slightly reinforeced as a fibrous cushion or collar around each coronary orifice. In normal senior bulls, (heart weight in the range of 20 to 28 kg) the width of the coronary arifices (fixed material) was found to be 8 to 20 mm, (right) and 12 to 25 mm (left).

TABLE 12

Data from the 40 elephants examined in this project

I. GRASSLAND

Ref. No.	Age Lamin. No.	Body weight kg	Heart weight kg	Hrt. lgth cm	Hrt. wdth cm	Hrt./ Body weight g/100g	Aver-age g/100g
male							
85	29.5	-	18.2	-	-	-	
87	30.5	-	16.3	-	-	-	
19	34	4100	19.5	-	-	.48	
84	38	-	25.1	48	48	-	
93	39	2870	15.3	46	48	.53	
18	41	5400	23.8	48	48	.44	
86	45	-	23.4	41	41	-	0.47
fem.							
23	24	2130	10.1	-	-	.47	
25	24	2080	9.0	-	-	.43	
22	33	2440	11.0	-	-	.45	
24	33	2620	11.7	46	46	.49	
88	34	-	14.7	-	-	-	
21	40	2770	13.0	-	-	.47	

TABLE 13

II. SCRUBLAND

Ref. No.	Age Lamin. No.	Body weight kg	Heart weight kg	Hrt lgth cm	Hrt wdth cm	Hrt/ body weight g/100g	Average g/100g *
male							
154	0	61	0.6	-	-	.985	
113	15	1389	6.8	-	-	.490	
110	24	2580	11.7	38	38	.455	
149	30.5	-	15.1	43	43	-	
150	31	-	16.4	-	-	-	
118	31	-	16.4	-	-	-	
119	39	-	19.4	46	41	-	
120	39	-	22.5	-	-	-	
108	39	5550	26.5	51	45	.478	
116	41.5	-	26.3	51	51	-	0.49
117	43	6070	27.5	51	47	.45	
121	45.5	-	26.1	-	-	-	
fem.							
114	1	369	1.87	21.5	21.5	.50	
112	29.5	2380	11.3	36	36	.47	
131	37	-	13.5	-	-	-	
127	37	-	12.6	-	-	-	
122	48	2920	14.9	43	43	.51	
107	52	2549	15.3	43	43	.60	

*(Excluding calves of less than 300 kg. body weight)

TABLE 14

III. MONTANE

Ref. No.	Age Lamin. No.	Body weight kg	Heart weight kg	Hrt lgth cm	Hrt wdth cm	Hrt/ body weight g/100g	Average g/100g *
male							
103	19	2480	14.4	43	38	.50	
134	24	-	11.7	-	-	-	
83	27	2665	14.7	46	41	.55	
99	28	-	15.8	-	-	-	
132	29.5	-	21.6	-	-	-	0.52
152	34	5000	25.8	56	46	.51	
fem.							
135	0.5	212	1.8	-	-	.85	
133	16	-	7.2	-	-	-	
100	24	-	9.25	-	-	-	

*(Excluding calves of less than 300 kg. body weight)

TABLE 15

Mean distribution (% area aorta wall) of intra-aortic Lipid and Calcium deposits

Molar age group	Portion of aorta	Mean lgth. aorta cm	Mean circumference of lumen cm	Thickness of aorta mm	Lipid R.L.	Lipid D	Lipid L.L.	Lipid V	Calcium R.L.	Calcium D	Calcium L.L.	Calcium V
1. MONTANE	Arch	19.5	-	15								
Habitat	I	97.5	14.0	3.7	0	2.2	0	0	0	0	0	0
Males	II	.	11.5	-	0	2.5	0	0	0	0	0	0
I - III	III	.	11.5	2.25	0	3.5	3.9	0	0	0	0	0
	IV	.	11.5	1.75	6.1	8.3	3.0	1.3	0	0	0	0
	V	.	11.0	1.90	3	5.2	2	6.5	0	0	0	0
		—										
IV.	Arch	20.0	-	22								
	I	101	15.0	3.4	0.5	6.5	4.3	1.8	0	0	0	0
	II	.	11.8	1.31	0	7.2	0	0	0	0	0	0
	III	.	11.8	1.73	0.7	5.4	0.9	4.7	0	0	0	0
	IV	.	11.0	1.75	3.8	5.9	3.5	3.5	1.2	1.1	1.3	0.4
	V	.	9.6	1.55	4.1	6.9	9.2	8.8	0.3	3.0	1.3	0.8
		—										
V.	Arch	22.0	-									
	I	110	17.5	3.9	2.5	1.1	0	6.4	0	0	0	0
	II	.	14.0	2.0	0	2.2	0	0	0	0	0	0
	III	.	13.0	1.8	0	3.2	0	0	0	0	0	0
	IV	.	13.0	1.7	0.7	3.7	0	1.1	0	0	0	0
	V	.	13.0	1.8	8.9	7.8	7.3	14.6	0	0	0	0
		—										
Females	Arch	13	-	8								
I - III	I	65	9.5	2.7	2.6	34.5	23.5	7.0	0	0	0	0
	II	.	7.5	-	0	16.7	0	0	0	0	0	0
	III	.	6.5	1.6	4.7	18.3	7.7	4.3	0	0	0	0
	IV	.	6.5	0.9	5.1	6.7	6.5	10.9	0	0	0	0
	V	.	6.25	1.1	5.7	12.0	6.0	4.0	0	0	0	0
		—										
IV.	Arch	17	-	9								
	I	85	13.0	3.6	0	5	0	1.67	0	0	0	0
	II	.	12.0	1.45	3	10.8	2.5	0	0	0	0	0
	III	.	12.0	2.0	0	10.8	14	13.3	0	0	0	0
	IV	.	10.0	1.9	10.7	21.2	16.7	7.4	0	0	0	0
	V	.	9.0	1.55	9.3	25.4	19.3	16.	0	0	0	0
		—										

(TABLE 15 cont.)

Molar age group	Portion of aorta	Mean lgth. aorta cm	Mean circumfer. of lumen cm	Thick-ness of aorta mm	Lipid R.L.	Lipid D	Lipid L.L.	Lipid V	Calcium R.L.	Calcium D.	Calcium L.L.	Calcium V.
2. Scrubland Habitat	Arch	15	-	9								
	I	75	13.0	2.95	6.7	32	10	0	0	0	0	0
Males	II	.	10.0	2.2	1.3	26	0	0	0	0	0	0
I - III	III	.	7.0	1.9	1	7.5	0	0	0	0	0	0
	IV	.	7.0	2.2	0	1	0	6	0	0	0	0
	V	.	6.0	2.0	10	33	12	4.5	0	0	0	0
IV	Arch	25	-	20								
	I	106	17.1	3.24	6.85	20.3	5.2	9.4	3.4	4.4	4.0	0.2
	II	.	11.6	1.75	3.0	14.1	1.7	1.0	2.8	9.0	1.3	6.1
	III	.	11.0	2.16	5.3	14.3	2.5	5.5	2.9	10.8	3.9	3.7
	IV	.	9.6	2.25	7.8	25.3	4.4	10.3	5.5	11.1	6.0	7.0
	V	.	8.6	2.40	25.1	26.5	11.5	11.3	9.3	17.9	7.9	5.3
V	Arch	25	-	23								
	I	125	18.5	3.88	12.8	38.6	13.0	9.1	1.2	5.6	0.9	2.1
	II	.	15.6	2.6	4.0	17.1	5.5	10.6	1.2	5.8	2.0	1.5
	III	.	14.1	1.9	5.8	10.5	4.1	7.1	0.8	4.1	0.2	1.6
	IV	.	12.9	1.59	7.2	20.9	5.6	9.5	3.8	6.0	3.4	3.6
	V	.	11.7	1.58	10.6	22.2	14.3	11.3	6.9	17.3	9.1	10.0
VI	Arch	24	-	22								
	I	120	18	5.2	9.3	71.5	8.5	11.0	1.8	4.8	1.5	1.7
	II	.	14	2.8	13.0	18.0	2.3	2.7	0.7	4.0	2.0	1.3
	III	.	10	2.7	7.0	10.3	6.7	7.0	0.3	0.7	0.3	0
	IV	.	9.5	1.75	5.3	7.0	3.3	7.3	0.7	0	1.3	0.7
	V	.	10	1.80	11.0	26.5	3.5	11.0	7.5	13.0	5.5	4.5
Females	Arch	12	-	9								
I - III	I	52.5	8.0	3.1	0	15.3	0	0	0	0	0	0
	II	.	8.0	2.4-1.0	0	9.2	0	0	0	0	0	0
	III	.	5.0	2.0-1.0	0	23.0	0	7.7	0	0	0	0
	IV	.	4.0	2.0	0	68.0	0.0	23.0	0	0	0	0
	V	.	4.0	0.82	25.0	53.0	20.0	53.0	0	0	0	0
IV	Arch	21	-	11								
	I	105	14.5	3.5	3.6	3.9	13.9	3.6	0	1.1	0	0
	II	.	10.0	-	6.0	37.0	0	0	0	0	3	0
	III	.	8.0	2.1	1.7	33.9	4.5	12.2	0	2.8	8.4	1.1
	IV	.	8.0	2.0	3.9	8.4	16.1	11.1	1.1	3.2	2.2	3.3
	V	.	6.5	1.9	6.7	39.4	7.3	13.4	12.0	16.0	1.6	6.0
V	Arch	22	-	12								
	I	110	15.5	3.85	29.0	37.0	22.5	28.9	4.9	4.0	0.5	0.9
	II	.	12.0	2.55	10.8	32.2	3.3	4.2	3.7	8.0	0.5	1.5
	III	.	12.0	1.40	15.5	37.0	9.7	8.9	2.6	7.3	1.1	0.8
	IV	.	10.0	1.75	14.0	40.0	16.8	25.0	8.7	10.5	10.5	18.0
	V	.	9.5	2.80	50.6	78.0	24.5	49.1	19.0	38.4	14.1	26.5
VI	Arch	24	-	10								
	I	115	17.0	4.88	20.8	57.5	19.2	12.3	1.7	3.0	2.6	2.0
	II	.	13.8	1.86	24.9	45.2	28.4	27.0	30.3	26.0	13.6	10.4
	III	.	13.8	1.45	22.7	41.8	25.1	16.9	19.4	32.9	19.9	5.4
	IV	.	12.0	1.55	20.0	45.6	25.7	8.9	13.0	8.3	7.5	7.8
	V	.	10.8	2.00	38.6	75.0	30.0	27.3	19.0	48.3	27.3	17.2

(TABLE 15 cont.)

Molar age group	Portion of aorta	Mean lgth. aorta cm	Mean circumfer. of lumen cm	Thick-ness of aorta mm	Lipid R.L.	Lipid D	Lipid L.L.	Lipid V	Calcium R.L.	Calcium D	Calcium L.L.	Calcium V
3/ Grass-land Habitat	Arch	19	-	16								
Males	I	90	13.3	4.3	0	5.4	0	0	3.7	8.7	9.6	4.0
IV	II	.	11.3	3.2	0	11.3	3.3	0	28.0	33.0	16.3	2.3
	III	.	9.8	2.33	1.5	23.8	19.0	10.1	10.4	78.3	13.9	10.7
	IV	.	8.0	2.1	14.3	12.0	4.1	12.3	13.8	19.5	9.6	12.5
	V	.	7.5	2.53	22.5	33.8	17.1	26.8	37.3	55.7	12.6	7.8
	VI	—										
V	Arch	23	-	20								
	I	110	16.8	4.67	6.2	11.8	1.9	7.1	12.2	36.7	5.8	3.6
	II	.	12.6	2.1	5.7	21.3	1.2	13.6	36.2	65.4	28.0	44.7
	III	.	11.0	1.71	10.8	11.3	4.0	7.7	59.8	78.0	64.9	49.8
	IV	.	10.4	2.0	9.6	13.1	8.4	8.3	80.6	89.0	82.2	72.9
	V	.	8.9	2.98	10.7	28.9	18.7	16.0	96.8	97.5	78.2	81.4
		—										
VI	Arch	30	-	22								
	I	130	19.0	5.0	2.7	11.7	5.1	1.5	1.7	4.6	0.3	1.2
	II	.	13.0	2.7	11.4	7.8	1.1	5.6	35.6	58.0	13.0	33.6
	III	.	11.5	2.57	5.5	5.5	5.7	0.7	59.3	76.5	33.0	9.7
	IV	.	10.0	2.51	2.6	13.4	5.8	9.6	68.0	92.5	92.3	27.3
	V	.	8.0	1.9	19.0	49.0	30.0	3.0	69.0	93.0	56.0	41.0
		—										
Females	Arch	18	-	16								
IV	I	92.5	12.0	3.75	0	2.8	0	0.6	0	5.9	0.9	1.7
	II	.	8	1.6	0	6.8	3.7	1.8	1.8	10.1	9.1	2.8
	III	.	6.5	2.0	0.5	35.0	6.7	11.7	10.7	30.8	4.9	17.9
	IV	.	6.0	2.0	3.2	12.8	4.4	7.8	13.3	34.9	20.2	9.7
	V	.	5.5	1.9	11.8	35.5	19.7	14.0	7.5	39.0	5.5	10.0
		—										
V	Arch	21	-	16.5								
	I	104	13.8	3.9	1.5	18.2	1.2	4.2	4.7	13.8	4.3	4.8
	II	.	10.0	2.05	9.2	22.8	1.2	5.4	34.0	54.4	40.3	25.7
	III	.	8.1	2.2	7.3	22.9	3.5	2.8	42.4	43.5	32.8	29.5
	IV	.	7.0	1.8	8.7	16.3	1.1	5.9	48.5	55.1	21.3	43.1
	V	.	6.9	1.95	14.5	32.6	5.6	17.4	77.0	79.0	78.1	80.0
		—										

TABLE 16

Body and heart weights, Uganda elephants (Buss 1966)
(unpublished data)

MALES				FEMALES				
Spec. No.	Body wt.	Heart wt.	Heart/ Body wt. g/100g	Spec. No.	Body wt.	Heart wt.	Hrt/ Body wt g/100g	Aver. g/100g ♂* and ♀
60	140	1.240	.89	48	304	1.8	.59	
40	141	1.215	.86	67	365	1.6	.44	
96	710	3.27	.46	58	520	3.6	.69	
55	810	4.95	.61	102	720	3.8	.53	
51	812	4.36	.54	82	790	4.28	.54	
53	880	6.3	.71	80	980	5.40	.49	
106	1060	5.40	.51	112	1145	6.3	.55	
94	1200	6.54	.54	39	1570	8.58	.56	
98	1275	7.65	.6	103	1580	7.2	.46	
2	1375	9.0	.65	100	1620	8.1	.50	
52	1485	9.9	.66	81	1880	9.4	.52	
36	1870	9.9	.53	59	1890	10.8	.57	
56	1975	9.6	.49	110	1900	9.45	.49	
1	2070	11.7	.56	108	1970	8.1	.41	
76	2150	10.8	.5	93	2030	9.0	.44	
104	2180	10.6	.49	88	2060	9.25	.45	
62	2200	10.1	.46	46	2100	11.25	.53	0.51
70	2240	9.9	.44	37	2200	10.8	.47	
19	2330	10.35	.45	22	2340	11.7	.50	
79	2520	10.8	.40	92	2420	13.5	.56	
78	2530	13.95	.50	73	2520	13.95	.52	
57	2800	14.85	.53	68	2560	14.4	.56	
86	2990	14.85	.50	23	2700	13.5	.5	
90	3090	14.95	.48	72	2760	14.85	.54	
89	3100	14.4	.47	105	2776	14.3	.52	
42	3120	14.85	.48	21	2800	14.85	.53	
3	3470	15.30	.44	47	3000	14.85	.49	
23	3540	17.10	.48	44	3160	16.20	.51	
121	3880	17.55	.45	27	3240	18.95	.57	
25	3940	17.10	.43	107	3480	18.45	.53	
124	4000	18.45	.46	31	3833	19.35	.50	
83	4080	18.00	.44					
84	4450	18.00	.41					
120	4700	23.00	.49					

*(excluding calves of less than 300 kg bodyweight)

FIG. 14

FIG. 14

RELATIONSHIP OF HEART WEIGHT : BODY WEIGHT.
AFRICAN ELEPHANT, *Loxodonta africana africana.*

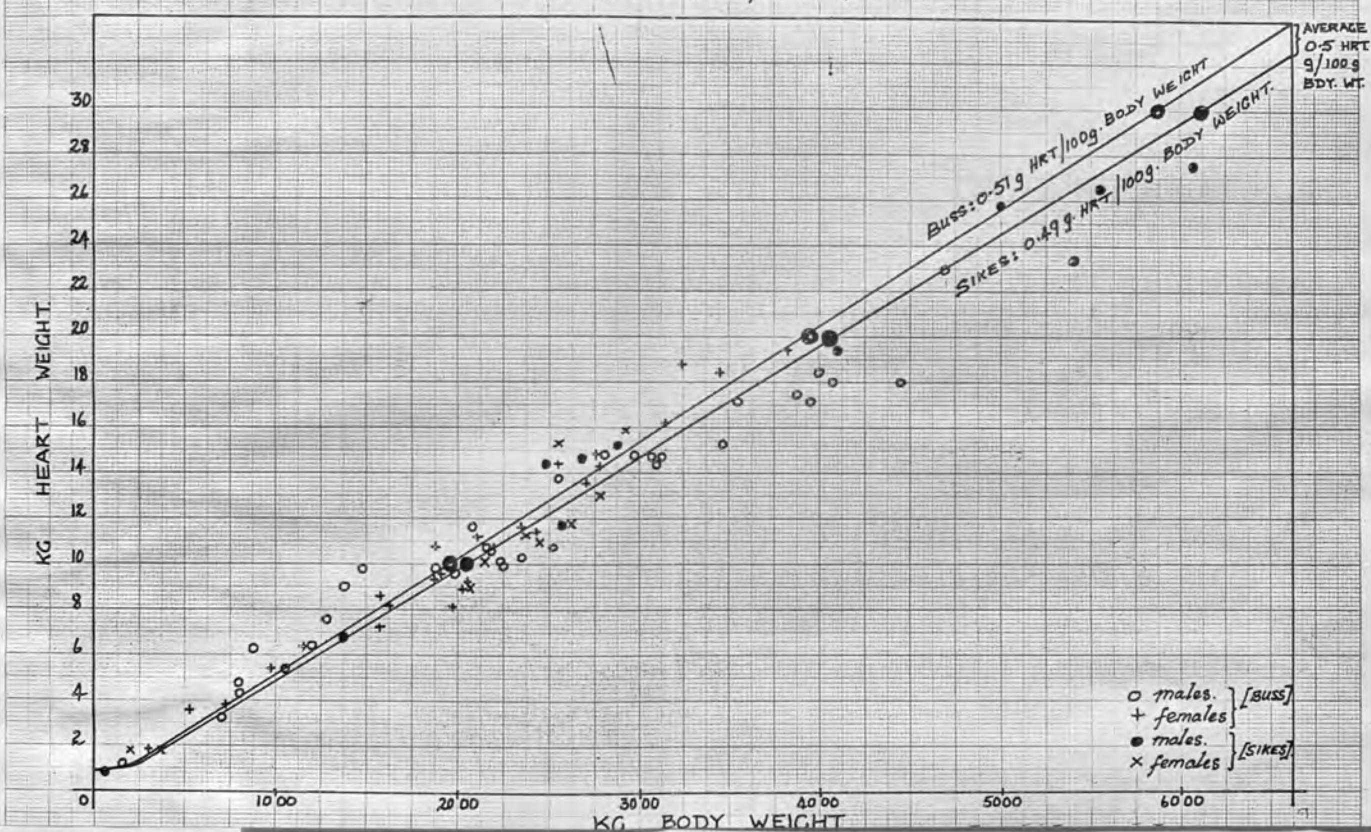
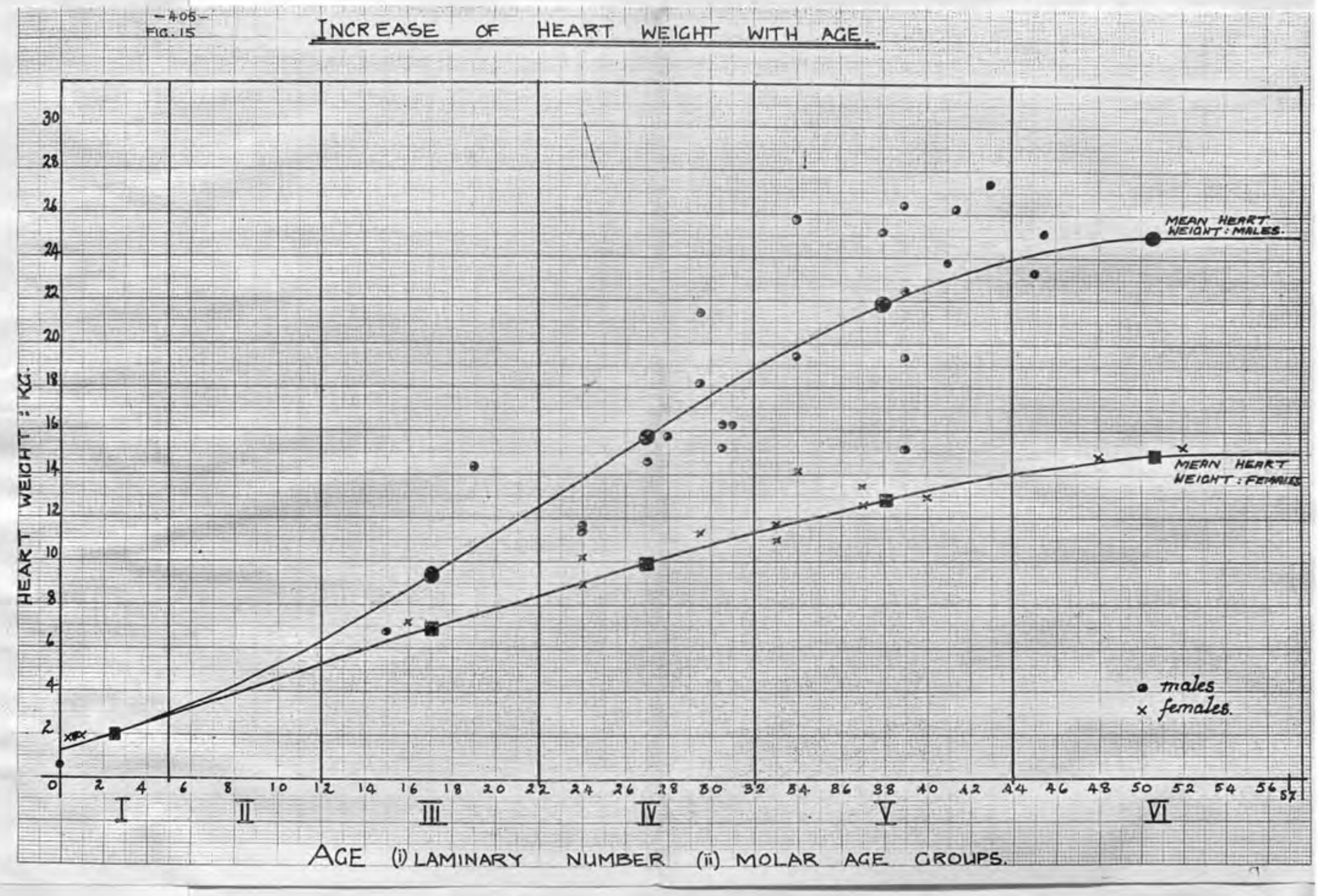
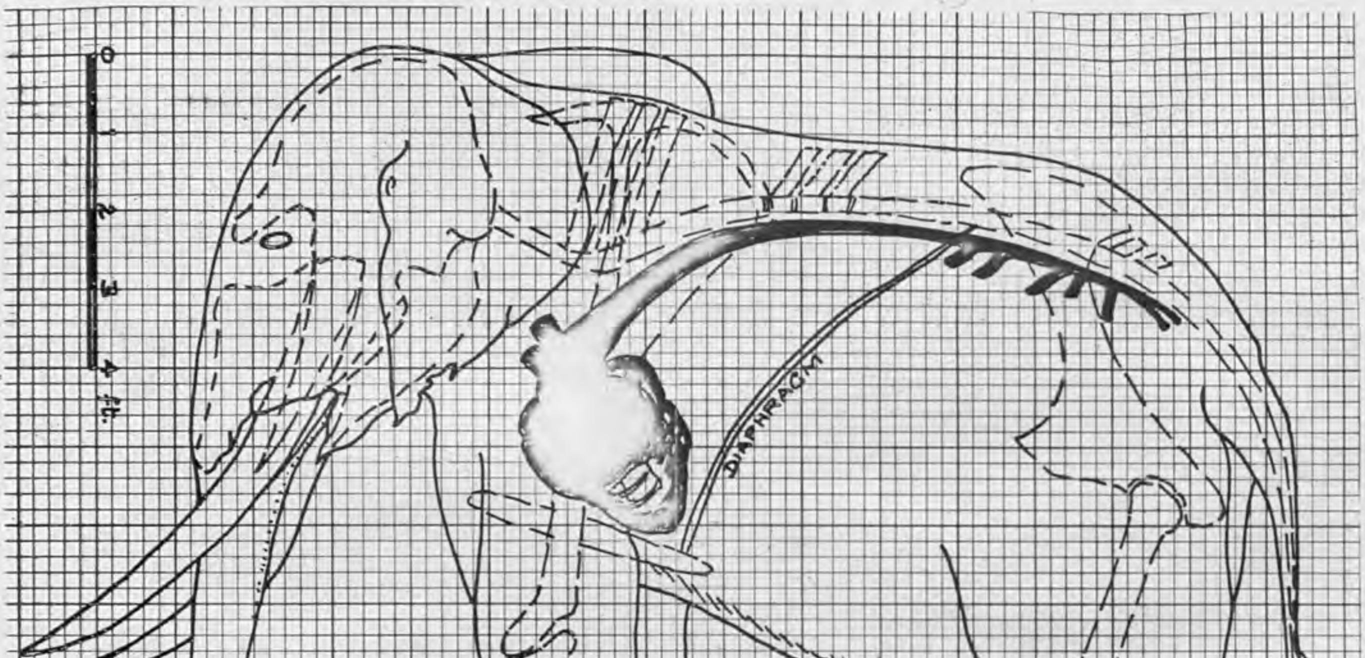


FIG. 15



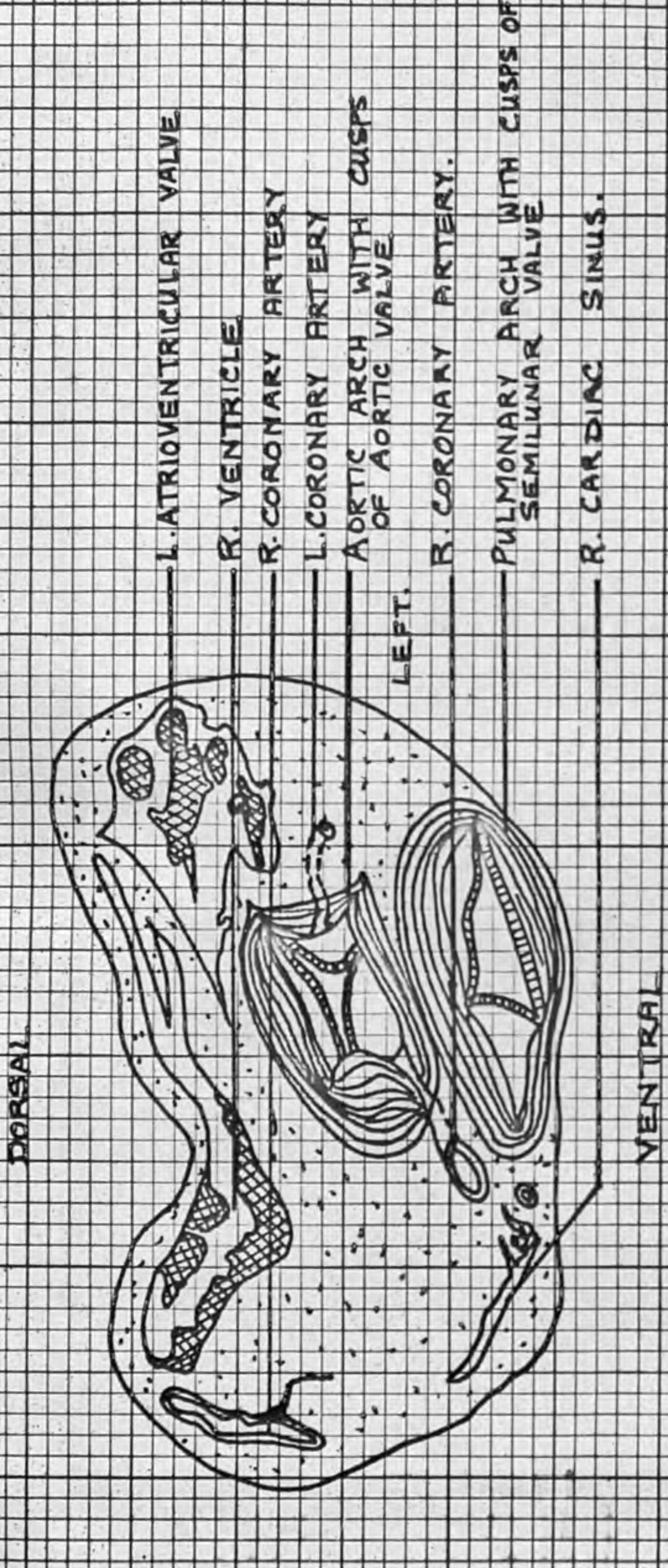
-405-
FIG. 15
INCREASE OF HEART WEIGHT WITH AGE.
HEART WEIGHT : KG.
MEAN HEART WEIGHT: MALES.
MEAN HEART WEIGHT: FEMALES
• males
× females.
I
II
III
IV
V
VI
AGE (i) LAMINARY NUMBER (ii) MOLAR AGE GROUPS.

FIG. 16



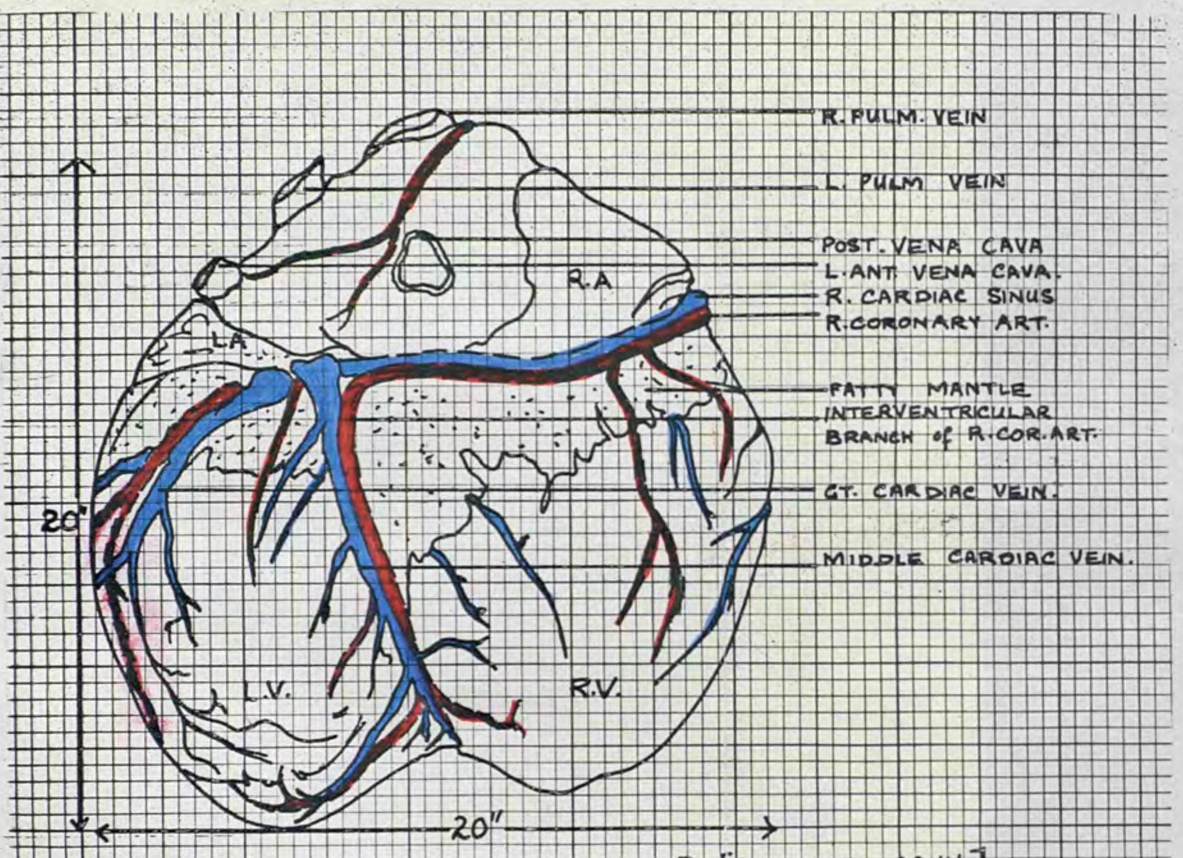
POSITION & RELATIVE SIZE OF THE HEART OF AN AFRICAN ELEPHANT (♂).

FIG. 17.



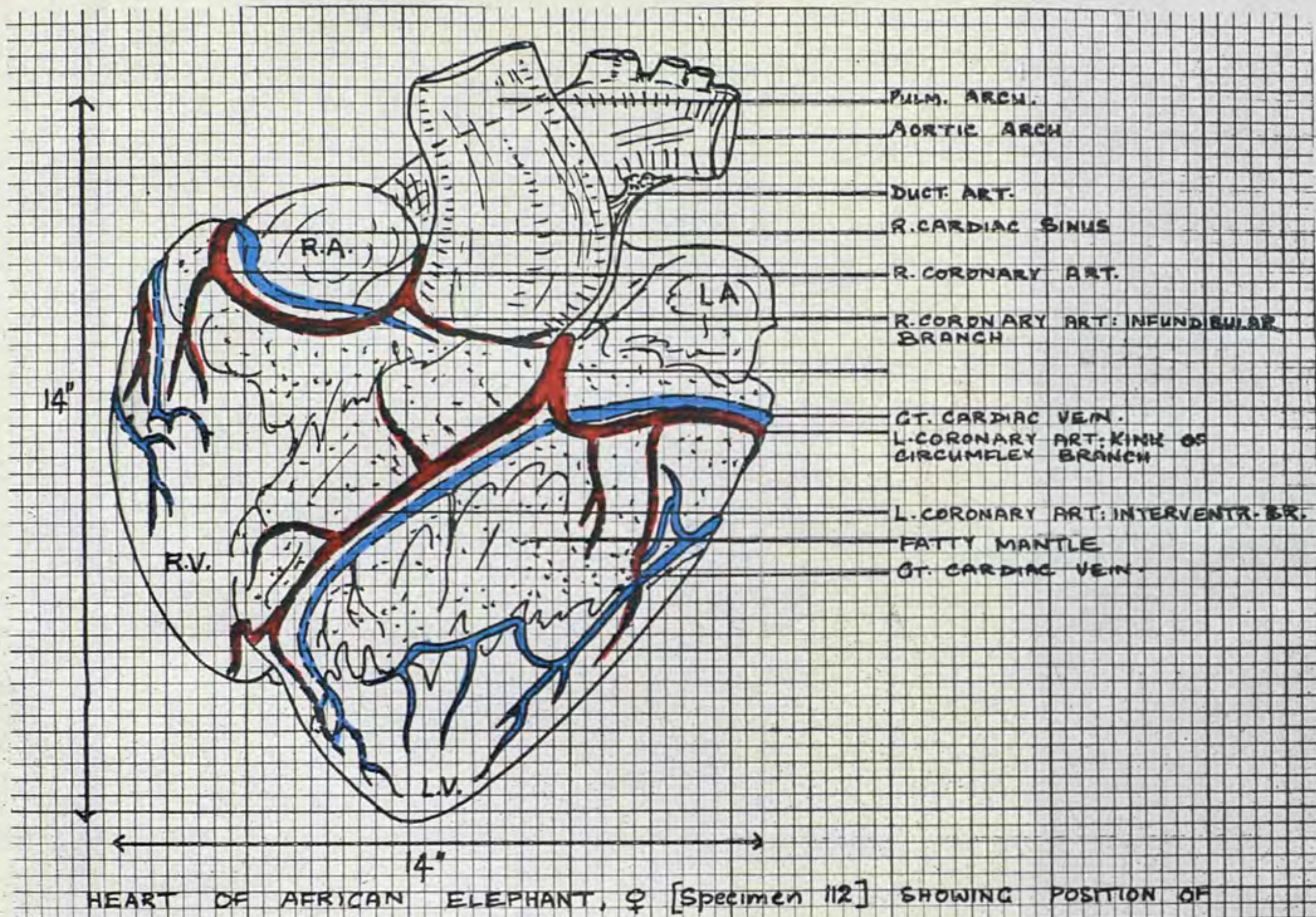
T.S. HEART OF FULL-TERM FOETUS OF AN AFRICAN ELEPHANT [SPECIMEN 154], ANTERIOR ASPECT.

FIG. 18



HEART OF AFRICAN ELEPHANT ♂ [SPECIMEN M.116]
SHOWING POSITION OF CORONARY ARTERIES & CARDIAC VEINS
IN SUBEPICARDIAL TISSUE [POSTERO-DORSAL ASPECT].

FIG.19



HEART OF AFRICAN ELEPHANT, ♀ [Specimen 112] SHOWING POSITION OF CORONARY ARTERIES & CARDIAC VEINS IN SUBEPICARDIAL TISSUE; LEFT VENTRO-LATERAL ASPECT.

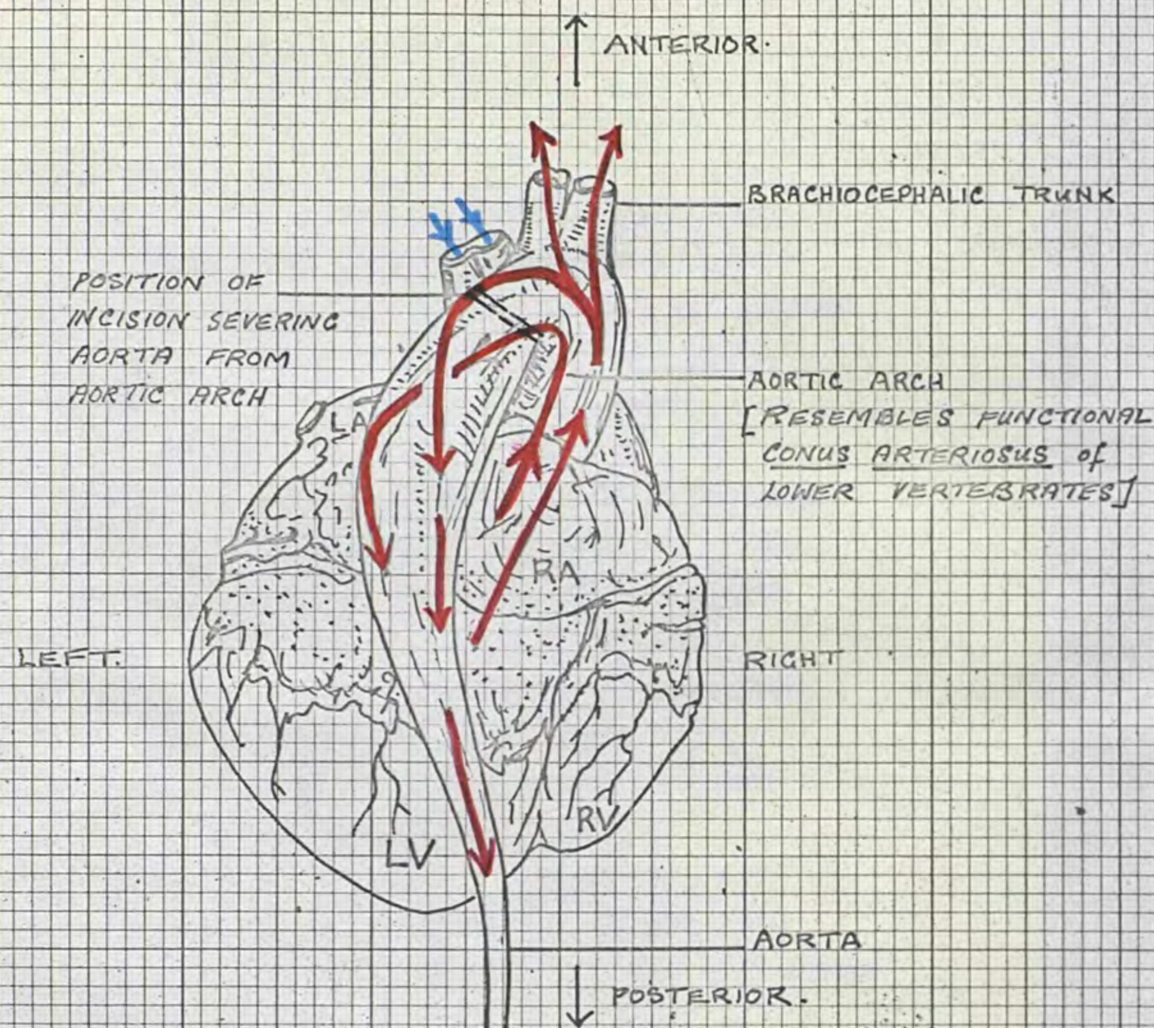
PLATE I

(a) Field autopsy on giraffe: removal of sample of femoral artery.

(b) As above: removal of eye lens.

(c) As above: <u>in situ</u> examination of coronary arteries.

FIG. 20



HEART OF AFRICAN ELEPHANT
DORSAL ASPECT.

FIGS. 21 - 27

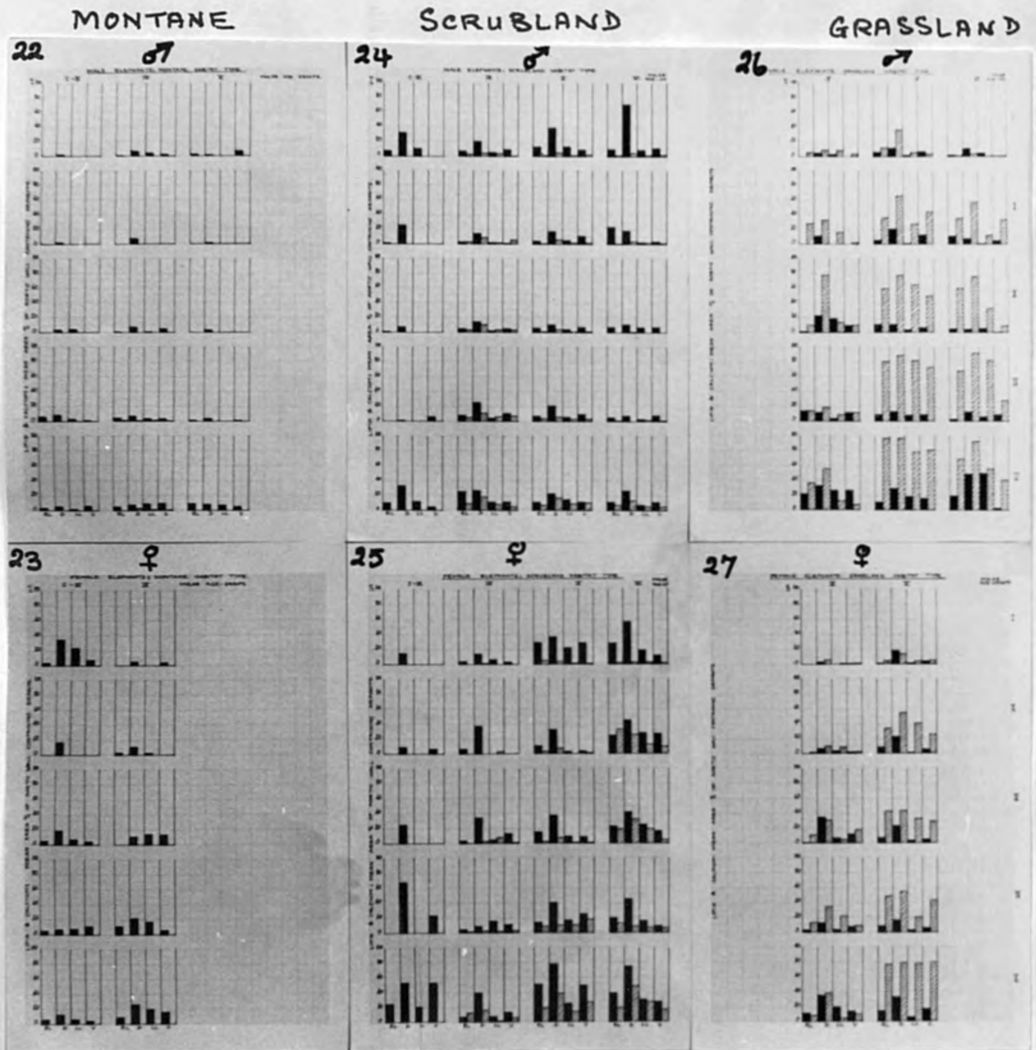
Explanation:

Each Figure (FIGS. 22 - 27) shows histograms of the mean area % of each quarter of each portion of the aorta wall containing lipid (black) and Calcium (cross-hatched) deposits, in different age groups of elephants from a particular habitat type. FIG. 21 shows a combined view of FIGS. 22 - 27.

The division of the aorta wall into 20 portions is illustrated in FIG. 28, and explained on p. 384.

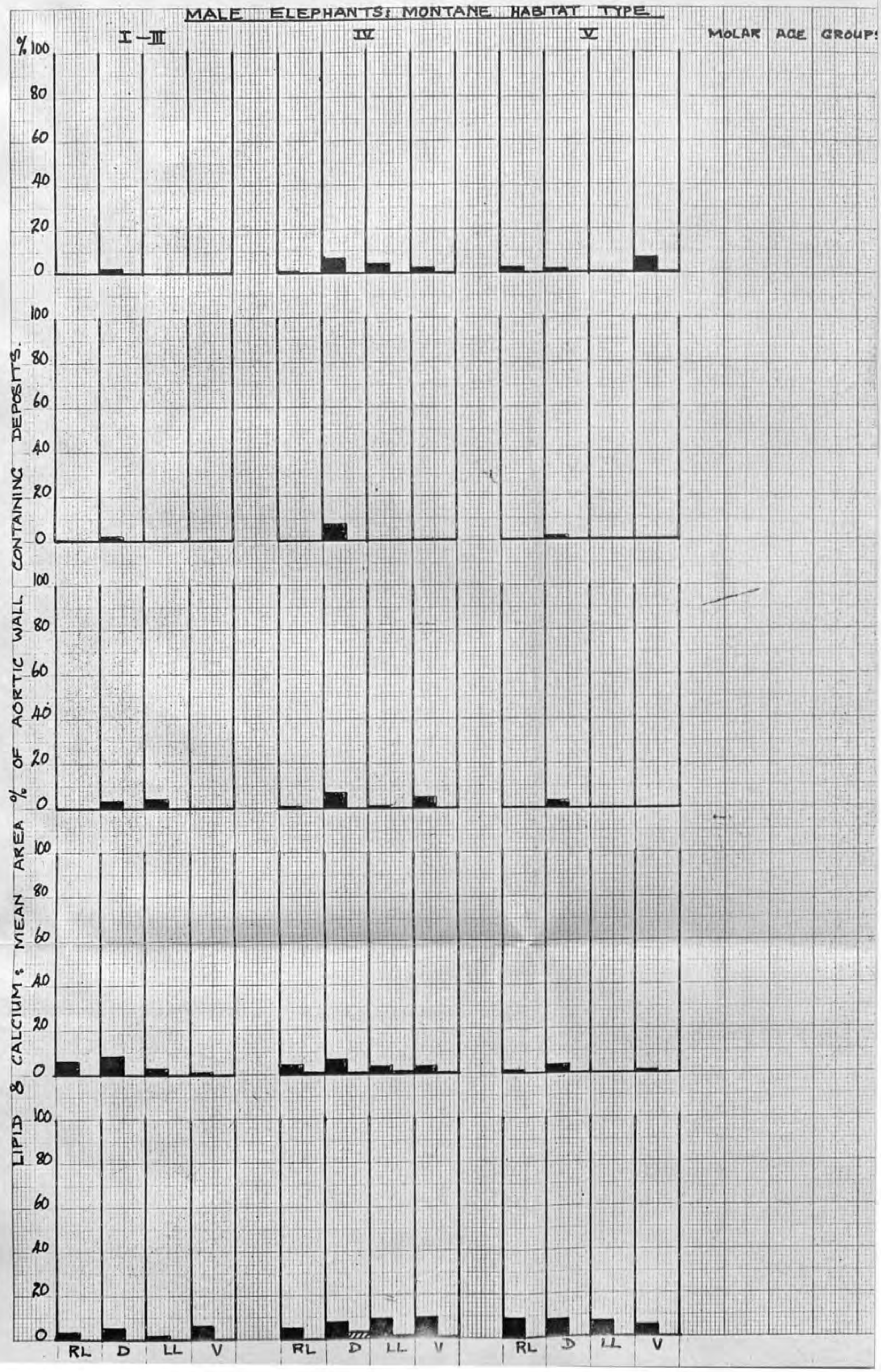
Owing to the rather small number of elephants of the lower age groups collected, it has been necessary to combine the data from molar age groups I - III. The Figures thus refer to data from groups I - III (calves and juveniles) in the left column of histograms on each sheet;
group IV (sub-adults) in the second column;
group V (prime adults) in the third column; and
group VI (senior adults) in fourth or right-hand column of each sheet.

FIG. 21.



A combined view of Fig. 22 – 27: For detail, see pp. 413 – 418

FIG. 22



MALE ELEPHANTS: MONTANE HABITAT TYPE
I–III
IV
V
MOLAR AGE GROUPS
% 100
80
60
40
20
0
LIPID & CALCIUM: MEAN AREA % OF AORTIC WALL CONTAINING DEPOSITS.
RL
D
LL
V

FIG. 23

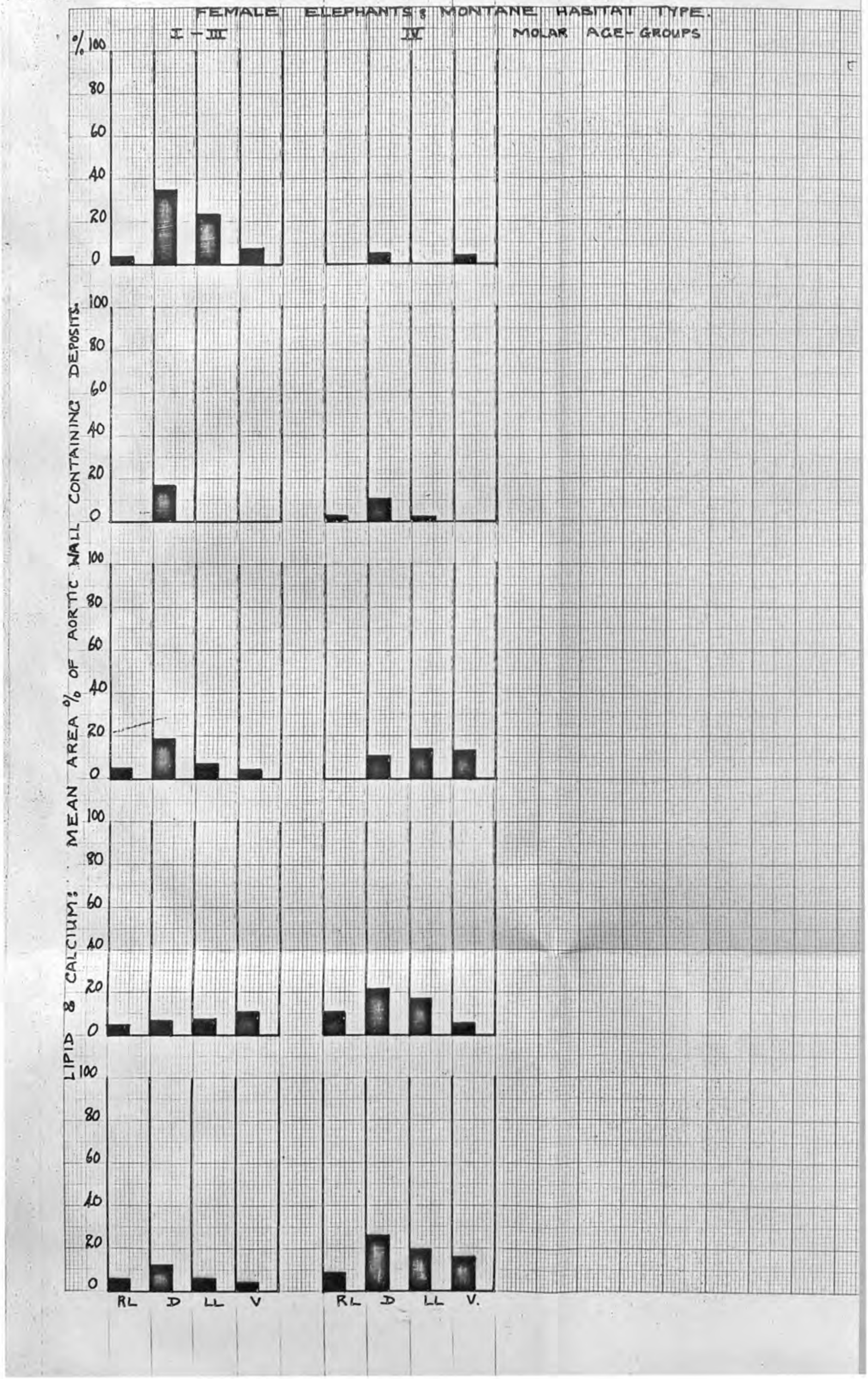
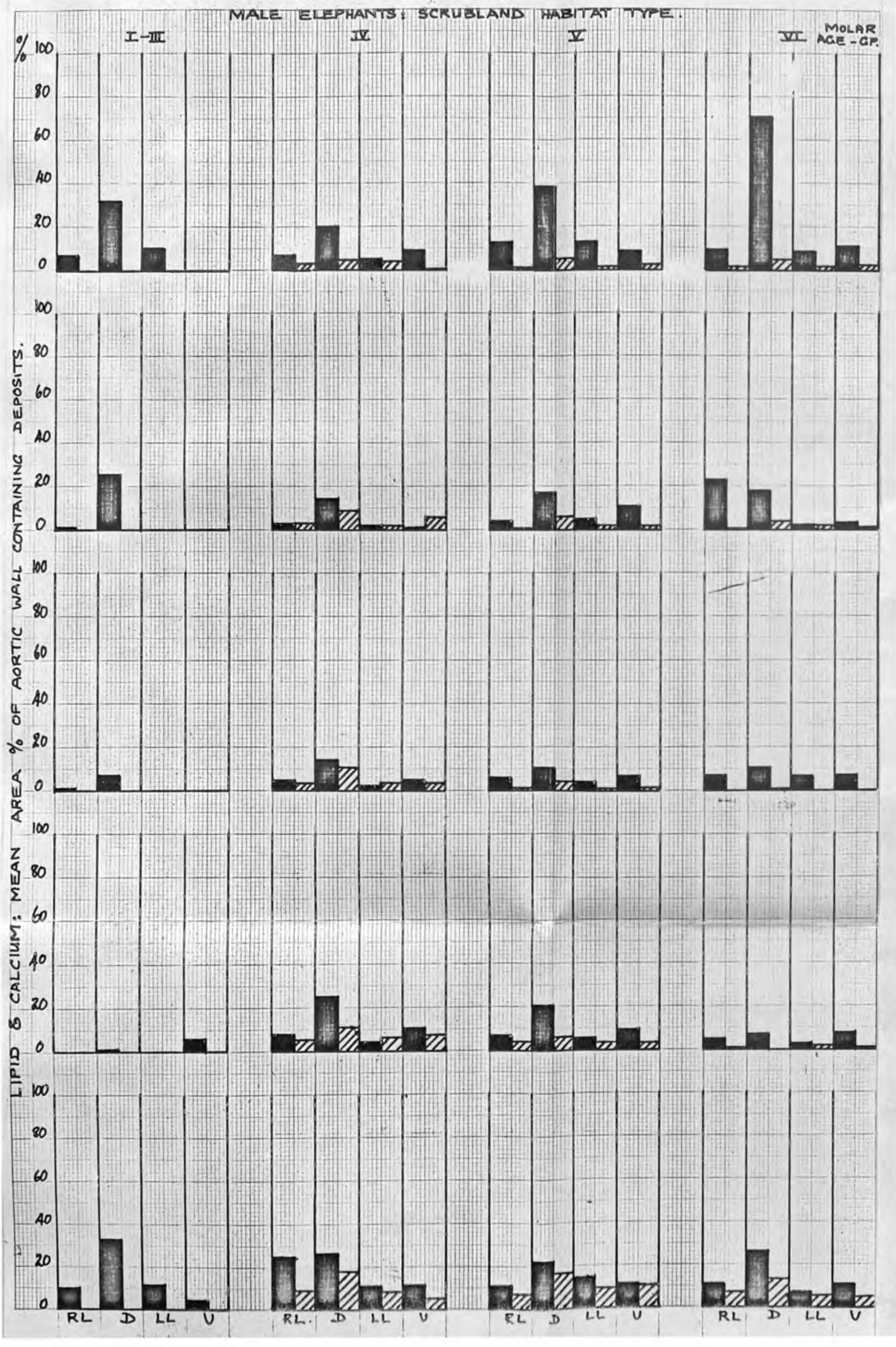

FEMALE ELEPHANTS: MONTANE HABITAT TYPE.
I – III
IV
MOLAR AGE-GROUPS
%
100
80
60
40
20
0
LIPID & CALCIUM: MEAN AREA % OF AORTIC WALL CONTAINING DEPOSITS.
RL
D
LL
V
RL
D
LL
V.

FIG. 24



MALE ELEPHANTS: SCRUBLAND HABITAT TYPE.
I-III
IV
V
VI
MOLAR AGE-GP.
%
100
80
60
40
20
0
LIPID & CALCIUM: MEAN AREA % OF AORTIC WALL CONTAINING DEPOSITS.
RL
D
LL
U

FIG. 25

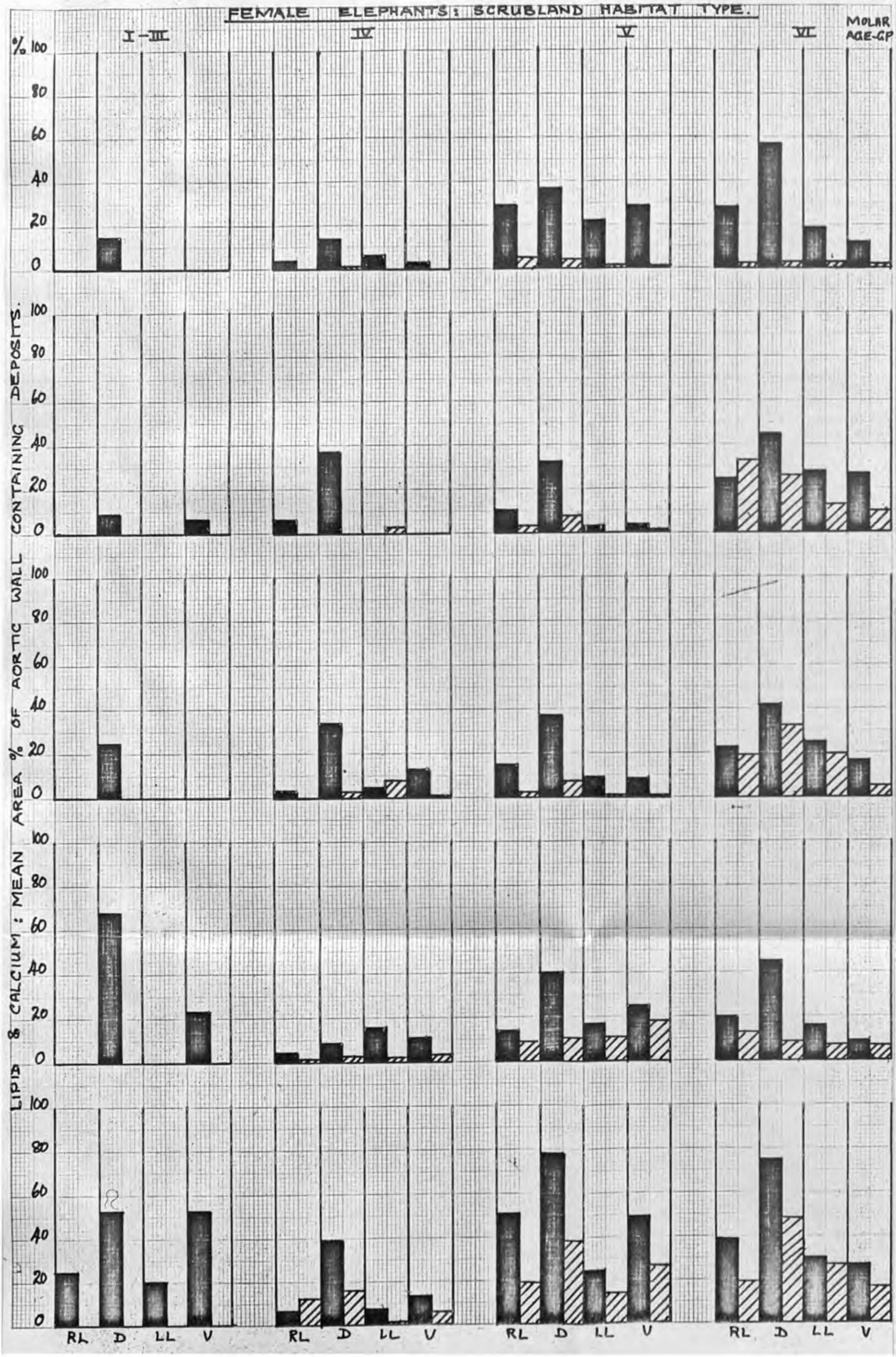

FEMALE ELEPHANTS: SCRUBLAND HABITAT TYPE.
MOLAR AGE-GP
I-III
IV
V
VI
%
100
80
60
40
20
0
LIPID & CALCIUM: MEAN AREA % OF AORTIC WALL CONTAINING DEPOSITS.
RL
D
LL
V

FIG. 26

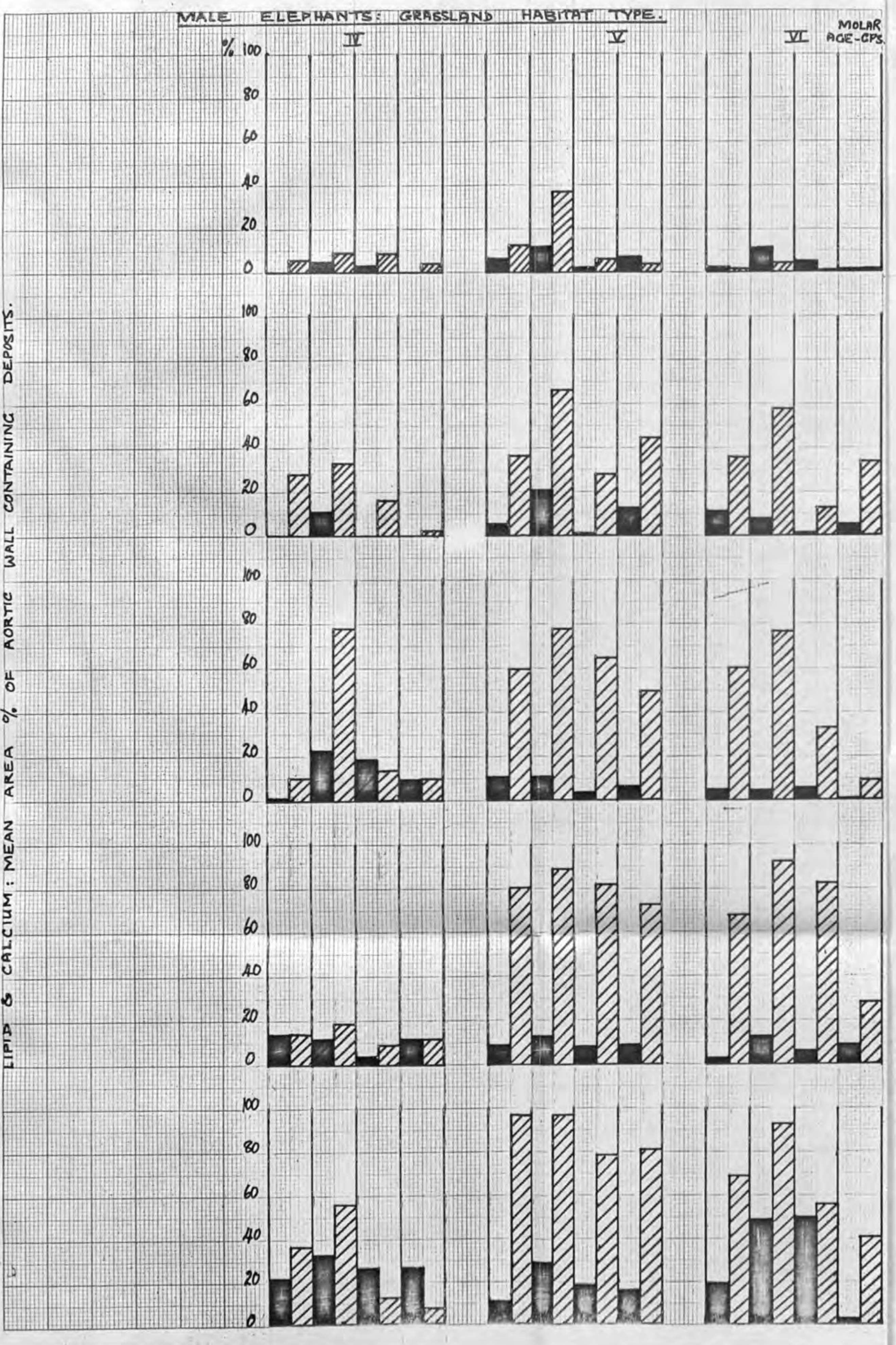

MALE ELEPHANTS: GRASSLAND HABITAT TYPE.
IV
V
VI
MOLAR AGE-GPS.
% 100
80
60
40
20
0
LIPID & CALCIUM: MEAN AREA % OF AORTIC WALL CONTAINING DEPOSITS.

FIG. 27

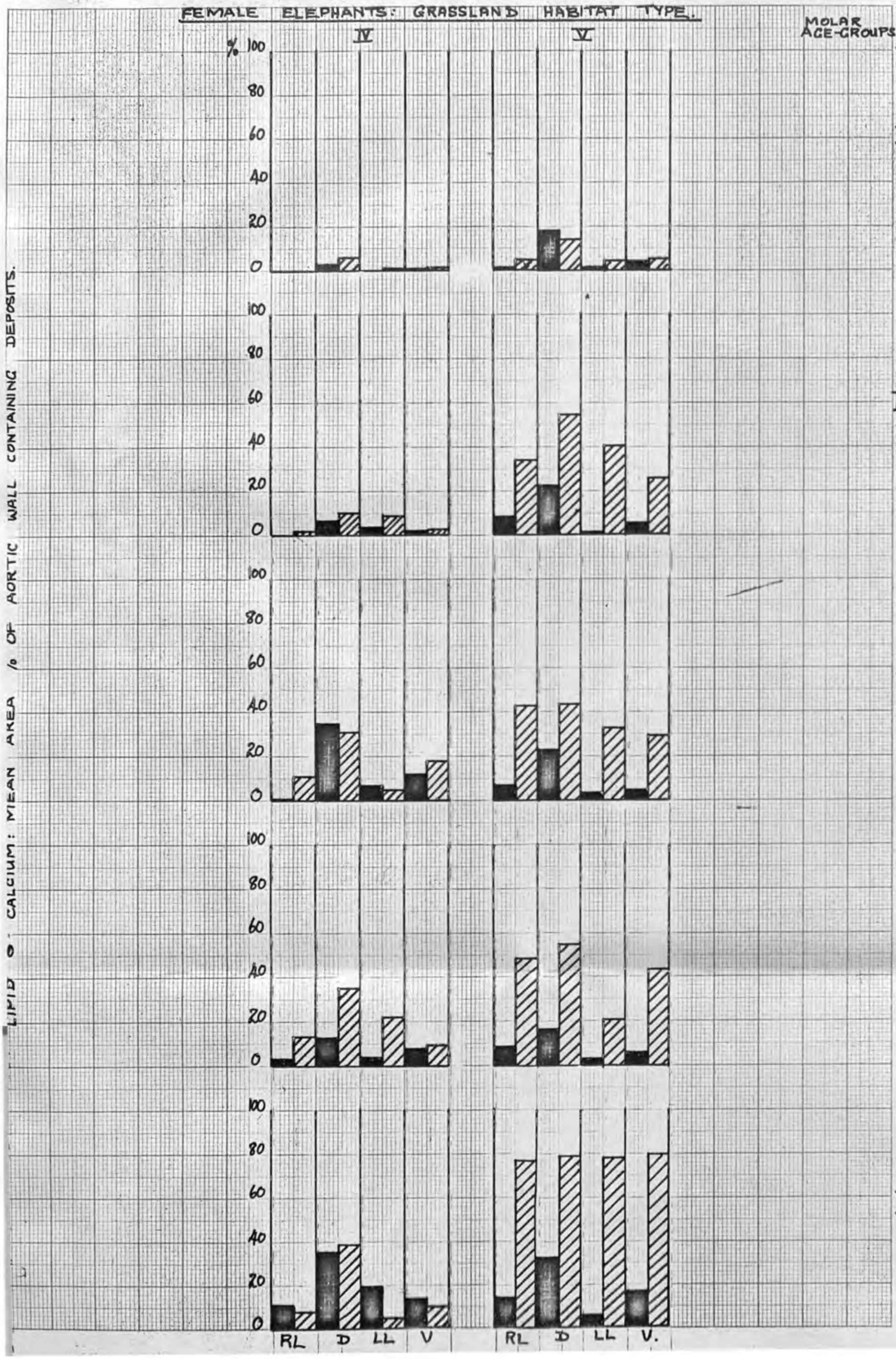

FEMALE ELEPHANTS: GRASSLAND HABITAT TYPE.
MOLAR AGE-GROUPS
IV
V
%
100
80
60
40
20
0
LIPID & CALCIUM: MEAN AREA % OF AORTIC WALL CONTAINING DEPOSITS.
RL
D
LL
V
RL
D
LL
V.

FIG. 28.

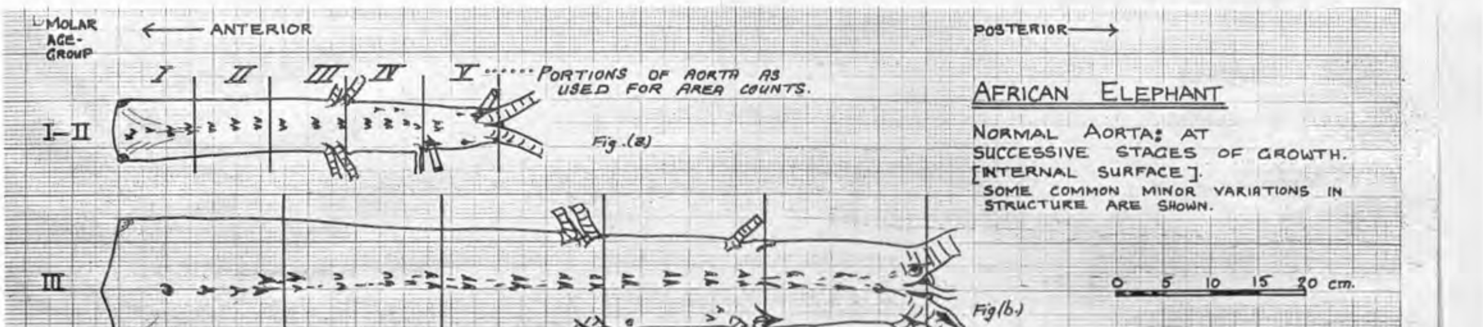

MOLAR AGE-GROUP
← ANTERIOR
POSTERIOR →
I II III IV V ...... PORTIONS OF AORTA AS USED FOR AREA COUNTS.
AFRICAN ELEPHANT
NORMAL AORTA: AT SUCCESSIVE STAGES OF GROWTH.
[INTERNAL SURFACE].
SOME COMMON MINOR VARIATIONS IN STRUCTURE ARE SHOWN.
I–II
Fig.(a)
III
0 5 10 15 20 cm.
Fig.(b.)
IV
VENTRAL (i)
L.LATERAL
DORSAL
R.LATERAL
VENTRAL (ii)
Fig.(c).
V
Fig.(d) AS IN LACT. ♀♀
VI
Fig.(e).

PLATE XLVII

(a) Field photograph: complete heart, aorta and right kidney. Specimen M.24.

(b) As above: interior view. Note: some calcific deposits (indicated by arrows) are macrospopically visible in this unstained aorta.

PLATE XLVII

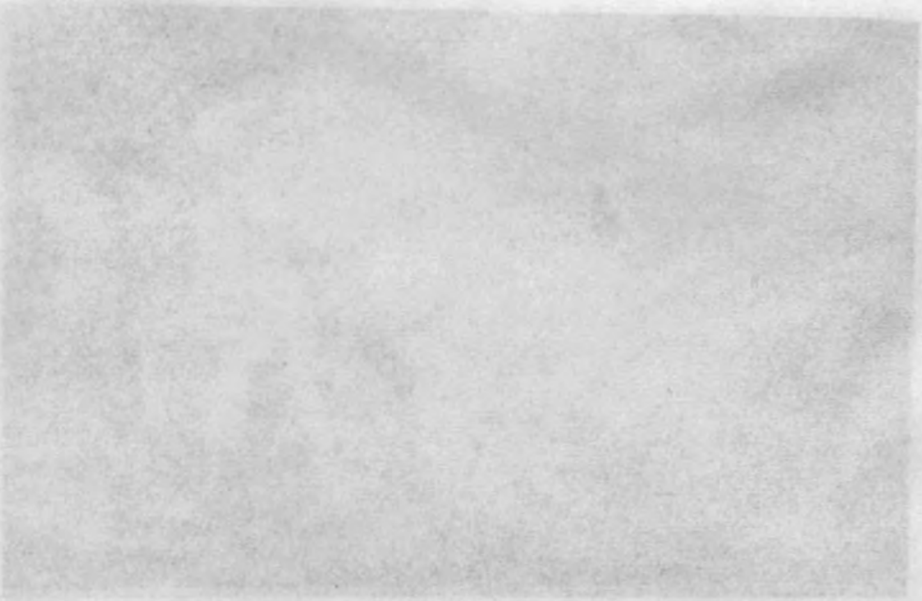
(a)

(b)

PLATE XLVIII

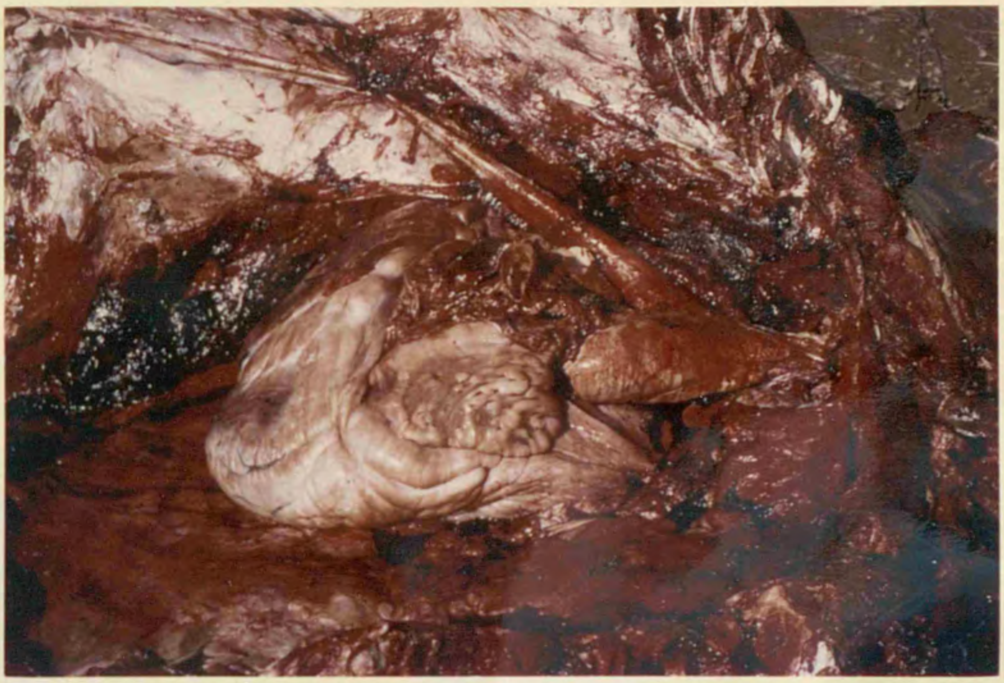
(a) Heart and aorta of elephant *in situ* in carcass, seen from right side. Specimen M.149.

(b) Interior of aortic arch of elephant, showing orifice of right coronary artery. Note: large cavity of the aortic arch recalling the *truncus arteriosus* of more 'primitive' vertebrates.



(b)

PLATE XLVIII



(a)

(b)

PLATE XLIX

(a) Semilunar valve: pulmonary arch of elephant heart.
M.24.

(b) Aortic valve, M.22.

(c) Sagittal view of part of left side of heart of elephant calf M.114.

PLATE XLIX

(a)

(b)

(c)

PLATE L

Comparison between two normal montane elephant hearts (b) and (c); and two scrubland elephant hearts (a) and (d).

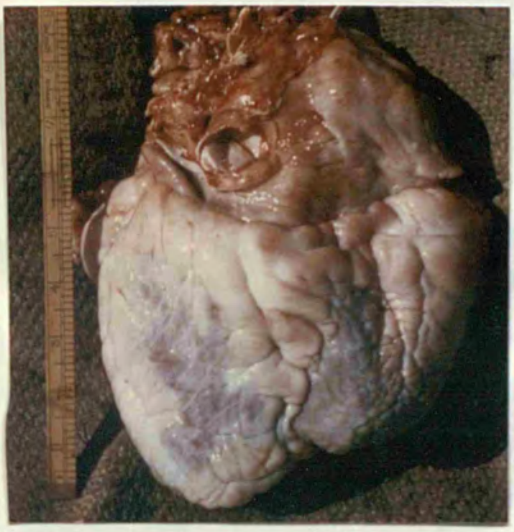
(a) Dorsal view of heart of female elephant calf M.114 (scrubland habitat type).

(b) Left vento-lateral view of heart of young male elephant M.83 (montane habitat type). Note pointed, single apex and large deposits of sub-epicardial fat masking the very slight ventricular bifurcation.

(c) Dorsal view of heart of senior bull elephant, M.152 (montane habitat type): showing pointed apex of left ventricle. Extensive, firm, fatty mantle, and very slight ventricular bifurcation.

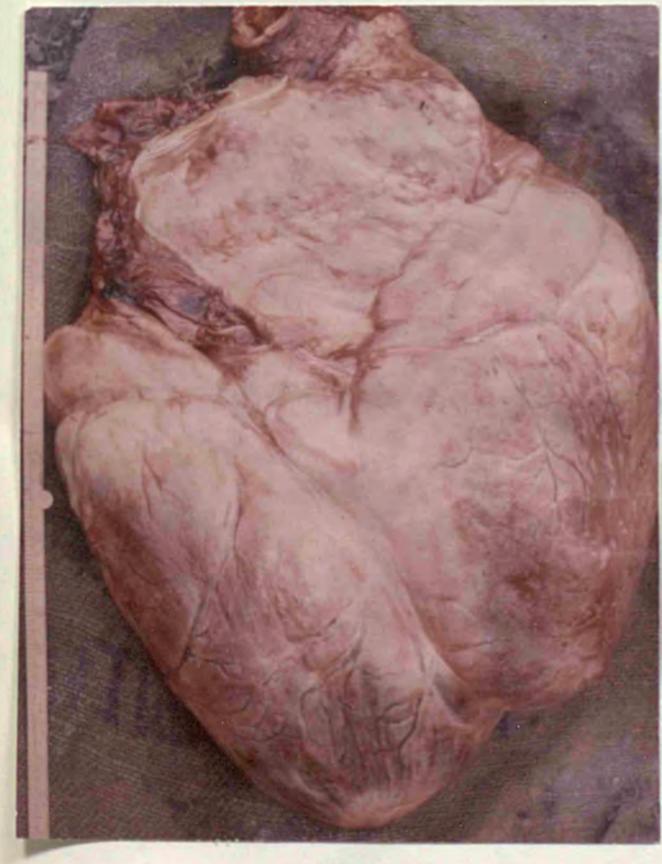
(d) Dorsal view of heart of elderly senior bull elephant, M.116, (scrubland habitat type): showing the prominent ventricular bifurcation, 'square' shape, and lean appearance of the heart.

PLATE L



(a)

(b)



(c)

(d)

PLATE LI

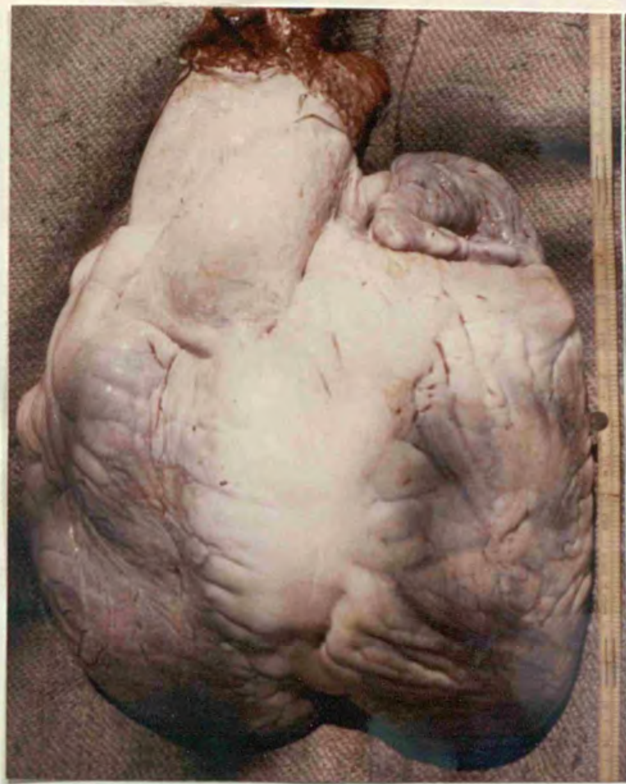
Hearts of 4 elderly scrubland and grassland elephants, all of which had extensive, grey atheroma-like plaques in the aortic arch and thickened, fatty plaques in the coronary arteries:

(a) dorsal view of heart of elderly bull elephant, M.86 (grassland habitat type). This heart was lean, flaccid and 'square', with the ventricular bifurcation very prominent.

(b) Left ventro-lateral view of heart of senior cow elephant, M.122, (scrubland habitat type). The heart is lean and the bifurcation prominent.

(c) Dorsal and (d) ventral views of the heart of the very elderly cow elephant M.107 (scrubland habitat type).

PLATE LI



(a)

(b)

(c)

(d)

B. The Aorta

i) Length and circumference of lumen

The fixed aorta of the youngest elephant collected (M.135), a calf of less than 6 months old, was 53 cm in length, i.e. aortic arch 8 cm plus aorta (*ductus arteriosus* to bifurcation) 45 cm. The maximum lumen circumference (at *duct.art.*) was 6 cm, and minimum 4.0 cm (in portion V), a ratio of 0.66.

The largest normal aorta collected (M.116, large elderly bull) was 155 cm long, i.e. aortic arch 25 cm plus aorta 130 cm; maximum lumen circumference 20 cm, minimum 14 cm, a ratio of 0.7. These figures represent total fresh lengths of approximately 64 cm (M.135) and 186 cm (M.116) respectively.

ii) Macroscopic structure

The unpaired coeliac and anterior mesenteric arteries usually arise separately in the ventral line of the aorta at the posterior end of portion III (see FIG. 28, p.419), and the renal arteries separately in the ventral line at the posterior end of portion IV. One renal artery usually lies slightly anterior in position to the other. Minor variations of this arrangement were not uncommon and appeared to bear no relationship to health or habitat.

Variations included the occurrence of coeliac and anterior mesenteric arteries with a common origin in the aorta, and similarly of both renal arteries with a common origin. Variations in the arrangement of the arteries at the bifurcation were also noted, although it was usual to find only two common iliac arteries, and the posterior mesenteric arteries originating at or near the termination of the aorta itself. However, cases were also noted in which a caudal artery originated independently at the bifurcation, and another in which there appeared to be separate origins of internal and external iliac arteries, although these were not conclusively identified as such.

The spermatic and ovarian arteries were noted in some cases to originate in the aorta itself and in others as branches of the renal arteries. The origin of the phrenic artery was not normally located in the aorta, and one supposes that it more often originates as a branch of the coeliac. Variations in the number, appearance and arrangement of the dorsal ostia both in the thoracic and abdominal aorta were very common and apparently completely individualistic.

No feature clearly distinguishing between the aortae of the male and female elephants in this collection was detected.

The presence of a supportive fibrous collar and posterior reinforcement 'ramp' associated with the ostium of every branch artery, large or small, originating in the aorta, occurred without exception. These were found to be more prominent and mainly fibrous in character in older animals, while in young animals they were less prominent, and almost invariably contained deposits of stored lipid - detectable with Sudan IV stain. The presence of these fatty deposits was not detectable macroscopically in the unstained fresh aorta.

iii) Microscopic structure

This is illustrated in Plates LII to LX, pp 457 to 473 In portion I of the aorta (anterior portion) the tunica intima is normally extremely thin (10 μ) and the tunica media very thick and elastic. In calves, 95 ± 5 elastic lamellae were counted in the anterior samples from portion I/dorsal, and 120 ± 5 in portion I/ventral. In an elderly bull, 125 ± 10 were counted in portion I/dorsal and 225 ± 10 in the anterior part of portion I/ventral. In Man there are said to be about 40 lamellae in the newborn and 70 in the adult (Ham 1965).

The ratios of mean thickness of intima to media in the standard samples taken from the normal elephant aortae were as follows:-

Portion of aorta	Dorsal line	Ventral line
I	0.006	0.005
III	0.007	0.006
IV	0.04	0.04
V	0.20 *	0.04

These figures must, however, be regarded with some reserve, as the variation of ratio within any one part of a single portion of the aorta is considerable, and the need for such exactitude in standardisation of the sampling tehnique was not fully realised at the time when the tissue samples were actually taken. A more extensive and exact standardised sampling technique would be necessary if the normal ratios of thickness of the intima to media were to be mapped accurately in detail for the whole normal aorta of each age group.

Portion I is the widest and thickest part of the aorta (Table~~s~~ 15, pp 400 to 402) and the media here normally contains

* (the ratio is unusually high at this point, where the dorsal crescentic ridge of thickened supportive tissue occurs just anterior to the bifurcation)

very little collagen and few smooth muscle cells, the elastic lamellae being closely packed together. Arterioles of the vasa vasorum penetrate towards the aortic lumen through 50% of the thickness of the media in this portion, and capillaries to 75% depth.

In the anterior part of portion II, the aortic lumen becomes somewhat narrower, and the proportion of smooth muscle cells in the media is found to increase in relation to the elastic fibres, the elastic lamellae becoming more widely separated from each other.

In portions III and IV, smooth muscle cells and collagen fibres predominate, and the internal elastic lamellae is distinguishable as a wavy fibrous line, interrupted at intervals, and staining readily with Verhoeff's elastin stain.

In portions I - III, the combined intima and media of the ventral line seem generally to be thicker than in the dorsal line, but are approximately equal in portion IV. In portion V, however, between the renal arteries and the bifurcation, not only is the dorsal wall thicker, but also the ratio of intima to media is greater.

In all portions, the intima of the fibrous reinforcement collars and ramps associated with ostia, contains a higher proportion of fine elastic and collagen fibres in the sub-endothelial and deep external layers than elsewhere. Almost invariably, extracellular lipid material can be detected in the deep layers of the intima of these collars and ramps, especially at the apex of the depression forming the posterior rim of the ostium, and on the slope of the 'ramp', just posterior and lateral to the 'collar' (Plate LV, LXIV, pp 463 and 481.

Luginbühl & Detweiler (1965) mention plaques with laminated caps at sites of vascular orifices but make no mention of the normal occurrence of these in the species which they studied.

The exact mode of functioning of these collars and ramps, probably not merely as reinforcing structures enabling the tissues to withstand haemodynamic stresses operating at each arterial branch and bifurcation (Branwood 1963), but also as self-adjusting constriction valves, has been discussed more fully in ch.6, pp 140 to 142 and 165 to 168. Plate XX, p.250, shows two portions of a longitudinal section of the collar and ramp of the 6th aortic ostium of an elderly hippopotamus. It will be seen that the elastic lamellae of the media terminate abruptly under the rim of the collar and are replaced by collagen fibres and smooth muscle with only a few fine strands of elastic fibre penetrating the collar itself. The intima is only slightly thickened within the ostium and a small amount of lipid material lies in the media at the apex of the 'funnel'.

In this particular section, intimal sudanophilic material was detected in the deep subendothelial layer of the intima on the posterior slope of the ramp. An identical situation obtains in the aortic ostia of the elephant, although the ostia in the latter species are always less prominent than those of the hippopotamus. The reinforcement 'collars' are always conspicuous at the origins of the larger branches - coeliac, anterior mesenteric and renal arteries - , but the 'ramps' appear to be very small and insignificant in proportion to the size of the orifice.

In the aortic arch, at the origins of the brachiocephalic trunks, and at the bifurcation, the supportive 'ridges' are very prominent in elephant. It is in these ridges that the earliest accumulations of lipid seem to occur. At the bifurcation, in addition, a crescentic or pointed arch of fibrous supportive tissue is sometimes visible, especially in older animals. This seems to be an anterior extension of the main dorsal ridge at the bifurcation of the iliac arteries. This crescentic or arch-like ridge seems to lie in the line of maximum mechanical stress occurring in this region of the aorta. It normally has the highest proportion of fibro-muscular tissue in both the intima and media as well as the greatest ratio of thickness of intima to media (even as high as 0.20; cf. p. 433) of the aortic wall in this region.

This structure also seems to be especially prone to medial mineralisation,and in very elderly buffalo and elephant mineralisation of the entire crescentic or arch-like ridge may occur. A complete calcified crescentic rod was extracted from this position in the aorta of the elderly buffalo M.31 and also from the elderly elephant M.107. The latter is illustrated in Plates LXX, p493 and LXXXI,p513 . This animal also showed extensive atheroma-like plaques throughout the aortic arch and aorta, and an aortic aneurysm between the origins of the coeliac and anterior mesenteric arteries.

A longitudinal section through the orifices of the renal arteries of the young suckling elephant calf M.135 (Plate LX(b),p.473) shows some degree of mineralisation of the elastica even at this early stage of development, although its chemical identity was not determined. Sudanophilic material was also located in the deep subendothelial layer of the intima in frozen sections of the same tissue.

C. Muscular Arteries

Sections of normal carotid, common iliac, brachial, femoral, and coronary arteries are illustrated in Plates LVIII, p.469 , LXI, p.475, LXII, p.477 , LXVII, p.487and LXXVII p.507. The reinforcement collars and ramps of branches of the muscular arteries are more prominent than those of the aorta in the elephant, and in elephants of every age group intimal lipid deposits were found associated with these collars and ramps in the extra-mural coronary arteries, usually on the distal slope of the ramp.

The ratio of thickness of intima to media in the extra-mural coronary arteries is about 0.7 - 0,9, and as in other arteries this varies according to its proximity to a curve ~~xx~~ or branch.

Lipid and mineral deposits in normal,muscular elephant arteries

This has been discussed in Appendix 4, pp 606 ,and it is concluded that the presence of lipid deposits within reinforcement 'collars', 'ramps' and 'ridges' of the aorta and muscular arteries is normal in elephant of all age groups, being particularly abundant in these locations in suckling calves, and pregnant and nursing cows.

In contrast, the presence of Calcium deposits detectable macroscopically by direct visual techniques, i.e. by radiography, in the aorta and muscular arteries is concluded to be abnormal. Nevertheless, as mentioned above, some apparent mineralisation of the aortic elastica of a suckling montane calf was found in the vicinity of the renal ostia.

D. Arterioles, Capillaries and Veins

No particular study of the smaller arteries, capillaries or veins has as yet been carried out on the material collected, but the eventual study of these is planned. Only cases of macroscopically obvious varicosity of veins have been noted here (p 448 - 449).

Cardiovascular Abnormalities

A. Heart

As has been shown, healthy elephants collected in the montane habitat type are considered to represent the norm. The large 'square', flaccid type of heart characteristically associated with elephants collected in the degenerate habitat types are thus regarded as abnormal. In these, muscle tonus was low, the fatty mantle reduced, and the bifurcation of the apex exaggerated.

The following additional, apparently normal, characteristics of the hearts of the grassland elephants were noted:-

i) fenestration of one or more cusps of the aortic valve occurred in 9 out of the 13 elephants collected; a similar fenestration of the cusps of the semilunar valves of the pulmonary arch was also noticed in a number of cases.

ii) Calcium flecks were found in the extra-mural coronary arteries in M.93, M.21, M.18 ~~and~~ M.22, M24, and M.149

iii) Lipid streaks and plaques occurred in the intima of the coronary arteries, additional to that in the reinforcement collars, ramps and ridges of the ostia of braches in specimens M.22, 24, 84, 93, 21, 18, and 86. The last of these, M.86, had long, projecting fatty plaques extending throughout the extra-mural coronary arteries.

iv) Roughness of the intima of the aortic sinuses occurred especially in the vicinity of the orifices of the coronary arteries in specimens M.22, 84, 18, and 86. M86 not only had a roughened intima in the aortic sinuses and their vicinity, but extensive 'pearly grey' plaques covered most of the internal surface of the aortic arch, being particularly thick in the vicinity of the brachiocephalic trunks. In M.18 the aortic arch contained buttons (0.2 - 1.0 cm diameter) and irregular soft white plaques in the arch itself and the origins of the brachiocephalic trunks. The internal surface of the arch in this specimen was wrinkled and rather rigid.

Slight occlusion of the orifice of the right coronary artery was noted in M.88 and M.22 (diameter $<$0.8.cm, compared with $>$ 1.2 cm as found in other elephants' hearts of comparable size).

v) A few fibrous epicardial 'tags' were noted on the atria of the heart of M.120. In this specimen, similar 'tags' were found on the peritoneum, and pericardium.

vi) A caseous lesion was noted in the endocardium of the left ventricle in the heart of M.122. On the basis of the tissue reaction, when stained, this is thought to have been caused by an inflammatory agent, such as Bacteria or Toxoplasma, although no identifiable organisms could be located in it (Smith 1967).

It seems very possible that an increase of the intimal thickening of the coronary arteries due to excessive lipid deposition in specimens M.18, 86 and 93, accompanied by advancing calcification of the elastic lamella, increased fenestration of the cusps of the aortic valve and loss of elasticity of the aortic arch could contribute to eventual terminal cardiac failure. The only available authentic record of terminal coronary insuffieiency in an elephant, confirmed by <u>post-mortem</u> examination, is that of Lindsay <u>et al</u>.(1956), in which he described the case of a captive Indian elephant in the San Francisco Zoological Garden. The natural death of two wild elephants in Uganda, supposedly due to terminal cardiac failure was described to the author in 1964 (Appendix 4, p 632).

The comparatively frequently recorded cases of elderly elephants dying of 'exhaustion' in deep mud wallows and steep-sided river beds might also suggest that a combination of the conditions described above could predispose the animal to collapse, following over-exertion while attempting to extricate itself from an extreme natural hazard. Such cases are, however, rarely witnessed and have apparently not yet occurred in circumstances suitable for subsequent autopsy examination, and comment here is perforce purely speculative.

B. Aorta

As mentioned earlier, p.439, the analysis of the quantitative data on the lipid and Calcium deposits found in the aortae of the elephants studied in this project indicates that the abnormalities associated on the one hand with the presence of Calcium in the media and on the other with intimal lipid extraneous to the ostial reinforcement 'collars', 'ramps' and 'ridges' are distinct and basically independent conditions. Nevertheless, in the extreme cases of aortic calcification found among grassland elephants (M.18, 21, 24, 86 and 93) extraneous intimal lipid deposits were closely associated in some parts of the aorta with intimal and medial Calcium deposits (Appendix 4, Plate II).

Although extraneous intimal lipid deposits were found to be more extensive in scrubland than in grassland elephants, in advanced cases from either habitat - where extensive soft, white, fibro-collagenous intimal plaques containing deep sudanophilic lipids overlay calcified areas of the internal elastic lamella and fibrous layers of the media -it appeared that the coincidence of these conditions resulted in tissue reactions in both layers. This possibly served to hasten the mutual development of both conditions together towards irreparable degeneration of the aorta wall.

As shown in Table 15 (pp.400 - 402) and the histograms, FIGS. 21 - 28 (pp.412-419), the earliest appearance of extraneous, intimal lipid deposits characteristically occurs diagonally across the anterior part of the aorta from the ventral towards the dorsal line, i.e. following the direction of the main force of the blood flow from the heart during ventricular systole. At the same time, extraneous intimal lipid deposits may begin to build up in the vicinity of the bifurcation as broad, soft plaques containing much lipid and little collagen (Plate LXX, p493 and Appendix 4, Plate II).

It is of note that in all cases the area of aortic wall containing lipid deposits is always least in portions II and III and greatest in portions I and V. In advanced cases, large deposits may also occur in portions IV. It is in those portions where the blood flow is steadiest, uninterrupted by curves or eddies, and where only minor branches originate, that lipid deposition is minimal. This distribution contrasts with that of Calcium, which usually occurs in greater quantities in the posterior (the more muscular) rather than the anterior (the more elastic) portions of the aorta and seems, especially in advanced cases, to be more widespread in its distribution around the aortic wall. Moreover, the intimal lipid deposition pattern seems to reflect the probable flow patterns of the blood within the aortic lumen, whereas the Calcium deposition appears to be independent of the blood flow patterns.

Whether this suggests that the actual physical character of the lipid droplets in the blood plasma in relation to the haemodynamics of the elephant is significant here, or whether the indications relate to mechanical stresses inflicted on the intima over areas of maximum fluid pressure, resulting in some degree of trauma to the intima, is beyond the scope of this study (French & Jennings 1965). Nevertheless, the observation raises questions which may be of significance in the field of comparative haemodynamics.

Fibrous, intimal buttons have been particularly noted within this characteristic pathway along which the extraneous lipid deposition proceeds, but confined to the anterior part (portion I) of the aorta. These were found in specimens M.119, 120, 122 and 149 (srubland) and M.23 and 24 (grassland). None was found in any montane specimen. These buttons closely resembled those occurring in dogs, described and illustrated by Lindsay & Chaikoff (1963), in which reduplication of the internal elastic lamina occurs and an irregular, initially vertical, proliferation of fibroblasts develops towards a layered arrangement of collagen and fine elastic fibres, which finally seem to replace most of the ground substance (Plates LXXI, LXXII and LXXIII, pp 493 – 499).

In other cases, large plaques and buttons contained, apparently, lipid globules within large proliferating cells, possibly macrophages or fibroblasts. In Plate LXXX (p. 515) a frozen section of one of several intimal lesions found in portion I of the aorta of specimen M.120 is illustrated. The intima is greatly thickened and contains numerous macrophages and fibroblasts, containing lipid globules surrounding an oval area. In this, both hyaline and granular material as well as an early calcific deposit may be seen. A similar lesion was described by Geer & Guidry(1965). The internal elastic lamella has been completely disrupted. The part of the lesion adjacent to the aortic lumen contains red blood corpuscles, of which some have been ingested by macrophages, and some organisation of cells resembling capillaries or sinusoids has occurred in this area. This lesion bears a close resemblance to Ogilvie's description of the typical haemorrhagic plaque of human atheroma.(1962)

This tissue was submitted for examination for the presence of parasites to Dr. M.J. Clarkson, Liverpool School of Tropical Medicine, and Professors Garnham and Nelson of the London School of Tropical Medicine and Hygiene. In each case, these workers stated that no parasitic organism could be detected within the lesion.(1967)(1967)

Intermediate in type between the haemorrhagic plaque described above and the early fibrous buttons, were numerous cases where the intima contained sudanophilic lipid deposits accompanied by various degrees of intimal thickening, disruption of the I.E.L. and proliferation of smooth muscle cells and fibroblasts. Examples of these are illustrated in Plates LXXVI, LXXVIII and LXXIX, pp 505, 509, 511.

C. <u>Muscular Arteries</u>

i) <u>Coronary arteries</u>

Intimal lipid deposits extraneous to the normal sites occurred in the following grassland elephants M.22, 23, 88, 84, 93, 21, 18 and 86. In some of these, the lipid-containing plaques appeared to be long, raised bands up to 5 cm x 1 cm in size, or oval areas of up to 1.5 cm maximum diameter. Similar plaques also occurred in specimens M.112, 149, 150, 118, 131, 127, 108, 117, 121, 122 and 107. These were particularly prominent in specimens M. 131, 127, 121, 122, and 107 (Plate LXVII).

Calcific deposits occurred in the coronary arteries (usually confined to the neighbourhood of their origin in the aortic sinuses) in specimens M.18, 21, 22, 24, and 93 (grassland) and 149 (scrubland)(Plate LXXVII).

ii) Iliac and femoral arteries

In a few cases of excessive intimal lipid deposition and thickening, the lumina of branch ostia have been partially occluded (e.g. specimens M.122, 131, 149, scrubland) and in the case of M.122 this affected the lumen of the entire right common iliac, external iliac, and femoral artery and was accompanied by both intimal and medial calcification.

The foot of this limb was swollen, the sole unusually soft, and the veins of the lower limb were varicose, but necrotic areas were not macroscopically evident at autopsy, nor was any ante-mortem thrombus found in the arteries of this limb. It is impossible to overlook either the implication that the marked occlusion of the main arteries of this limb, due to combined lipid and Calcium deposition with intimal thickening, had possibly preceded the swelling of the foot and the varicosity of the veins, or the similarity of the condition to cases of arterial occlusion in Man involving the lower limbs.

This particular elephant was a very elderly animal and, although it occupied the position of seniority in its herd, it had been observed prior to its collection for study to show typical signs of old age - a 'flat-footed' gait, tendency to 'slump' when relaxed, and a 'gaunt' appearance. Although specific lameness had not been noted, it is possible that this could have been overlooked owing to crowding by the other members of the herd and the presence of long grass and high bushes.

iii) <u>Paired dorsal branches of the aorta</u>

In several specimens, in grassland elephants, extreme occlusion of the ostia of some of the dorsal branches of the aorta occurred, due to the presence of medial and intimal Calcium deposits (Plates LXVIII, LXXI, LXXIV, pp 488, 495, 501) and in M.93, 18, 21, 24 and 86 there was partial occlusion of the common iliac and posterior mesenteric arteries. In no case was significant occlusion of renal arteries, or renal infarction, noted, although early medial calcification was found in the renal, anterior mesenteric and coeliac arteries of specimens M.88, 93, 21 and 18.

Extreme occlusion of the dorsal branches of the aortae of elephants must be supposed to cause some anoxia of the intercostal and lumbar musculature and the skin of the dorsum, and it was very noticeable at autopsy that the dorsal skin in such animals was consistently found ~~at autopsy~~ to be unusually dry and calloused, while the flanks and dorsum had a 'wasted' appearance.

iv) Brachial arteries

The brachial arteries rarely contained any Calcium deposits, although extraneous intimal lipid was frequently noted. The forelimbs of elephant are extremely mobile and are constantly in use for digging, pushing, and occasionally (though much less commonly than in the Indian elephant) for breaking timber, and one supposes that any significant occlusion of the brachial arteries would result in the very rapid incapacitation of an elephant.

v) Carotid arteries

The carotid arteries in numerous cases were found to contain extraneous lipid deposits, especially in the region of the bifurcation, and in several cases fairly extensive calcification. Another feature noticed to be associated in every case with the advanced cases of aortic calcification examined at autopsy, was a distinct 'drooping' of the head from the shoulders. No healthy elephant of any age group was seen to adopt a similar posture, but a number of live elephants were seen and photographed in both grassland and scrubland, which adopted this posture constantly, were emaciated and moved laboriously and stiffly (Plates LXXXIX(c) and XC, pp 552,554).

One supposes that the posture may result from insufficiency of the blood supply to the flanks, dorsum and neck, due to occlusion of the relevant branches of the aorta. Intercostal insuffieiency could possibly affect the general health and mobility of elephant acutely, due to the fact that the pleura is adherent to the chest wall and therefore dependent on its muscular action for both successful expiration and inspiration.

Cardiovascular Abnormalities and the Environment

As shown quantitatively (Appendix 4, p 606) there is a definite correlation between the occurrence of cardiovascular abnormality in the African elephant and the environment. Both of the more important types of abnormality found, namely (i) the occurrence of extraneous intimal lipid deposits with proliferation of intimal cells, disruption of the internal elastic lamella, and occasional intimal calcific deposition, and (ii) the occurrence of extensive medial calcification of the aorta and muscular arteries, are found to be associated with stressed or degenerate habitats, the recognisable stresses consisting of:

i) prolonged exposure to unmitigated sunlight;

ii) over-population;

iii) a restricted diet;

iv) frustration of the migratory habit associated with a breakdown of environmental conditions suited to the birth and nurture of young calves, and with boredom and lack of exercise for the adults.

In the 'control' or 'natural' habitat type studied, extremes of temperature and altitude, and irregular hunting did not appear to act as 'stresses' for wild elephant at all, and on the contrary appear to serve as beneficial stimuli: data have not been available to see whether these factors would still act as beneficial stimuli if the environment were placed under other stresses causing degeneration of the forest and/or severely restricting the migration of the elephants.

The degree of degeneration of the habitat seems to bear a direct relationship to the onset and extent of the occurrence of arterial disease in elephant. The Uganda grasslands are at present in a very advanced state of degeneration, and calcific deposits in the aorta seem to occur in all the adult elephants in those populations.

In the scrubland areas, there is an indication in the material examined in this project (although the sample is inadequate for statistical confirmation) that it is the young and prime adult age groups in the male elephants, and all age groups in the females, that are most severely affected by aortic Calcium deposition - i.e. all nursing cows and those animals born and reared in and around the Tsavo National Park and its environs since the observed onset of vegetational degeneration in the area and the simultaneous rapid advance of human encroachment on the dry-season forest refuges. This represents a period of about 25 years. Of all the elephants studied, however, it is the elephants of this environment which generally show the most extensive occurrence of significant, truly atheroma-like lesions of the arterial intima.

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PLATE LII

Standardised samples of aortae:

(a) L.S. aorta, portion I/dorsal line. Specimen M.119. Verhoeff & van Gieson stain. x 100.

(b) L.S. aorta, portion I/ventral line. Specimen M.119. V. & v.G. stain. x 100.

In these samples the tunica intima of portion I is seen to be very thin indeed, whereas the tunica media is thick and closely laminated with elastic membranes. Branches of the _Vasa vasorum_ penetrate the media deeply here.

PLATE LII

(a)

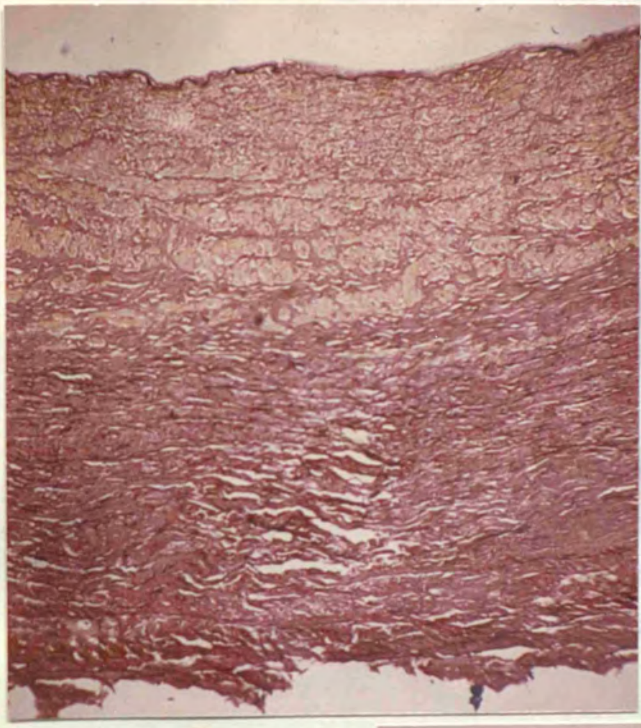
(b)

PLATE LIII

(a) L.S. aorta portion III/dorsal line, specimen M.119. A greater proportion of smooth muscle and fewer elastic layers occur here. Apparent gaps in the internal elastic lamella probably represent normal fenestrations, as there is no sign of duplication here.
V. & v.G. stain. x 100.

(b) L.S. aorta portion III/ventral line, specimen M.119. Alcian blue stain. x 100.

PLATE LIII



intima
i.e.l.

(a)

(b)

PLATE LIV

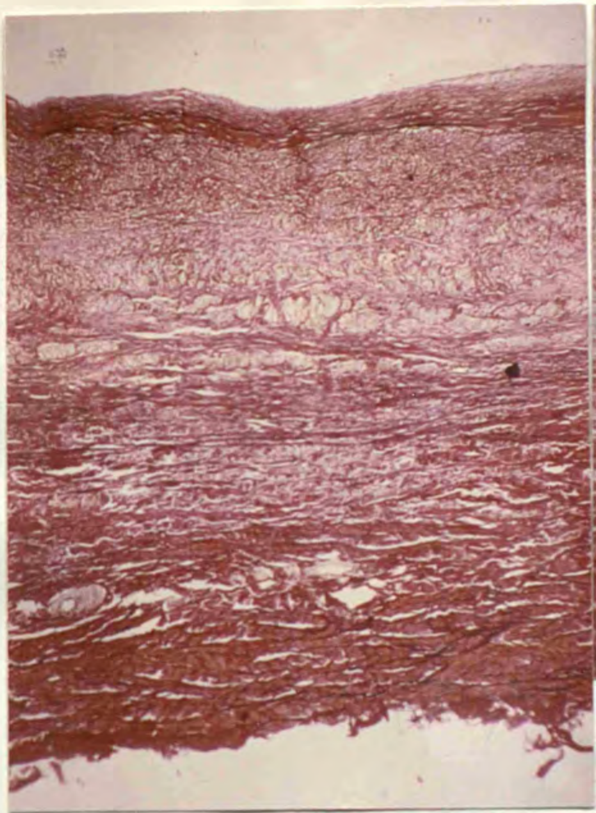
(a) L.S. aorta portion IV/dorsal line, specimen M.119. Here the intima is thicker in proportion to the media. No lipid deposits were detected in the tissue from which this section was cut, but duplication of the I.E.L. has occurred and may, with the thickening of the intima, represent early degenerative changes resulting in the formation of an atheromatous plaque. Scattered atheroma-like 'buttons' were found in portion I of the aorta of this specimen (see Plate LXXI(c). V. & v.G.stain. x 100.

(b) L.S. aorta portion IV/ventral line, specimen 119. Alcian blue stain.

(c) L.S. aorta portion V/dorsal line, M.119. This section includes the lower slope of the crescentic, or arched supportive ridge lying in the dorsal line at the bifurcation. Early duplication of the i.e.l. can be seen. In this case some lipid was detected in the deep subendothelial layer of the intima. This also may represent very early degenerative changes which could subsequently result in the formation of an atheromatous plaque.

(d) L.S. aorta portion V/ventral line, M.119. Gaps in the i.e.l. here probably represent fenestrations. The intima is not thickened. The media here consists mainly of layers of muscle cells and collagen fibres.

PLATE LIV

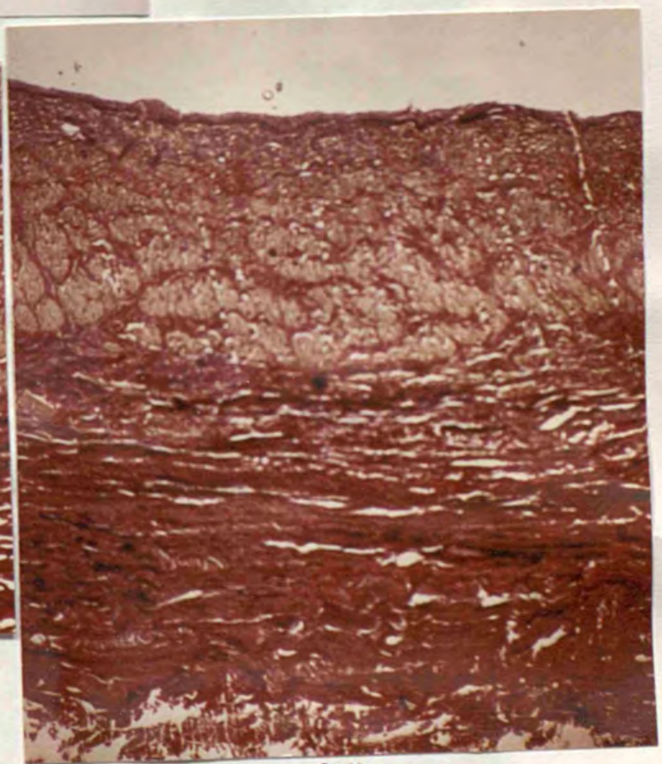


(a)

(b)

intima
i.e.l.

(c)



(d)

PLATE LV

L.S. supportive structure of the ostium of an intercostal artery originating in the thoracic aorta of an adult elephant. The i.e.l. is not disrupted or duplicated. It is interrupted only by its normal fenestrations; small lipid deposits occur in the superficial subendothelial layers of the intima of the slope of the 'ramp'. Another comparable deposit of lipid (not seen in this photograph) also occurred in this section in the apex of the ostial depression. Sudan IV and haematoxylin. x 50.

PLATE LV

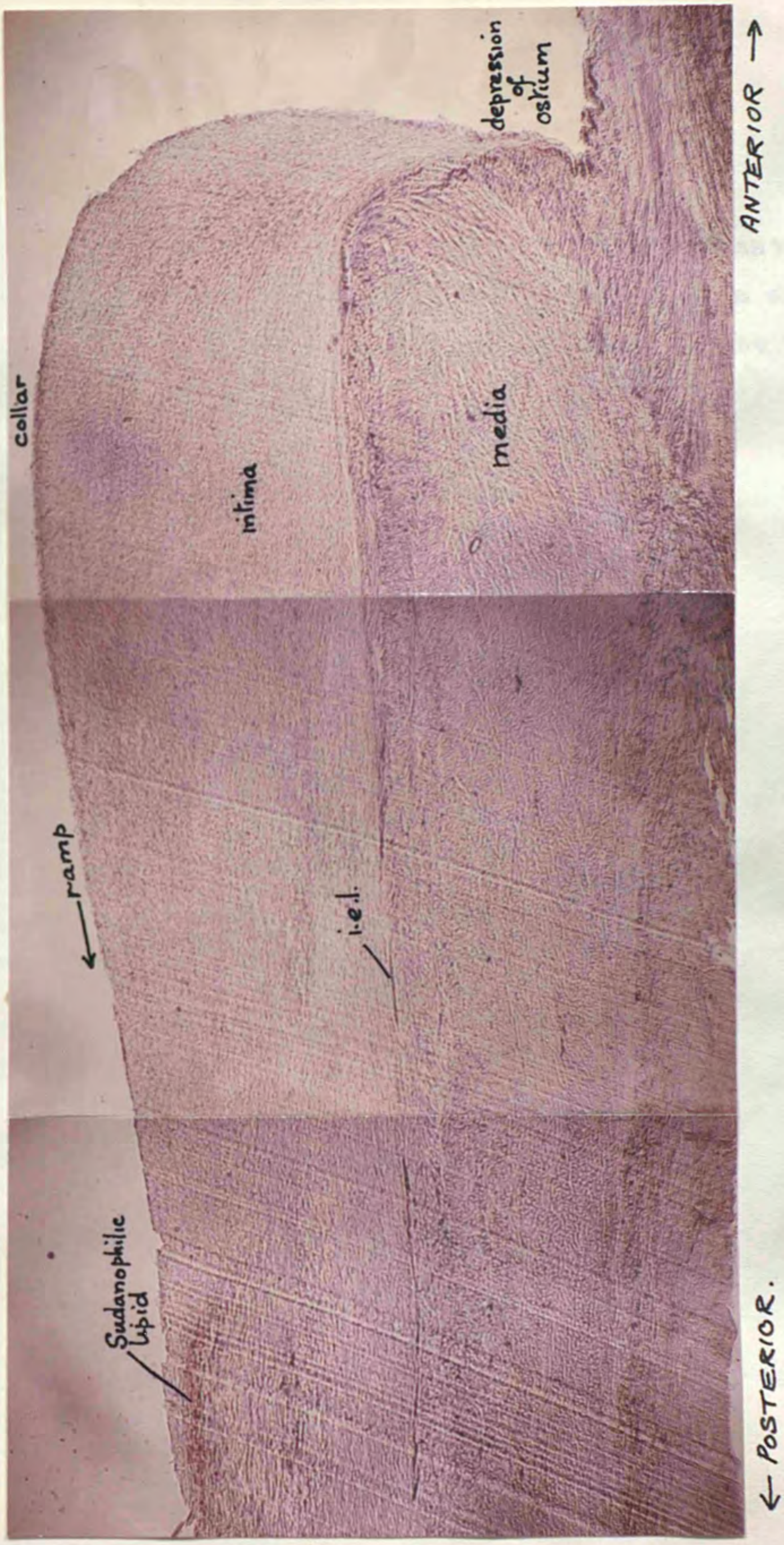

depression of ostium
ANTERIOR →
collar
intima
media
← ramp
i.e.l.
Sudanophilic lipid
← POSTERIOR.

PLATE LVI

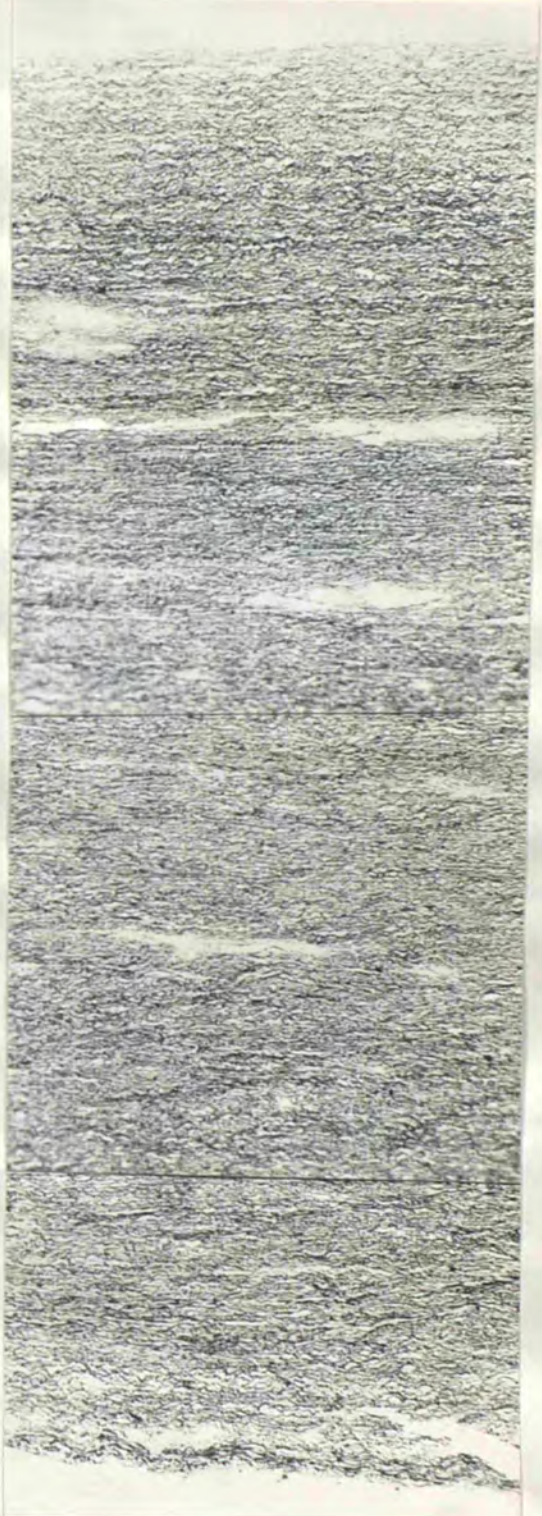
Normal aorta of elderly male elephant:
Note increasing thickness of intima and of ratio of intima to media towards the posterior end of the aorta (Plates LVI and LVII)

(a) L.S. portion I/dorsal line.
V. & v.G. stain. x 50.

(b) L.S. portionI/ ventral line.
V. & v.G. stain. x 50.

PLATE LVI

(a)



(b)

PLATE LVII

Normal aorta of elderly male elephant (see Pl.LVI)

(a) L.S. portion III/dorsal line.
V. & v.G. stain. x 50

(b) L.S. portion III/ventral line:
V. & v.G. stain. x 50

(c) L.S. portion IV/dorsal line.
V. & v.G. stain. x 50

(d) L.S. portion IV/ventral line.
V. & v.G. stain. x 50

(e) L.S. portion V/dorsal line.
V. & v.G. stain. x 50

(f) L.S. portion V/ventral line.
V. & v.G. stain. x 50

(g) Area 'A' of (e) above x 100, showing the normal reinforcing fibres of the deep subendothelial layers of the intima in the dorsal supportive arched ridge at the bifurcation. Note that the i.e.l. here shows gaps representing its normal fenestration, but no duplication and no mineralisation.

PLATE LVII

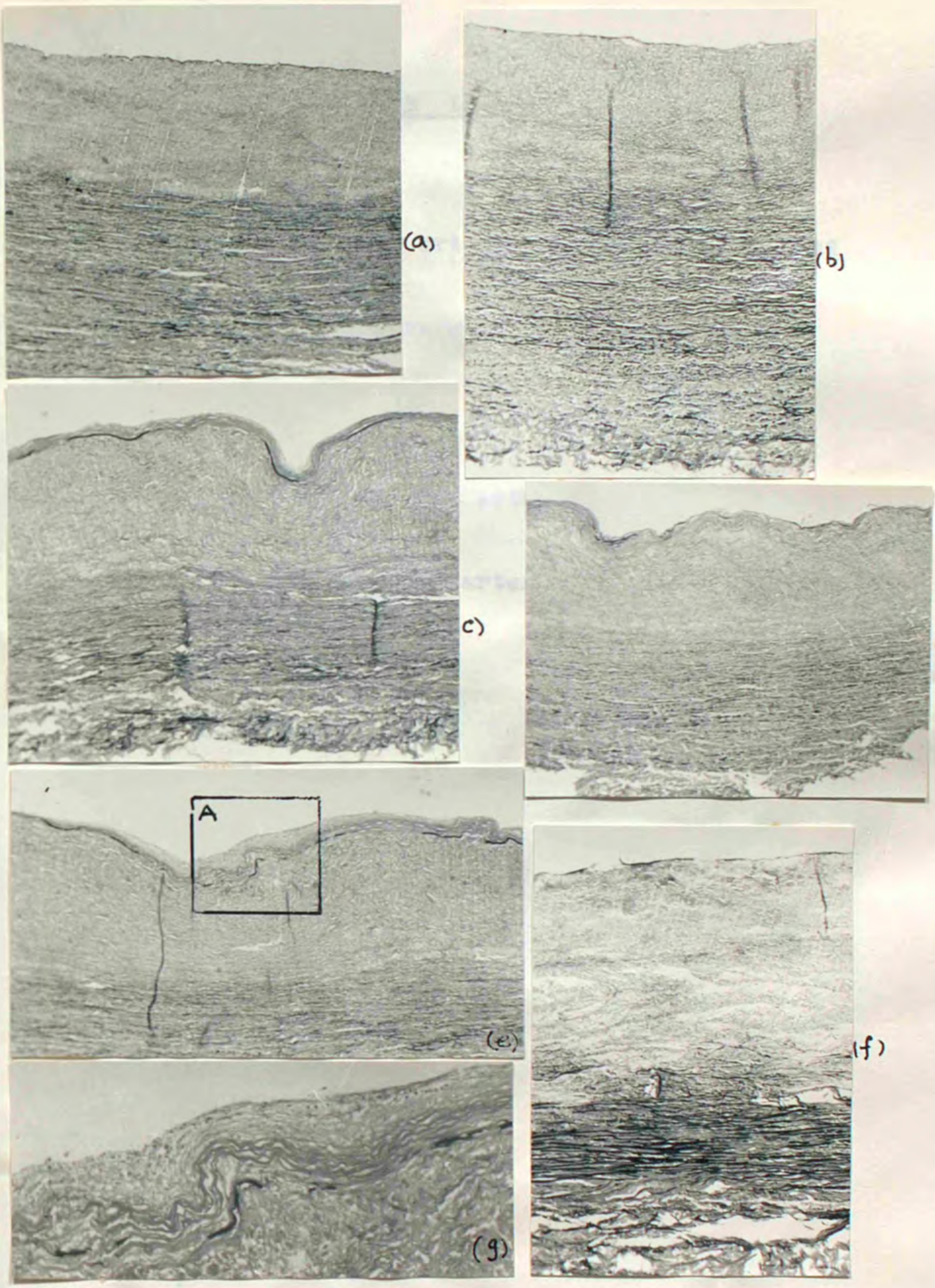


PLATE LVIII

Normal muscular arteries, adult bull elephant

(a) T.S. Coronary

(b) T.S. Carotid

(c) T.S. Brachial artery

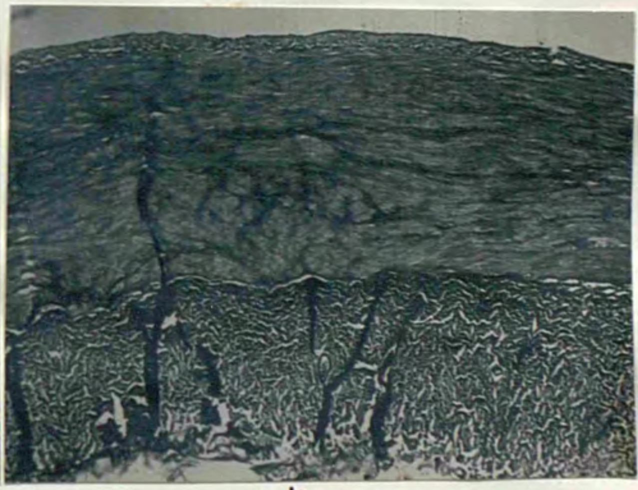
(d) T.S. Femoral artery

PLATE LVIII

(a)

(b)

(c)



(d)

PLATE LVIX

Normal aorta of female elephant,M.135, calf (under 6 months old, from montane habitat type)

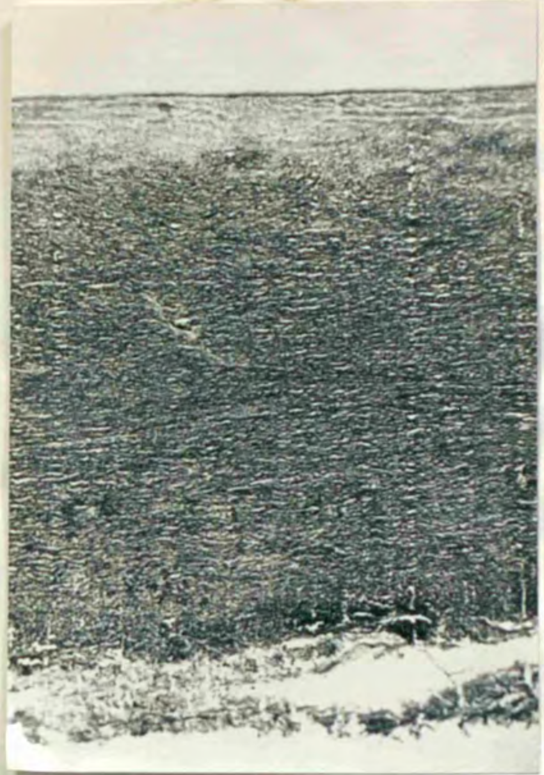
(a) L.S. portion I/dorsal line. x 50

(b) L.S. portion I/ventral line. x 50

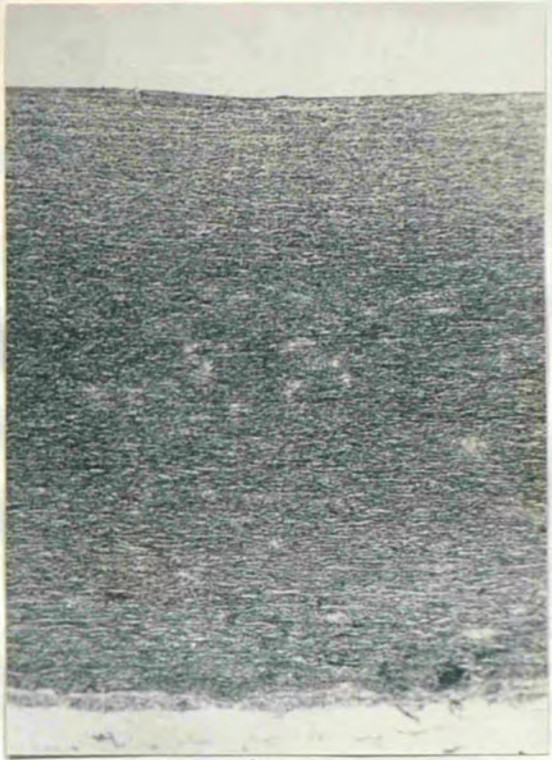
(c) L.S. portion III/dorsal line. x 50

(d) L.S. portion III/ventral line. x 50

PLATE LVIX

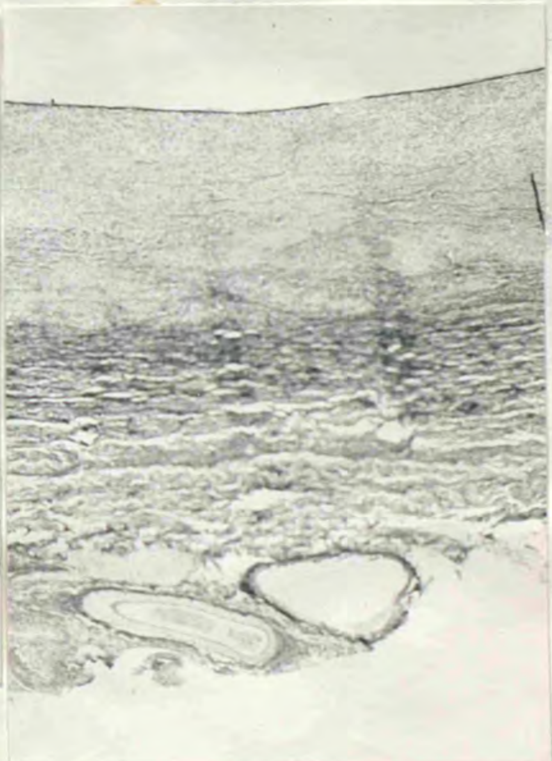


(a)



(b)

(c)



(d)

PLATE LX

Normal aorta of female elephant calf M.135, under 6 months old (from montane Habitat type)

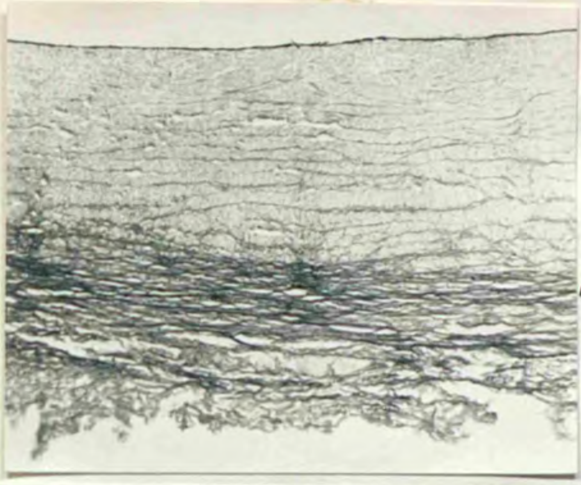
(a) L.S. portion IV/dorsal line . x 50

(b) L.S. portion IV/ventral line. x 50
(between separate origins of renal arteries)
Note early heavily staining deposits on, and medial to, i.e.l. These deposits were not chemically identified, but did not appear to be calcific.

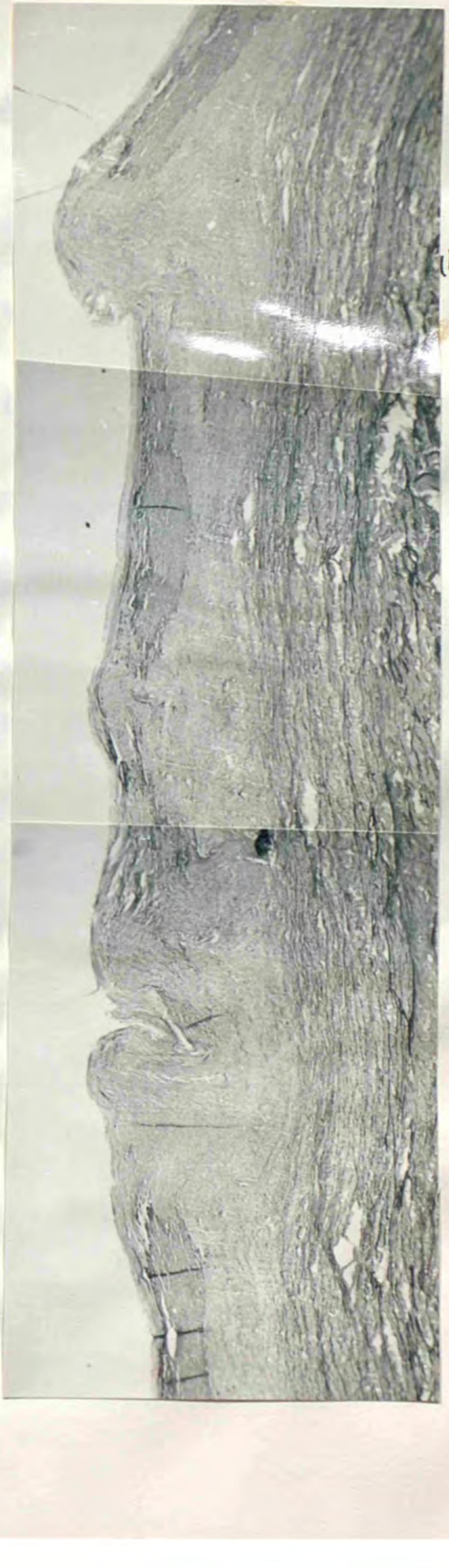
(c) L.S. portion V/ventral line. x 50

(d) L.S. portion V/dorsal line. x 50

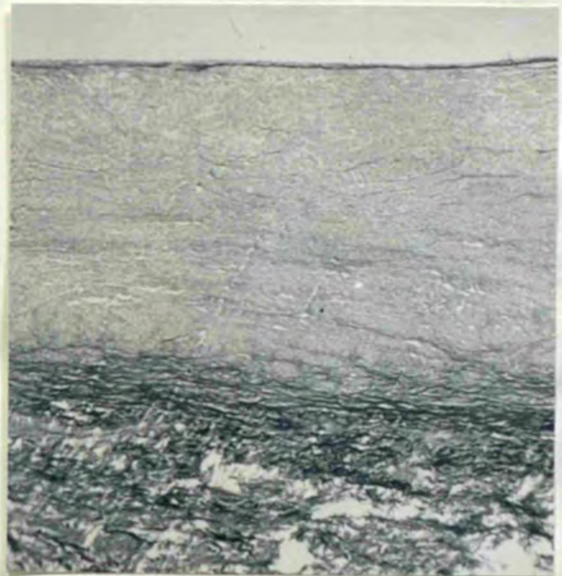
PLATE LX



a)



(b)



(c)

d)

PLATE LXI

Normal muscular arteries of female elephant calf M.135 (under 6 months old; from montane habitat type)

(a) T.S. common iliac artery. x 50

(b) T.S. carotid artery. x 50

(c) (d) T.S. right and left coronary arteries, 5 mm from origins. x 50

(e) T.S. intramural coronary artery. x 50

PLATE LXI

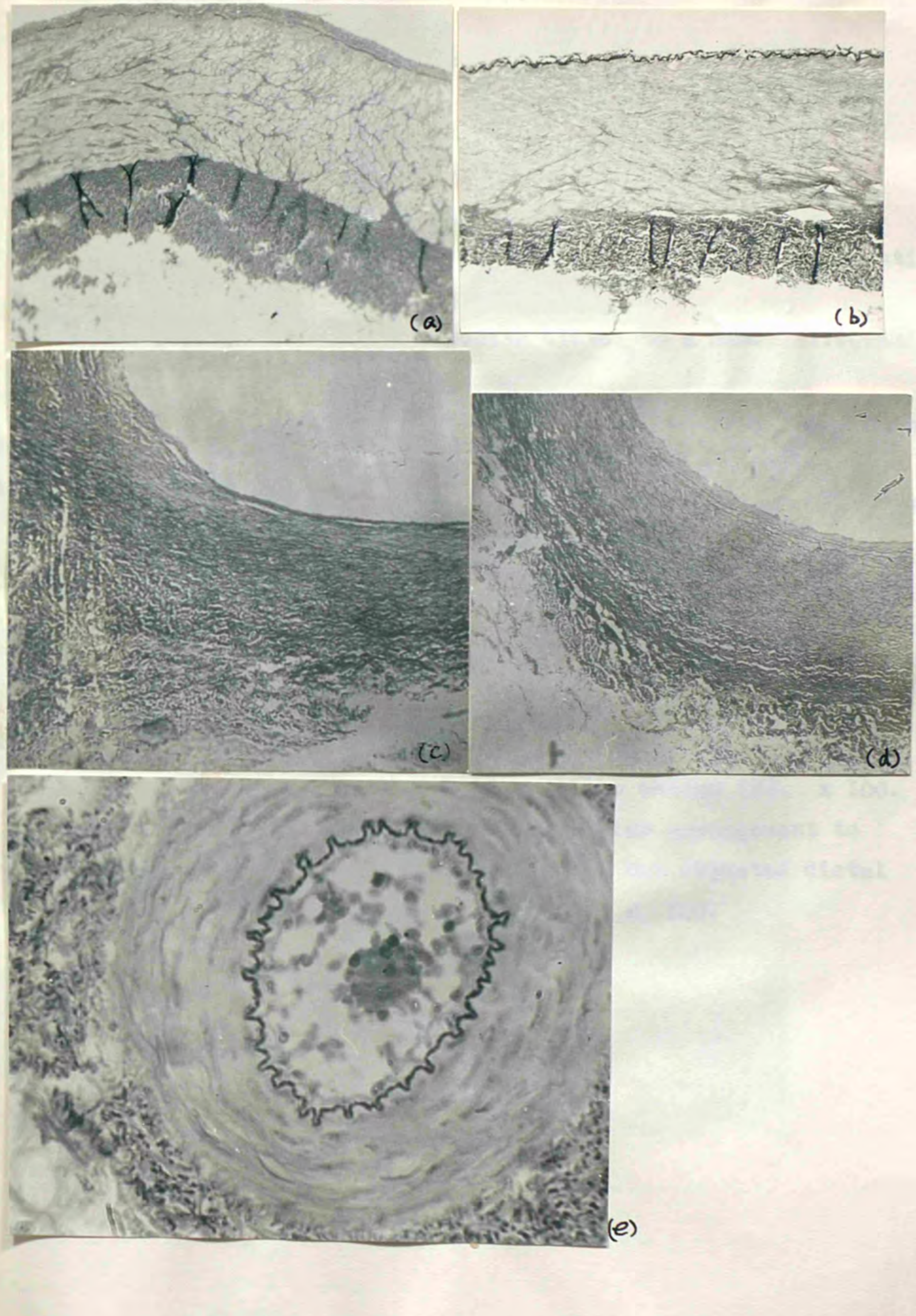


PLATE LXII

Normal deposits of sudanophilic lipid (S) in the intima of the extramural coronary arteries of a yearling elephant calf. In each case the deposit is associated either with an ostium or with a bifurcation.

(Sudan IV & haemalum stains)

(a) Intimal lipid deposits distal to a minor bifurcation. x 50.

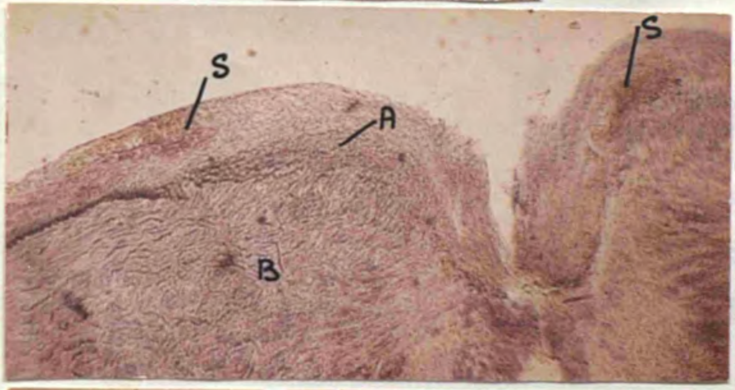
(b) T.S. ostium of a branch artery: intimal lipid deposits are seen i) in the side of the ostial depression; ii) in the slope of the collar, lateral to the ostium. Note the apparent disruption of the i.e.l. This seems not to be a pathological disruption, but actually a normal arrangement frequently noted by the author at the point of re-orientation of the longitudinal axis of the smooth muscle cells and elastic fibres, to form a musculo-elastic collar around the distal edge of the ostium (B). x 100.

(c) L.S. coronary artery: a similar arrangement to that described in (b) above, but situated distal to a coronary bifurcation. x 100.

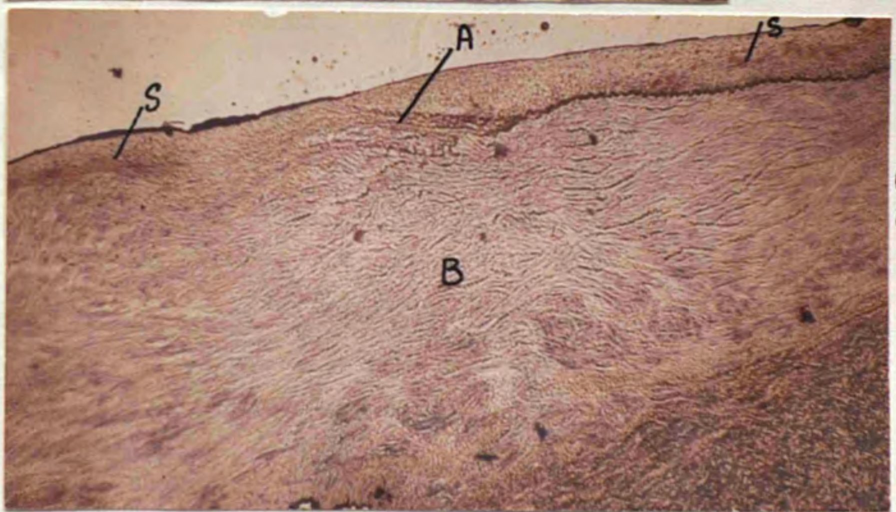
PLATE LXII

→ PROXIMAL

(a)
L.S.



(b)
T.S



(c)
L.S.

PROXIMAL. →

PLATE LXIII

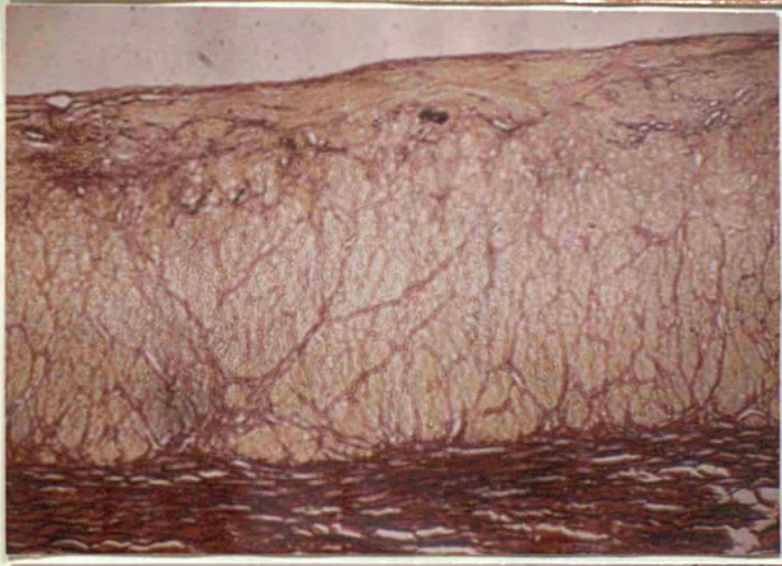
(a) Patent ductus arteriosus in yearling elephant calf, M.114. A patent duct.art. was also noted in an Asiatic elephant calf examined by Finlayson (1965). V. & v.G.stain. x 50

(b) T.S. normal carotid artery, specimen M.103. V. & v.G. stain. x 100

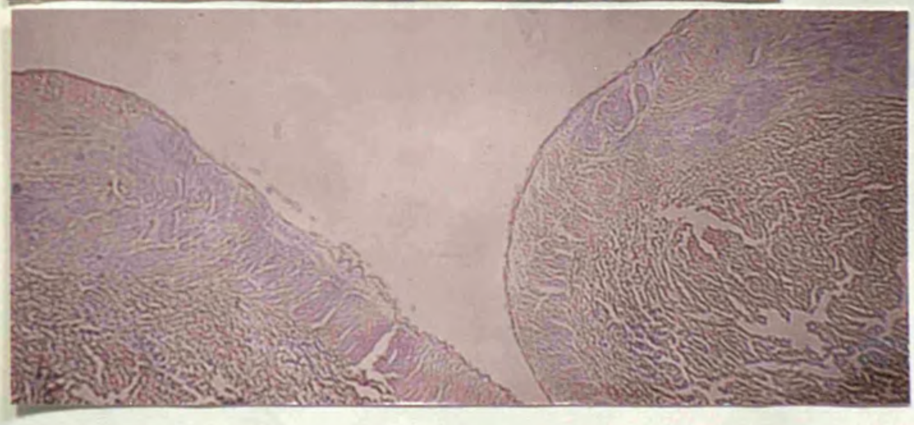
(c) L.S. ostium in normal renal artery. Specimen M.83. Sudan IV and haemalum; frozen section.
No lipid was seen within the ostium, but a small deposit was seen in the intima of the ostial ramp (beyond the limit of the photograph).

PLATE LXIII

(a)



(b)



(c)

PLATE LXIV

Internal surface of normal elephant aortae.

(a) Specimen M.133 (montane, juvenile), portion I (dorsal ostia). Fixed, but unstained.

(b) Specimen M.133 (montane, juvenile), portion IV/dorsal line. Fixed, but unstained. Ostial collars (C) and ramps (R) are clearly visible although not prominent; part of the ridges(G) of the coeliac and mesenteric arteries are also clearly visible.

(c) Specimen M.114 (scrubland; calf) portion IV with heavy sudanophilic lipid deposits in the intima of the dorsal ostial collars and ramps, and the ridges of the coeliac and anterior mesenteric arteries.

(d) Sudanophilic deposits in the intima of the collar, ramp and ridge of the origin of the right renal artery. Specimen M.132 (adult male, montane).

PLATE LXIV

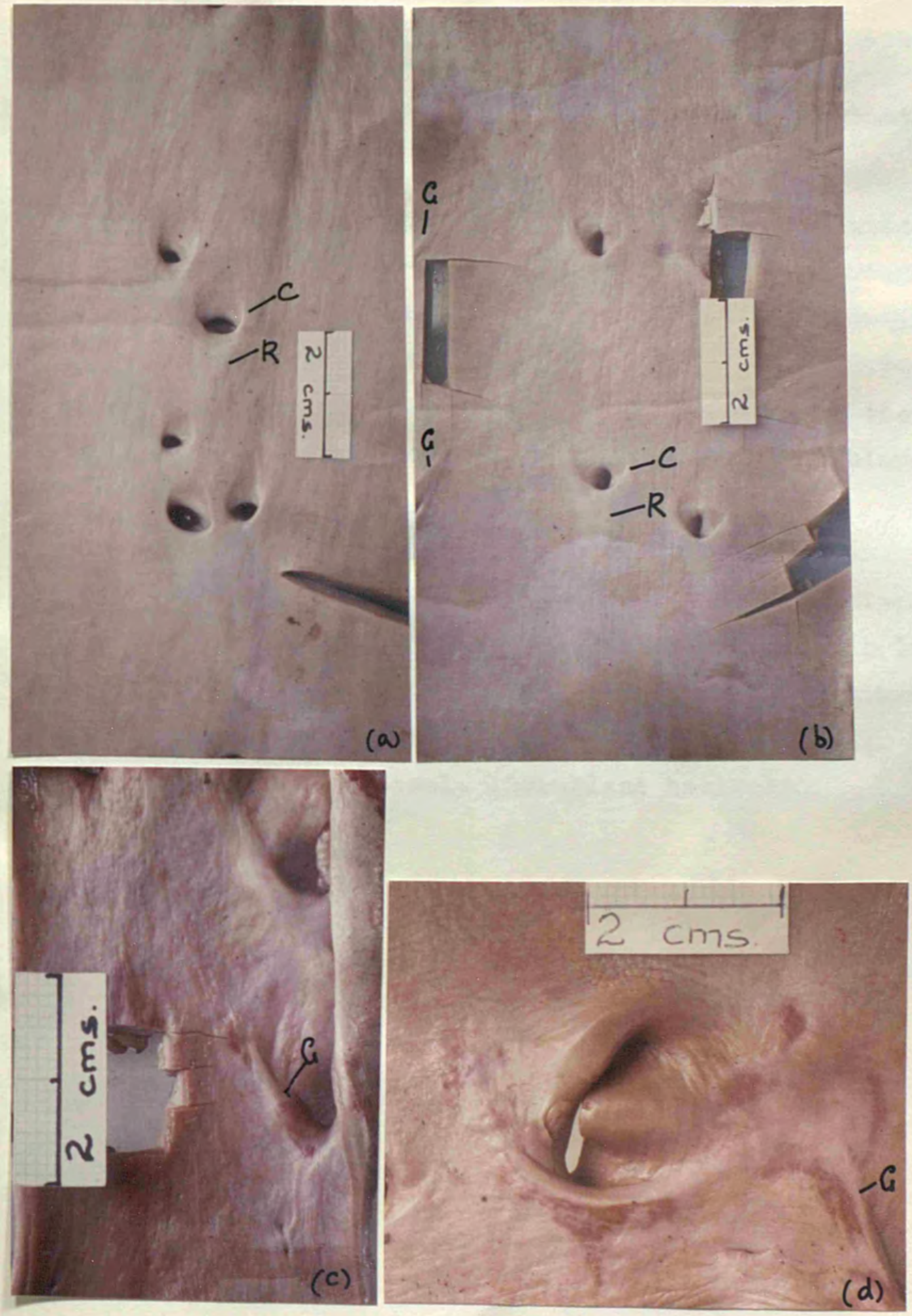


PLATE LXV

PLATE LXV

Internal surface of the aortae of elderly elephants

(a) Specimen M.107 (portionI/dorsal).
Very elderly and decrepit cow with extensive pearly-grey atheroma-like plaques throughout the aorta, and containing irregular intimal deposits of lipid extraneous to the normal sites. Note very reduced lumina of the paired dorsal branch arteries. (Scrubland habitat)

(b) Specimen M.117 (portion I/dorsal).
No abnormality of the aorta of this elephant was detected. Traces of sudanophilic lipid can be detected within the ostial collars. The lumina of the ostia are apparently quite normal. (Scrubland habitat)

PLATE LXV

(a) (b)

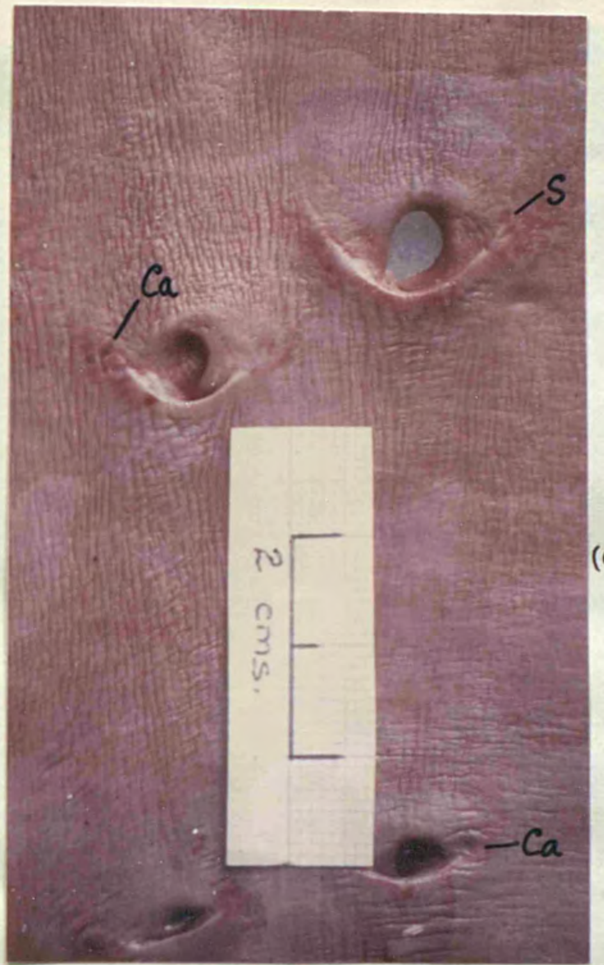
PLATE LXVI

Early calcific deposits in the aorta wall.

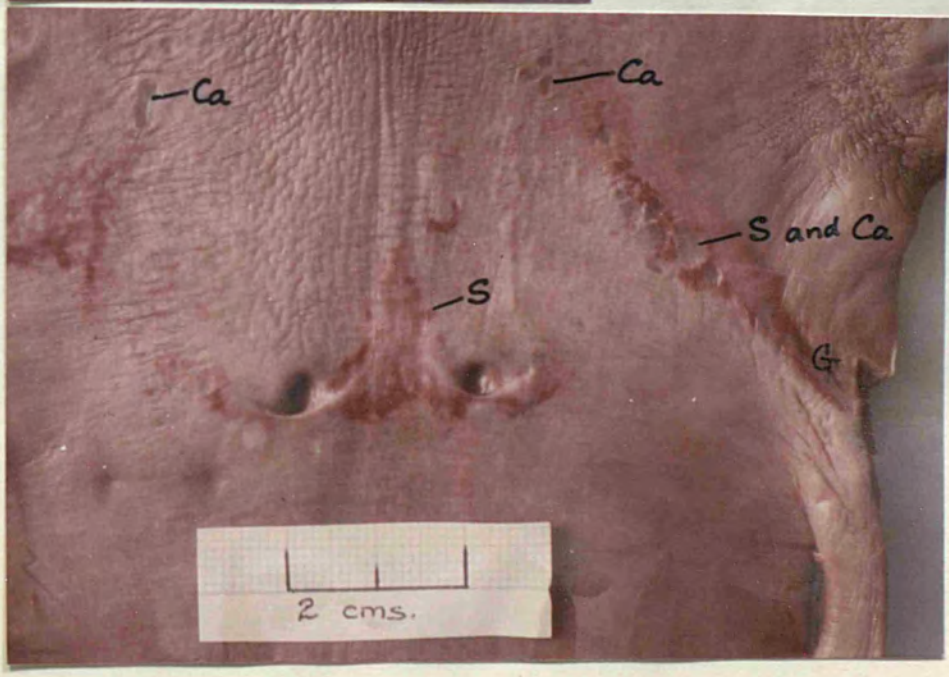
(a) Very early medial Calcium deposition. M.131 (adult, scrubland), portion III/dorsal. Frequently a depression of the intima occurs over each focus of calcification, so that some of these areas are readily detectable macroscopically with the naked eye. Radiography, however, revealed additional calcific deposits situated in the deeper layers of the media. It was not possible to differentiate macroscopically between calcific deposits of the intima and the media.

(b) As above: specimen 131, portion III (dorsal and lateral lines), including part of the supportive ridge (G) of the origin of the coeliac artery.

PLATE LXVI



(a)



(b)

PLATE LXVII

Internal surface: coronary and brachial arteries of elephants:-

(a) M.149 (adult male, scrubland): atheroma-like lipid plaque (P). (Coronary artery)

(b) M.131 (adult lactating female, scrubland): heavy sudanophilic lipid deposits within the ostial collars and ramps. (Coronary artery)

(c) M.122 (elderly, lactating female, scrubland): sudanophilic deposits (S) extending into the intima beyond the limits of the ostial collars and ramps. (Coronary artery)

(d) M.117 (elderly bull, scrubland): intimal sudanophilic lipid deposits on the supportive ridges (G) at the orifice of a branch of the brachial artery.

PLATE LXVII

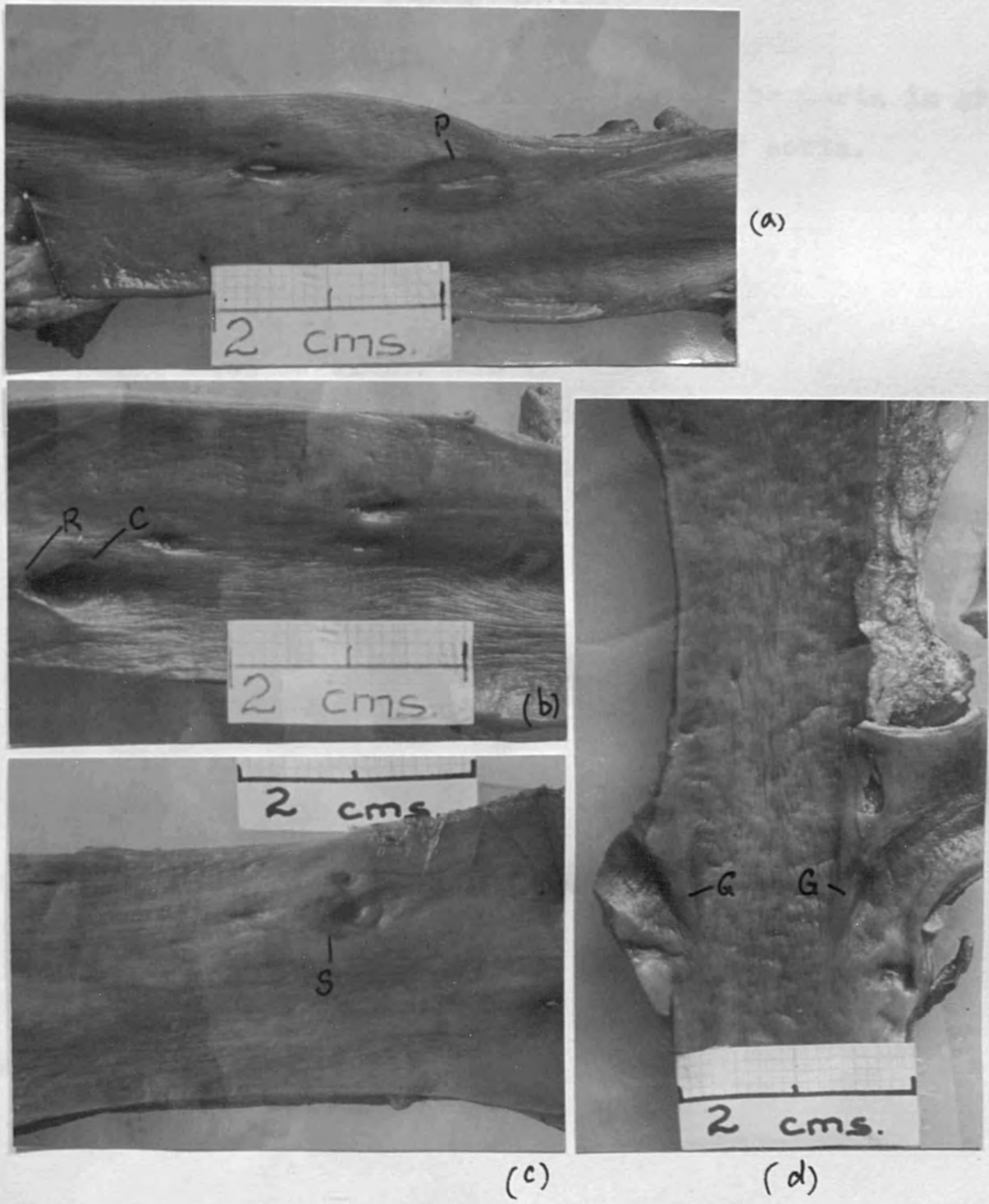


PLATE LXVIII

Heavy medial calcification of the aorta in grassland elephants: internal surface of aorta.

(a) M.21, portion II/dorsal line.
Early calcific deposits.

(b) M.18, portion V/dorsal line.
Heavy medial calcific discs and plates occur so closely packed that the aortic wall resembles a rigid pipe, with acutely constricted lumen, and ostia of the smaller branch arteries totally occluded.
Sudanophilic lipid deposits in these specimens were ~~almost~~ negligible.

PLATE LXVIII

(a) (b)

PLATE LXIX

Internal surface of elephant aortae:

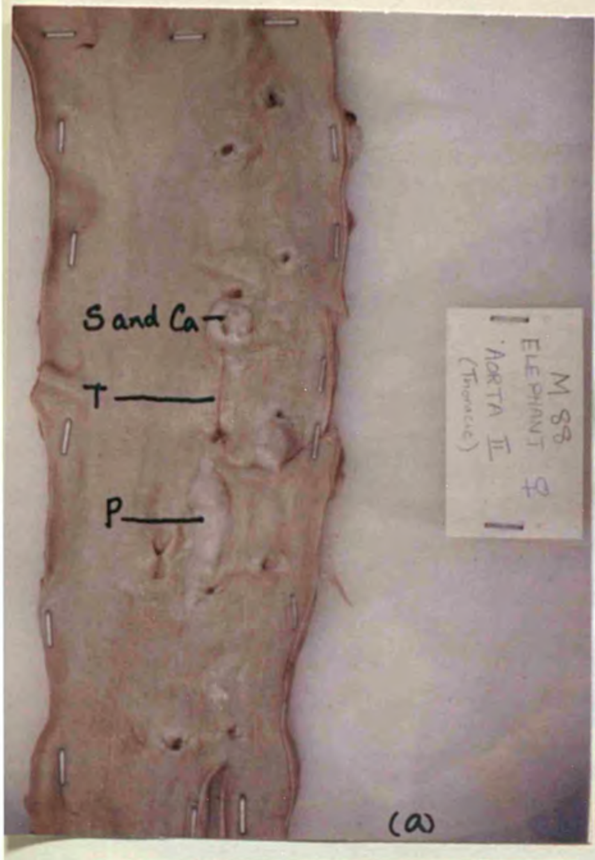
(a) M.88 (adult lactating female). Pearly-white plaques in the dorsal/right lateral lines of portion III. A longitudinal ante-mortem split in the intima with reparative proliferation of the endothelium suggests a traumatic occurrence. (T) This elephant (grassland habitat) also had a grossly enlarged liver (68 kg) and spleen (20 kg). The liver contained 1.17 kg. of large bile stones (see ch.12,p 533) This cow had a very young calf (not her first) at foot. (Field photograph of fresh, unstained aorta).

(b) Specimen M.131 (adult lactating female, scrubland). A longitudinal, linear arrangement of medial calcific discs in portion III/ventral line, associated with lipid deposits, suggests the possibility that pressure exerted on this portion of the aorta might result in injury to the aortic wall. Perhaps stretching of the coeliac or anterior mesenteric arteries associated with pregnancy; or, in the case of M.88 (above) with an abnormally enlarged liver; or even pressure caused directly or indirectly by an abnormal enlargement of the abdominal viscera, might cause localised injury of this nature to the aortic wall.

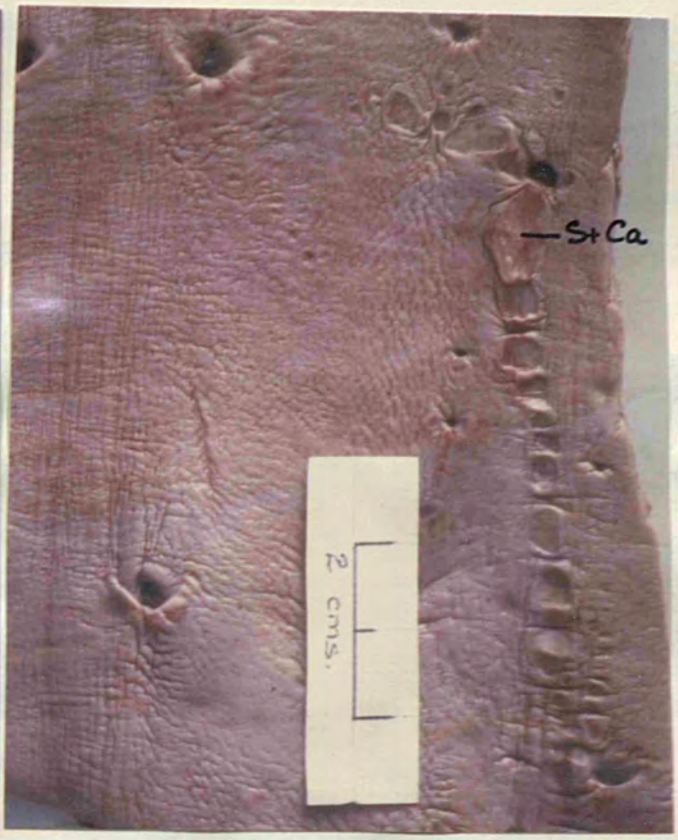
(c) Atheroma-like plaques containing heavy intimal sudanophilic lipid deposits extraneous to the normal sites in adult male elephant M.149 (scrubland).

(d) As above; atheroma-like plaque overlying medial calcific deposits.

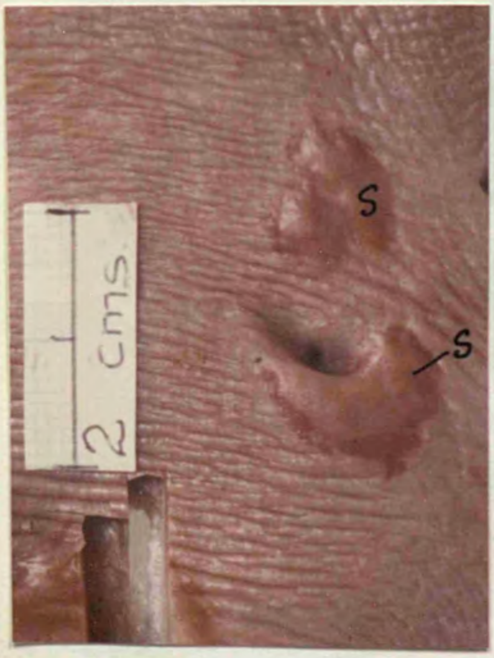
PLATE LXIX



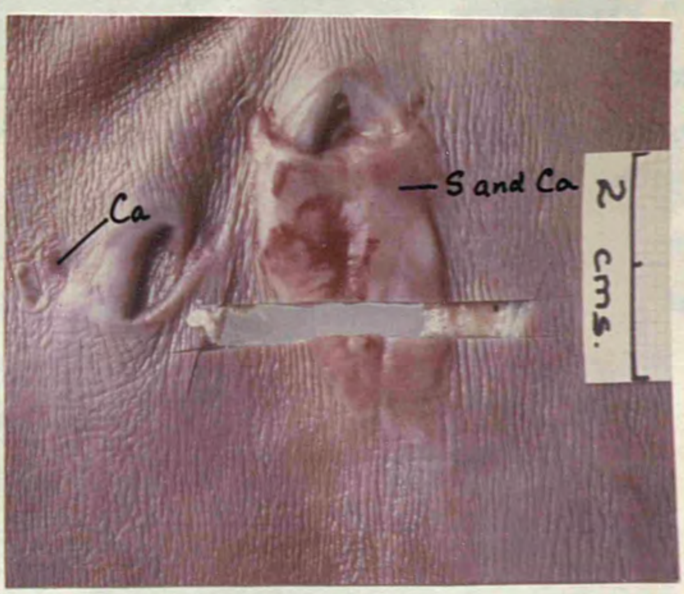
(a)



(b)



(c)



(d)

PLATE LXX

Field photographs of the internal surface of the fresh aortae of specimens M.107 and M.122 (elderly cow elephants, scrubland), showing extensive pearly-white atheroma-like plaques (P). Subsequent treatment with Sudan IV stain revealed extensive intimal lipidosis and localised intimal calcification (see Plate LXV, p.482).

(a) Portion I: pearly-white atheroma-like plaques lying diagonally from the direction of the duct.art., across the right lateral line and into the dorsal line, to continue posteriorly along the dorsal line.(M.107).

(b) Portion III: pearly atheroma-like intimal plaques and an aneurysm in the ventral line between the origin of the coeliac and anterior mesenteric arteries (A) Lumina of ostia very constricted.(M.107).

(c) Portion V:(bifurcation) showing the crescentic calcific rod lying along the dorsal arched supportive ridge. A few small calcific deposits are seen at the orifices of the iliac arteries. (M.107)

(d) Portion V of the aorta (and left common iliac artery) of M.122, showing extensive pearly-white atheromatous plaques associated with both intimal and medial calcific deposits and some ulceration (U). The plaques (P) also extend into the iliac arteries.

PLATE LXX

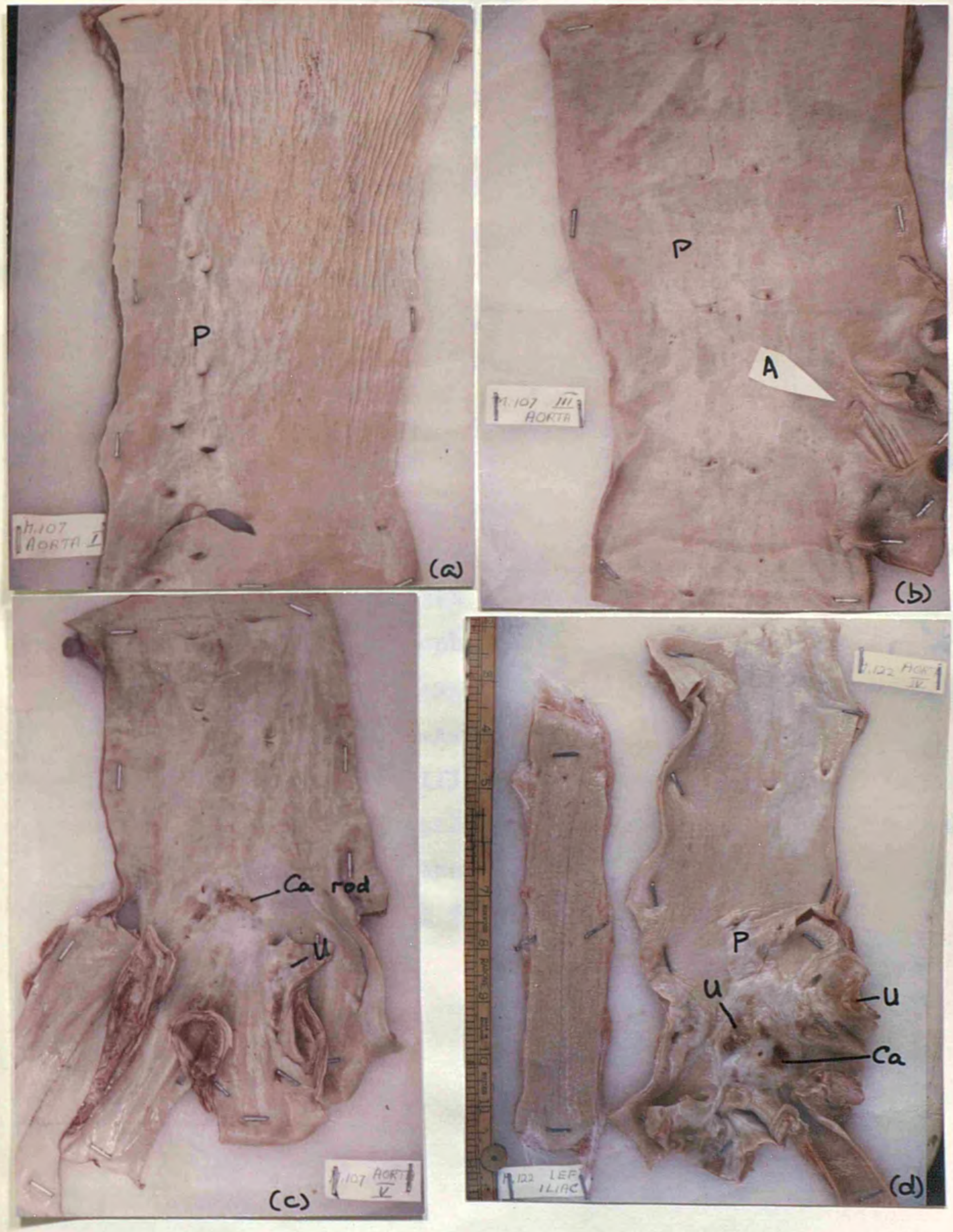

P
M.107 AORTA I
(a)
P
A
M.107 III AORTA
(b)
Ca rod
U
M.107 AORTA V
(c)
M.122 AORTA IV
P
U
U
Ca
M.122 LEFT ILIAC
(d)

PLATE LXXI

(a) Field photograph of the internal surface of Portions II/III of the aorta of M.93, a grassland elephant, showing the macroscopic appearance of heavy calcification (unstained, unfixed).

(b) Atheroma-like haemorrhagic plaques in the aortic arch of elephant M.120 (scrubland). The apparent large size is actually approximately equivalent in the elephant to a similar type of plaque which might occur in a human aorta.

(c) L.S. intimal 'button' in portion I of the aorta of specimen M.119 (scrubland). It is devoid of sudanophilic lipid deposits but shows fibrous hyperplasia and disruption of the i.e.l. (Stain P.A.S.) x 50.

(d) Portion III of aorta of specimen M.93 (see (a) above) showing calcific plates lying along the medial side of the i.e.l. (decalcified L.S., V. & v.G. stain) x 50.

PLATE LXXI

(a)

(b)

(c)

(d)

PLATE LXXII

(a) - (b) Enlargement (continuous photograph) of an aortic 'button',similar to that shown in Plate LXXI(c), p.494, in portion I of the aorta of specimen M.149 (scrubland).
Disruption of the i.e.l. and fibrous hyperplasia characterise the lesion, which is devoid of sudanophilic lipid deposits (frozen L.S.; Sudan IV and haematoxylin) x 100.

PLATE LXXII

(a)

(b)

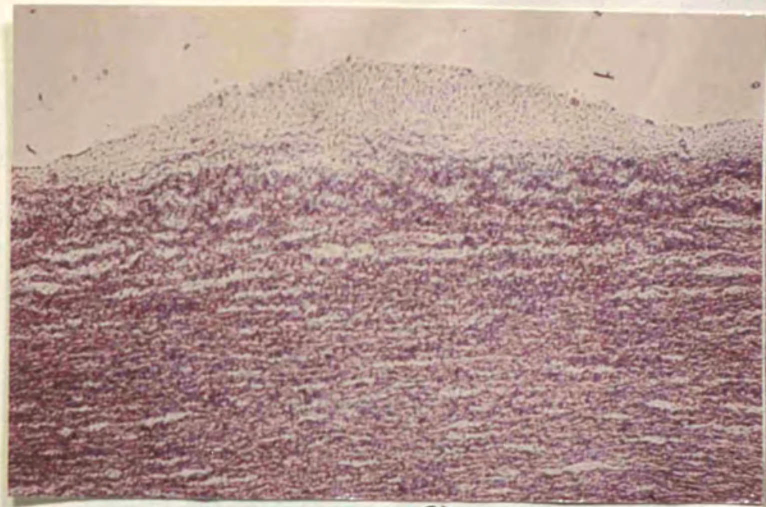
PLATE LXXIII

(a) Frozen T.S. fibrous 'buttons' in portion I of the aorta
(b) of specimens M.23 and M.24 (grassland).
(Sudan IV and haemalum) x 50.

(c) L.S. aorta, portion III, of M.108 (scrubland).
A fresh lesion (L) possibly caused by an inflammatory agent in the tunica media, underlies a 'plate' (P) of elastic fibres laden with calcific deposits. The i.e.l. itself is heavily mineralised. A lower layer of fibres (M) also shows early mineralisation. No parasites could be specifically identified in this focal lesion, but it is not impossible that there may have been some such causal agent.
(Stain Alcian Blue) x 50.

(d) A heavy, laminated calcific deposit deep in the media of the aorta of specimen M.93 (grassland)
(Stain H.& E.) x 50.

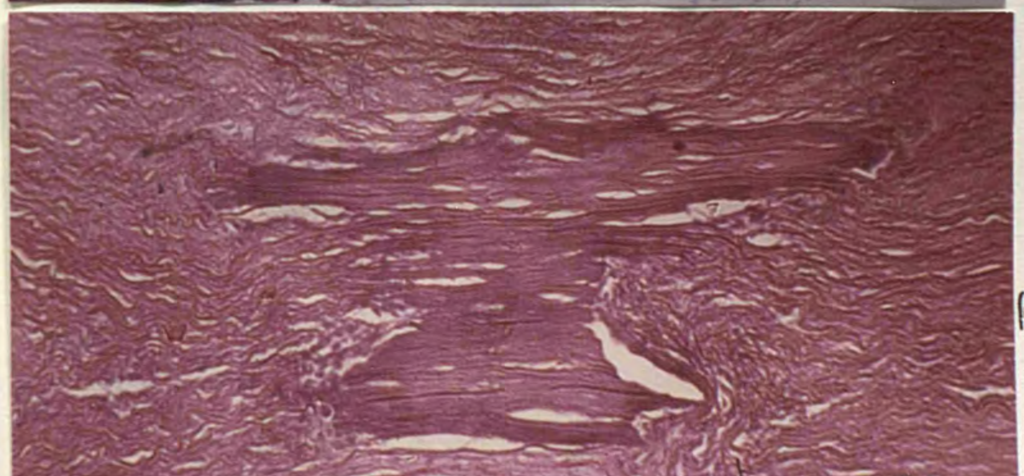
PLATE LXXIII



(a)

(b)

(c)



(d)

PLATE LXXIV

(a) 'Foamy', atheroma-like plaque in aortic arch of M.122 (scrubland elephant) with degeneration of the i.e.l. and several underlying layers of the elastica of the media. (Stain V.& v.G.) x 50.

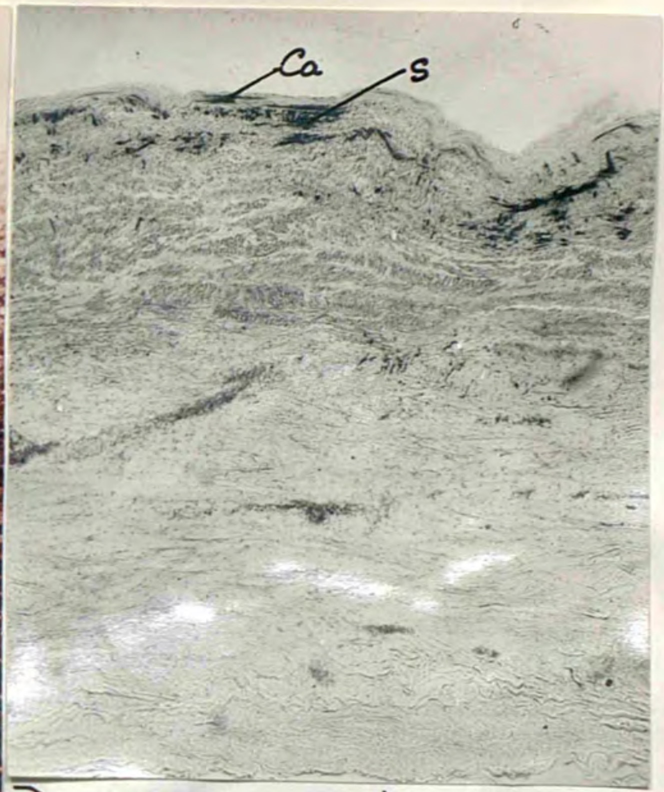
(b) L.S.portion III/dorsal line of specimen M.18 (grassland) showing associated calcific and sudanophilic lipid deposits in the thickened intima of this elderly elephant bull.

(c) Fibrous hyperplasia of the intima of portion III of the aorta of M.107 (very elderly scrubland cow elephant) with the intrusion of a heavy calcific deposit lying on the i.e.l. (Frozen T.S.; Sudan IV and haematoxylin). x 50.

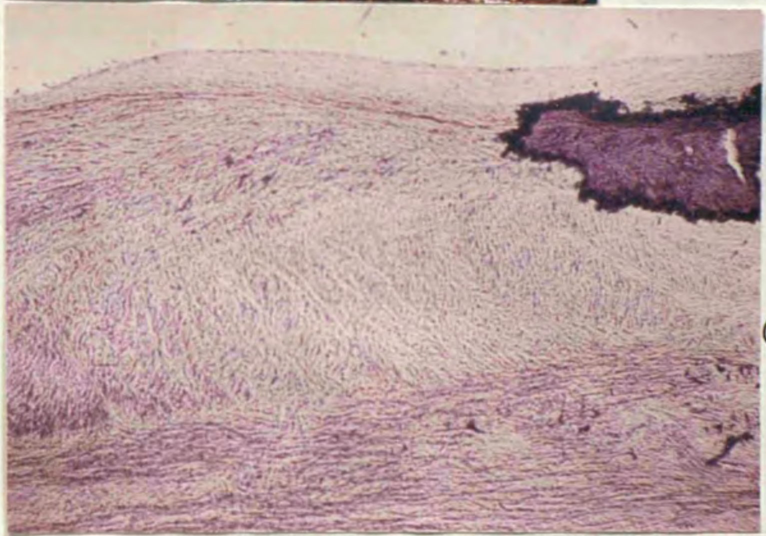
(d) Specimen M.18 (see (b) above): L.S. portion V/ventral line of the aorta, showing heavy calcific deposits in the intima. (Sudan IV and haemalum) x 50.

PLATE LXXIV

(a)



(b)



(c)

intima

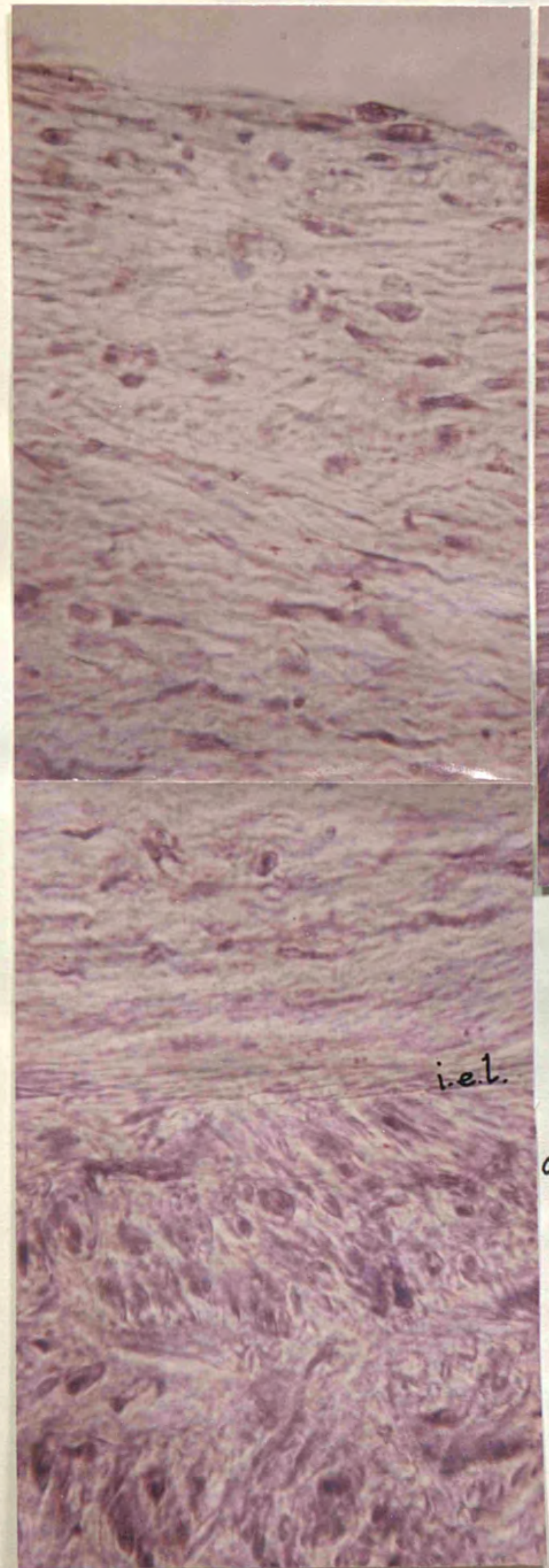
(d)

PLATE LXXV

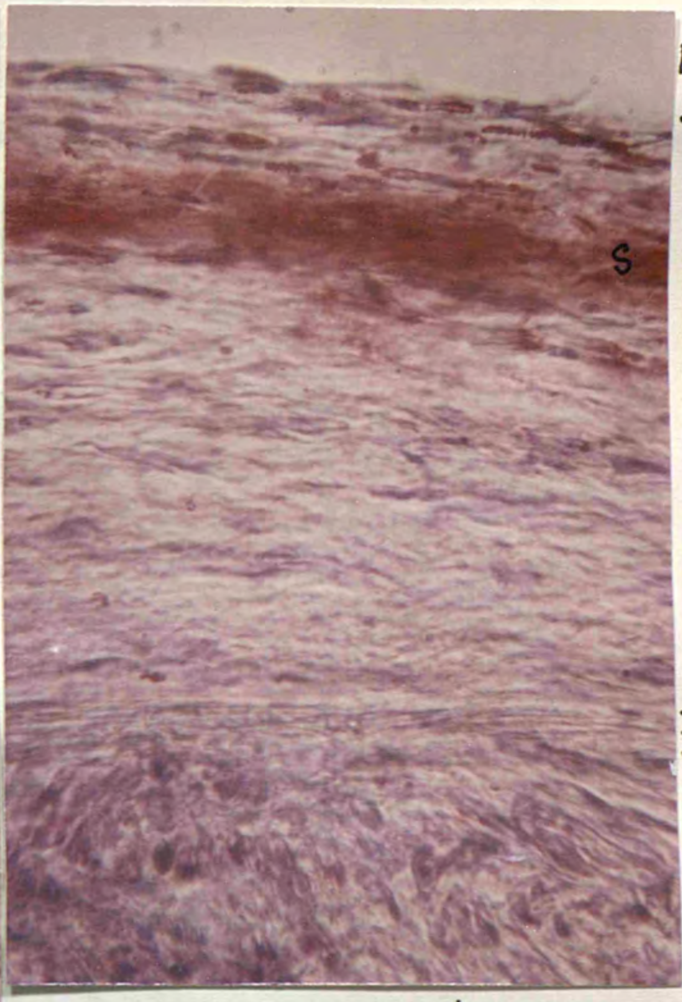
(a) L.S. of the aorta of specimen M.131,(scrubland) a senior, but not elderly, lactating cow elephant. The intima is thickened and minute traces of intracellular lipid can be detected in some individual cells. The i.e.l. is intact and single. Frozen section 10 μ.
(Sudan IV & haematoxylin, x 400)

(b) As above:
but sectioned nearer to the edge of the same thickened plaque: intimal sudanophilic lipid can be detected both intra- and extra-cellularly, and the i.e.l. is intact.
(Frozen section 10 μ; Sudan IV & haematoxylin) x 400.

PLATE LXXV



a)



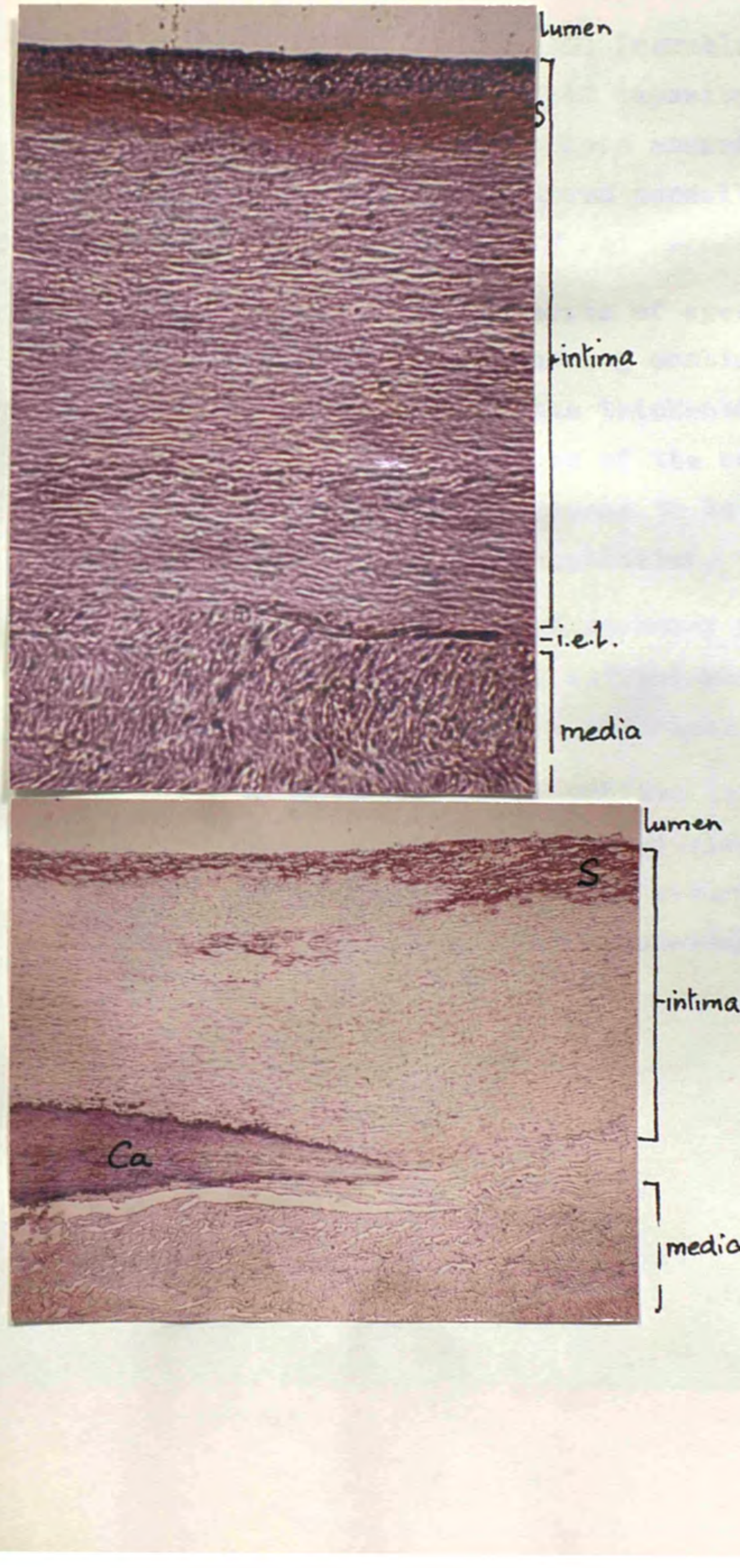
(b)

PLATE LXXVI

(a) L.S. thickened intimal plaque in portion II of aorta of specimen M.107 (elderly cow elephant, scrubland). Unlike the plaques of the aorta of the lactating cow M.131 (Plate LXXV), the intima is here seen to be fibrous and laminated, and the i.e.l. somewhat disrupted (Frozen section, 12 μ, Sudan IV and haematoxylin) x 100

(b) As above, portion V of the aorta of M.107, showing intimal calcific deposits (Ca) associated with lipidosis (S) in the superficial layers of the thickened intima, and disruption of the i.e.l.

PLATE LXXVI



(a)

(b)

PLATE LXXVII

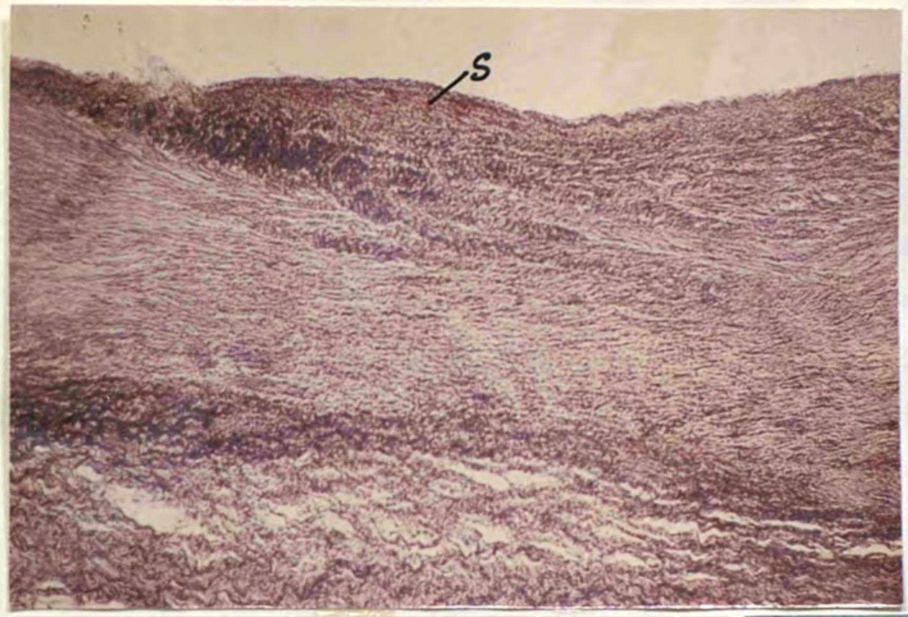
(a) T.S. coronary artery M.107 (scrubland elephant), showing sudanophilic lipid deposits in the intima in a site extraneous to those associated with supportive structures known normally to contain lipid deposits (Sudan IV and haematoxylin) x 50.

(b) L.S. of portion IV of aorta of specimen M.149 (srubland elephant), showing combined lipidosis and mineralisation in the thickened intima, and very early mineralisation of the underlying medial elastica. The i.e.l. seems to be disrupted, but does not appear to be duplicated.

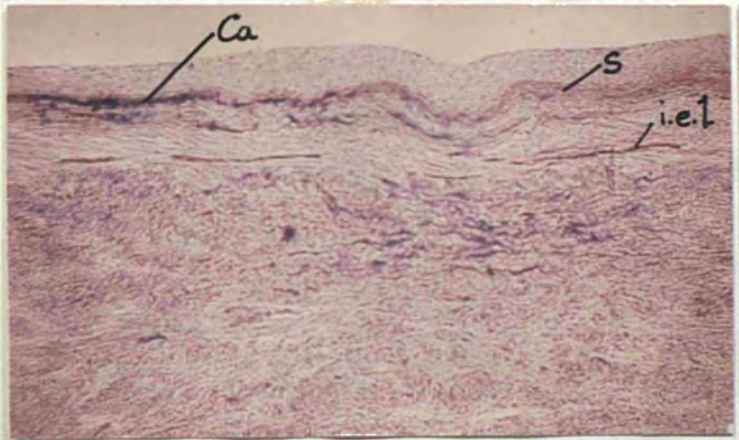
(c) T.S. thickened intima of coronary artery of specimen M.149, showing intimal mineralisation (modified haematoxylin - methylene blue) x 100.

(d) T.S. thickend intima of portion II/dorsal line of aorta of specimen M.149, showing combined lipidosis and mineralisation with disruption of the i.e.l. (Sudan IV and haematoxylin) x 100.

PLATE LXXVII

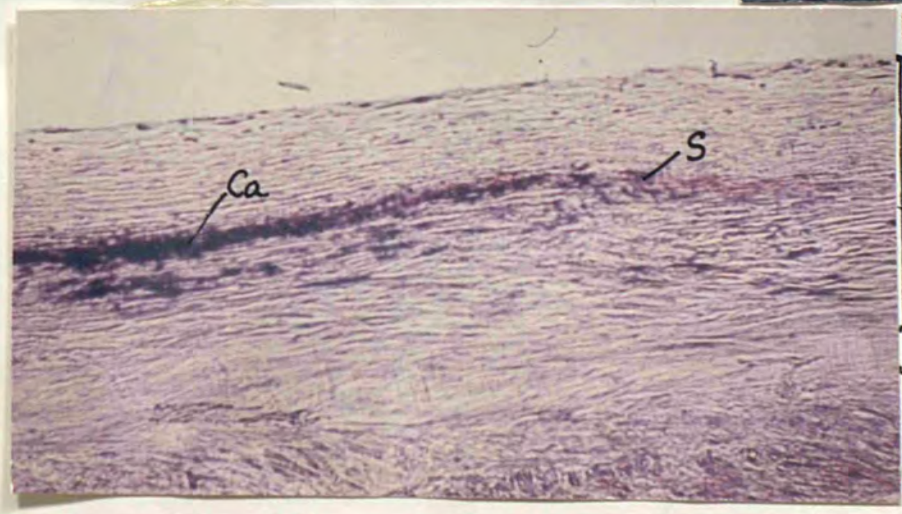


(a)



(b)

(c)



(d)

PLATE LXXVIII

L.S. of intimal plaque in aorta, portion III/ ventral line, of specimen M.122 (very elderly cow elephant, scrubland) showing lipid deposits in the deep subendothelial layers of the intima (Sudan IV) x 100.

PLATE LXXVIII

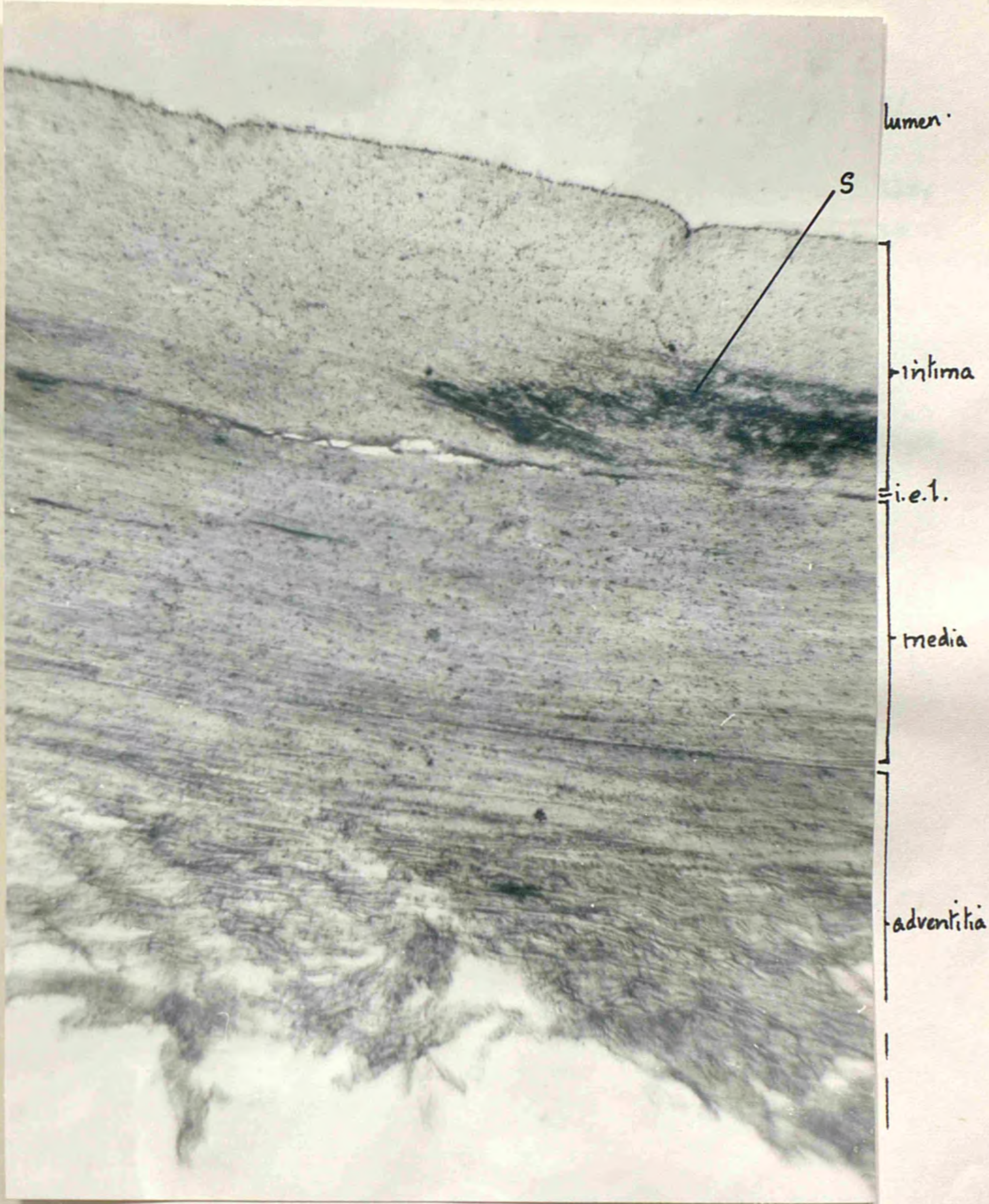


PLATE LXXIX

(a) L.S. of hyaline intimal plaque in portion V/ dorsal line of aorta of specimen M.122 (scrubland elephant). Widely separated cells, (apparently smooth muscle) lying in extensive amorphous ground substance, overlie the disrupted i.e.l.

This in turn overlies a layer of medial degeneration from which smooth muscle cells appear to be en passage to the intima, through the disrupted i.e.l. (b)

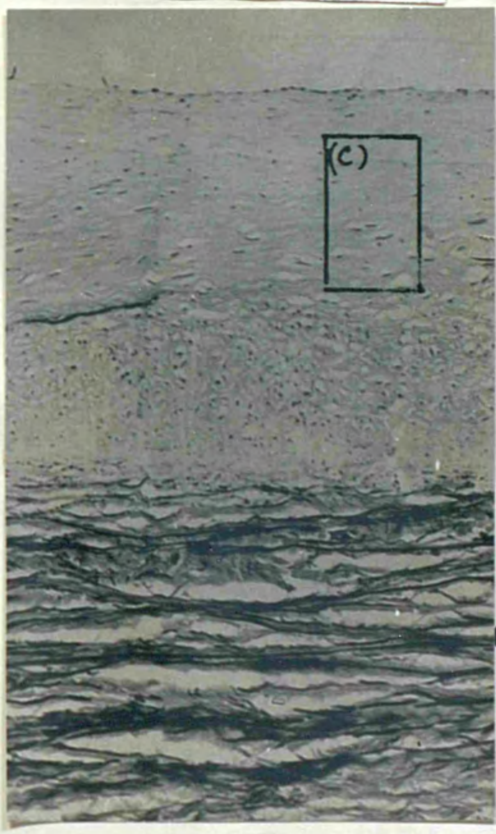
(c) Part of the same hyaline plaque. x 400

(H. & E. stain)

PLATE LXXIX

(a)

x50



(b)

x100

(c) x400

PLATE LXXX

T.S. of haemorrhagic intimal lesion found in portion I of the aorta of specimen M.120 (scrubland bull elephant). (Stain Sudan IV & haemalum).

(a) Sinusoid formation and area of infiltration of red blood cells from the aortic lumen into the lesion. Numerous macrophages containing sudanophilic lipid globules occurred both in the hyaline and haemorrhagic areas of this plaque.

(b) Developing sinusoids in the lesion.

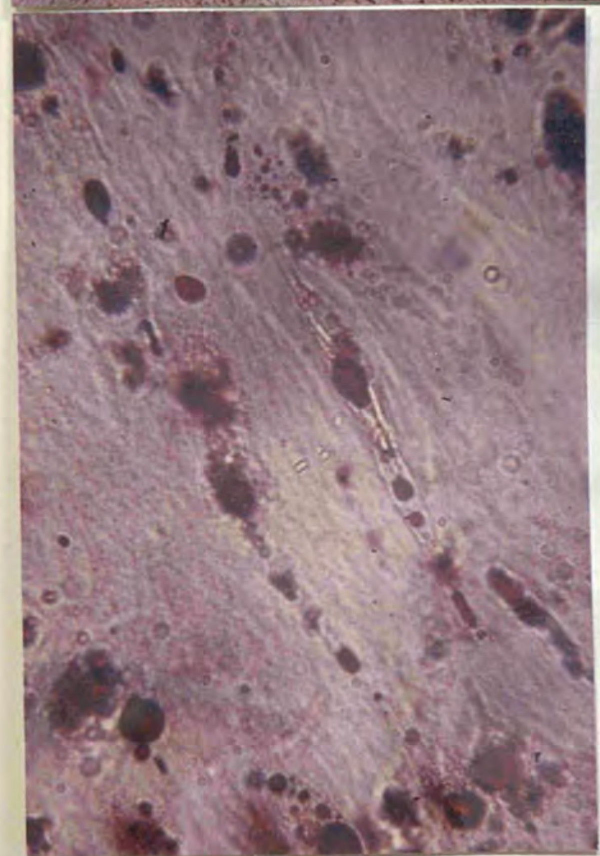
(c) Intracellular lipid in some very large, elongated cells thought possibly to be macrophages or fibroblasts, and some extracellular lipid globules.

(d) Sudanophilic lipid deposits in the deep layers of the lesion.

PLATE LXXX

(a)

(b)



(c)

(d)

PLATE LXXXI

Radiographs of the aortae of elephants:

(a) M.107: aorta potion V/dorsal, showing the crescentic calcified rod lying in the line of the supportive arch of thickened fibrous intimal and medial tissue, normally found at the bifurcation.
The area-grid for making quantitative counts is shown.

(b) M.131: early calcific deposits in the aorta portion V/dorsal line (at bifurcation).

(c) M.86: calcific deposits at the junction of portions III - IV in the aorta.

PLATE LXXXI

(a)

(b)

(c)

Chapter 12

Other Traumatic, Congenital and Pathological Conditions

Scope of this study

Traumatic, congenital and pathological conditions which were macroscopically obvious at autopsy are described only briefly here, in order to record their occurrence, and to note instances which may have some relevance to cardiovascular abnormalities found. As described in Chapter 7 (species other than elephant), the systematic, detailed histopathological examination of the reference collection of micro-slides of tissues collected as autopsy routine for all specimens, is still pending. It is planned to carry out a comprehensive systematic study of these tissues in the near future.

The pathology of the Indian elephant has been extensively studied (Evans 1910), (Halloran 1955), but up to date such studies on the African elephant have been somewhat limited. In some cases the present study (for example of the lesions found in elephant tusks) is not yet complete, and it is not always possible to determine whether the lesions are entirely traumatic, or entirely pathological in character, or whether a primary traumatic occurrence has been complicated by a secondary pathological condition.

ABNORMALITIES OBSERVED:

1. Teeth

A. Tusks

Although tuskless African elephant occur in particular localities apparently as a distinct genotype, it is more usual for large tusks to develop and to function as extremely useful 'tools' for feeding, and clearing paths through the undergrowth. They also appear to be used in behavioural patterns connected with courtship, establishment of herd leadership, disciplinary behaviour towards calves and juveniles, as well as defense. It is widely stated among experienced elephant hunters and game wardens that tuskless elephants are frequently inclined to be unusually irritable and aggressive.

Normal tusk growth is illustrated in Plates XLIII-XLVI pp 375-381. A deciduous pair of 'milk' tusks is shed soon after birth and immediately replaced by the continuously growing permanent ones (Sikes 1966b). In the bulls, these grow larger in proportion, have a relatively shorter pulp and a blunter tip than the cows. In the cows, the pulp is relatively longer and more slender, and the tip (unless broken off) more pointed. The healthy tusk is somewhat flexible and does not break easily. In commerce, 'bull ivory' and 'cow ivory' are distinguishable and used for different markets.

Tusks sold on the commercial market are graded according to the traditional classification:-

"<u>Vilaiti</u>:	'soft' tusks (<u>Loxodonta africana africana</u>) sound; >40 lb dry weight;
<u>Vilaiti gandai</u>:	'hard' tusks (<u>L. africana cyclotis</u>) sound; >40 lb dry weight;
<u>Cutchi</u>:	'soft' tusks; sound; 20 - 40 lb;
<u>Cutchi gandai</u>:	'hard' tusks; sound; 20 - 40 lb;
<u>Calasia</u>:	all cow tusks > 10 lb and 2 - 3 in. maximum diameter;
<u>Fankda</u>:	all bull tusks; sound; 10 - 20 lb;
<u>Maksub</u>:	all ivory, bull or cow, 5 - 10 lb;
<u>Dandia</u>:	all ivory, bull or cow, < 5 lb;
<u>Chinai</u>:	all defective tusks." (Anon. 1957-66).

<u>Defective tusks are recognised while still complete by:</u>

i) the presence of a central black spot at the tip (Plates LXXXV, LXXXVIII, pp. 544 & 548). This is indicative of the failure of the dentine to close over the pulp tip and apparently without exception indicates mechanical weakness in the ivory - a defect equally inconvenient both to the live elephant and to the manufacturers of ivory goods. ii) The presence of irregularities of the dentine within the pulp cavity; these may be present either as cavities in the dentine or as extrusions of dentine into the pulp lumen. iii) ~~Tusks with~~ Broken tips, deep longitudinal cracks in the dentine, surface wear of the dentine forming grooves or ridges, and damage due to bullets or spears (Plate LXXXII p 538). Colyer (1936), Colyer & Miles (1957) and Miles & White (1960) have described numerous cases of abnormalities in elephant tusks. *

When sawn into sections, the mechanical weakness of the tusk consequent on these abnormalities is evident. 'Ivory pearls' or 'seeds', and 'ivory trees', under mechanical stress, form lines and centres of weakness from which a split in the tusk may be initiated. Tusks showing transverse growth waves and corrugations near the base are not regarded as commercially defective.

* I am indebted to Mr. Robin Pereira, Government Ivory Warden, Mombasa, Kenya, and to his colleagues for instruction and guidance in the practical evaluation of tusks; and to Mr. V.H. Waljee, Accredited Ivory Merchant, Mombasa, Zanzibar and India, for demonstrating the techniques for handling the different classes of ivory, and for cutting ~~for me~~ selected sections of defective ivory for further study.

When specimen M.120, which had long tusks with slender curved tips, was shot, it fell forward, embedding the tip of the left tusk in the ground before rolling over onto its right side. The tusk split and the tip broke off, revealing the presence of 'pearls' along the line of mechancial weakness where the tusk had split (Plate LXXXV p 544).

Specimen M.149 possessed only one normal tusk (left) length 160 cm, diameter 13 cm, weight 15 kg. The other was found to be completely defective and apparently had never grown normally. It consisted of the main tusk proper, which was a mere stump, surrounded by four small, subcutaneous, supernumerary tusklets. Large quantities of malodourous pus streamed from an abscess down the surface of the main tusk. Numerous 'pearls' occurred throughout both the pulp and the formed dentine. This case is illustrated in Plates LXXXIII and LXXXIV pp 540 542 and resembles several similar cases described by Colyer (1936).

It seems that the original cause of this abnormality was probably an injury, but that a secondary bacterial infection may have followed, setting up a complex inflammatory reaction in the pulp tissue, resulting in abnormal activity of the odontoblasts (Miles 1966). Although it might be supposed that this condition caused the elephant considerable pain and inconvenience, no other evidence of its stressful effect was noted at autopsy. The adrenal glands, for example, appeared to be perfectly normal both macro- and microscopically, as did all other organs. Slight calcification of the aorta and some Lipid deposition in the aortic and coronary intima had occurred, but its amount and distribution closely resembled that of M.150, another bull elephant of similar age and status shot in company with M.149.

Plate LXXXII p 538 shows the tusk and pulp reaction to what seems to have been a long-standing injury to the base of the tusk. (Specimen 117) In this case 'reactionary dentine' had formed extrusions into the pulp and even formed a longitudinal partition within it (Miles & White 1960). One supposes that this reaction originated from an injury to the base of the tusk, although no agent such as a bullet was located.

The tusks of M.103 seem to resemble the cases described by Miles & White (1960), where early injury may have caused exposure of the pulp tip with the formation of abscesses there, resulting in the development of a permanent longitudinal fistula through the distal dentine. This would account for 'spot' (see above), recognised (from the external appearance) by ivory merchants as a reliable indication of defective ivory. 'Spot' was observed and photographed by the author in the tusks of a captive African bull elephant, aged about 14 - 15 years, in a zoological garden in Germany (Plate LXXXVII p 548).

A number of specimens collected in the scrubland habitat type in Kenya showed oval or round-shaped haemorrhagic lesions on the surface of the pulp adjacent to the dentine. A patch of reactionary dentine matching the position of the pulp lesion always occurred, although it varied in character, sometimes forming a deep cavity in the dentine, a mere 'rough' patch, or an actual extrusion of dentine into the pulp itself. In section, these lesions showed extravasation of blood from the capillaries into the neighbouring tissues, where an inflammatory reaction had occurred with excessive histiocyte proliferation and in some cases also a slight granulation.

Further detailed investigation of these lesions is planned, as these seem not to be due to any direct external injury. It seems improbable that such small, widely separated, localised haemorrhagic lesions would result from indirect trauma due to external stresses incident on the surface of a large tusk. It seems more probable that the cause might be an internal inflammatory agent carried in the lymph or the blood. One cannot overlook the possibility that, if due to such an inflammatory agent, such as toxoplasmas or bacteria carried in the blood, there might be some relevance to an aortitis noted in some of the same specimens (Appendix 4 ; Sikes, in press; p 606)

Due to the deep cone-shaped 'cul-de-sac' formed by the usual physical position and shape of the highly vascular tusk pulp, one would suppose that the return of venous blood from the tusk might readily become impaired. This might happen especially where the tusks grow so large and heavy that the head cannot any more be raised for active use in breaking down the higher branches of trees.

No description of this condition could be located in the literature, and Miles (1966) confirmed that no data had previously come to his notice relating to it.

B. Molars

Abnormalities of the molars were very few and insignificant in the specimens collected. A slightly abnormal growth of cement was seen in the roots of the molars of several of the grassland elephants ~~(Plate p)~~. Laws (1966) stated that he had observed the presence of supernumerary molars, although these were not illustrated and may possibly have been parts of normal molars which had become separated from the remainder of the tooth, due to dehydration and cracking of the cement - a common occurrence if elephant molars are allowed to dry out completely for examination and storage and ~~then~~ subjected to extreme temperature changes.

2. <u>Trunk</u>

Only four cases of abnormality of the trunk were noted, of these one (partial paralysis of the trunk) was seen in a living bull elephant which was not collected for study. This elephant was observed in company with three other bulls for a period of about an hour, during which they approached a water hole at midday, drank, moved to a wallow, wallowed, moved to a dust bath, dusted, and finally moved off. The animal in question had great difficulty in drinking, and always spilled a considerable quantity of water from its trunk during its very awkward transit to the mouth. It later approached the wallow with its companions, but stood aside, the trunk draped over one tusk, watching them.

It did not enter the wallow. At the dust bath, it made a token effort to dust, the pathetic attempt resulting in total failure to aim correctly or blow dust over its body. (Plate LXXXIX p 552).

Specimen M.86, an elderly and decrepit bull, collected in Uganda, which had an open, suppurating trunk wound (Plate LXXXVII p 548). The mouth also contained pus and was full of fly larvae and eggs. This type of injury might have been inflicted by a poacher's spear.

Specimen M.152 was an exceptionally large and healthy middle-aged montane bull. A fistula near the trunk tip seemed not to inconvenience it. One may suppose that the trunk tip could have been perforated by a sharp mountain bamboo spike during calfhood.

Specimen M.87 was remarkable in that it had lost the distal third of its trunk, the wound caused by some injury ~~injury~~ having successfully healed. Contrary to the traditional belief that elephants cannot survive after the loss of the trunk tip, this bull was comparatively well grown and healthy. Stomach contents indicated a diet consisting solely of ~~of nothing but~~ grass, and this had been masticated to a very fine consistency. While alive, this elephant was not seen to make any attempt to reach arboreal fodder or bark, and it seems probable that the trunk had lost the power to cope with anything heavy or hard. Its ability to drink was not observed, but its proximity to the bank of the Nile might suggest that it drank direct in the deeper water with the mouth. It is difficult to imagine an adult elephant surviving the recovery period of an injury of this magnitude, but if it occurred while still a suckling calf, it would seem possible that it could later adopt the habit of drinking with the mouth, direct from deep water. The obvious causal agents to suggest for an injury of this kind would be crocodile, or perhaps a poacher's snare or spear. (Plate LXXXVI p 546).

3. Ears

Lop-ears were observed in specimen M.86 and in five other living elephant which were not collected (Plate LXXXVII p 548). This condition, and another abnormality of the ear, common in captive elephants (Plate LXXXVII p 548) are discussed in Appendix 7 pp 262-263 (Sikes 1966a). Lop-ears in wild elephant are commonly supposed to be due to injury of the cartilage. In chapter 11, pp 451 , I have suggested, as another possible cause, partial occlusion of the orifice of the posterior auricular artery as a result of advanced arterial calcification occurring in grassland and scrub-land elephants. Specimens with lop-ears may frequently be observed feeling the ear orifice with the trunk, or even blowing dust into it, as if irritated.

A small circular ~~hole~~ perforation, made by a hunter's bullet passing through the external ear was noted in specimen M.103, and in a live elephant in the Queen Elizabeth National Park a similar scar was seen.

Torn and frayed edges to the ears of older elephants are frequently noted, apparently the result of tearing by thorn bushes and by fighting. Warble fly was frequently encountered in the ear (see ch. 4).

The pinna of the ear is the main external organ connected with body temperature regulation in the African elephant, a fan-like arrangement of superficial blood-vessels occurring on the medial side (Plate LXXXVIII p 550). In this respect it is probably of greater importance to the African than to the Indian elephant, the pinna of which is much smaller, with deeper blood vessels. Characteristically, when African elephant feed or rest, during the heat of the day the ears 'flap' rhythmically with a 'punkah' action, exposing the medial surface of the ear to air currents.

At such times, the fanlike blood vessels are readily seen, even in live wild elephants, to be distended and prominent, while in the cold temperature of early morning and evening in the montane habitat they are contracted and externally completely invisible. In Zoo elephants, the distension of these vessels can apparently be controlled voluntarily, an observation re-iterated to the author both by the Veterinary Officers and the Keepers of different Zoological Gardens, when describing attempts to take blood samples from the veins of the pinna.

The ability of the pinna to function normally is thus of great importance to elephant, and its dysfunction, as in lop-ear, must be a serious inconvenience.

4. Eyes

Only one case of blindness in elephant was noted, in a very poor specimen living in the Tsavo National Park, which was obviously also in a very bad general state of health (Plate XC p 554).

Frechkop (1955) remarks on the fact that the elephant and the wild pig are the only ungulates with a round pupil, a feature normally associated with forest and shade adapted animals, and evolutionarily said to be nearer to the ancestral forms of ungulates than other forms, such as rupicoline, desert, semi-aquatic and arboreal groups which have become anatomically better suited to the more recently adopted biotopes.

It may be that constant exposure to bright sunlight in the stressed lowland habitats has an adverse effect on the eyesight of such elephants, for one would expect the eyesight of shade-adapted species to function optimally in light of low intensity. Elephant in forest habitats are notoriously more alert to the presence of hunters, and therefore more difficult to hunt, but one has found no data to suggest if this is due primarily to the better scent, hearing or eyesight in forest habitats.

5. Limbs

No abnormalities of the limbs were noticed other than the swollen feet of specimen M.122 (discussed in ch. 11, p448) and of specimen M.86 (Sikes 1966b), and of the frequent occurrence of large thorns embedded in the soles of the feet of scrubland elephant (Sikes 1966a). Fifty-six such thorns were counted in the sole of one forefoot of specimen M.108 (Plate LXXXVI p546). Wear and tear on the hooves is directly related to the type of terrain in which the elephants occur. The soles and ~~toes~~ hooves were found to be much smoother and more regular in the grassland than in the rock-strewn scrubland areas. Montane elephants often have very thick, calloused soles and torn hooves, presumably associated with rock-scrambling, a pastime at which they are very agile and which they apparently enjoy as a form of 'play' behaviour.

6. Tail

The condition of the tail seems to be a good indicator of the general health of the elephant. Elephants of all ages in good health usually have a thick tuft of long, flexible hairs on the tail tip. These are much prized commercially, about 100 commerciably saleable hairs being available in a good tail-tuft. In ill-health, however, the hairs become brittle and break off short, or are lost entirely. They frequently turn grey in old age. In the present survey, the montane elephants generally had the thickest tail-tufts.

In a montane habitat in Uganda, one case of a live cow elephant which had lost part of its tail was noted (Sikes 1966a). It is presumed that this was due to faulty hunting procedure, as it is customary for the owner of the carcass to cut off the tail immediately after the death of the elephant. Cases have not infrequently been described (Bell 1960) in which an elephant had been merely stunned by the hunter and later recovered and escaped tail-less.

7. Dorsum, flanks, quarters, and skin

Dryness of the skin and wasting of the musculature of the dorsum, flanks and quarters was noted in many elephants in grassland habitats, and some in scrubland. It was not seen in any montane elephants observed or collected. The condition is discussed in ch.11, p450 and may account in part for the excessive bark-rubbing and consequent tree-ringing of the few trees in the stressed grassland and scrubland habitats.

One specimen, M.120, had three large, subcutaneous boils, the size of tennis balls, in the left axilla and flank. Histopathological examination of these is planned.

8. Reproductive organs

Although whole ovaries, and samples of testicular tissue, were collected as routine from the specimens in this project, examination of these is not yet complete. Buss & Savidge (1966) have described changes in reproductive behaviour in different elephant populations in Uganda, which may bear some relationship to habitat degeneration and elephant population stress.

The only gross abnormalities noted in the reproductive tract were seen in specimen M.25, which had raised inflamed nodules on the vulva, and in M.23, a young pregnant cow, which had a knot in what was thought to be the left Fallopian tubule (Plate LXXXVIII p 550). Both these specimens were collected by the Murchison Falls Park authorities, but information as to the ultimate findings on them has not yet been made available.

It was noted that the youngest pregnant or lactating cows, M.23 and M.100, were about 13 years old (laminary age FM/IV/2) and the oldest M.122 was very elderly ~~(FM/VI~~ (FM/VI/4; Sikes 1966b). The elderly bull M.121 (laminary age FM/VI/1-2) was the only one in which there appeared to be no active production of spermatozoa in the testes, and yet, surprisingly, in status this elephant was the senior bull associated with a mixed herd containing nursing cows with calves.

M.133 had a cystic ovary; this has not yet been examined histologically.

9. Spleen

One case of double spleen was noted (M.122). The tissue of each portion appeared to be normal and functional, the portions weighing 9 kg and 285 g respectively. This is presumed to be a congenital abnormality. (Plate LXXXVIII p 550).

10. Liver

Bile stones were found in bulls M.108, M.117, and in cow M.88.

In specimen M.88, all the 'stones' and 'gravel' collected from the liver weighed 1.17 kg, the largest stone having a diameter of 7.5 cm. These were analysed by courtesy of the Department of Pathology of Addenbrooke's Hospital, Cambridge, and found to consist mainly of bilirubin with a little cholesterol (Mitchinson 1966). The whole liver of M.88 weighed ~~about~~ 68 kg, whereas the normal livers of comparable animals weighed about 45 kg.

Flukes were identified in the liver in several elephants, and in M.108 a large Trematode was found, which has not yet been identified. (Clarkson 1967). The relevant parasites are listed in Table 5 pp 89 - 95.

11. Kidney

Cystic kidneys were found in specimens M.107 and M.120; these specimens await further study.

12. Lungs, brain, pituitary and thyroid glands

Systematic study of tissue samples from these organs is pending. Professor Garnham, of the London School of Hygine and Tropical Medicine, has kindly undertaken to examine the brain tissue for the presence of parasites. Heavy parasitic infestations were found in the lungs of elephants collected in the Murchison Falls National Park, and all the relevant material is in the hands of the Parks authorities.

13. Digestive tract

No particular studies were made of the digestive tract apart from the collection of random samples of stomach, caecal, and rectal contents. Dr. E.M. Cruickshank, Dunn Nutritional Laboratory, University of Cambridge, has kindly agreed to analyse these against serum samples, in an attempt to elucidate the nature of the deranged Calcium metabolism of the grassland elephants.

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PLATE LXXXII

(a) Specimen M.108.
Tusk pulp showing scattered haemorrhagic lesions thought not to be traumatic.

(b) Specimen M.117.
Irregularities of the tusk pulp thought to be due to a furmer injury to the tusk (c) and (d).

(c) and (d) Reactionary dentine in the tusk of specimen M.117, shown by Colyer (1936) and Colyer & Miles (1957) usually to be caused by injury to the tusk.

PLATE LXXXII

(a)

(b)

(c)

(d)

PLATE LXXXIII

Specimen M.149, scrubland bull elephant:

(a) tusks *in situ* ;

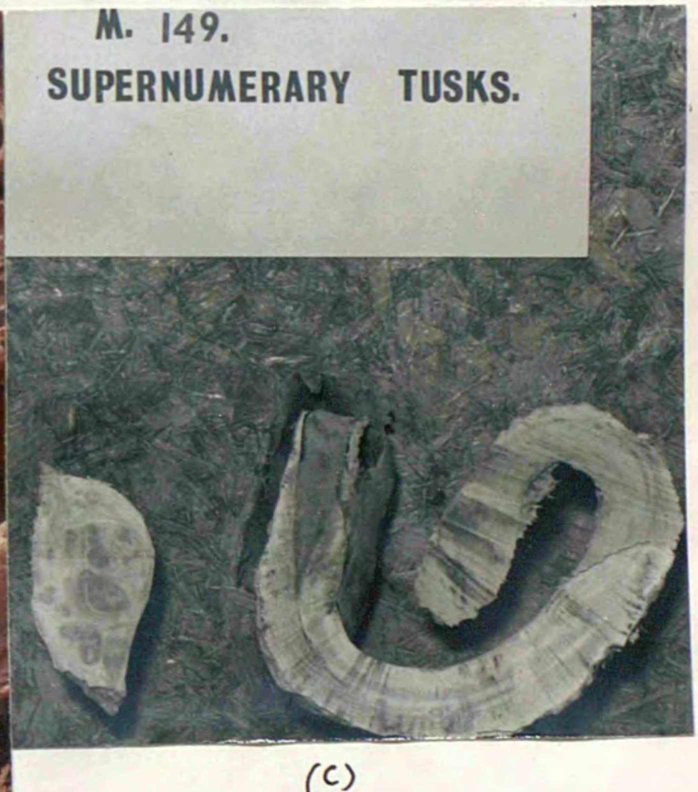
(b) supernumerary tusk near base of main right tusk;

(c) L.S. two of the supernumerary tusks associated with the main right tusk.

PLATE LXXXIII

(a)

(b)



(c)

PLATE LXXXIV

(a) (b) L.S. portions of the main right tusk of specimen M.149 (see Plate LXXXIII) with its pulp.

PLATE LXXXIV

(a)

(b)

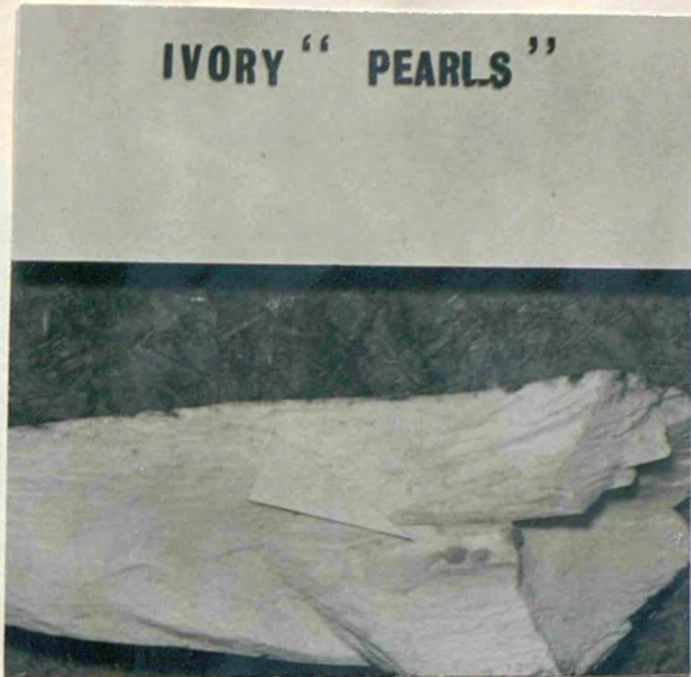
PLATE LXXXV

(a) Ivory 'pearls' or 'seeds' in the split portion of the tusk of specimen M.120.

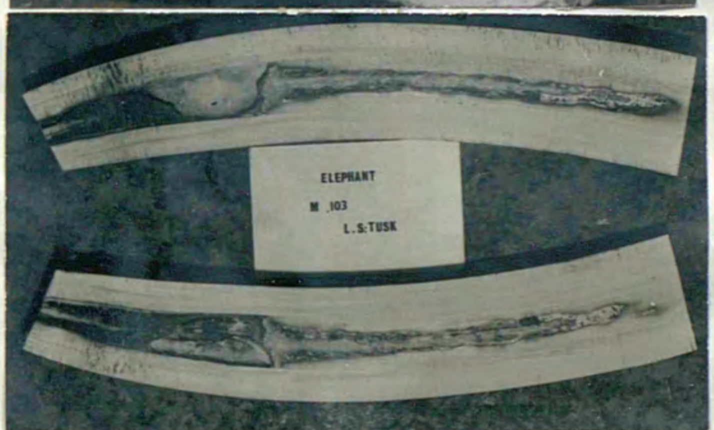
(b) L.S. diseased tusks of specimen M.103, with a fistula of the dentine, or 'spot'.

(c) Defective tusks. Note M.113, a juvenile scrubland male elephant already showing marks on the inside of the dentine matching similar pulp lesions to those of M.108 illustrated in Plate LXXXII (a).

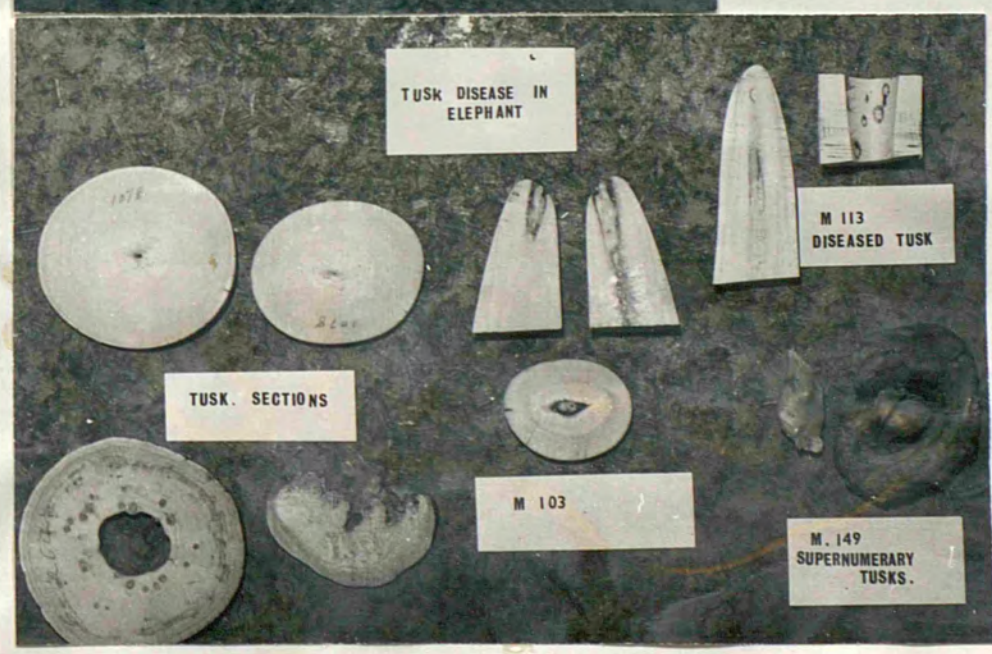
PLATE LXXXV



(a)



(b)



(c)

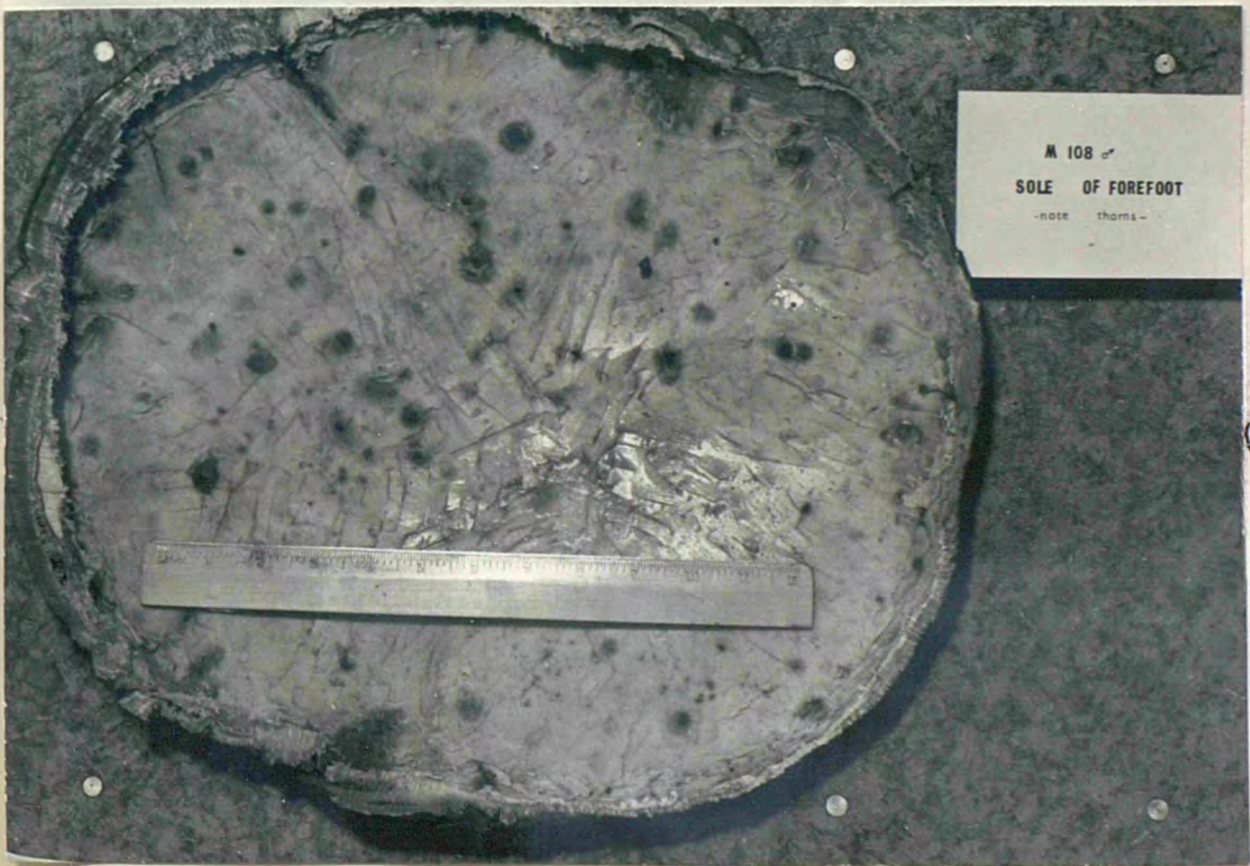
PLATE LXXXVI

(a) Trunk of M.87 (Uganda grassland)

(b) Sole of foot of M.108 (Tsavo environs, scrubland) showing large number of embedded thorns. These are thought to cause considerable inconvenience to the elephant. They were not found in elephants collected in other habitat types.

PLATE LXXXVI

(a)



(b)

PLATE LXXXVII

(a) Lop-eared cow elephant in Queen Elizabeth National Park, Uganda.

(b) Abnormal ear turn-over, as frequently seen in captive African elephants.

(c) Suppurating wound in trunk of specimen M.86 (Uganda grassland).

(d) Defective tusks showing 'spot' in captive African bull elephant.

PLATE LXXXVII

a)

b)

(c)

(d)

PLATE LXXXVIII

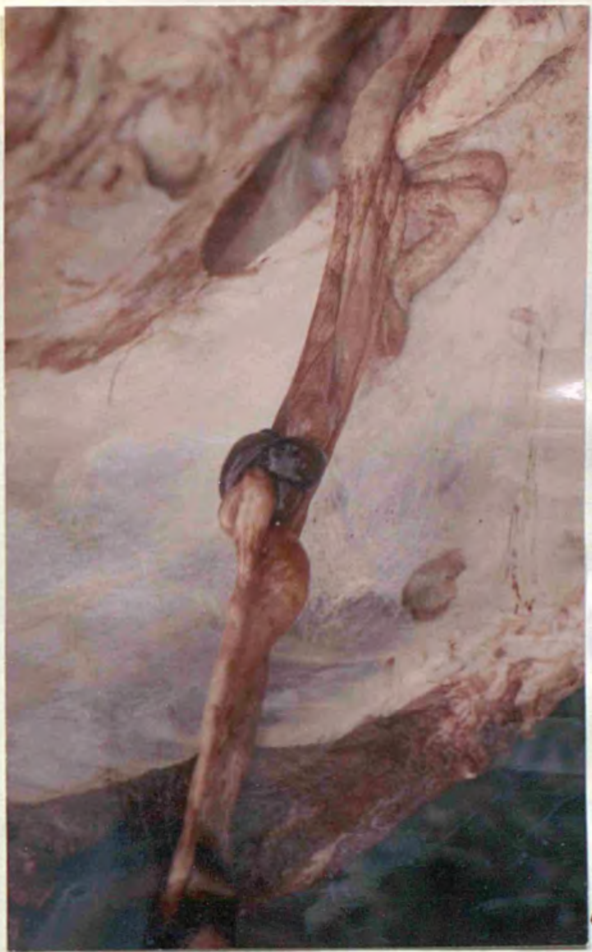
(a) Torsion knot in reproductive organs of specimen M.23 which was also pregnant (b).

(b) Foetus of M.23.

(c) Double spleen. Specimen M.122 (female, scrubland).

(d) The extensive blood supply of the normal African elephant ear: M.154.

PLATE LXXXVIII



a)

(c)

(b)

(d)

PLATE LXXXIX.

(a) Partial paralysis of the trunk: an elephant observed in the Tsavo National Park.(Scrubland).

(b) Ditto.

(c) A very decrepit elephant observed in the Murchison Falls National Park, standing in the Nile waters, showing the 'drooped head' stance found to be generally associated with ill-health.

PLATE LXXXIX


(a)


(b)

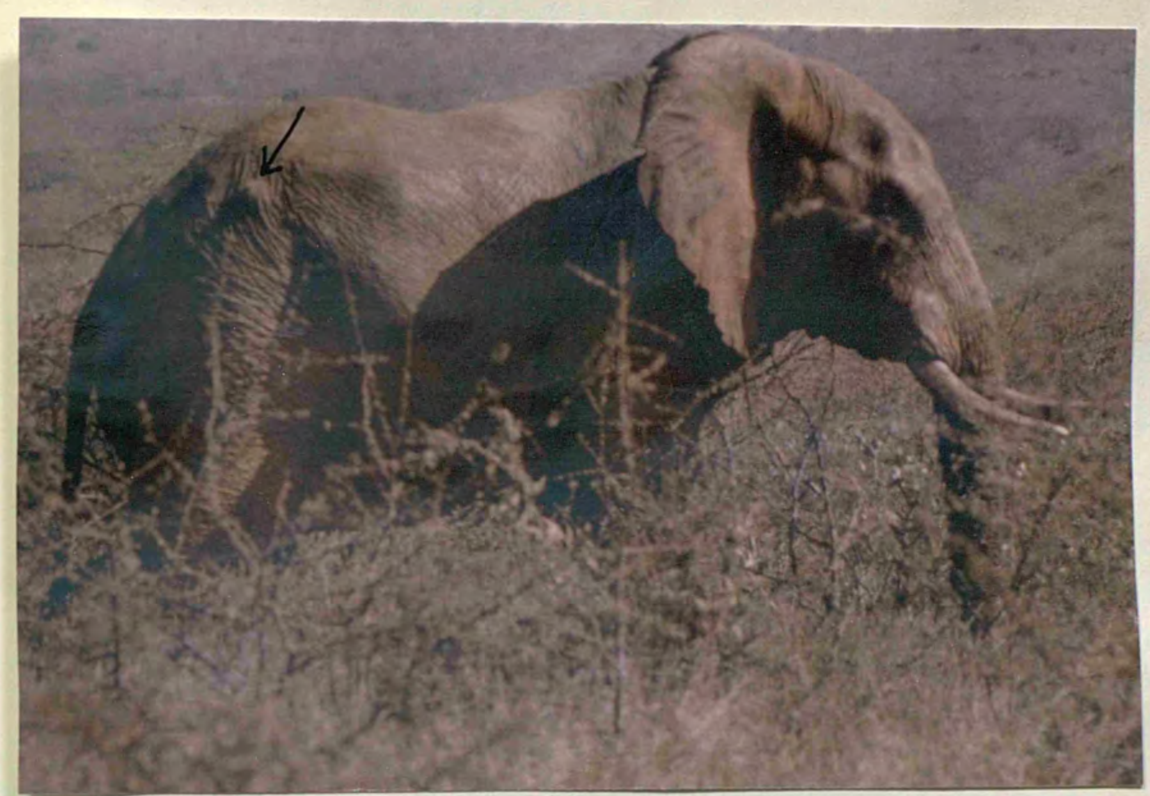

(c)

PLATE XC

(a) Elephant observed in the Tsavo National Park with large subcutaneous swellings resembling the boils seen in specimen M.120.

(b) A very poor animal observed in the Tsavo National Park, very immobile, blind in one eye, and with the 'drooped head' stance that seemed to be generally characteristic of advanced aortic calcification.

PLATE XC



(a)

(b)

DISCUSSION

Although the basic raison d'être of this survey was its ultimate relevance to current research on the pathogenesis of human atherosclerosis, its immediate character, purpose and emphasis concerned the ecology of cardiovascular disease in freeliving wild mammals and birds. It is neither within the scope of this thesis, nor is it within the competence of the author, to assess the findings in relation to atherosclerosis in Man, beyond the need to identify, if possible, the lesions observed. The discussion follows the order of the hypotheses and ~~required~~ field tests listed in the Introduction, pp 5–17

i) Hypothesis

Since it appears that only a few genera of the vertebrates so far examined in captivity are susceptible to true atheroma, while some are resistant to it in conditions other than experimental, and in others the susceptibility line cuts through the group, susceptibility may be dependent upon some factor operating within the species.

Field test required

To what extent and in what conditions in nature does arteriosclerosis, and in particular atheroma, occur in freeliving wild animals, and is it confined to the same groups of susceptible animals as in captivity?

The definitions of 'arteriosclerosis' and 'atherosclerosis' as currently accepted internationally, are quoted in ch.1, pp 18 – 26 . Difficulty was encountered, however, very early in the field work over the application of the definition of 'atherosclerosis', This was due to the fact that occurrences of lipid-containing thickenings of the intima associated with fibro-muscular supportive structures of the arterial wall, which appear to be normal and almost universal in freeliving wild animals, do not appear to have been clearly differentiated from atheroma in the terminology of comparative medicine from atheroma.

The term 'fatty streak' (Fiennes 1965) describes certain manifestations of the normal occurrences, but does not really differentiate, for example, the aortic 'streaking' or 'smudging' associated with pregnancy and lactation from the normal deposits in the collars, ramps and ridges. Other workers (Gresham & Howard 1961) have regarded 'fatty streaking' as a preliminary stage in the pathogenesis of atheroma.

Moreover, it was found during this project that these supportive structures of the arteries appear to possess specific anatomical characteristics. In some cases, they even possess anatomic adaptations which seem to be related to specialised behavioural and environmental characteristics of the species (ch.6,pp 140 – 142). The vulnerability of these structures to trauma has been frequently referred to in the literature. Among these authors may be mentioned Langhaas (1866), Ribbert (1918), Aschoff (1925), Holman <u>et al.</u>(1957), Zugibe & Brown (1960), Buck (1963) and Bertelsen (1963). Duncan (1963) emphasised the mechanical stresses to which they are normally subjected, and Boucek (1965) described the pressures exerted on the extramural coronary arteries during ventricular systole and diastole, which cause coronary angulation and oscillation about the supportive thickenings. Tjøtta (1963) showed that in man atheromatous lesions of the coronary arteries are predominatly localised in the curvatures. Robertson (1960) referred to mechanical strains at the bifurcation and Gillman (1964) discussed possible differential mechanical forces set up during growth in various arteries and parts of arteries. Hugh & Fox (1963) discussed, from the viewpoint of hydraulic engineering, the probable fluid dynamics of circulatory cavitation.

The issue has become somewhat confused, however, by the treatment of all these structures by some authors as 'lesions' (Thurlbeck 1965), or 'points of trauma' (Sodeman 1961). Nevertheless, the anatomy of certain of these supportive structures was described by Wagenvoort (1954) as "muscular rings at points of branching from the aorta" and Conti (1953) called them "cushions of smooth muscle and elastic fibres". Stehbens (1960) referred to "intimal pads containing stratified layers of smooth muscle and elastic fibres in the cerebral arteries of foetuses and infants", and added that he noticed no associated endothelial proliferation.

Robertson (1960) described longitudinal bands of smooth muscle in the subendothelial layer representing a progressive development of branch pads, and thought this development may be associated with cells entering the bands by passing through the fenestrated internal elastic lamella.

Finlayson (1965) stated, inter alia: "It would seem probable... that such appearances (intimal supportive thickenings closely related to vessel ostia and branchings) may be fundamentally normal, and not pathological (see ch. 6 p 140)

In order to achieve sufficient descriptive range, the terms 'ostial collars', 'ramps' and 'ridges', and 'bands' and 'threads', have been coined. These are defined in ch.6, pp 142 to 143. The search for descriptive terms in the literature, adequate to differentiate between the different types of supportive structure encountered in a single aorta, was disappointing, and it appears that the exact anatomy and mode of functioning of these structures has neither been fully explored in Man, nor in the study of comparative mammalian functional anatomy.

Intimal lipid deposits were usually present within the rim of the ostial collar in the aorta, and almost invariably present in the intima of the ostial ramp of both the aorta and the coronary arteries, and in the ridges at the bifurcation of the aorta and carotid arteries. It also occurred very commonly in the ridges of the brachiocephalic trunk (or trunks) and the branches of the brachial artery. Bertelsen(1963) went so far as to state that completely normal aortic tissue contains considerable amounts of lipid, and that this lipoidal depository commences even during infancy.

The quantitative estimation of lipid deposits in the aortic wall of elephant indicated that its presence, confined within the intima of the supportive thickenings, is normal in freeliving, wild African elephants in unstressed habitats. (Appendix 4 , pp 633 and ch.11, pp 430 to 438). In the general survey of 44 other species of mammals, it was readily detected in these sites in all species, except zebra and one or two small carnivores. Even one zebra showed traces of intimal aortic lipid, and it may be simply that the techniques used were inadequate to detect minute quantities of lipid macroscopically. Since microscopic examination in these very small specimens was usually based on sites in which lipid was first macroscopially located, it is possible that the presence of lipid in these particular specimens was indeed overlooked.

Another complication to the interpretation of the term 'susceptible' relates to the universal occurrence of extensive fatty 'smudges' (less clearly demarcated than 'fatty streaks') and increased fatty deposition in the supportive structures in lactating and/or pregnant females. It seems reasonable to think that this is a physiological process, related to the normal changes in lipid metabolism associated with lactation and pregnancy, and hence with its hormonal control (Boyd 1963; Likar et al.1965;

Bizzi et al. 1963; Malinow & Moguilevsky 1961; Malinow et al. 1961; Moskowitz & Wissler, ~~N.W.~~ 1961). A seasonal relationship to the occurrence of variations in arterial lipid deposition could not be identified in the present survey. A seasonal variation in lipid metabolism has, however, been demonstrated in rats (Thorp 1963).

The assessment of the range of freeliving wild species 'susceptible' to atheroma must therefore be qualified. A distinction needs to be drawn between what appears to be the perfectly normal, possibly universal, physiological deposition of lipid, (associated with the normal musculo-elastic ostial 'collars', 'ramps' and 'ridges', and the 'bands' and 'threads' of intermediate sites), and pathological lipid deposition.

It seems illogical to relegate the manifestation of what appears to be a normal physiological process to the category of a pathological phenomenon. That this process may become pathological in certain circumstances, however, is most probable, and indeed focal degeneration of the intima undoubtedly tends to be localised at these very sites. The crux of the matter seems to lie, therefore, in the elucidation of the conditions, perhaps traumatic, perhaps due to disturbed metabolism, or perhaps even inflammatory, which precipitate the onset of degeneration at these or other sites. In defining 'susceptibility' to atheroma, therefore, it seems most probable that any animal capable of depositing lipid in the aortic intima at all, even as a normal physiological process, is 'susceptible'.

An even more penetrating question with regard to freeliving wild animals, and perhaps even to man, is:- just how far can the environment deviate from the optimal 'norm' to which a given species is naturally adapted, before stress factors begin to operate on (a) individuals with genetic or age-status-health weakness, (b) the population unit? And at what point do these stress factors begin to cause sufficient alteration of the internal environment - perhaps as some kind of psychosomatic reaction - to disturb normal tissue metabolism, in this case particularly that of lipid and mineral salts?

As the survey was carried into its second phase, the investigation of the ecology of cardiovascular disease in elephant, it became clear that the onset of degenerative changes in the arteries could be traced to comparatively early stages in the degeneration of the habitat, and its sequelae in general imbalance of the ecosystem and changes in the physique and behaviour of the species.

ii) <u>Hypothesis</u>

In view of hypothesis i) (above), while it appears that some naturally frugivorous or omnivorous groups (*e.g.* *Psittacidae*, *Suidae*) are resistant to atheroma, other members of these groups, naturally graminivorous or experimentally secondarily fed a ~~graminivorous~~ diet of seed or grain are atheroma-susceptible.

<u>Field test required</u>:

Can a naturally-occurring situation be found where a freeliving wild species, normally omnivorous or frugivorous, has become secondarily graminivorous and if so, can any nutritional relationship be found between the occurrence of arteriosclerotic lesions and the change of dietary habit?

Several naturally-occurring situations meeting these requirements were observed in East Africa during the first phase of the field survey, where recognisable, comparatively isolated communities were associated with different habitats, exhibiting different nutritional and stress factors. These included certain bird communities, chimpanzees, baboons, galago, and elephant.

The bird communities were ruled out, however, for the purpose of this study, owing to the difficulty of ageing and recognising individual wild birds, and their basic anatomical and physiological difference from mammals, and in particular man. The extensive study of chimpanzee was out of the question due to the current rapid diminution in numbers of the species in the wilds. Wild baboons were already the subject of intensive study by American and other workers. The galago was not favoured by the Director of the Nuffield Institute of Comparative Medicine, under whose authority the survey was carried out.

The African elephant had a great many advantages to commend it as a suitable subject for this particular field test (Appendix 2 p 596-597), but it also had obvious disadvantages. Nevertheless, it was selected by the Nuffield Institute of Comparative Medicine Cardiovascular Committee, a decision which has proved to be most rewarding. Not only did it provide a positive answer to the question raised by hypothesis(ii) (above) and indicate the potential value of extending this type of ecological study to other, additional wild species; but also the material for the formulation of a very simple, new field ageing technique for wild elephant. It also threw new light on at least one aspect of the current problem of wild elephant management in African National Parks.

The findings on the 2nd hypothesis and field test are fully discussed in Appendix 4 pp 632 to 638 (Sikes, in press).

iii) Hypothesis

It appears that:

a) animals susceptible to atheroma are those which under natural conditions would have an especially large intake of vitamin C in fruits or shoots, but are secondarily deprived of it;

b) all those (Man and the sub-human Primates, guinea-pig, poultry), known to be unable to synthesise vitamin C, are among the susceptible groups;

c) none of the resistant species is known to require vitamin C in the diet;

d) the development of atherosclerosis is associated with hypercholesterolaemia, and blood cholesterol levels can be lowered by the addition of certain of the unsaturated fatty acids to the diet;

e) the organ responsible for the metabolism of the unsaturated fatty acids is the adrenal, and that this gland requires vitamin C for the purpose (Ratcliffe & Cronin, 1958);

f) the increasing popularity of the empirical feeding of sprouted grains for captive and experimental rodents and some species of birds is due to its beneficial properties, supposedly deriving from the vitamin contents which are high in germinating seeds;

g) the vitamin C requirements of different groups of mammals and birds need re-appraisal, the essential fatty acid/ascorbutic properties of a diet <u>per se</u> being an insufficient criterion; the progress of the physiological condition of 'fatty streaking' to a pathological condition may reasonably be supposed to be associated with a change from a high vitamin diet (fruit, roots, shoots) to one of seeds or grains low in these nutritional components, and possibly antagonistic to them.

<u>Field test required:</u>

Can any naturally-occurring ecological situation be found, suggesting a possible vitamin-arteriosclerosis relationship?

The field conditions prevailing in this survey were such that it is quite impossible to be specific about a vitamin-arteriosclerosis relationship. An extension of the programme to include experimental studies on, for example, the galago, might have provided the conditions necessary for more specific investigations on this problem. As mentioned on p.564, however, this proposal was deemed to be inexpedient. Nevertheless, as shown in App. 4,p 606 (Sikes, in press), there is an environmental correlation between the extreme occurrence of medial calcification of the aorta in grassland elephant and the apparent absence of dietary constituents normally considered to be vitamin-rich; the occurrence of aortic lipidosis in scrubland elephant, where dietary constituents supposedly vitamin-rich are reduced in availability; and the total absence of medial calcification of the aorta and pathogenic aortic lipidosis in montane elephants, where the diet is rich, varied, and abundant, and presumably contains all essential nutritional components in adequate amounts.

iv) Hypothesis

When wild animals are over-crowded in an abnormally restricted territory and subjected to conditions inducing disrupted inter- and intra-specific behaviour response, they show signs of stress having the effect of limiting the population and reducing longevity(Ratcliffe & Cronin 1958; Fiennes 1963).

Field test required:

Can any naturally-occurring situation be found where a stressed population of a single species can be compared with a non-stressed population? If so, is any relationship indicated there between stress factors and the occurrence of arteriosclerosis?

The extreme over-crowding of the elephant populations and its effects in the degenerate grassland and scrubland habitats has been discussed at length in Appendix 4, pp 606 to 653 (Sikes, in press) and Appendix 7 (Sikes 1966c).

What constitutes 'stress' to wild African elephant populations has been discussed in ch. 11 pp 451 to 453 . Buss & Savidge (1966) have shown that already factors have begun to operate in one section of the grassland elephant populations (namely Murchison Falls National Park, South Nile Bank population) reducing breeding rate.

I have indicated (Appendix 4) that extreme aortic medial calcification appears to reduce longevity in the population. The findings of this survey, in the case of the African elephant studied in three different habitat types, seems clearly to confirm the hypotheses of Ratcliffe and Cronin (1958) and Fiennes (1963) that overcrowding in abnormally restricted territory in conditions disruptive to inter- and intra-specific behaviour tends to limit the population and reduce longevity.

In the case of the African elephant, relevant stress factors appear to be:

i) prolonged exposure to unmitigated sunlight;

ii) overpopulation;

iii) a restricted diet;

iv) frustration of the migratory habit, associated with a breakdwon of environmental conditions suited to the birth and nurture of young calves, and with boredom and lack of exercise for the adults.

Factors such as extreme changes of temperature and altitude, and irregular hunting did not appear to be stressful to healthy elephant populations living in a 'natural' environment, but on the contrary appeared to have beneficial effects.

It was mentioned above that two incidental findings of this survey have immediate practical relevance to current problems of elephant management in Africa. The first of these relates to the pressing need for a simple and reliable field method for assessing and describing the age of living elephants (by age-groups) and of elephant carcasses. It is not possible on available data to ascribe ages above 30 years on any but an entirely arbitrary basis to the African elephant. The ~~term~~ 'molar age' (a term coined in Africa and currently in use by game control officers and hunters) may by this method be accurately assessed. The stage reached in the normal progression of the molars along the mandible, is described by relating the position of the anterior molar in wear to the <u>foramen</u> <u>mentale</u>.

This may be refined further by determining which lamina is currently in position over the <u>foramen</u> <u>mentale</u>. Thus, the 'molar age' and/or 'laminary age' can be named. If an arbitrary year-age is required, this may, with reasonable accuracy, be applied to the molar-laminary assessment from the chart (p 370) up to 30 years of age. The method depends on the correct identification of the molars in wear, described in Appendix 6 (Sikes 1966b).

The second finding relates to the fact that there is an indication that advancing medial calcification of the aorta occurs in the Tsavo National Park mainly in male elephants of under 25 years old, and in nursing cows.

It is the molar age groups IV/1- V/5 that are already most affected by the degeneration of the habitat, while groups V/5 and VI (senior adults) are little affected at present. These are still normally reproductive and consist of very fine stock, whereas the above group of sub-adults and prime adults (IV/1-V/5) contains some very poor stock, as assessed during autopsy measurement and on the hoof, and compared with animals in the equivalent montane age-groups. The onset of the effects of habitat degeneration on these elephants may thus be traced approximately to the beginning of the Second World War, - i.e. when incursions into the coastal forests first became extensive, and when interference with the natural water supplies in the arid Tsavo area and environs first began to show their effects.

There is, therefore, an indication here that, although the apparent adaptibility of individual living elephants to degeneration of the environment may be temporarily remarkably effective, the long-term effect on the whole population and subsequent generation may prove to be ultimately irreversible. Younger animals, now developing and maturing in a degenerating environment, seem to show early physical defects which may reduce the viability and longevity of the whole population. This has already been shown to be the case in Uganda grassland elephants (Buss & Savidge 1966), and in the case of the Tsavo elephants the results of this survey suggest that an early stage in a similar process has already been reached. The inescapable implication of these findings in relation to elephant ecology is that the natural processes which may tend to overcome imbalance between elephant population and habitat i) begin to operate at a very early stage in habitat degeneration; ii) strike first at the younger age groups.

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SUMMARY

A field survey was carried out in East Africa by the author in which field tests were made on the basis of four hypotheses relating to arteriosclerotic occurrences observed in captive mammals and birds.

The survey was carried out in two phases: i) a general survey of susceptibility to cardiovascular disease, in which 43 species of freeliving wild mammals and 25 species of birds were examined; ii) an intensive survey of the ecology of freeliving wild African elephants in three different habitat types (one 'natural' and two 'stressed') (Introduction).

PART I (Vol.I)

1. Difficulties over the variable use of the terms 'arteriosclerosis' and 'atherosclerosis' in comparative medicine were noted, and their use throughout this survey defined. No attempt was made, however, to relate the findings directly to existing theories on the biochemical nature of the pathogenesis of atheroma in man. The emphasis here is primarily ecological: the relationship of cardio-vascular disease to the condition of the environment (Ch.1).

2. Emphasis throughout was placed on the importance of collecting specimens on which a good range of field data was available; autopsy could be performed immediately; and from which serum, the whole undamaged heart, aorta and samples of other muscular arteries could be collected and treated suitably for subsequent study. A reference collection of routine samples of other tissues for

histology, data on body measurements, and material for ageing the specimens was compiled. Subsequent laboratory examination of the material included quantitative estimations of aortic lipid and Calcium deposits in elephant, paraffin and frozen micro-sectioning and staining of all tissues by routine techniques. More detailed histopathology and histochemistry was outside the scope of this survey (Ch.2).

3. The environment from which the specimens were collected in the first phase of the survey included six distinct habitat types.

The selection of these specimens for collection was based on somewhat broad ageing and status criteria, but these generally proved appropriate to the basic requirements. Analytical specimen - status - habitat lists were drawn up (Ch.3).

4. Parasites: the parasite collection is listed, and a few interesting cases involving the cardiovascular system are described. (Ch.4).

5. Blood serum was collected and analysed by various techniques by different workers. The results are tabulated in ch. 5.

6. The techniques for the examination and description

of cardiovascular material from all species, other than elephant, are described in ch. 6. It was found necessary to redefine the word 'susceptibility' in relation to apparent arteriosclerotic disease in freeliving wild animals. This was because the presence of intimal sudanophilic material associated with normal anatomical arterial supportive thickenings appeared to be almost universal, its absence at these sites being the exception rather than the rule.

It was also found that these normal supportive thickenings of the arteries, and in particular of the aorta, apparently possess specific anatomical characteristics which seem to have a functional relationship to the habits of the species. In an extreme case, the klipspringer, the supportive thickenings of the aorta in the region of the origins of the coeliac and anterior mesenteric arteries (common origin) and the two renal arteries (common origin) are apparently modified to form a valve-like structure, which may be capable of diverting the main blood flow to the viscera during browsing while in a vertical posture, and to the hind limbs during rock vaulting. In this species, the ostia of the intercostal arteries are reduced in number, slanted diagonally to the longitudinal axis of the aorta, and guarded by a cusp-like collar; and the ostia of the branch arteries were absent in the abdominal aorta.

Failure to locate detailed descriptions of the anatomy of the aortic ostia in the literature of medicine or comparative anatomy, and the inadequacy of the terms variously introduced by the few authors who have noted the peculiar anatomy of the ostia in comparative cardiovascular studies, necessitated the coining of five ~~descriptive~~ new terms to describe the five main variants of normal supportive thickenings which may be encountered in a single aorta, namely: 'ostial collars', 'ramps', and 'ridges'; and 'bands' and 'threads'.

An analytical list tabulating the occurrences of normal arterial lipid deposits, arterioscleroses, atheroma-like lesions, and arteritides found in the specimens collected, is given in ch. 6. Comparable occurrences in taxonomically equivalent groups of captive animals are also indicated.

7. A few interesting traumatic and pathological cases are mentioned.

/PART II

PART II.(Vol. II)

8. Techniques peculiar to specimen and data collection, autopsy procedure, and the examination of material in the case of African elephants are described (ch.8).

9. The selection of three different habitat types (one the 'control' or 'natural' type; two 'degenerate' or 'stressed'), and some detail as to their geology, hydrology, climate, and vegetation, is given. The plants named are those which are known to be used by elephant for food and/or provide shade at midday, and privacy for calving. The changes in migration and breeding habits of elephant consequent upon economic and social developments in East Africa were investigated in some detail in order to discover which types of stress really affect elephant populations and which do not (ch.9).

10. The need for a simple reliable formula for the assessment and description of age in the African elephant became apparent. A new technique, based on molar eruption, but differing radically from previous methods, was therefore derived from the ageing material of the complete age series examined in this survey and has been described (Sikes 1966). When additional data were published by Laws (1966), it was

found that they coincided almost flawlessly with the data from this survey, and it was possible to draw a complete age-reference chart, suitable for general field use; based on the combined data derived from material from over 400 elephants (ch.10).

11. Two main manifestations of cardiovascular disease were differentiated in free-living wild African elephant: i) Atherosclerosis; atheromatous lesions included the occurrence of simple 'buttons', with intimal subendothelial hyperplasia and disruption of the internal elastic lamella; streaks containing subendothelial lipid deposits and disrupted i.e.l.; complex, thickened plaques with inter- and intra-cellular lipid deposits, muscle cell and fibroblast hyperplasia and disruption of the i.e.l. sometimes with mineral deposition and metaplasia; and finally large haemorrhagic lesions. ii) Medial calcification.

Aortic lipid deposits in the ostial collars, ramps and ridges, and intermediate bands and threads is universal in normal elephants, whereas the presence of calcific deposits is abnormal. Aortic hyperlipaemia, unaccompanied by degenerative changes, appears to be a normal physiological occurrence of pregnant and/or lactating elephants.

Atheromatous lesions were usually most extensive in the aortic arch, spreading into portion I of the aorta, and at the bifurcation, spreading into portion IV and even portion III. They also occurred in a few cases in the coronary arteries. In some cases partial ostial occlusion was found. In contrast, medial calcification occurred mainly in the muscular part of the aorta and larger muscular arteries, but a few extreme cases were found where it extended throughout the aorta, including the aortic arch and coronary arteries. In some cases it caused total occlusion of the ostia of smaller branch arteries of the aorta.

The pathogenesis of atherosclerosis and medial calcification ~~occurred~~ appeared to be independent~~ly,~~ but seemed to be correlated with the degree of habitat degeneration and probably reflected the restricted diet, the excessive exposure to sunlight, and stresses due to overpopulation, frustration of the migration urge, and denial of access to forested calving grounds. (ch.11).

12. A few interesting cases of trauma, congenital abnormalities, and other pathological occurrences in elephant are mentioned (ch.12).

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The need for a field survey of the ecology of arterial disease in freeliving wild animals was first recognised and emphasised by Mr. R.N. T-W- Fiennes, Pathologist, Zoological Society of London, under whose guidance, and with whose constant encouragement, it has been carried out. I am indebted to him for all his help.

Specialised advice and guidance as to the relationship between the findings in animals and human pathology has been kindly given by Professor J.E. Smith, Department of Morbid Anatomy, University College Hospital Medical School, London, and supervision on the zoological side by Professor P.M. Butler, Department of Zoology, Royal Holloway College, University of London. The project, in its earlier stages, was carried out under the auspices of the Nuffield Institute of Comparative Medicine, Zoological Society of London, and latterly of Royal Holloway College, University of London. For this help and cooperation I am most grateful.

I also wish to thank the following: Miss E.v.Bernuth for assistance in innumerable ways, not only in the field but also in the documenting of specimens and the typing of this thesis; Dr. G. du Boulay and Miss P. Verity of the Nuffield Institute of Comparative Medicine for carrying out the Calcium radiography; Dr. M.J. Clarkson, Liverpool School of Tropical Medicine, for identifying the endoparasites and advising on chapter 4; Dr. J.H. Moore, Hannah Dairy Research Institute, Ayr; Mrs. von Vignau, Faculty of Veterinary Medicine, University of East Africa, Nairobi; Dr. I.D.P. Wootton, Post-graduate Medical School, London; Dr. W. Dangerfield, North Middlesex Hospital, and Dr. M.Crawford and Mr. J. Paterson of the Nuffield Institute of Comparative Medicine, for carrying out the serum analyses. Mr. J. Savidge, formerly Scientific Warden of the Murchison Falls National Park for co-operation in collecting material from the first seven elephants. The Directors and members of staff of the National Park and Game Departments of Kenya and Uganda for authorising and advising on the collection of specimens. Professor A.E.W. Miles, Dental School, London Hospital Medical College, for examining, and advising on, the tusk collection. Mrs. Maini and Mrs. Berry for help with the preparation of certain micro-slides. Dr. G. Weddell and Miss G. Douglas of Oxford University Medical School for supplying the Richardson fixative used for the elephant tissues; Dr.A.Harthoorn, Dr. R.Laws and Mr. H.R. Binns, East Africa for the allocation of laboratory, bench and storage space in their departments. Mr. Lucas, Kew Gardens, and Mr. G. Cansdale, formerly Forest Officer in Africa, for advice on chapter 9 and for the identification of plants from the habitats studied;

Messrs. Mutarimbo, Charai, Lesirian and the team of African workers who assisted in carrying out the elephant autopsies so successfully and gave loyal help often in exceptionally demanding conditions; Mr. G. de P. Colville, owner of Oserian, Kedong and Ndabibi Ranches, Kenya, for generous permission to collect the 'high ranchland' specimens on his land, and for the temporary use of a house; and Chief Maora, El Wuas area of Masailand, for his friendship, advice and unstinting help in the collection of 'high scrubland' specimens.

Many others have rendered assistance in this project, which is perhaps an unusual one in the wide range of scientific disciplines it touches, as well as in the vast geographical area covered.

* * * * * * *

APPENDICES.

APPENDIX 1.

FIELD EQUIPMENT LIST

(as used in second phase of field work)

1. Two Landrover trucks, 109 ins. wheelbase.

One fitted with double aluminium roof and 2" wire mesh sides, locking rear doors. Fittings included regulation gun-safe, roof shelves for cameras, ammunition etc., racks to hold 10 4½ gal. capacity jerry cans containing 16 gals water, 16 gals petrol, 4 gals kerosine, 4 gals 40% formaldehyde, plus 4 gals industrial spirit and 4 gals acetone; one ¾ cu ft. capacity refrigerator, later replaced by 7 lb and 10 lb capacity Carbon dioxide cylinders, and one spare battery.

The other vehicle was a station wagon and carried 10 gals petrol and 10 gals water, and was used primarily for transport of personnel, specimens and camp equipment.

2. Armoury

One .450 cal. D/B rifle

One .375 cal. mag. rifle

One 12-bore D/B shotgun, with .410 adaptor

One .22 rifle fitted with telescopic sight.

3. <u>Processing boxes, flasks and packs</u> (as prepared for each day's work).

A. One haversack for blood and eye-lens collecting, adequate for 5 animals.

i) 60 shoulderless 10 ml cap. polythene bottles with hinged lids.

ii) Five polythene blood withdrawal syringes (sterilised and sealed in polythene bags).

iii) Ten steriseal 20 ml cap. syringes with 20 serum needles.

iv) Marking pens and pencils.

v) Two sizes scalpel handles and spare blades.

vi) Measuring tape.

vii) Ten specimen tubes containing Richardson's Fluid for collecting eye-lenses.

viii) One box micro-slides for blood smears.

B. One plywood, fitted processing box, containing:

i) Roll of dissecting instruments.

ii) 100 polythene specimen tubes containing 10% formol-saline.

iii) 100 polythene bags (4 sizes).

iv) Three rolls of sellotape for sealing polythene bags.

v) Bundles of plastic labels, and two rolls of fine labelling wire.

vi) 100 5-ml and 10-ml capacity sterile polystyrene serum tubes.

vii) One 500-ml capacity bottle methyl alcohol and one bottle Giemsa stain for blood smears.

viii) 30 stiff, 12 x 9" polythene mounting boards.

ix) One large and two small long-arm stapling machines with spare staples.

x) Sundry minor items, e.g. string, rubber-bands, 10 gm packs of Sodium chloride etc.

C. One large, 3-tier thermos flask, containing fresh ice in all compartments - (after serum separation, the centre tier was used for serum storage, and the ice replaced by 'dry ice' from the carboneige machine at the base camp; alternatively, the serum was transferred to the portable fridge).

D. One plywood processing box containing:

i) Polythene dishes, trays, and small buckets.

ii) Skinning knives, rasps, hones, butchers' bone choppers and saws, insecticide sprays, Vim, soap, rubber gloves, dettol, aprons, towels, dish-cloths etc.

4. <u>Weighing equipment</u>

A. For large animals:

i) Tripod legs and head (Sikes 1966 b,p.282).

ii) One chain block and tackle.

iii) One 12-cwt Salter scale.

B. For small animals, larger internal organs etc.: One 60-lb Salter spring scale.

C. For very small animals and birds, and delicate organs: One triple-beam balance (Ohaus) 610 g. capacity, kept in specially fitted plywood travelling box.

5. <u>Sundry tools and equipment</u>

A. For large-animal autopsies:

One bag containing four 4-ft long viscera hooks; Twelve pangas (East African machetes); two lumber-jack axes; 30 ft. heavy steel chain; 50 ft nylon climbing rope; a reel of cotton picture cord (used for tying off intestines for weighing).

B. One box containing vehicle repair tools and spares.

C. One bag, containing 1 cwt fine, commercial salt.

D. Canvas awning for shading the processing wok and equipment at the carcass.

E. Two folding tables and stools.

6. Camp equipment

Three tents (one for assistants, one for storage of specimens and equipment, one for the author); one army bivouac tent for emergencies and when an overnight guard had to be kept at the carcass.

Sundry accessory camp kit and food supplies.

7. Photographic equipment and binoculars

Asahi-Pentax 35 mm camera-body, with interchangeable 55 mm and 300 mm lenses, mounted lightmeter and filters.

Binoculars 6 x 24 "Alpin 160" (Kern).

8. Maps: As supplied by the Government Survey Department map offices in Nairobi/and Kampala.

9. Permits: As issued by Police, Game and Parks Departments of the Kenya and Uganda Governments.

Field record: NUFFIELD INST. COMPAR. MED.

Spec. No.	
Sex	
Date	

SPECIES

FILOFAX REGD. TRADE MARK

Locality	
Bdy. temp.	Age gp. estimate
Bdy. wt.	
Lgth. n/t.	
Hd. lgth.	Sex status/condit.
Hd. wdth.	
Ear/wg. span	
Neck	
Back	Herd composition
Tail	
Girth	
Ht. wthrs.	
F. leg	Habitat type
H. leg	
Horns: tips	
str.	Fd./water availability
curve	
rings	
base	Season/climate
Scars/inj.	
Colour	
	Stress factors
Samples taken:	
Lens	
Baculum	
Serum	Capture/kill:
Bl. sm. thk.	time
Bl. sm. thn.	ammo.
Marrow sm.	distance
Ectopar	posit. bullet
Endopar	other
Skin	

BCM/FILOFAX LONDON FORM NO.9

Turn over

Organ/tiss.	Wt.	Histol. Smpl.	Large Smpl.	Photo	Remarks
Carotid a.					
Thyr./parath.					
Brachial a.					
Iliac a.					
Fem. a.					
Heart					
Pericardium					
Coronary a.					
Aorta.					
Renal a.					
Mesent a.					
Cerebral a.					
Lung					
Liver					
Spleen					
Kdy.					
Adr. gl. R.					
,, ,, L.					
Ov./test R.					
,, ,, L.					
Mamm. gl.					
Uterus.					
Placenta					
Foetus					
St./cr. gizz.					
Stom. cont.					
Pancreas					
Small int.					
Caecum					
Col./rect.					
Faeces					
Urine pH.					
Pituitary					
Brain					
Teeth					COLLECTOR S. K. SIKES

APPENDIX 2

The Zoological Society of London

THE NUFFIELD INSTITUTE OF COMPARATIVE MEDICINE

REPORT (Abridged)

to the Cardiovascular Research Committee

by

Miss S. K. Sikes

7th October 1964

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General

In the seven months, February/September, 1964, spent in Kenya and Uganda, I examined 84 mammals (35 spp) and 26 birds (18 spp). These were collected in game parks, hunting areas, native pasture lands, and European-owned ranches. As far as possible, older animals were carefully selected, and younger ones generally ignored. In pursuing this policy, I had in mind not only the fact that our most likely candidates for atheroma findings would be elderly, but also that we should respect the attempts of game departments and parks to conserve wild life.

Unfortunately, working throughout the rainy season, we also had to contend with impassable tracks, getting stuck in the mud, the rather widespread movements of animals, and the unpleasantness - often impossibility - of doing post-mortems in mud and rain. It also meant that the forests were inaccessible to us, so primate and parrot collection was practically out of the question.

On arrival in East Africa, some resistance towards scientific collecting was noticed, especially in Uganda, where there is a feeling among Government personnel that sometimes inexperienced and irresponsible groups of scientific collectors had shot out game somewhat indiscriminately and inefficiently. In the circumstances, I felt sure that the right approach should be one of very selective collecting and clean killing.

Co-operation with other workers

Since there should be considerable advantages to be derived from co-operation with other scientific workers on cropping and research schemes, and this is enjoined by game departments, I spent some time with the members of the Nuffield Unit of Tropical Animal Ecology (the NUTAE) at Mweya, Queen Elizabeth Park. I found, however, that their technique was to handle a large number of specimens of one kind of animal simultaneously - thus 6 warthog were shot and examined, and the carcasses removed within 3 hours; 26 hippo were shot, examined, sold and cut up as meat, in 7 hours. In these circumstances it was quite impossible to obtain the parts of the specimens I needed, in the condition required, or the supporting data, or consistent measurements.

Working with John Savidge and his wife on the scientific elephant cropping at Murchison was, in contrast, extremely valuable, as full co-operation was possible, and I had the benefit of the assistance of his own well-trained team of Africans and his equipment. On another occasion, in Kenya, I was asked to allow a young American research worker and his wife to accompany me, so as to give them an idea of camping and field collecting. They wanted only one kidney, and urine and serum samples from each animal, so this was a very happy and valuable arrangement.

Dr. Harthoorn of the Pre-Clinical School of the Faculty of Veterinary Science, University College, Nairobi, has given invaluable assistance in placing a well-equipped office and laboratory at my disposal. He is fully prepared to offer the facilities of his histology room, and the services of his technician, suggesting that we, on our side, allow him to have samples of normal tissues from specimens for building up a library of normal tissues from wild animals. I am most grateful to him for his help in this way, as it has greatly facilitated my work.

Findings

Cardiovascular lesions were seen in 33 mammals (15 spp) and 3 birds (2 spp). On macroscopic examination, 17 of these showed aortic plaques, streaks and ulcers. Microscopic examination is not yet complete, as the bulk of the specimens have only just reached London, but, in those examined so far, two ostriches appear to be the only ones showing intimal plaques containing lipid deposits comparable to atheroma. Buffalo showed aortic ulcers, fatty streaks, and medial calcification thought to be associated with the burrows of a Nematode <u>Onchocerca sp.</u> Hippos, an oryx, a gerenuk, a jackal, and a hyena, showed aortic plaques and ulcers associated with the presence of heavy endoparasitic infestations in other organs. In the case of the hyena, parasitic burrows of very small size and ulcers recalling the appearance of those in buffalo, were seen in the aorta.

In addition to the examination and preservation of the heart and aorta (or portions of these) of every specimen, samples of other organs for histological examination, parasites, blood smears, serum and ageing material have been collected, as well as relevant data on size, weight, and ecological factors. It has not yet been possible to examine in detail any of this supporting material and data.

Elephants proved to be of particular interest. All of the seven examined in the Murchison Falls Park, including two middleaged bulls (about 45 years old), 2 middleaged cows and 3 younger cows, showed aortic lesions in various stages of development. In every case these occurred in the abdominal aorta and common iliac arteries, with the maximum concentration between the bifurcation and the renal arteries. None was seen in the thoracic aorta, but in two cases isolated plaques were seen in the carotid and brachial arteries. The aortic plaques showed a thickened intima containing lipid deposits, and calcified discs in the media. It is not yet clear to what extent the intimal deposits and thickenings are directly associated with the medial calcification. In contrast to the Murchison elephants, an old bull taken in an unrestricted montane habitat in Kenya showed no aortic lesions at all.

The most significant features of these findings in elephants are that, although it is quite the most difficult and expensive species to examine due to its sheer physical bulk, we have here an animal which shows an incidence of aortic sclerosis apparently related to a particular habitat or area, whose age can be fairly accurately estimated in years, whose individual range, feeding habits and food availability can be studied, and whose population density and reproductive capacity can be reliably estimated. Moreover, this is an animal not at present subject to severe conservation restrictions, and of which several thousand are shot annually on control and permit. It is a species in which we might, with further study, be able to find a correlation between the incidence of aortic lesions and one or more environmental factors.

Acknowledgments

In concluding this report, I should like to say what a privilege it is to do this work, and how utterly absorbing it is. My only fear is that, with growing nationalism, and political tensions in African independent territories, we may have difficulty later on in pursuing this work to its conclusion. At present, we have nothing but friendliness and co-operation for the project, and I think you will thus understand my eagerness to continue the field collecting as urgently as possible, while the personnels who have the information on the ecology of the various areas are still in Africa, and the game departments are still in a position to assist us.

APPENDIX 3

Case Report on "Sheila", Asiatic Elephant, Destroyed at the Belvue Zoological Gardens, Belfast, on 27th January 1966

History

"Sheila" was imported as a young calf to the Belvue Zoological Gardens from India or Burma. She was believed to be about 20 years old in January 1966.

During 1965, she had been losing condition, and on several occasions injured her keepers. Her hind-legs had become oedematous and then recovered. Sores had erupted on the dorsum, and she had developed a curious habit of turning up her trunk and blowing air against a partially healed lesion, about 3 ins. diameter, that had developed on the under-surface about two feet from its tip. She did this particularly when irritated. She had become difficult to handle and unreliable, and the Director of the Zoological Gardens had decided to have her destroyed.

The author spent the afternoon, prior to the administration of euthanasia in the stable observing the elephant and noted the following: (i) large pieces of undigested cut potato and apples were passed in the faeces; (ii) she continually returned to a loose piece of metal flooring, to which she bent down and rubbed her right tusk and cheek; (iii) she had the unusual habit of standing with her mouth partly open; (iv) she kept blowing air over the lesion on the trunk; (v) she was very emaciated.

<u>Euthanasia</u> (Abstract of report by the Veterinary Surgeon)

Euthanasia was performed inside the stable by first injecting Phencyclidine hydrochloride ("Sernylan", Parke-Davis, London) by means of projectile syringes fired from a Cap-Chur rifle (Palmer Chemical & Equipment Co. Atlanta, Georgia) and subsequently by intravenous injection of Pentobarbitone sodium ("Trinaven", Astra-Hewlett, Watford, Herts.) after the elephant was recumbent. This method has been previously used successfully by Manton(1963).

The animal's weight was estimated at 2½ tons, the total amount of "Sernylan" administered was 5.34 g or approximately 3.5 mg/kg., given in 4 separate injections, the first two syringes containing 1.67 g each, and the 3rd and 4th containing 1.0 g. each. The animal became recumbent 30 minutes after receiving the first large dose of the drug but had been ataxic for about 15 minutes before "going down".

The animal showed no reaction on cutting down to a vein at the base of the ear lobe, where - after blood samples had been taken - an intravenous injection of 210 grains of Pentobarbitone sodium was made. An additional dose of barbiturate, bringing the total dose to 445 grains (28.8 g.), was administered as there was still some very slow breathing. This proved sufficient, and the final total dose of barbiturate was thus 1.9 mg/kg.

Autopsy

The author's report (sent to the Director and Veterinary Officer in charge of the Belvue Zoological Gardens, as authorised by the Pathologist, The Zoological Society of London) follows:

"1. Malocclusion of the jaws, due to the formation of a large tumour on the buccal side of the right proximal molar (in the mandible) in wear, was the probable cause of generalised malnutrition. ~~A piece of wood, wedged between the opposing distal and proximal upper molars may or may not have been connected with the formation of the~~

~~tumour, but in any case~~ The tumour was probably of traumatic origin and had probably developed over a period of several years. A slight deformity of the proximal molar in the mandible, resulting from its abnormal growth, seems to have caused pressure on the nerve, undoubtedly causing pain, and hence the unreliable temper of the animal in recent months.

2. Blood

The reports on the detailed analyses are as follows:-

i) "Apart from a slight iron anaemia, this elephant appears to have a normal blood picture. As with all the elephants so far examined here, there is a higher percentage of lymphocytes than neutrophils. No parasites were found." (Miss S. Hook)*

ii) "Analysis of the serum by gas chromatography suggests a protein deficiency similar to that occurring as a result of malnutrition in Primates" (Biochemist)*

iii) "Compared with Primates, a well developed blood coagulation mechanism was found, similar to that obtained on two African elephants studied here." (Dr. C. Hawkey)*

(* Nuffield Institute of Comparative Medicine, The Zoological Society of London, Regent's Park)

3. Internal organs and skin

Lesions of the dorsal skin and distal end of the trunk, and a history of weakness in the forelegs, appear to be due to malnutrition. Failure to masticate hay and potato feed was evident from examination of stomach and caecum contents, and faeces. Congestion of adrenal glands, kidney and cardiac muscle was undoubtedly the immediate result of the technique used for destroying the elephant. Two minute, heavily calcified parasitic cysts found in the liver were considered to be of no significance, as no other parasites were found. Comparatively little reserve fat was found in any part of the body.

In conclusion, it seems that the declining condition and unreliable temperament of "Sheila" were due primarily to injury some years ago to the right mandible, resulting in the development of a molar tumour. This, in turn, prevented the normal forward progression of the lower molars along the mandible, and at the same time caused increasing malocclusion of the jaws. Inadequate mastication resulted in generalised malnutrition, while the deformed molar probably caused mandibular pain, accounting

/PLATES

for the unreliable behaviour of the animal.

Such tumours are familiar to those handling working elephants in Asia (Evans 1910). If the condition was recognised in time, it might be possible to correct it in a docile animal by removal of the distal molar, and, by use of the rasp, of the tumour on the proximal molar. This might enable the normal molar progression in the mandible to correct itself."

(sgd) S.K. Sikes,
Nuffield Institute of Comparative Medicine, London.
17th February 1966.

Subsequent findings

1) Details of the subsequent investigations of serum amino-acids are given in Table 7 , ch. 5. p.133.
2) Scattered, calcified intimal and medial plaques were found in the aorta, but intimal lipid deposits were negligible in the aorta, and absent in the coronary, carotid, brachial and femoral arteries.

References:

Manton, V.J.A.(1963). Vet. Rec. 75: 1223
Evans, G.H. (1910). "Elephants and their Diseases". Rangoon: Government Printer.

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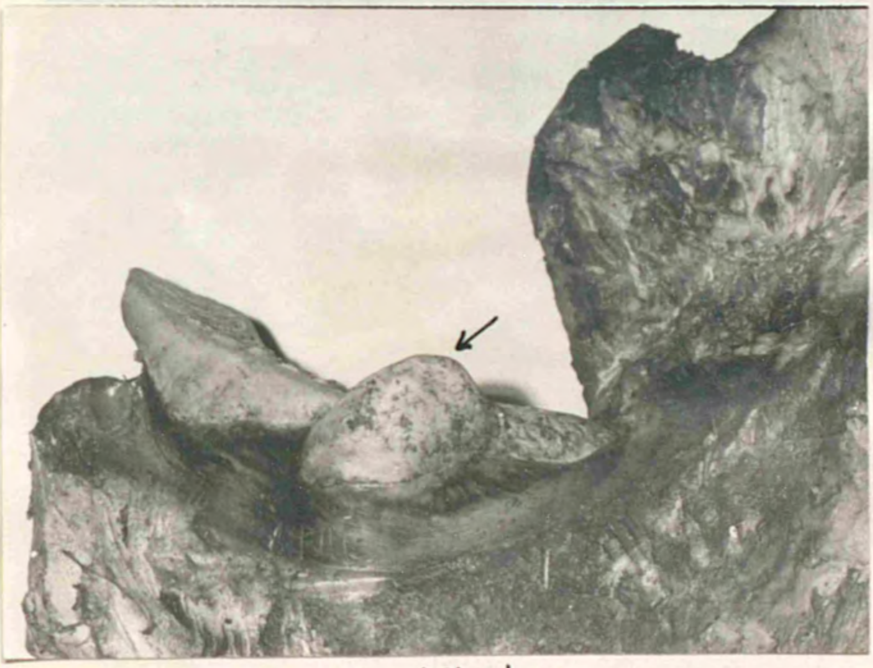
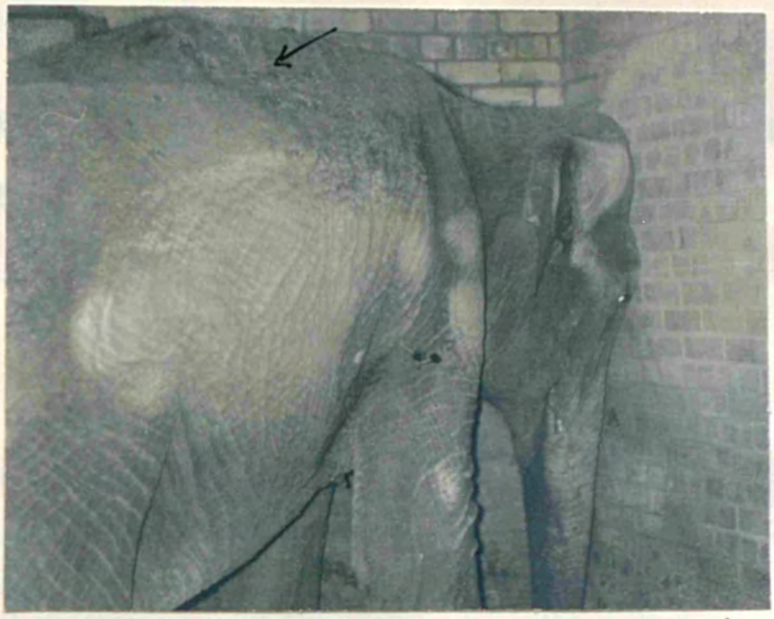


R. mandible of "Sheila"
(arrow: molar tumour)



'Sheila", with tranquillizer darts in right shoulder. Arrow shows poor condition of dorsum.

APPENDIX 4

OBSERVATIONS ON THE ECOLOGY OF ARTERIAL DISEASE IN THE AFRICAN ELEPHANT (Loxodonta africana) IN KENYA AND UGANDA

by

Sylvia K. Sikes

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Running Title: Arterial Disease in the African Elephant

Publication
The papers at the Symposium, together with their related discussions, will be published in 'Symposia of The Zoological Society of London,' and edited by Dr M. A. Crawford.

Read, and accepted for publication, on 11/xi/66.

OBSERVATIONS ON THE ECOLOGY OF ARTERIAL DISEASE IN THE AFRICAN ELEPHANT (*Loxodonta africana*) IN KENYA AND UGANDA

by

Sylvia K. Sikes *

Complete aortae, and samples of selected arteries, were recently collected for detailed study from forty African elephants (*Loxodonta africana*) in Kenya and Uganda. In every case a wide range of additional data was obtained, relating to the status of each individual elephant from which material was collected, and to its ecological background. These elephants were collected from three distinct habitat types, and a correlation is indicated between the occurrence of certain arterial abnormalities which have been found in the elephants, and ecological differences in the habitat types.

It seems possible that the effects of the modern human pressures, which frequently directly affect the vegetational cover, soil character and animal migrations in a given environment, may also indirectly influence

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* Department of Zoology, Royal Holloway College, University of London

the behaviour patterns and physiological rhythms of elephants. Such combined pressures may also result in nutritional imbalance, influencing Calcium and Lipid metabolism, and producing associated changes in arterial structure.

Contents:

I. INTRODUCTION

Forty wild African savannah elephants (<u>Loxodonta africana africana</u>) were collected for study in the course of a research project to investigate the incidence of cardiovascular disease in free-living wild mammals and birds.** The aim of this project was

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** financed by the British Heart Foundation.

to attempt to assess the susceptibility of free-living as compared with captive animals (Fiennes 1965).

In the case of the elephants, each was first observed alive in order to establish its individual ecological status, and then examined in detail *post mortem*. It was found that elephants are not only susceptible to cardiovascular disease in their natural environment, but that manifestations of cardiovascular abnormality appear to be related both in character and degree to differences in habitat type within the natural environment.

In the past, East African elephants are known to have undertaken long-distance, directional migrations, which may have covered several hundred miles annually during transitional seasons, in addition to their more localised meanderings during specific seasonal periods. Nowadays, however, closure of their long-distance directional migration routes and encroachment on forests, formerly used as feeding and calving grounds, has occurred due to the expansion of human settlement areas (Buechner, Buss *et al.* 1963; Bourlière 1965; Sikes 1966a). The elephants have therefore tended to become concentrated within national parks and game reserves, and their environs, to change their migratory, feeding and breeding habits, and in some cases probably also their herd structure and behaviour patterns (Buss & Smith 1966). It has also resulted in the comparative isolation of specific elephant communities, a situation which has been used here as the basis for defining the three habitat types from which the elephants examined in this project were collected.

The background study of the natural behaviour patterns and physiology of East African elephants is also rendered particularly confusing by the fact that the most detailed and accurate studies have been carried out only within the past decade and have generally been applied to elephants already partially adapted to comparatively restricted and rapidly degenerating habitat ranges (Buss 1963). The initial selection of the habitat types studied in this project was therefore deliberately made to include an unrestricted type, containing large areas of heavy natural vegetational cover in the form of well-watered, shady indigenous montane forests, in which the range was comparatively free as far as elephant herd movements were concerned, and which was not overpopulated by elephants.

II. MATERIALS AND METHODS

A. Selection of elephants

The collection of the elephants from which the material used in this project was obtained was to some extent selective, since random sampling would have been neither advantageous in the early stages of the study, nor feasible. First, it was necessary to select elephants representative of each of the main age groups, so as to study the normal growth and development of the heart and aorta; secondly, the selection of elephants showing definite signs of ill-health was necessary in the expectation of obtaining, among them, some showing arterial abnormalities; thirdly, principles governing game control and conservation necessitated strict limitation of the number collected, so that only those were killed which could be given a comprehensive autopsy with the minimum disturbance to other animals, and the minimum wastage of consumable and saleable products, as well as material of scientific value.

The actual number of animals examined is therefore unusually limited for a study of this kind, but it is believed that this approach is fully justified by the comprehensive range of reference data, and material of scientific interest collected, in addition to the actual cardiovascular material. The co-operation of other workers in specialised fields in the evaluation of this additional material has been much appreciated, and it is hoped that, in due course, all the material collected will be examined and evaluated.

B. Cardiovascular material

Routine body measurements and photographs were obtained prior to autopsy and, whenever possible, the carcass was weighed. The complete heart and aorta were then removed for immediate examination, measurement and photographs, and a standardised set of additional samples was taken comprising blood serum, selected arteries, tissues for histological examination, samples of stomach, caecal and rectal contents, material for age determination, and parasites. Any abnormalities were noted and portions of appropriate organs and tissues preserved for further study. A wide range of reference data and material was thus available in every case.

The aorta was cut into portions which were mounted in linear order on polythene boards. These were covered individually with protective perforated polythene bags and stacked in tanks for fixation in 10% formol-saline at the field base. Standardised samples of the following arteries were also mounted and fixed in the same way:- femoral, brachial, carotid, cerebral, coronary, superior mesenteric, coeliac and renal.

The heart was freed *in situ* from the pericardium and large vessels, leaving the aortic arch intact as far as the point of attachment on it of the *ductus arteriosus*. It was then removed, washed internally and externally with water, swabbed, weighed and photographed. A single continuous incision was made, running through the right atrium, tricuspid valve, right ventricle, and pulmonary arch, and a similar one through the left atrium, mitral valve, left ventricle, and aortic valve and arch, to permit an immediate internal examination. Coronary arteries were exposed and slit longitudinally for in situ examination, and samples removed for mounting as described above. In most cases only the portion of the heart containing the aortic valve, openings of the coronary arteries, and the aortic arch was preserved. However, four complete hearts were also preserved, including one weighing 14.5 kg. from a young, adult bull.

The evaluation of the cardiovascular material collected is still in progress. Results from two techniques already applied to the material may, however, be relevant to nutritional studies. In the first, gross staining of the whole aorta by Sudan IV was used to indicated the presence and extent of intimal lipid deposits (Holman, McGill et al. 1958), and in the second, X-ray techniques were used to indicate the Calcium deposits. In each method, the area of aorta wall containing the chemical deposit was then determined by making direct counts, using a grid of ½ cm squares laid over the aorta, and expressing the result as a percentage of the total area of the aorta wall.

III. DESCRIPTION OF THE THREE SELECTED HABITAT TYPES (Fig. I)

The three selected habitat types studied, from which the forty elephants were collected, were all located in East Africa. Each type did not necessarily consist of a single continuous area and in two cases comprised separate areas with similar ecological features. The geographical position of these is shown on the map, but the extent of each is indicated there only as a rough approximation.

A. Montane. Alt. 5,000-10,000 ft (m.1: Mt.Ruwenzori; m.2: Mts. Kenya, Kinangop and Satima; m.3: Mr. Kilimanjaro).

Each of the three areas of the montane habitat type contained extensive high-altitude indigenous forests, with a wide,free range for elephant movement and migration and abundant supplies of fresh, flowing surface water. Mean annual rainfall in all these areas exceeds 150 cm (Anon. 1962). In this habitat type, the elephants were also incidentally exposed to irregular disturbance and culling by licensed hunters and game control teams. The variety and abundance of nutritional material in these areas contrasts markedly to the limited range of fodder available to the elephants in the low grasslands and scrubland. Generally, a greater proportion of tree products (including roots, bark, woody fibre, foliage and fruit) is used in the diet, although bamboo is also much favoured as food in the areas where montane bamboo forest occurs.

Elephants in the montane areas characteristically spend most of the hotter periods of the day deep in the humid, shaded forest glades and thickets, feeding continuously, and emerging on to the high moorlands and open glades usually only in the evening, night and early morning. This behaviour also still characterises lowland elephants found in the few parts of Africa where unrestricted, natural tropical forests are still available to them. (Buss 1963; Risley 1966). It is also very noticeable how much more agile and active montane elephants are, and how much better their general physical condition, compared with those confined to the more restricted, over-browsed and shadeless lowland areas.

B. Grassland. Western Uganda; alt. 2,000 - 5,000 ft (g.1: Queen Elizabeth Park and environs; g.2: Murchison Falls National Park and environs)

The 'grassland' areas refer to those occurring in Western Uganda, typically dominated nowadays by Hyparrhenia grasses. Buechner and Dawkins (1961) have shown that the grassland, as seen today in the Murchison Falls National Park and its environs (g.2), really represents degenerate woodland, and now contains only a few relict trees and very small forest stands indicative of a former heavily wooded area, dominated by the genera Vitex, Terminalia, Combretum, Ficus etc. Mean annual rainfall for these areas is in the range of 100 - 125 cm, and abundant surface water occurs throughout the areas at all seasons. The transition from woodland to grassland is probably mainly due to the combined effects of fire, tsetse control clearance schemes, and the increasing concentation in recent years of elephant. These elephant have largely become non-migratory, insofar as they have been forced to abandon their former long-distance directional migrations by the closure of their migration routes, and have adopted a primarily graminivorous diet. (Buechner & Dawkins 1961; Buechner, Buss et al.1963; Buss 1961).

C. Scrubland. Tsavo National Park (East), Kenya, and environs. Alt. 500 - 5,000 ft.

This habitat type occurs in the Eastern Tsavo National Park and its northern and eastern environs. Nowadays it consists of degenerate *Commiphora* - *Acacia* mixed woodland (Bax & Sheldrick, 1963), typified by eroded undulating plains carrying a thin, irregular grass cover, in places interspersed with trees and thorny bushes. This scrubland type differs fundamentally from the Uganda grasslands, both geologically and hydrographically. It lies in the eastern drainage area of Kenya on a Pre-Cambrian Basement Complex. Most of this area consists of gently undulating plains, with a thin cover of pink or reddish sandy loam, interrupted at irregular intervals by extrusions of Tertiary and Quaternary volcanic rocks, which have assumed the form of characterful mounds and ridges with small accumulations of volcanic ash and pumice soils in the parts affected by weathering (Parsons 1928; Sikes 1934; Anon. 1962). The area is drained by only three permanently flowing, widely separated rivers, the Uaso Nyiro, Tana, and Athi-Sabaki-Galana, and their minor tributaries. Apart from these, the areas is characterised by the sparsity of naturally occurring surface water in the dry seasons and, as may be expected, carries a fauna comprising both arid-adapted and migratory species (Sikes 1966 c). Mean annual rainfall is between 25 and 75 cm only (Anon. 1962).

The rapid present-day transition in this area from woodland to shadeless grassland is due here, as in West Uganda, to the combined factors of fire, and continuous over-concentration of elephants. Here again, the concentration of elephants has resulted both from encroachment by human settlements on former forested calving and feeding grounds in the neighbouring coastal and montane areas, and by the closure of former migration routes. In this case, however, an additional, much more powerful, influence has been the introduction to the arid and semi-arid areas of artificial surface water supplies.

In the first instance, this was associated with the construction of the Mombasa-Uganda railway with its maintenance and refuelling halts situated every ten miles. At each halt, a large tank supplied by piped water was installed, with sleeve and spillage area, which soon attracted and 'held' a variety of wild animals. Secondly, it was due to the introduction of storage dams associated with the development of permanent villages and townships, and later with the development of the Tsavo National Park itself. Habitat destruction by elephants has become centred in the areas around these artificial watering points. In one case within the Park, devastation of almost all the ground within a 20-mile radius of the dam has occurred. Elephant feeding and drinking habits in this area tend to be very irregular, and continuous exposure to the sun often prolonged (Sikes 1966c).

IV. DESCRIPTION OF ARTERIAL ABNORMALITIES OBSERVED, AND THEIR OCCURRENCE IN RELATION TO HABITAT TYPE

A. Relative age, and age grouping in relation to

normal cardiovascular structure and development

One of the primary objectives in the present investigation has been to try to establish the normal structure and development of the aorta and coronary arteries, and to see whether any apparent abnormalities show a relationship to the ageing process and/or the ecological background.

The relative age of an African elephant may best be assessed on the basis of molar eruption, which is unique in character in the Proboscidea. In the African elephant, a linear progression of six molars moves distally (anteriorly) along each half-jaw. In each mandible the complete linear series of molars consists of a potential total of 57 laminae. As each lamina reaches a position above the foramen mentale of the mandible, its roots are resorbed, and the crown becomes liable to fragmentation. The potential maximum life span of the African elephant thus has a possible 57 laminary increments. The relative age of an African elephant may therefore be described either by direct reference to the number of the individual lamina situated above the foramen mentale of the right mandible (Table I, column 3), or by reference both to the relevant molar and the number of its own lamina then positioned above the foramen mentale (Table I, column 2), (Sikes 1966b).

No uniform system of age grouping, as used generally in ecological studies, has been satisfactorily applied up to the present time in the case of African elephants. This is probably due to the lack, in the past, of a specific and reliable field ageing technique. It is convenient to describe African elephants in terms of molar age groups. From the ecological, behavioural and economic aspects, however, it is undoubtedly more realistic to follow the natural social age groups which typically occur in gregarious species having a highly developed community structure. A naturally occurring social age group system found in wild elephant communities, compared with molar age groups, is indicated in Table I, column 1.

From measurements made at autopsy on aortae in situ, and subsequent comparative measurements on fixed material, it was found that the normal aorta is about 35 cm long just before birth, 170 cm in a large, fully grown bull of 340 cm shoulder height, and 130 cm in a fully grown cow of 260 cm shoulder height. The normal ratio of the internal circumference of the lumen at the attachment scar of the ductus arteriosus to that just distal to the renal arteries in a young calf is 0.7, and in an adult animal 0.6. Infestigations of the detailed histology of the normal aorta in different age groups is still in progress.

Triangular fibrous reinforcement plaques occur in all the normal elephant aortae available. These lie just distal to the ostium of each branch artery and are readily visible to the naked eye on the intimal surface, usually having a slightly paler colour than the adjacent intimal surface in the fresh aorta. In these reinforcement plaques, both the intima and the media are thickened and more fibrous than the neighbouring areas. In all calves and juveniles examined, sudanophilic material was abundant within, and confined to, these reinforcement plaques. This was also true of the montane specimens (with the exception of the young lactating cow, specimen No.100) of the adult age groups. It seems reasonable, therefore, to suppose that the presence of sudanophilic material within the intima of these reinforcement plaques is typical of the normal elephant aorta.

With a single exception (specimen No.132), no calves, and juveniles at all, or montane specimens of any age group, contained any deposits of Calcium either in the tunica intima or the tunica media, directly detectable visually, or by the histological or X-ray techniques used, up to the present stage in this investigation. Incineration techniques cannot be applied to the available specimens until the other investigations on them have all been completed. Specimen 132 was a young bull collected from an area marginal to the montane habitat type, bordering on scrubland, and may be a transitional case. Even specimen 152, an older bull, in molar age group V, taken in a true montane habitat, had no detectable aortic Calcium deposits. Unfortunately, elderly bulls are rarely obtainable for study in unrestricted montane hunting zones, having been almost entirely shot out for the ivory trade.

B. Abnormalities found in the aortae examined

i) Congenital abnormalities

Very few congenital abnormalities were observed in the aortae examined. In one case the coeliac and superior mesenteric arteries (specimen No.121),in another both renal arteries (specimen No. 84) had a common origin in the aorta. In several cases, variations in the position of the ostia of the vertebral arteries in the dorsal wall of the aorta were noted. One condition, frequently but not invariably, found was an irregular degree of fenestration in the cusps of the aortic and pulmonary valves of the heart. Detailed examination of these is not complete, and it is not clear whether these may have any effect upon blood flow in the coronary arteries and the aorta.

ii) Aortic lipidosis

As indicated above, the presence of sudanophilic material within the tunica intima of the fibrous reinforcement plaques of the elephant aorta appears to be normal. However, all the specimens collected from scrubland and grassland habitats also had sudanophilic material distributed in areas of the intima additional to the fibrous reinforcement plaques. The exact location and percentage area of the aorta wall containing sudanophilic material in cases also showing heavy Calcium deposits was difficult to assess accurately, but areas containing sudanophilic material generally seemed to be less clearly defined than in cases with low Calcium percentages.

Sudanophilic material was generally abundant in well-defined areas in lactating cows, the Sudan IV stain assuming a more orange-red colouration than in other specimens. The only cow collected in advanced pregnancy had a strikingly high lipidosis of the aorta, of an order only found otherwise in the very senile and decrepit old cow, No.107. It is possible that this represented a combination of factors relating to the pregnancy itself as well as to an additional aortitis of unknown aetiology.

In some cases, a condition resembling atheroma, characterised by the presence of fibrous 'buttons', 'streaks' and larger plaques, often also containing sudanophilic material, and sometimes overlying intimal and medial Calcium deposits, also occurred in elephants from the scrubland and grassland habitats. In a few of these cases some extensive plaques also occurred, presenting a 'pearly grey' appearance in the fresh aorta, often described as typical of a true atheromatous plaque (Bertelsen 1963).

One cannot escape the impression that the orange-red staining, typically found in the aortae of the lactating cows, may represent a specific type of lipid deposit, perhaps of a temporary nature. This point, however, would only be elucidated by a detailed biochemical analysis of the intimal lipids in the different types of plaque.

Yet another characteristic type of plaque, found in the aortae of elephants from both scrubland and grassland habitats, contained sudanophilic material associated with the presence of Calcium and resembled similar plaques seen in the aortae of other species of ungulates, and usually associated with the presence of migratory parasitic worms. In two of the specimens from the grassland habitat (Nos. 21 and 23) parasitic nematode worms thought to be Toxascaris elephantis were located in the ventral adventitia of the thoracic aorta, but none has yet been conclusively located or identified within the media or intima of an elephant aorta.

These findings seem to suggest that the deposition of limited amounts of sudanophilic material in the aortic intima of the African elephant takes place as a normal occurrence within the fibrous reinforcement plaques, and that some increase in sudanophilic deposits, possibly associated with a reversible biochemical change, may also be a normal occurrence during the period of lactation. On the other hand, an extensive distribution of intimal sudanophilic material in fibrous and calcified 'buttons', 'streaks' and'plaques' seems to be abnormal, the lesions falling into three fairly distinct types, namely those resembling human atheroma, those resembling lesions associated in other species with the presence of migratory parasitic worms, and those apparently resulting from an aortitis of unknown aetiology.

The scattergram, Fig. 2, indicates the cases in which an increase in lipidosis occurred during lactation.

iii) Calcium deposits in the tunica intima and tunica media of elephant aortae

No Calcium deposits were detectable by the methods described here in the aortae of any of the calves, juveniles, or montane elephants collected, with the exception of specimen No.132 mentioned above.

In most of the Calcium-positive aortae, the Calcium deposits within the aorta followed a consistent pattern of development. Deviations from this pattern, however, occurred in a few cases, where the shape and arrangement of the plaques showed some resemblance to aortic plaques found by the author in other species of East African ungulates to be associated with the presence of migratory parasitic worms. Particular examples are the filariid worms Elaeophora poeli (Sandground 1938; Dinnik, Walker et al.1963) and Onchocerca armillata (Yamaguti 1963; Chodnik 1957; Clarkson 1964).

In Fig. 3, the percentage area distribution of Calcium deposits in the combined media and intima of the aortae of the elephants examined is shown to be markedly higher in the grassland than in the scrubland habitat. Detailed analyses of intra-aortic area distribution of Calcium tend to confirm the indication that all adult elephants from the lowland habitats studied are susceptible to some degree of Caclium deposition, but that this occurs to amuch greater degree in the Uganda grassland habitat type.

Although the author was unable to detect any recognisable signs indicative of a condition of high aortic lipidosis by long-range observations on the living, wild animal, such signs were evident in the case of elephants with advanced Calcium deposition in the aorta. Such elephants are markedly immobile and sluggish and tend to stand with the head drooping forward from the shoulders. The skin of the dorsum usually appears to be particularly keratinous and dry, with the ridge prominent, and the quarters 'falling away'. Often there is general emaciation. When disturbed, such elephants often appear to be aggressive and irritable, but rarely seem to react with sustained vigour. The appearance of such animals often suggests premature senility.

Measurements of the aortae containing Calcium deposits show that there is a startling constriction of the lumen even in the early stages of calcification and in advanced cases an almost total loss of elasticity. The ratio of the internal circumference of the lumen at the attachment scar of the ductus arteriosus to that distal to the renal arteries was found in two cases to be only 0.4. The posterior portions of the aortae of these specimens (Nos. 18 and 93), both from the Uganda grassland habitat, resembled rigid pipes when removed fresh from the carcasses at autopsy. In the most advanced cases, total occlusion of some of the ostia of the vertebral arteries was found, as well as partial occlusion in a few cases of the ostia of the testicular, ovarian, renal and common iliac arteries.

In no case has Calcium been detected within the coronary arteries of these specimens, but a marked narrowing of the coronary ostia occurred in specimens Nos. 93, 18, 21 and 86, with some loss of elasticity in the aortic arch. Calcified plaques were also located within the carotid, brachial, common iliac and femoral arteries in a number of cases. The hearts of some specimens with advanced Calcium deposition were noticeably larger and more flaccid, but lighter in weight than hearts from other elephants of comparable size and age. It seems possible therefore that advanced arterial calcification of this type may impair circulatory efficiency.

Although no evidence is available as to whether thrombi ever occur in the blood-vascular system of the African elephant, a case of fatal coronary insufficiency has been described in a captive female Indian elephant (Lindsay, Skahen et al. 1956). The naturally occurring deaths of two African elephants, supposedly due to cardiac failure, were witnessed independently by Senior National Parks Officers, in grassland areas, and described in detail to the author. It is possible that these cases could be attributed to coronary insufficiency associated with advanced arterial calcification. It is also possible that the condition could, in a very heavily affected elephant population such as that occurring nowadays in the Murchison Falls National Park and environs, bring about an overall reduction of potential longevity.

V. CONCLUSIONS AND DISCUSSION

From the intitial investigations made on the cardiovascular material available from the forty African elephants recently collected, it is apparent that sudanophilic material in the aorta, confined to the areas of fibrous reinforcement plaques, occurs normally in elephants from all types of habitat. The occurrence and distribution of sudanophilic material in other areas of the aortic wall of the elephant, however, appears to vary in character. No specific factor related to the habitat can at present be suggested as showing a direct connection with the presence of these abnormal fatty plaques, beyond noting their absence (except during lactation) in montane elephants.

The deposition of Calcium in the elephant aorta, however, appears always to be abnormal. When it occurs, it usually develops in a distinctive distribution pattern common to elephants collected both from grassland and scrubland habitats, but differing markedly in degree in comparable age groups from the two habitats, advancing much more rapidly in the grassland elephants, and apparently considerably reducing their mobility and potential longevity.

In attempting to suggest an environmental factor which might be directly or indirectly correlated with the ecology of this Calcium derangement in elephants, nutritional factors would seem to be obviously important. The almost total lack of arboreal products such as fruit, bark, woody fibre and foliage in the diet of the grassland elephants might suggest a mineral and/or vitamin deficiency or imbalance indirectly affecting Calcium metabolism (Cameron 1964; Abraham 1964; Sodeman 1961). The change from a mainly arboreal diet to an almost exclusively graminivorous one might have caused a significant change in the relative levels of Calcium and Phosphorus directly available in the diet (Bax and Sheldrick 1963); or perhaps the almost complete restriction of these elephants to the environs of reserve and park areas may have denied them their former direct access to essential mineral supplies in salt licks on the migratory routes.

The mineral contents of water supplies may also differ in the different habitat types, but, although this may be important (Sodeman 1961), they have not yet been chemically investigated in this context.

However, the most striking single ecological feature obviously differing in the three habitat types from which the elephants in this study were collected is the degree to which indigenous forest cover still exists.

Elephants in the montane habitats still live in conditions which have probably been natural to them for centuries. Fodder consists predominantly of arboreal browse and chew, and exposure to direct sunlight is limited, the warmer parts of the daytime being spent in the cool forest glades. Calving is confined to the privacy of the cool forest depths, and calves are never subjected to long periods of exposure to the sun during treks to and from watering points or feeding grounds.

The denial of access by elephants to unspoiled indigenous forest areas, and confinement to the limited areas available in the environs of lowland reserves and parks results in abnormal pressure on fodder supplies. Trees are felled and stripped of bark, foliage and fruit, with the consequent reduction of available shade, and remaining forest stands are progressively destroyed. The elephant community structure is upset through overcrowding due to the reduction of available ground space and closure of migration routes; and such elephants often indulge in frustrated aggressive behaviour resulting in apparently wanton habitat destruction.

If uncontrolled firing of the bush also occurs, as it does every year in both the Uganda grassland and the Tsavo scrubland, the situation is aggravated yet further and, as previously mentioned, in the Tsavo scrubland the over-concentration of elephants is also particularly high around artificial water supplies.

With excessive exposure to the sun, the skin becomes abnormally dry, a condition also particularly associated with heavy aortic calcification (Abraham 1964). The elephants attempt to alleviate this situation by the repeated use of mud-therapy, by wallowing and then powdering the skin with dry dust, but as the 'mud-pack' dries and cracks the irritation recurs, and they constantly rub against the few remaining tree trunks, thus effectively ring-barking and killing them. This behaviour contrasts, both in the degree to which it occurs and its effect on the trees, with that of elephants in natural montane habitats.

Habitat destruction has advanced so far in the Uganda grassland environment that some elephants suffer almost constant, year-long daytime exposure to the sun. In the Tsavo scrubland the change is as yet incomplete but is advancing rapidly towards a similar situation. (Bourlière 1965). It is impossible to overlook the implication here that prolonged exposure to direct sunlight may have particular significance, especially in relation to the derangement of Calcium metabolism indicated in the elephants studied, in the progressive deposition of Calcium in the aorta wall. Hypervitaminosis D is known to be directly associated with aortic Calcium deposition in mammals (Sodeman 1961; Abraham 1964; Cameron 1964), and it may therefore be supposed that excessive exposure to sunlight, of a species normally shade-adapted, could be associated with the occurrence of aortic Calcium deposits. Length and periodicity of exposure to light, however, are also known in certain species of mammals and birds to be correlated with seasonal and migratory rhythms, and associated endocrine changes (Rowan 1925; Farmer 1955; Delost 1960; 1962; Thomson 1964).

Although a distinct ecological correlation is indicated by the findings of this pilot study on wild African elephants between cardiovascular disease patterns and environment, data are still inadequate to suggest whether an explanation for this correlation should be sought in the direct effects of prolonged exposure to sunlight on metabolism; the indirect effects of light stress on the endocrine system; stress set up by a combination of overpopulation and the frustrated migratory habit; or simply the balance and availability of essential nutrients in the diet.

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/Acknowledgments

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/Plates

PLATES

I. Viewof the internal surface of the dorsal aspect of portions of the aortae of four African elephants

1. Portion of thoracic aorta of montane bull elephant, M.132, showing the position of reinforcement plaques (rp) but no detectable abnormality.

2. Portion of thoracic aorta of an elderly scrubland bull elephant, M.116, with no detectable abnormal deposits of Calcium or sudanophilic material, but showing a distinctive wrinkling of the intimal surface,seen in several elderly bull elephants and thought to occur in the normal thoracic aorta, typically associated with old age.

3. Portion of abdominal aorta of a lactating cow elephant from scrubland habitat, M.131, showing early calcification (c) associated with the presence of extensive raised plaques containing heavy deposits of sudanophilic material (s). Slight occlusion of the ostium (o) is evident.

4. Portion of the abdominal aorta of the very elderly scrubland cow elephant, M.107, showing a crescentic rod of organised Calcium deposits rsembling bone (c), lying just proximal to the bifurcation.

(Plates)

Heavy intimal deposits of sudanophilic material (s) are evident in the vicinity of the calcareous rod.

II. View of the internal surface of the dorsal aspect of portions of the aortae of four African elephants.

1. Portion of the thoracic aorta of a grassland bull elephant, M.18, showing advancing calcification with the deposition of large discs of intimal and medial Calcium (c) and a severe reduction in the diameter of the ostium of a branch artery (o).

2. Portion of the abdominal aorta of a grassland bull elephant, M.93, proximal to the origin of the renal arteries, causing rigidity and severe narrowing of the aorta, and very advanced occlusion of the ostia of branch arteries (o).

3. Portion of the abdominal aorta of the grassland bull elephant, M.93, showing the exceptionally large and heavy Calcium deposits (c) with associated, diffusely distributed sudanophilic deposits (s).

4. Portion of the abdominal aorta of the grassland bull elephant, M.93, showing advanced occlusion of two ostia of dorsal branch arteries (o), and the total occlusion of the two others (to) in the vicinity of the origin of the renal arteries.

TABLE I

TABLE OF AORTIC CALCIUM & LIPID DISTRIBUTION

Molar Age Group & approx. Status in Herd	Laminary Age	Laminary No. ∅	Spec. Ref. No.	Sex	Habitat Type+	Ca.% (area)	Lipid% (area)	Notes
Foetus	I/0	0	154	m –	– S –	0	0	Near-term
I – II Calves	I/0-1	0.5	135	– f	– – M	0	26.1	
	I/1	1	114	– f	– S –	0	11.4	
III Juveniles	III/3	15	113	m –	– S –	0	7.1	
	III/4	16	133	– f	– – M	0	2.8	
	III/7	19	103	m –	– – M	0	2.3	
IV Sub-Adults	IV/2	24	134	m –	– – M	0	3.6	
	IV/2	24	110	m –	– S –	2.2	6.7	
	IV/2	24	23	– f	G – –	8.2	8.5	early preg.
	IV/2	24	100	– f	– – M	0	8.8	lactating
	IV/2	24	25	– f	G – –	14.0	7.7	
	IV/5	27	83	m –	– – M	0	3.7	
Prime Adults	IV/6	28	99	m –	– – M	0	3.5	
	IV/7-8	29.5	132	m –	– – M	1.9	5.9	
	IV/7-8	29.5	112	– f	– S –	3.3	13.0	lactating
	IV/7-8	29.5	85	m –	G – –	17.2	9.7	
	IV/8-9	30.5	87	m –	G – –	14.4	10.1	
	IV/8-9	30.5	149	m –	– S –	5.0	14.1	septic tusk
	IV/9	31	150	m –	– S –	11.3	9.0	
	IV/9	31	118	m –	– S –	4.3	7.1	
V	V/1	33	22	– f	G – –	46.8	9.6	
	V/1	33	24	– f	G – –	36.8	8.6	
	V/2	34	19	m –	G – –	60.5	12.7	
	V/2	34	88	– f	G – –	17.0	13.2	lactating
	V/2	34	152	m –	– – M	C	2.5	
	V/5	37	131	– f	– S –	6.5	17.6	lactating
	V/5	37	127	– f	– S –	9.7	34.1	full-term preg.
	V/6	38	84	m –	G – –	27.6	11.7	
Senior Herd Leaders	V/7	39	93	m –	G – –	65.0	9.4	very poor condition
	V/7	39	119	m –	– S –	5.0	15.4	Aortitis
	V/7	39	120	m –	– S –	1.7	7.6	
	V/7	39	108	m –	– S –	3.7	8.6	
	V/8	40	21	– f	G – –	44.4	10.4	
	V/9	41	18	m –	G – –	57.8	7.1	
	V/9-10	41.5	116	m –	– S –	5.7	6.9	
	V/11	43	117	m –	– S –	3.6	21.5	Tusk disease & aortitis
VI	VI/1	45	86	m –	G – –	39.4	8.2	gen. septicaemia
	VI/1-2	45.5	121	m –	– S –	2.5	13.9	aortitis
	VI/4	48	122	– f	– S –	9.7	17.2	lactating
Lone & senile	VI/8	52	107	– f	– S –	20.7	42.7	senile
Absolute limit of life span	–	57	–	–	–	–	–	

x Deposit-containing area of aorta wall is expressed as percentage of wall of whole aorta.

∅ Actual lamina, out of total sequence of 57, situated above foramen mentale of rt. mandible.

\+ G: Grassland; S: Scrubland; M: Montane.

TABLE II

Mean aortic area percentages containing Calcium deposits in two molar age groups in the three habitat types

Molar Age Group	Grassland	Scrubland	Montane
IV	13.4	5.2	0.3
V	44.5	5.1	-

* * * * * * * * * * * *

11/11/66

FIG. 1.

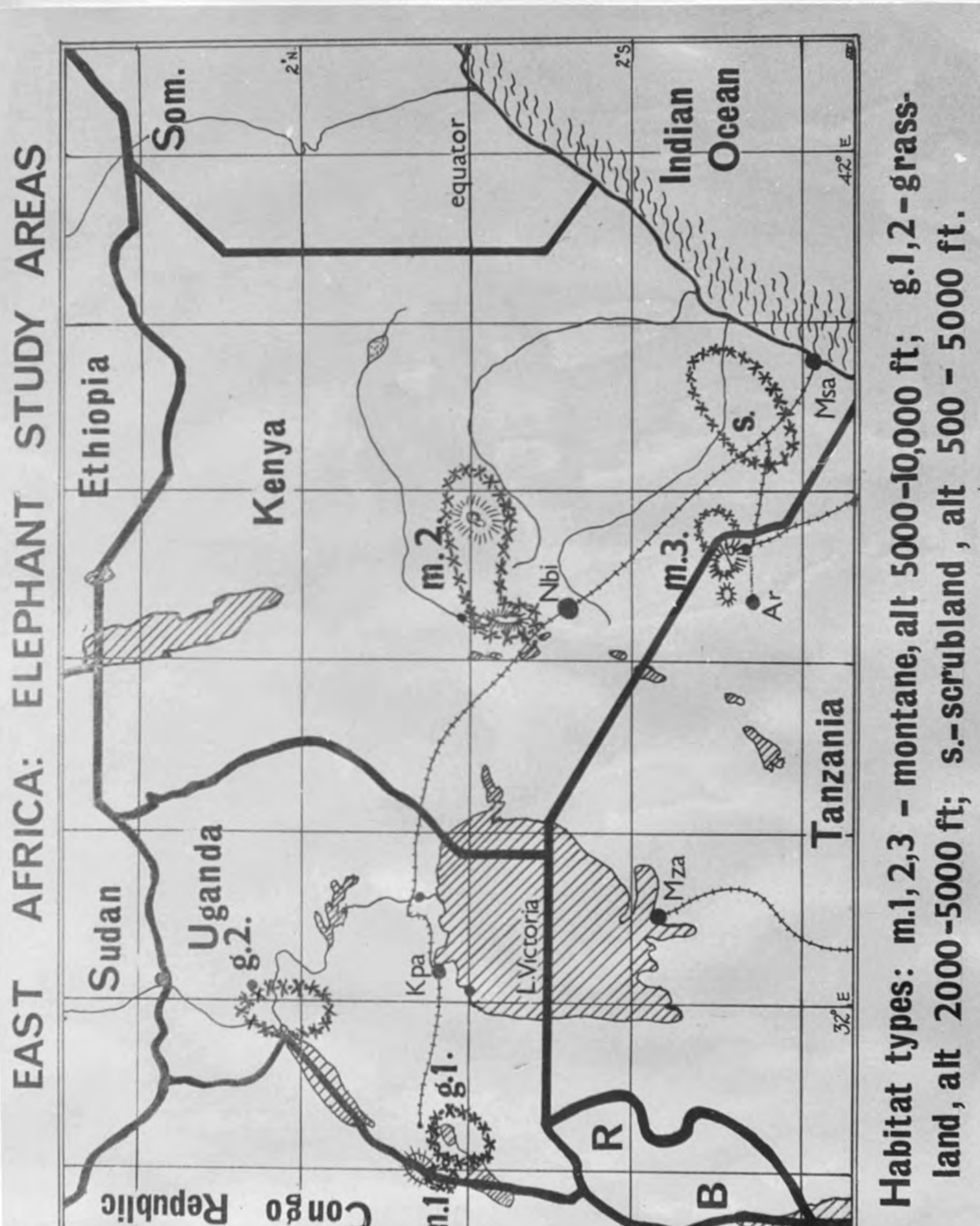
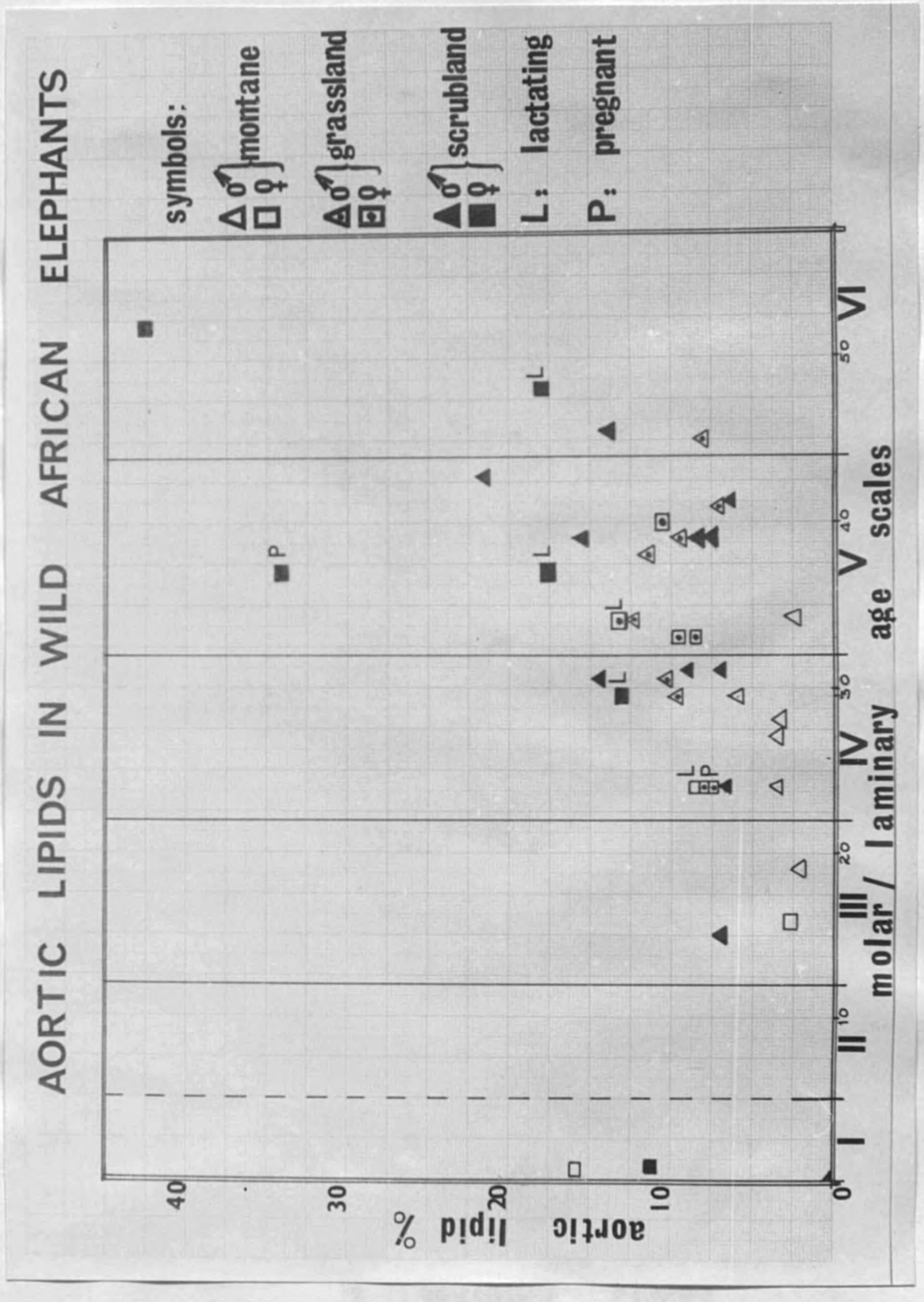

EAST AFRICA: ELEPHANT STUDY AREAS
Sudan
Uganda
g.2.
Ethiopia
Som.
Kenya
Congo Republic
m.1
g.1.
Kpa
L.Victoria
Mza
R
B
Tanzania
m.2
Nbi
m.3.
Ar
s.
Msa
equator
Indian Ocean
2°N
2°S
32° E
42° E
Habitat types: m.1, 2,3 - montane, alt 5000-10,000 ft; g.1,2-grassland, alt 2000-5000 ft; s.-scrubland, alt 500 - 5000 ft.

FIG. 2


AORTIC LIPIDS IN WILD AFRICAN ELEPHANTS
symbols:
♂ ♀ montane
♂ ♀ grassland
♂ ♀ scrubland
L: lactating
P: pregnant
aortic lipid %
0
10
20
30
40
I
II
III
IV
V
VI
molar / laminary age scales

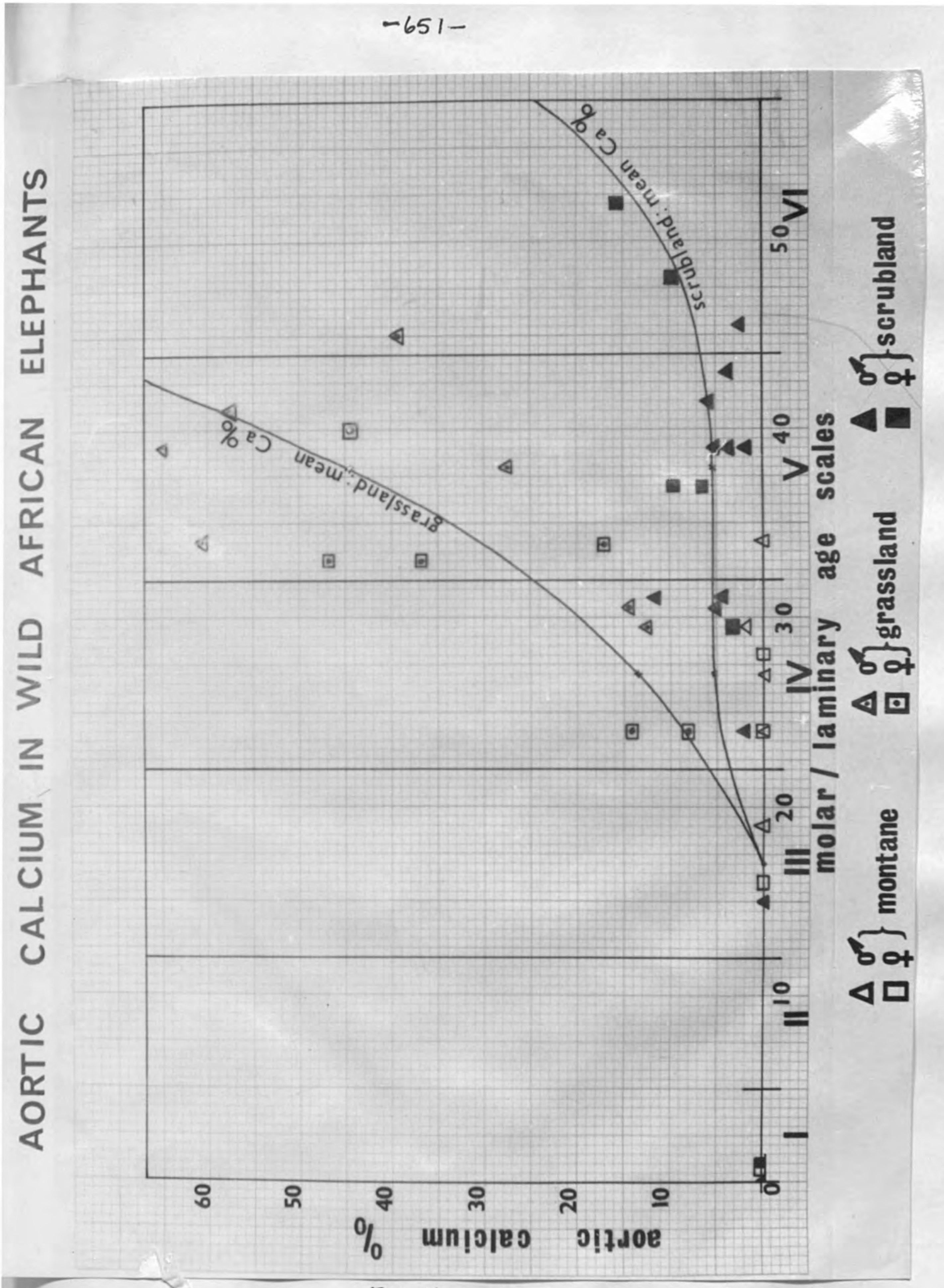
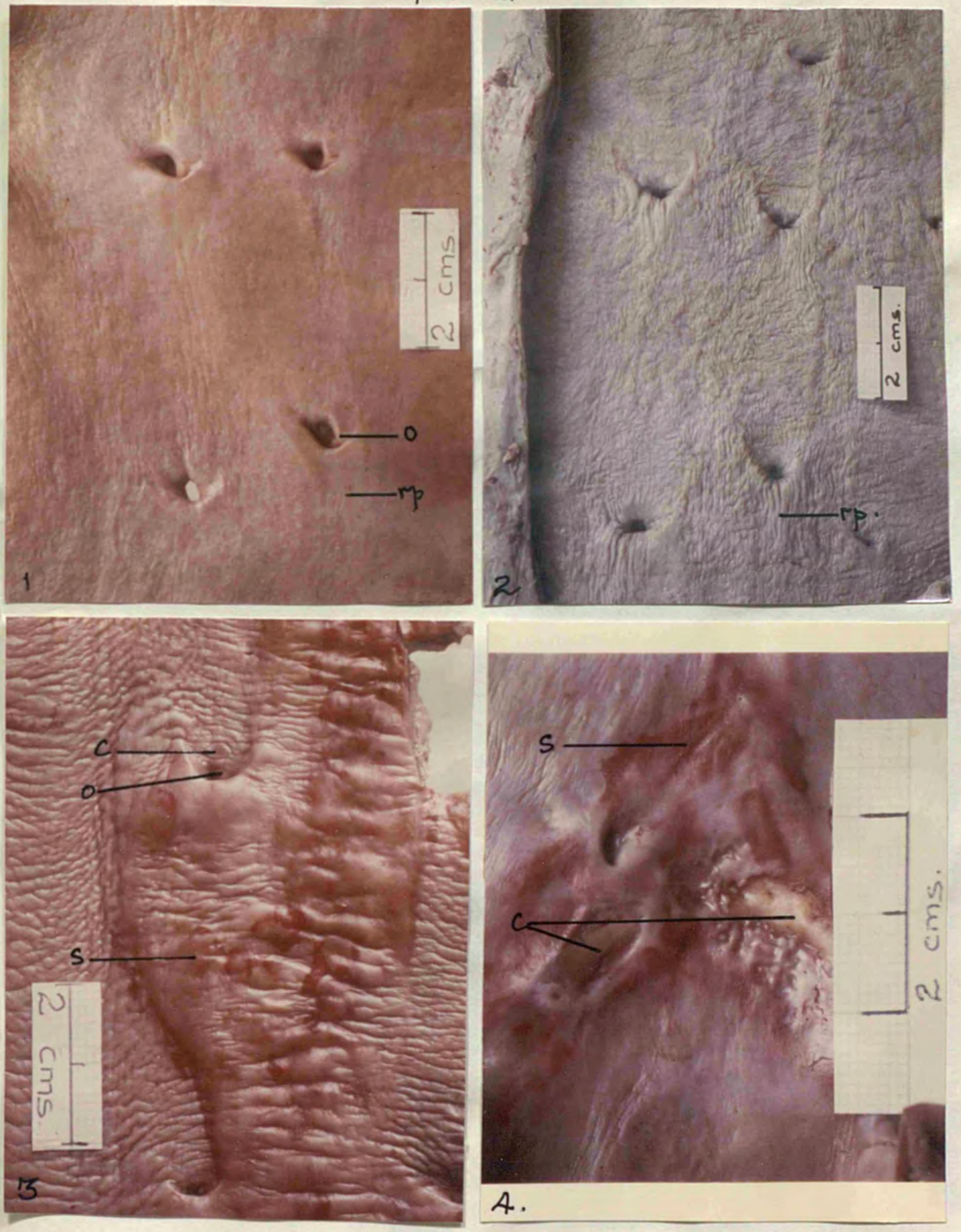

AORTIC CALCIUM IN WILD AFRICAN ELEPHANTS
aortic calcium %
60
50
40
30
20
10
0
grassland: mean Ca %
scrubland: mean Ca %
I
II 10
III
20
IV
30
V
40
50 VI
molar / laminary age scales
♂ ♀ } montane
♂ ♀ } grassland
♂ ♀ } scrubland

FIG. 3.

PLATE I

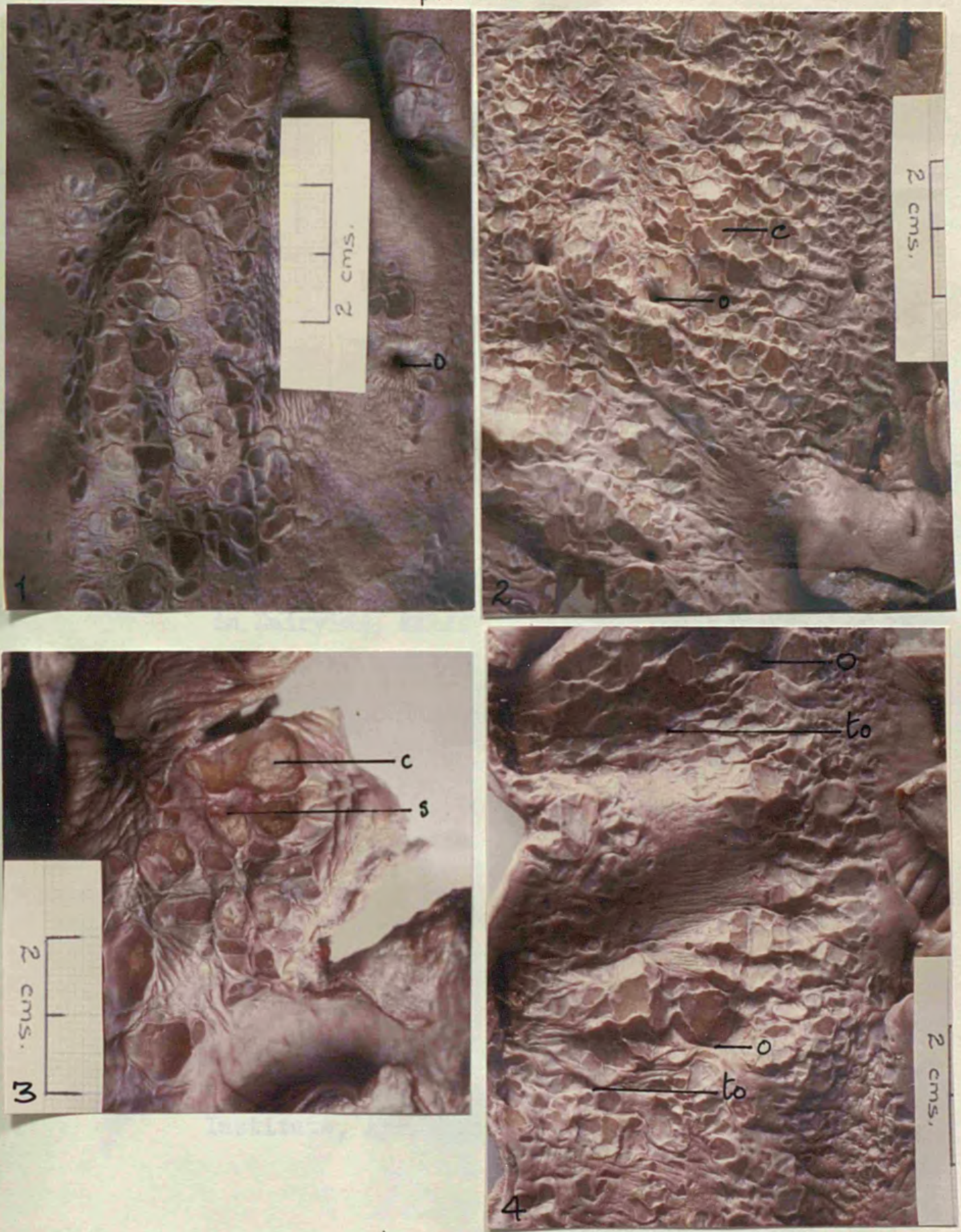
proximal



distal.

PLATE II

proximal.



distal.

THE SERUM AND ADRENAL LIPIDS

OF THE AFRICAN ELEPHANT, *Loxodonta africana*

by

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THE SERUM AND ADRENAL LIPIDS OF THE AFRICAN ELEPHANT (Loxodonta africana)

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Comp. Biochem. Physiol.

The serum and adrenal lipids of the African elephant were analysed by silicic acid chromatography and gas-liquid chromatography. The results obtained were compared with the results reported in the literature for other species. The cholesterol esters and phospholipids of elephant serum contained appreciable concentrations of $\Delta^{8, 11, 14}$ eicosatrienoic acid. The total lipid content of the elephant adrenal gland was particularly high and cholesterol esters accounted for about half of the adrenal lipids. $\Delta^{8, 11, 14}$ eicosatrienoic acid was also present in appreciable amounts in the adrenal cholesterol esters and phospholipids.

THE SERUM AND ADRENAL LIPIDS OF THE AFRICAN ELEPHANT, *Loxodonta africana*

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Abstract - 1. The serum and adrenal lipids of the African elephant were fractionated by chromatography on columns of silicic acid into cholesterol, cholesterol esters, triglycerides, unesterified fatty acids and phospholipids. The fatty acid compositions of the various lipid fractions were determined by gas-liquid chromatography.

2. The results obtained for the African elephant were compared with the results reported in the literature for other species of mammals. In many respects the composition of the serum lipids of the African elephant was similar to that of the rat and rabbit but was markedly different from that of the ox and man.

3. Unlike the serum cholesterol esters and phospholipids of other animals, these two lipid fractions in the serum of these elephants contained appreciable concentrations of $\Delta^{8,11,14}$ eicosatrienoic acid.

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4. The total lipid content of the African elephant adrenal gland was particularly high (63% of the dry tissue). Cholesterol esters accounted for almost half of the adrenal lipid. $\Delta^{8, 11, 14}$ eicosatrienoic acid was present in substantial amounts in the adrenal cholesterol esters and phospholipids.

INTRODUCTION

In the course of a research project currently in progress for the investigation of the incidence of cardiovascular disease in free-living wild animals*, for comparison with recent findings in captive wild animals (Finlayson, Symons & Fiennes 1962; Fiennes 1965; Finlayson 1965) the African elephant, Loxodonta africana, was found in certain localities to be susceptible to a condition resembling atherosclerosis. In semi-restricted habitats, such as national parks and their neighbourhood, with high-density elephant populations, the incidence of the condition was high, whereas in unrestricted habitats containing low-density elephant populations the incidence was very low.

Meaningful interpretation of the cardiovascular disease patterns seen in those African elephants and their correlation with one or more environmental factors must depend upon the possession of adequate general background data both on the biology of the species itself, and on the ecology of the particular habitats studied. It has been possible, during the present project to obtain abundant background data on forty elephants of both sexes and representing the main ~~all~~ age groups of the potential life span of the species, and also from 3 contrasted habitats. From these data it is hoped to determine firstly the normal structure and development of the blood vascular system and of the blood chemistry, and secondly to identify any deviations from the norm in the forty elephants ~~being~~ studied.

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* Financed by the British Heart Foundation

The analysis of serum lipids from the blood of five of these African elephants and adrenal lipids from a sixth are described here and the ~~very interesting~~ results are discussed, and compared with the results of similar analyses made for other species of mammal.

MATERIALS AND METHODS

(a) Animals and field collection of material

The African elephants used in the current study on cardiovascular disease were shot in Uganda and Kenya during the period 1964-5, and in every case examined in considerable detail post mortem in the field. Consistent body measurements, gross samples of the main organs, ecological data, and standardised samples for histology and histochemistry, as well as blood serum, were routinely collected for further study. In addition, the adrenal glands of one elephant were specially extracted from the freshly-killed carcass in the minimum time possible and frozen down for subsequent lipid analysis.

The method used for the collection of blood, and the separation of serum from the five elephants of which the lipid analysis is described here, was determined after testing different methods in the field with varying degrees of success. The successful collection of blood from shot animals depends to a large extent upon the type of bullet used, and its site of entry and passage into the body. Initially therefore it was necessary to determine experimentally the best method of killing the animal.

Since the use of the tranquillizer dart technique was not practicable in the prevailing circumstances, the specimens were shot using a heavy-calibre sporting rifle. It was found that the use of a solid, angle-tipped bullet fired into the brain ensured the collection of adequate quantities of blood and the separation of clear serum. This method had the added advantage of causing instantaneous death, so that no reactions to sudden stress resulting from fear or pain occurred, and the adrenal glands were apparently quite unaffected. Moreover if the "temple shot" was used even the pituitary gland, as well as the main arteries supplying the brain, were undamaged.

Since an elephant shot in the temple usually falls towards the rifle, and the <u>post mortem</u> examination is best performed with the left flank uppermost, the majority of elephants collected were shot from the right. As the veins of the ear often collapse at death, these were usually ignored for purposed of blood collection, and the blood was ~~usually~~ collected from the left jugular vein.

The jugular vein is very thick and elastic in the elephant, and sited deeply in the neck, but is readily exposed by dissection with ~~means of~~ a scapel fitted with a large detachable blade. Withdrawal of blood was best performed by inserting a polythene tube of about 5 m.m. diameter into a small incision in the vein, and directing the blood flow through the tube into the blood bottles. The collection of blood could usually be completed within fifteen minutes of the death of the elephant.

The blood bottles (the straight-sided polythene type, without shoulders, was found to be very suitable) were allowed to stand undisturbed in the coolest place available, and the clots freed in due course from the walls by means of a glass rod. As soon as adequate serum had separated, it was drawn off by means of disposable syringes and transferred to polystyrene tubes which were immediately placed in the central compartment of a 3-tier flask containing ice in both the upper and lower compartments. Since elephant serum clots, vigilance was necessary to ensure that the freshly separated serum was drawn off in good time. The successfully collected serum was flown to the United Kingdom for the analyses described.

The speedy removal of the adrenal glands for lipid analysis presented some difficulty, and it was first necessary to locate and shoot a suitable elephant in a place immediately accessible to the vehicles carrying personnel and equipment. In spite of almost ideal conditions in this case, it was nevertheless impossible to extract the adrenal glands from the carcass and transfer them to ice in less than one hour after the death of the elephant.

(b) Extraction of lipids and methods of analysis

The lipids were extracted from the samples of serum by the method of Nelson & Freeman (1959) and from the adrenal gland by the method of Folch, Lees & Stanley (1957). The total lipid contents of the purified extracts were determined gravimetrically. The serum lipids were separated into cholesterol esters, cholesterol, triglycerides, unesterified fatty acids and total phospholipids by chromatography on columns of silicic acid (100 mesh; A.R.; Mallinckrodt Chemical Works, New York, U.S.A.) according to the method of Moore & Williams (1964a) and on columns of Florsil (Koch-Light Laboratories Ltd., Colnbrook, Bucks) according to the method of Carroll (1961). The adrenal lipids were separated into cholesterol esters, cholesterol, triglycerides and total phospholipids by chromatography on columns of silicic acid as described by Moore & Doran (1962). The unesterified fatty acid fraction of the adrenal tissue was not analysed since preliminary experiments showed that this fraction accounted for less than 1% of the total adrenal lipids. The efficiency of the separations of the lipid fractions on the columns of silicic acid was continually checked by chromatography of portions of each fraction on thin layer chromatoplates of Silica Gel G (Mangold, 1961) with a solvent system of light petroleum (b.p. 40 - 60°) - diethyl ether (90: 10v/v). The various fractions obtained from the columns of silicic acid were analysed for glyceride glycerol (Moore, 1962), cholesterol

(Abell, Levy, Brodie$ & Kendall 1952; Brown 1959), phosphorus (Allen 1940) and unesterified fatty acids (Albrink 1959). Weights of cholesterol esters and triglycerides were calculated arbitrarily as cholesterol oleate and triolein respectively. Weights of phospholipids were obtained by multiplying the lipid phosphorus values by 25 (Wittcoff 1951). The fatty acids present in the various lipid fractions were converted to the corresponding methyl esters by the transesterification procedure of Stoffel, Chu & Ahrens (1959). The methyl esters were analysed by gas-liquid chromatography on both non-polar and polar columns (Moore & Williams 1963a, 1964c). The non-polar columns consisted of 10% (w/w) Apiezon L (APL) grease on 100 - 120 mesh celite and the polar columns consisted of 10% (w/w) polyethylene glycol adipate (PEGA) also on 100 - 120 mesh celite. Identification of the methyl esters of the fatty acids was achieved by comparison of their retention times on the two types of columns with those of known standard methyl esters and by plotting the logarithms of their retention times relative to methyl palmitate on PEGA columns against the logarithms of their retention times relative to methyl palmitate on APL columns (James 1959). In addition, the relative retention times of the methyl esters of certain of the polyunsaturated fatty acids on PEGA columns were compared with the relative separation factors of Ackman & Burgher (1963). A check on the number of double bonds in each fatty acid was made by fractionating certain of the samples of methyl esters on thin-layer plates of silica gel G - silver nitrate (95:5, w/w) with a solvent system of light petroleum (b.p. 40 - 60°) - diethyl ether (85:5, v/v). This technique (Morris 1962) separated the methyl esters into saturated, monoenoic, dienoic, trienoic and tetraenoic acid esters. The separated zones were scraped from the plates and the methyl esters were eluted from the silica gel G - silver nitrate with hexane - diethyl ether (50:50 v/v). The resulting methyl ester fractions were then analysed by gas-liquid chromatography. Thus, by these procedures, the number of carbon atoms and the number of double bonds in each fatty acid could be established. The positional distribution of the double bonds in the C_{20} trienoic acid fraction was determined by a method similar to that of Chang & Sweeley (1962) described in detail by Moore & Williams (1966c). This method involved the oxidative degradation of the poly-un saturated fatty acid fraction and the analysis of the methyl esters of the resulting dicarboxylic acids by gas-liquid chromatography on a non-polar column (celite - APL, 90:10, w/w) at 175°.

RESULTS

Serum lipids

The five samples of elephant serum were found to be very similar in lipid composition and there were no obvious differences with respect to age or sex. Therefore, in

Tables 1 to 5 mean values and their standard errors are given for the five samples of serum rather than the individual values for each sample. For comparison, Tables 1 to 5 also contain results taken from the literature for the serum or plasma lipids of other species. These results for other species have been taken only from those papers that report investigations in which the various animals were given normal diets and in which the methods of analysis of the serum or plasma lipids were similar to those employed by us.

The concentrations of total cholesterol, triglyceride and phospholipid in elephant serum (Table 1) are similar to the corresponding values reported by McKinney & Luck (1964) for a single female elephant. In the serum of the elephant, the concentrations of the various lipid components are similar to the corresponding concentrations of the various lipid components in the plasma of the rat (Olivecrona, 1962a) and rabbit (Moore & Williams 1964a). The concentration of total lipid in elephant serum was similar to that in ox plasma (Duncan & Garton 1962), but in ox plasma the concentrations of free and esterified cholesterol were considerably greater and the concentration of triglyceride was considerably lower than the concentrations of the corresponding lipids in elephant serum. It should be noted that the concentrations of all the lipid fractions in the serum or plasma of the elephant, rat, rabbit and ox are markedly lower than the corresponding concentrations of the various lipid fractions in the serum of man (Schrade, Biegler & Böhle 1961).

The fatty acid composition of the cholesterol esters isolated from elephant serum, together with the compositions of the serum cholesterol esters of some other species are given in Table 2. In Table 2 (and elsewhere in this paper) the shorthand designation suggested by Farquhar, Insull, Rosen, Stoffel & Ahrens (1959) is used to denote the various fatty acids. Unesterified fatty acids constituted about 78% of the fatty acids esterified with cholesterol in elephant serum. As in the serum or plasma cholesterol esters of the rat (Olivecrona 1962b), rabbit (Moore & Williams 1965) and man (Schrade, Biegler & Böhle 1961), palmitic acid was the major saturated fatty acid present in the cholesterol esters of elephant serum. In spite of the fact that the elephant is a herbivorous animal, the concentration of linolenic acid (18:3) in the serum cholesterol esters was surprisingly low. In this respect, the fatty acid composition of the serum cholesterol esters of the elephant is in marked contrast to that of the serum cholesterol esters of the ox (Duncan & Garton 1962). However, the most unexpected finding was the presence of appreciable amounts (5.6% of the total fatty acids) of a C_{20} trienoic acid in the cholesterol esters of elephant serum. This polyunsaturated fatty acid does not occur in the serum cholesterol esters of the other species listed in Table 2.

Although Mead & Slaton (1956) have shown that a C_{20} trienoic acid ($\Delta^{5, 8, 11}$ eicosatrienoic acid) accumulates in the tissues of animals given a diet deficient in essential fatty acids it was unreasonable to suppose that the elephants examined by us were deficient in essential fatty acids. The identity of the C_{20} trienoic acid present in the cholesterol esters of elephant serum was therefore investigated further. When this C_{20} trienoic acid was oxidatively degraded by the technique of Chang & Sweeley (1962), suberic acid (C_8) was found to comprise over 90% of the resulting dicarboxylic acids. If the C_{20} trienoic acid present in the cholesterol esters of elephant serum had been $\Delta^{5, 8, 11}$ eicosatrienoic acid then oxidative degradation would have resulted in the formation of the C_5 dicarboxylic acid, glutaric acid. If it is assumed that the double bonds of naturally occurring non-conjugated polyunsaturated fatty acids are present in divinyl methane ($=CH-CH_2-CH=$) arrangement then it would appear that the C_{20} trienoic acid in the cholesterol esters of elephant serum was $\Delta^{8, 11, 14}$ eicosatrienoic acid(homo - γ - linolenic acid). This conclusion was strengthened by a comparison of the retention data for this trienoic acid on PEGA columns with the relative separation factors reported by Ackman & Burgher (1963).

The fatty acid composition of the triglycerides present in the serum of the elephant is given in Table 3. Saturated acids comprised a fairly high proportion (56%) of the total fatty acids present in the serum triglycerides of the elephant.

The proportion of saturated acids in elephant serum triglycerides was more than that in the triglycerides of the serum or plasma of the rat (Olivecrona 1962b), rabbit (Moore & Williams 1966a) and man (Schrade, Biegler & Böhle 1961), but was less than that in the plasma triglycerides of the ox (Duncan & Garton 1961). The high proportion of saturated fatty acids in the plasma triglycerides of the ox is presumably a reflection of the intensive hydrogenation of dietary polyunsaturated fatty acids by rumen bacteria (Reiser & Reddy 1956). In the elephant, rat, rabbit and man, palmitic acid (16:0) is the predominant saturated fatty acid present in the serum or plasma triglycerides but stearic acid was the major saturated acid in the plasma triglycerides of the ox. Relatively low concentrations of the polyunsaturated fatty acids occurred in elephant serum and ox plasma triglycerides.

The composition of the unesterified fatty acids in elephant serum are given in Table 4. In general, the composition of the serum unesterified fatty acids is similar to that of the serum triglycerides (Table 3). This similarity in composition of the unesterified fatty acids and triglycerides is also apparent in the serum or plasma of the other species listed in Tables 3 and 4. Attention should perhaps be drawn to the fact that in the serum of the elephant and man and in the plasma of the rat and rabbit, the unesterified fatty acids contain higher concentrations of stearic acid (18:0) and lower concentrations of oleic acid (18:1) than do the triglycerides. The reasons for the differences have been discussed by Moore & Williams (1966a) in terms of the metabolic relationships that exist between the unesterified fatty acids and triglycerides in the blood and the triglycerides in the adipose tissue.

The fatty acid composition of the serum phospholipids of the elephant are given in Table 5. Qualitative examination of the elephant serum phospholipids by thin-layer chromatography (Skipski, Peterson & Barclay 1964) indicated that, as with the serum or plasma of most species, lecithin was the major component. The results in Table 5 show that there were approximately equal proportions of total saturated and total unsaturated fatty acids present in the elephant serum phospholipids. This finding would be consistent with the fact that the structure of the glycerophosphatides isolated from most natural sources is such that saturated fatty acids occupy the α-position, whereas unsaturated fatty acids occupy the β-position (Moore & Williams 1963b, 1964c). The serum phospholipids of the elephant are similar to those of the ox (Duncan & Garton 1962) in that stearic acid is the major saturated fatty acid present. In man (Schrade, Biegler & Böhle 1961) palmitic acid is the major saturated fatty acid present in the serum phospholipids. The serum phospholipids of the elephant contained appreciable concentrations of C_{20} and C_{22} polyunsaturated fatty acids that were not detected in the serum cholesterol esters, triglycerides or unesterified fatty acids. As in the serum cholesterol esters, a C_{20} trienoic acid was present in the serum phospholipids and structural studies showed that this fatty acid was probably $\Delta^{8, 11, 14}$ eicosatrienoic acid.

Adrenal lipids

The lipid composition of the elephant adrenal gland is given in Table 6 from which it may be seen that the total lipid content was particularly high. A high content of total lipid appears to be a characteristic feature of the adrenal tissues of many other species such as the rat, (Ostwald, Shannon, Miljanich & Lyman 1964; Angelico, Cavina, D'Antona & Giocoli 1965), guinea pig (Ostwald, Shannon, Miljanich & Lyman 1964), rabbit (Moore & Williams 1966c), dog (Chang & Sweeley, 1963) and man (Riley 1963.). Almost half (47.7%) of the lipid of the elephant adrenal gland was accounted for by cholesterol esters. The results in Table 6 also show that about 87% of the total cholesterol occurred in the esterified form. Similar findings have been reported for other species (Riley 1963; Ostwald, Shannon, Miljanich & Lyman 1964; Chang & Sweeley 1963; Angelico, Cavina, D'Antona & Giocoli 1965; Moore & Williams 1966c). In the adrenal lipids of the elephant, triglycerides and free cholesterol were relatively minor components and unesterified fatty acids occurred only in trace concentrations.

The fatty acid compositions of the cholesterol esters, triglycerides and phospholipids isolated from the adrenal gland of the elephant are given in Table 7. It should be noted that the cholesterol esters and phospholipids of the adrenal gland of the elephant contained appreciable concentrations of the C_{20} trienoic acid that was identified as $\Delta^{8,11,14}$ eicosatrienoic acid (homo-γ-linolenic acid). Unlike the finding of this acid in the cholesterol esters and phospholipids of the serum, this observation was not particularly surprising since homo-γ-linolenic acid has been reported to occur in the adrenal ~~gland~~ lipids of the ox (Klenk & Eberhagen 1961), dog (Chang & Sweeley 1962), rabbit (Moore & Williams 1966b,c) and man (Riley 1963). There was a broad similarity in the fatty acid composition of the cholesterol esters of the adrenal tissues of the elephant and rabbit (Moore & Williams 1966c) but in the cholesterol esters of the elephant adrenal gland, the concentration of homo-γ-linolenic acid was higher and the concentration of 22:4 (adrenic acid, Chang & Sweeley 1962) was lower than in the cholesterol esters of the rabbit adrenal gland. In spite of the preponderance of unsaturated fatty acids in the adrenal cholesterol esters (Table 7), the concentration of arachidonic acid (20:4) in the cholesterol esters was markedly less than the concentration of this fatty acid in the triglycerides and phospholipids of the elephant adrenal gland.

DISCUSSION

Perhaps the most interesting result of this investigation was the finding of appreciable amounts of homo-γ-linolenic acid in the cholesterol esters and phospholipids of elephant serum. Although homo-γ-linolenic acid is known to be a substantial constituent of the fatty acids present in the adrenal glands of a number of species (Klenk & Eberhagen 1960; Chang & Sweeley 1962; Moore & Williams 1966b,c), this polyunsaturated fatty acid does not normally occur in more than trace concentrations in the serum or plasma lipids of animals (e.g. see Tables 2 and 5). Since nothing is known about the fatty acid composition of the natural diet of the elephants it must remain a possibility that the homo-γ-linolenic acid present in the serum lipids could have been of exogenous origin. However, this possibility seems rather unlikely for there have been no reports of the occurrence of homo-γ-linolenic acid in plant lipids (Hilditch & Williams 1964). It seems most likely therefore that the homo-γ-linolenic acid was of endogenous origin and was synthesized in the tissues of the elephant. According to Mead (1960), arachidonic acid ($\Delta^{5, 8, 11, 14}$ eicosatetraenoic acid) is synthesized from linoleic acid ($\Delta^{6, 9}$ octadecadienoic acid) by a metabolic pathway that involves γ-linolenic acid ($\Delta^{6, 9, 12}$ octadecatrienoic acid) and homo-γ-linolenic acid

($\Delta^{8, 11, 14}$ eicosatrienoic acid) as intermediates. It has been shown that the arachidonic acid content of the liver or blood lipids of the rat, for instance, increases when the diet is supplemented with linoleic acid (Mohrhauer & Holman 1963). However, neither γ-linolenic acid nor homo-γ-linolenic acid occur to any extent in the liver or blood lipids of the rat so it must be assumed that the conversion of γ-linolenic acid to homo-γ-linolenic acid and the conversion of homo-γ-linolenic acid to arachidonic acid both take place at a very rapid rate in rat liver. In the cholesterol esters and phospholipids of elephant serum, the concentrations of homo-γ-linolenic acid were very similar to those of arachidonic acid (Tables 2 and 5). The polyunsaturated fatty acid composition of the serum lipids of the elephant, as with other species, will presumably be a reflection of the relative rates of the various types of metabolic interconversions that are undergone by the polyunsaturated fatty acids in the liver. Thus, it seems likely that the rate of synthesis of arachidonic acid from homo-γ-linolenic acid in elephant liver is much slower than it is in the liver tissues of the rat and many other species. A relatively slow conversion of homo-γ-linolenic acid to arachidonic acid appears to be a characteristic feature of the metabolism of polyunsaturated fatty acids by the adrenal glands of various animals (Moore & Williams 1966c). A further similarity in the metabolism of polyunsaturated fatty acids by elephant liver and the adrenal gland is suggested by the presence of 8.0% of adrenic acid ($\Delta^{7, 10, 13, 16}$ docosa-tetraenoic acid) in the serum phospholipids (Table 5). This tetraenoic acid is not normally found in the serum lipids of animals but is chacteristically found, as its name would imply, in the adrenal lipids of many species (Klenk & Eberhagen 1960; Chang & Sweeley 1962; Ostwald, Shannon, Miljanich & Lyman 1964; Carroll 1962; Riley 1963; Moore & Williams 1966c).

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TABLE 1 - CONCENTRATIONS (mg/100 ml) OF THE VARIOUS LIPID COMPONENTS IN THE SERUM OF THE ELEPHANT. MEAN VALUES ARE GIVEN WITH THEIR STANDARD ERRORS. FOR COMPARISON, VALUES ARE ALSO GIVEN FOR THE RAT, RABBIT, OX AND MAN.

	Elephant serum	Rat* Plasma	Rabbit† plasma	Ox‡ plasma	Man≠ serum
Total lipid	220 ± 17	225	204	291	701
Total cholesterol	67.3 ± 4.0	64.4	50.5	127	205
Esterified cholesterol	49.6 ± 3.2	40.4	33.8	98.5	131
Free cholesterol	17.8 ± 0.78	24.0	16.7	28.0	74.0
Triglyceride	29.8 ± 4.7	24.0	50.3	14.0	178
Unesterified fatty acid	10.5 ± 0.81	17.0	15.7	7.0	27.0
Phospholipid	78.5 ± 5.7	92.0	67.3	75.0	202

* Olivecrona (1962a), † Moore & Williams (1964a)

‡ Duncan & Garton (1962), ≠ Schrade, Biegler & Böhle (1961)

TABLE 2 - FATTY ACID COMPOSITION (WEIGHT PERCENTAGE OF THE TOTAL) OF THE CHOLESTEROL ESTERS IN THE SERUM OF THE ELEPHANT. MEAN VALUES ARE GIVEN WITH THEIR STANDARD ERRORS. FOR COMPARISON, VALUES ARE ALSO GIVEN FOR THE SERUM OR PLASMA CHOLESTEROL ESTERS OF THE RAT, RABBIT, OX AND MAN.

Fatty acid	Elephant serum	Rat * plasma	Rabbit† plasma	Ox‡ plasma	Man≠ serum
14:0	1.0 ± 0.16	-	-	0.7	1.1
16:0	14.0 ± 1.2	17.7	18.3	5.5	11.7
16:1	2.8 ± 0.28	3.7	4.1	2.8	6.0
17:0	0.3 ± 0.03	-	-	0.5	-
17:0br	0.8 ± 0.12	-	-	-	-
18:0	1.8 ± 0.27	4.8	3.5	1.5	2.5
18:1	21.2 ± 0.82	13.3	27.9	5.6	18.7
18:2	42.4 ± 2.8	13.6	35.2	52.4	48.4
18:3	1.3 ± 0.16	-	1.4	22.9	1.1
20:3	5.2 ± 0.14	-	-	-	-
20:4	5.6 ± 0.44	47.1	1.8	-	5.0

* Olivecrona (1962b), † Moore & Williams (1965)

‡ Duncan & Garton (1962), ≠ Schrade, Biegler & Böhle (1961)

TABLE 3 - FATTY ACID COMPOSITION (WEIGHT PERCENTAGE OF THE TOTAL) OF THE TRIGLYCERIDES IN THE SERUM OF THE ELEPHANT. MEAN VALUES ARE GIVEN WITH THEIR STANDARD ERRORS. FOR COMPARISON, VALUES ARE ALSO GIVEN FOR THE SERUM OR PLASMA TRIGLYCERIDES OF THE RAT, RABBIT, OX AND MAN.

Fatty acid	Elephant serum	Rat* plasma	Rabbit/ plasma	Ox≠ plasma	Man≠ serum
14:0	2.6 ± 0.31	-	2.6	1.1	1.5
16:0	40.5 ± 1.16	31.7	35.0	24.0	27.8
16:1	2.6 ± 0.36	4.0	3.6	4.8	7.7
17:0	1.4 ± 0.18	-	-	6.8	-
17:0br	1.0 ± 0.20	-	-	-	-
18:0	10.2 ± 1.6	5.3	5.5	30.0	3.6
18:1	31.9 ± 1.4	28.9	27.7	24.3	36.4
18:2	5.2 ± 0.58	20.9	20.2	4.6	12.7
18:3	0.2 ± 0.04	-	0.6	1.9	1.0
20:3	0.9 ± 0.19	-	-	-	-
20:4	0.9 ± 0.22	9.2	0.8	-	3.0

* Olivecrona (1962b), / Moore & Williams (1966a),

≠ Duncan & Garton (1962), ≠Schrade, Biegler & Böhle (1961)

TABLE 4 - COMPOSITION (WEIGHT PERCENTAGE OF THE TOTAL) OF THE UNESTERIFIED FATTY ACIDS IN THE SERUM OF THE ELEPHANT. MEAN VALUES ARE GIVEN WITH THEIR STANDARD ERRORS. FOR COMPARISON, VALUES ARE ALSO GIVEN FOR THE SERUM OR PLASMA UNESTERIFIED FATTY ACIDS OF THE RAT, RABBIT, OX AND MAN.

Fatty acid	Elephant serum	Rat* plasma	Rabbit† plasma	Ox‡ plasma	Man≠ serum
14:0	3.8 ± 0.54	-	3.6	1.8	2.0
16:0	38.8 ± 1.9	33.8	37.7	18.5	27.5
16:1	2.8 ± 0.46	2.8	4.4	3.9	7.3
17:0	0.7 ± 0.13	-	-	2.0	-
17:0br	0.6 ± 0.04	-	-	-	-
18:0	14.4 ± 0.85	9.6	12.0	24.1	15.3
18:1	26.2 ± 1.3	35.4	22.7	39.3	25.4
18:2	7.8 ± 0.68	18.3	12.2	5.2	13.4
18:3	0.2 ± 0.04	-	0.4	3.3	0.9
20:4	1.3 ± 0.18	-	0.7	-	2.4

* Olivecrona (1962b), † Moore & Williams (1966a),

‡ Duncan & Garton (1962), ≠ Schrade, Biegler & Böhle (1961)

TABLE 5 - FATTY ACID COMPOSITION (WEIGHT PERCENTAGE OF THE TOTAL) OF THE PHOSPHOLIPIDS IN THE SERUM OF THE ELEPHANT. MEAN VALUES ARE GIVEN WITH THEIR STANDARD ERRORS. FOR COMPARISON, VALUES ARE ALSO GIVEN FOR THE SERUM OR PLASMA PHOSPHOLIPIDS OF THE RAT, RABBIT, OX AND MAN.

Fatty acid	Elephant serum	Rat* plasma	Rabbit† plasma	Ox≠ plasma	Man≢ serum
14:0	0.9 ± 0.11	-	-	-	0.7
16:0	15.4 ± 0.70	20.5	25.6	16.2	31.0
16:1	0.9 ± 0.10	0.9	0.6	1.1	3.5
17:0	0.8 ± 0.06	-	-	4.4	-
17:0br.	0.3 ± 0.07	-	-	-	-
18:0	32.6 ± 1.3	21.2	21.0	26.8	12.5
18:1	12.2 ± 1.0	4.3	12.8	16.3	15.0
18:2	12.3 ± 0.76	15.4	28.2	14.1	21.2
18:3	0.7 ± 0.04	-	1.1	2.4	0.9
20:0	1.4 ± 0.27	-	-	-	-
20:1	1.4 ± 0.27	-	-	-	-
20:2	1.2 ± 0.10	-	-	-	-
20:3	6.2 ± 0.25	-	-	-	-
20:4	6.3 ± 0.24	36.2	4.2	-	8.1
22:4	8.0 ± 0.19	-	-	-	-
22:5	4.0 ± 0.26	-	-	-	-
22:6	0.8 ± 0.09	-	-	-	-

* Tinoco, Shannon & Lyman (1964), † Moore & Williams (1964b)

≠ Duncan & Garton (1962), ≢ Schrade, Biegler & Böhle (1961)

TABLE 6 - CONCENTRATIONS (mg/100g DRY TISSUE) OF THE VARIOUS LIPID COMPONENTS IN THE ADRENAL GLAND OF THE ELEPHANT.

Total lipid	63.1
Total cholesterol	20.6
Free cholesterol	2.71
Esterified cholesterol	17.9
Triglyceride	2.96
Phospholipid	27.3

TABLE 7 - FATTY ACID COMPOSITION OF THE CHOLESTEROL ESTERS, TRIGLYCERIDES AND PHOSPHOLIPIDS ISOLATED FROM THE ADRENAL GLAND OF THE ELEPHANT

Fatty acid	Cholesterol esters	Triglycerides	Phospholipids
14:0	2.6	2.7	0.6
16:0	22.3	41.8	24.6
16:1	4.7	3.2	1.1
17:0	0.6	0.5	0.3
17:0br	0.4	0.2	0.3
18:0	8.9	8.3	14.6
18:1	36.3	19.5	23.2
18:2	4.3	4.3	5.8
18:3	0.2	0.2	0.2
20:0	0.3	0.2	0.1
20:1	0.8	0.3	0.1
20:2	2.1	1.1	1.1
20:3	7.5	0.7	5.6
20:4	1.7	4.4	16.5
20:5	0.6	0.8	0.4
22:1	0.2	0.4	0.2
22:2	0.3	0.3	0.3
22:3	0.7	1.0	0.2
22:4	1.2	2.1	0.3
22:5	3.0	0.9	2.8
22:6	0.6	1.6	0.3

TABLE 8 - FIELD DATA ON THE ELEPHANTS OF WHICH SERUM AND ADRENAL LIPIDS ARE DESCRIBED

Elephant No.	Specimen for analysis	Sex	Physiological age*	Approx. Chrono-logical age*	Locality & habitat type	Other Notes
M.100	Serum	♀	FM:IV/2	13 yrs	S.W.Uganda: unres-tricted; montane	Lactating; first calf at foot
M.83	Serum	♂	FM:IV/5	15 yrs	Kenya: unres-tricted; montane	-
M.149	Adrenal	♂	FM:IV/8-9	18-19yrs	Kenya: semi-restr. scrubland	-
M.88	Serum	♀	FM:V/2	25 yrs	S.W. Uganda; semi restricted; grassland	Lactating
M.152	Serum	♂	FM:V/2	25 yrs	Kenya: unrestricted; montane	-
M.93	Serum	♂	FM:V/7	Over 30 yrs	S.W. Uganda; semi restricted. grassland	-

* Sikes (1966)

Appendix 6

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The African elephant, *Loxodonta africana*: a field method for the estimation of age

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The need for a field method of determining and describing the relative age of African elephants collected in their natural habitat arose during a recent research project, and has led to an attempt to formulate a laminary age standard for use in the field, based upon direct observations and measurements on the lower right molars. For this purpose a series of 31 African elephants of both sexes, covering almost the complete potential age range of an elephant's life, and of known body condition, locality and size, has been used as the basis for constructing a reference chart of molar laminary age. Eye lens weights were also obtained for 26 of these specimens, but, although indicative of a direct correlation with laminary age, they were obtained in insufficient numbers to provide an adequate sequence. Each of the specimens used was first observed alive, then shot and examined *post mortem* during the course of a research project * on cardiovascular disease, in which the determination of relative age formed an integral part.

Contents

Introduction

The need for the widespread "cropping" of the African elephant, *Loxodonta africana*, in various parts of Africa in recent years has opened up unprecedented opportunities for various types of research on the species. During a current study of cardiovascular disease in wild animals, a series of 32 African elephants of both sexes (of which one was carrying an almost full term foetus) were first selected after careful observation, then shot and examined in detail *post mortem* by the author. Another seven, shot during a National Park "cropping scheme", were also photographed and examined *post mortem* in as much detail

* Financed by the British Heart Foundation.

as circumstances permitted. The complete series of 40 elephants (in which the foetus is counted as a separate specimen), collected in Kenya and Uganda, thus includes all age-groups from the near-term foetus to a very elderly cow. All the specimens in this series were of the "savannah" type of African elephant.

An evaluation of cardiovascular disease must, of necessity, take account of the ageing process in order to distinguish between normal and pathological conditions. It had been assumed that the abundance of literature concerning age determination in elephants, based on molar development, would render the compilation of the relative age sequence in the specimens collected during the present study a comparatively simple procedure. This, however, proved not to be the case, and the necessity for devising a straightforward molar laminary age standard, based entirely upon direct measurements, and referable to a simple graphic chart as a field guide, soon became evident. In the following descriptions and discussion the word "elephant" is used throughout to denote only the African elephant, *Loxodonta africana*.

In the series currently under examination, the molars of all 40 elephants were photographed in the field. The right mandibles of 31 of these specimens were also cleaned, macerated and the molar roots fully exposed on the medial, or lingual, aspect. Some left mandibles were also retained for comparison. Particular attention was also paid to the preservation and examination of the proximal molars developing within the alveolar pockets.

Morrison-Scott (1938, 1947), after the painstaking examination of a vast amount of material, listed 11 different approaches to the measurements and indices that may be used in identifying and ageing a given molar, and described the "ridge formula", concluding that a reliable ridge formula could not, in fact, be constructed. He proposed the "laminary index" and "enamel loop index" as useful methods, but was inconclusive as to a really reliable formula for the identification of any but the first two molars of each half-jaw. The confusion undoubtedly arose in the first instance because both data and terminology were initially derived from the study of fossil teeth. Second, the study of the molars of modern elephants was based, of necessity, almost exclusively upon museum specimens which possessed inadequate field data on sex, physical condition and locality.

In the present study, an attempt has been made to approach the subject primarily from the aspect of the whole, living animal in its natural environment, and second from studies *post mortem*. Thus, in every case, the examination of the jaws and teeth has been based not only upon actual measurements, obtained by consistent procedures, but also upon visual information about the living specimen in its environment. From these data, the graphic reference chart of molar laminary age (Table II) has been constructed. The chart has subsequently been tested against data obtained from specimens of known age and tooth history, at present in captivity in zoological gardens, and approximate year-age reference points have been indicated. The oldest available elephant of known age, whose molars could be examined clearly, is "Diksie" of the gardens of the Zoological Society of London. At the time of writing (Feb. 1966), she is 27 years old (Sharpe, 1946), and her approximate laminary age at 25 years has been indicated on the chart. Although there is as yet limited information available upon which to base a comparison of ageing and growth rate in captive and free-living elephants, comparative measurements of shoulder height and laminary age so far obtained indicate a close degree of correlation. Body weight and girth, however, seem to be greater in proportion to laminary age and shoulder height in captive elephants than in free-living specimens, a difference which may be reasonably explained in terms of the combined factors of constant availability of abundant food, and restricted facilities for exercise and migration in the case of the captive animals.

Unfortunately, in spite of the abundance of well-intentioned guesses, regarding the potential longevity of the elephant, and the widespread tendency to assume nowadays that the elephant's life-span is broadly similar to that of the human (Evans, 1910; Sanderson, 1963), there is absolutely no reliable evidence in the case of the African elephant as to what the maximum age may really be. Nor has it been possible to obtain a single jaw, or detailed drawing of such a jaw, from an elephant of actually known age above 27 years old. At the Basle Zoological Gardens detailed records have been kept of five elephants (two bulls and three cows) from the time of their arrival in Basle as approximately yearling calves in 1952. Lang (1965) has measured the molar fragments discarded by these elephants over a period of about 13 years. Johnson & Buss (1965) have examined a large number of half-jaws collected in Uganda and have constructed an age curve, on which they have assigned approximate age increments up to about 40 years old. It is, however, to be observed that the authors have indicated the introduction of molar V into wear at only 10 years old, and no. VI at 20 years—points which are neither confirmed in the specimens of the present study series (by comparison with the body measurements and descriptions of the molars given by them), nor in the captive elephants at Basle, Hanover or London.

None of the above authors, unfortunately, suggested a simple, workable standard for field use, either for molar identification, or for age assessment, which would enable the research worker in the field, at the carcass, to describe and assess the molar age of a given elephant with the minimum of effort and equipment. Moreover, avoidance of the necessity for transporting the bulky jaws to the base camp or laboratory would be a great advantage where the need to assess the age of the specimens is necessary, but not of prior importance, in a given research project or cropping scheme.

An attempt is made here to provide such a method which will enable the worker to identify the molars in wear and to ascribe a provisional laminary age to a given specimen in the field. Since the laminary age chart and field data given in Tables I and II are derived from elephants collected only in Uganda and Kenya, it is possible that differences in actual molar size might occur in specimens collected in other parts of Africa. It is unlikely, however, that the basic laminary age pattern will be found to differ significantly in normal specimens collected in other localities. On-the-spot measurements, photographs, and the extraction and preservation of the two lower right molars in wear, as well as of that developing in the alveolar pocket, if present, is recommended for subsequent confirmation of the provisional field assessment. It is also here suggested that, until sufficient accurate data become available, the age of African elephants is best referred to as *laminary age*, rather than in terms of annual increments. As additional exact data from captive elephants of known age become available, it will be possible to convert the laminary age increments to annual increments.

Materials and methods

The following measurements from 40 elephants (of which 25 were bulls and 15 cows), were taken as consistently and accurately as possible, and in as many cases as circumstances permitted. The specimens which were collected and preserved for further laboratory examination, are indicated.

Body weight

Wherever conditions permitted, the carcass was weighed piecemeal, 5% being added to the total to cover fluid loss due to evaporation and spillage during the *post mortem* examination. Since every animal was killed by means of a solid bullet in the brain, there was little, if any, blood loss and usually no defaecation or urination at the time of death, since death was instantaneous. The figure of 5% was determined on the basis of the findings of Ledger (1963), and after allowing for differences which might arise due to the specialized method used in shooting and dismembering the carcasses of the elephants for study. Little fluid loss took place from the intestines, stomach and caecum, as these were tied off into lengths, *in situ* and then weighed length by length. Johnson & Buss (1965) have devised a method of very careful on-the-spot estimations of blood loss in each case, but their specimens were mostly killed by means of the heart-shot, when heavy blood loss inevitably followed.

It is known that an elephant may drink up to 20 gal water at one time, and probably up to 35 or 40 gal in 1 day. A large animal may be able to drink more than 20 gal at a time. Thus, a variation of up to 100 kg is to be expected according to when the elephant last drank—i.e. up to at least 3·5% of body weight on an average-sized mature elephant. Field equipment has unfortunately not been available with which to make a sound estimate of the degree of accuracy of the method used in the present study by comparison with the direct weight measurement of the whole carcass of a full-grown elephant. As a guide, however, the present method, although imperfect, has proved useful, and is similar to that currently in use by most workers who make any attempt to weigh elephant carcasses in the field in East Africa.

A 12 cwt scale was used, raised by a pulley block with chain tackle, on a home-made tripod consisting of three 6 ft by 2 in. steel pipes, into which three 6 ft by 1·5 in. steel pipes were inserted to a depth of 12 in., where they were supported in each case on a small inset bar. The tripod head was made of three angled pieces of 1 in. rod, welded and depressed centrally, so that the hook of the pulley block would not slip off, and arranged at 120° to each other, the angled ends sliding into the tops of the 1·5 in. pipes. When dismantled, the whole formed a compact 6 ft long bundle.

Length

This was measured by two different methods, neither of which proved to be either reliable or useful.

(a) Total length was measured by stretching the trunk forward as far as possible and the tail backward, marking each extremity with a vertical pole and taking a direct straight measurement between the poles.

(b) Length over dorsal curves was measured by means of a flexible tape-measure from trunk tip to tail tip.

Both the above measurements proved very unreliable due to the variable extensibility of the trunk and the position of the head after falling. The latter varied according to the length of the tusks and to irregularities of the terrain.

Height at withers

This measurement has proved both accurate and useful. Since an elephant usually falls on the side towards the rifle, when shot in the temple, this shot was used for killing all except 4 of the specimens in this study. Sometimes, in falling, the forefoot flexes, but, if straightened by hand immediately after death, may be measured very accurately by placing a pole vertically on the ground against the withers, and then measuring direct to the outer edge of the sole. If this is impossible, the measurement is best conducted in 3 stages on the lateral surface: (a) withers to lateral epicondyle of humerus; (b) epicondyle of humerus to styloid process of ulna; (c) styloid process of ulna to edge of sole. The measurement thus obtained is closely comparable to that commonly used in finding the shoulder height in living elephants in captivity.

Girth

Usually it is possible to push a tape-measure under the carcass just posterior to the elbow, and to measure the whole girth. In other cases, the half-girth is measured from the spine to the ventral midline and then doubled. In every case the girth was measured just posterior to the elbow and withers, as in girthing a horse, and never over the belly, which all too rapidly expands immediately after death.

Ear: height, width and turn-over

While experience of these measurements may be of some value in making a rough assessment of the age group of the living elephant in the herd, it is not easy to apply these measurements to the present study on age, as it is found that it is difficult to obtain them consistently and accurately, especially in the case of the dorsal turn-over.

Foreleg and hindleg

The following measurements were consistently taken: (a) foreleg: elbow to edge of sole, length and breadth of sole, and circumference of forefoot at edge of sole; (b) hindleg: stifle to edge of sole, length and breadth of sole and circumference of hindfoot at edge of sole. Apart from noting that the hindleg length from stifle to edge of sole is usually 2 or 3 in. less than that of the foreleg from elbow to edge of sole in a full-grown African elephant, and that each of these measurements is respectively almost identical to the circumference of its own foot, all these measurements have been disregarded for the present study with the exception of forefoot circumference. This measurement is of some value when spooring elephant, as an age-group indicator.

Weight of internal organs

Various internal organs were weighed consistently in every case, but are considered inapplicable to the study of age estimation in the field.

Photographs

In every case, photographs of the molars were obtained in the field and have been successful and of great value in understanding the molar ageing process. Irregularities between upper and lower molars and right and left sides have thus been photographically recorded and have enabled the author to make a check on the value of the use of the right mandible as the standard means of obtaining the laminary age. Unfortunately, a measuring tape or rule was not placed on the specimen for reference in every case. This is of no importance in the 31 specimens where the jaw has been collected for subsequent study, but in the other cases where the omission has occurred it is a serious disadvantage.

Mandibles

In 31 elephants, the mandibles were disarticulated from the skull, and divided with an axe at, or near, the fused symphysis mandibulae. The right mandible was then cleared of flesh and skin and opened with an axe or machete along the medial, or lingual face, to expose the molars in wear, as well as any additional developing molars in the alveolar pockets. If undamaged during this procedure, the complete encapsulated alveolar molar was labelled and preserved in formalin in a plastic bag. If damaged, the separate laminae were collected and subsequently cleaned, dried and labelled individually at the base camp. African field assistants proved themselves, after a little practice, to be very efficient at carrying out this procedure.

Eye lenses

Whenever circumstances permitted, the eyeball lying uppermost was removed whole, opened by a lateral incision and the lens forced gently into a tube of Richardson's Fixative (Richardson, 1960) by applying pressure on the back of the eyeball. The lens was thus not touched directly at all either by hand or instrument. Unfortunately, lenses were not obtained from any of the 7 specimens from the Murchison Falls National Park, and in some other cases the extraction of serum was of prior importance and necessitated delaying the extraction of the lens until it was too late, and decomposition had already set in. It was hoped that these would provide a useful check on age assessments made by the examination of the molars.

Subsequent to the return to the laboratory the following procedure was used:

Mandibles

These were macerated and dried, and placed in a line in apparent age order on a long bench. Any preserved developing molars were returned to their respective mandibles and attempts to finalize the sequence by combining laminary counts, measurements of grinding length, enamel loop width, and the calculation of laminary indices were made, using the methods summarized by Morrison-Scott (1947). When the results of this process were used in conjunction both with the broad trends obtained from body measurements and with field notes on the herd-status in life of each specimen, considerable confusion resulted.

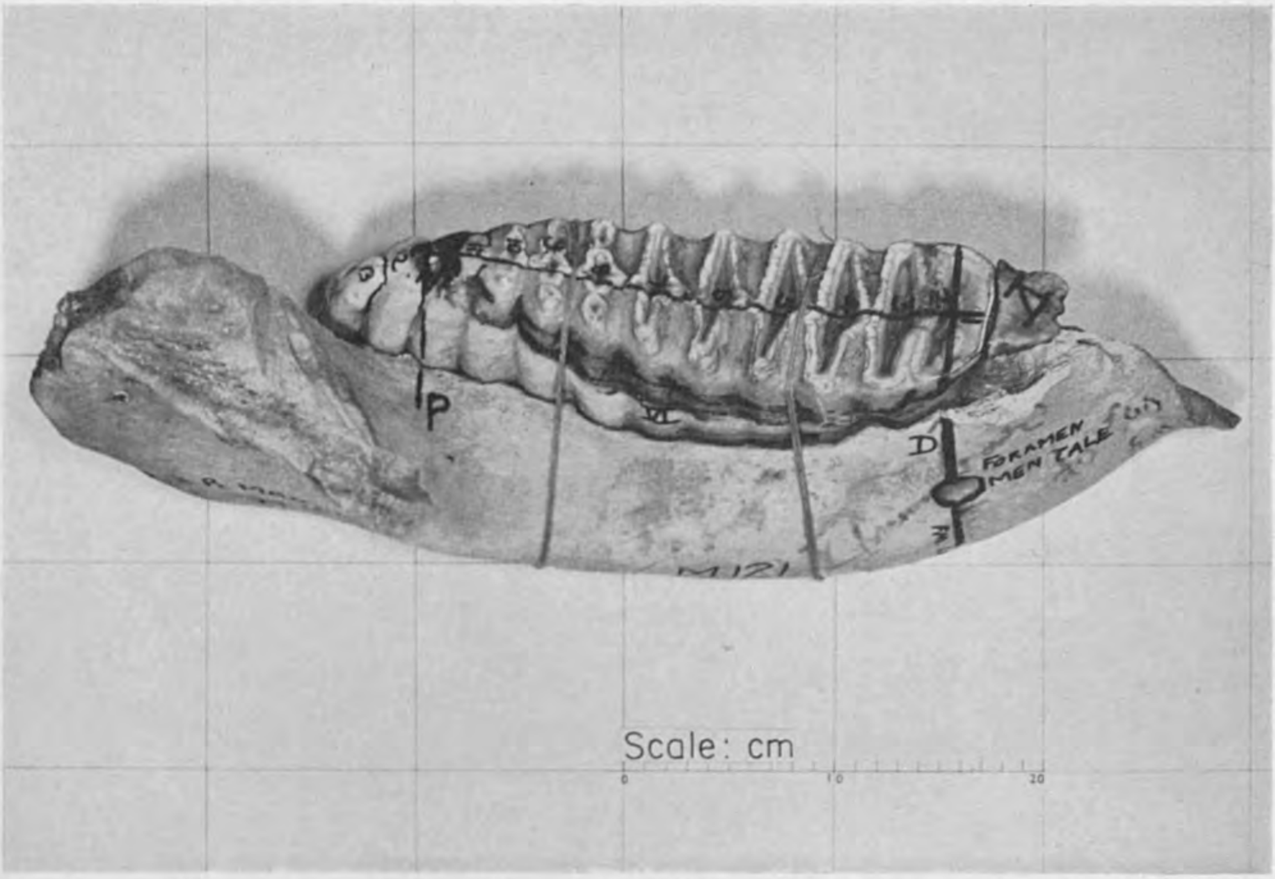
Thus, an attempt was made to reassess the whole situation, and to determine first the true number of potential laminae for each molar in the lower half-jaw series, and second to see if during the molar progression any stable reference point could be found, whereby the laminary picture at any given tooth-age could be reliably described. The *foramen mentale* was found to be an excellent reference point. It is observed that at a point (as yet undetermined regarding its exact location) within the arbitrary transverse section of the mandible which would pass through the centre of the foramen mentale, erosion of the root of the lamina currently located in this section begins. As the molars move anteriorly, the erosion of the root, from a point about half-way down its distal face spreads both up and down the root until it is wholly resorbed. When this occurs the thin, now well-worn surface layer of the part of the tooth lying anterior to the foramen mentale is liable to fracture sooner or later during mastication, the fragments either being dropped from the mouth or swallowed. Some enzymic activity operating on the molar roots at this point within the mandible suggests itself as a possible mechanism here.

Using the foramen mentale as a reference point, new sets of laminary counts, measurements of total grinding length, maximum grinding width, and molar weight were made. These findings are summarized in Table I. The measurements used in the table were made as follows:

(i) *Total grinding length*. A line was drawn vertically through the foramen mentale, up the mandible and molar, and across the grinding surface of the molar. On this line, from a point approximately at the centre of the molar, the distance was measured backwards to the proximal end of the grinding surface of the molar, or molars, currently in wear (Plate I(a)).

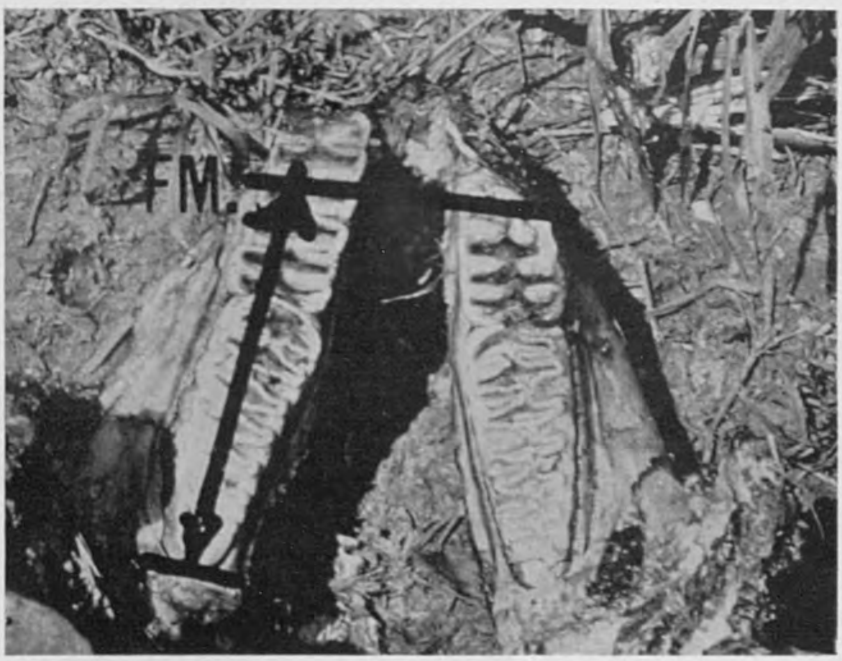
(ii) *Maximum grinding width*. This is simply the greatest measurement obtainable with dividers or a caliper of the outer edges of the enamel loops in current wear lying proximally to the foramen mentale reference line on the grinding surface.

(iii) *Molar weight*. The weights given are those obtained for the individual right molar or molars in current wear, after complete drying.



(a)

distal



proximal

(b)

PLATE I. (a) The method used for identifying the lamina above the *foramen mentale*. A lower right mandible containing molars V (fragment) and VI is shown. The vertical line through the foramen cuts molar VI between laminae 1 and 2, giving a laminary age of FM : VI/1–2. The maximum grinding length is the distance measured from the FM line to the proximal end of the grinding surface in wear, P. Maximum grinding width is the maximum width on the outer edge of the widest enamel loop in wear, lying proximally to the FM line.

(b) Uneven development of molars. Since measurements are only made proximally to the FM line, uneven fragmentation distal to this line does not affect the measurement of maximum grinding length and width.

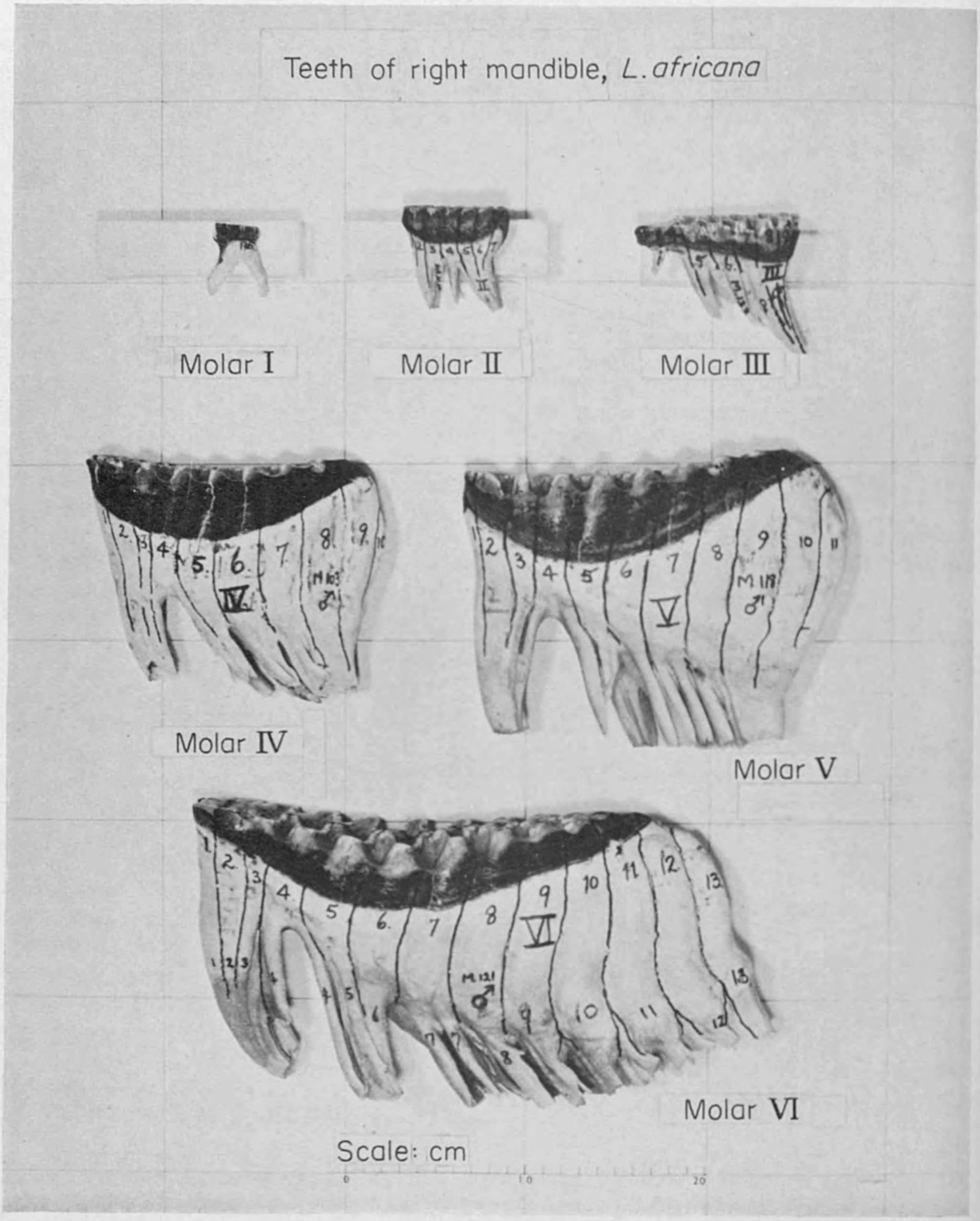


PLATE II. (a) Molars of the right mandible (medial aspect). In each case a typical well-developed molar is shown, the laminae being numbered from the distal (left) to the proximal end.

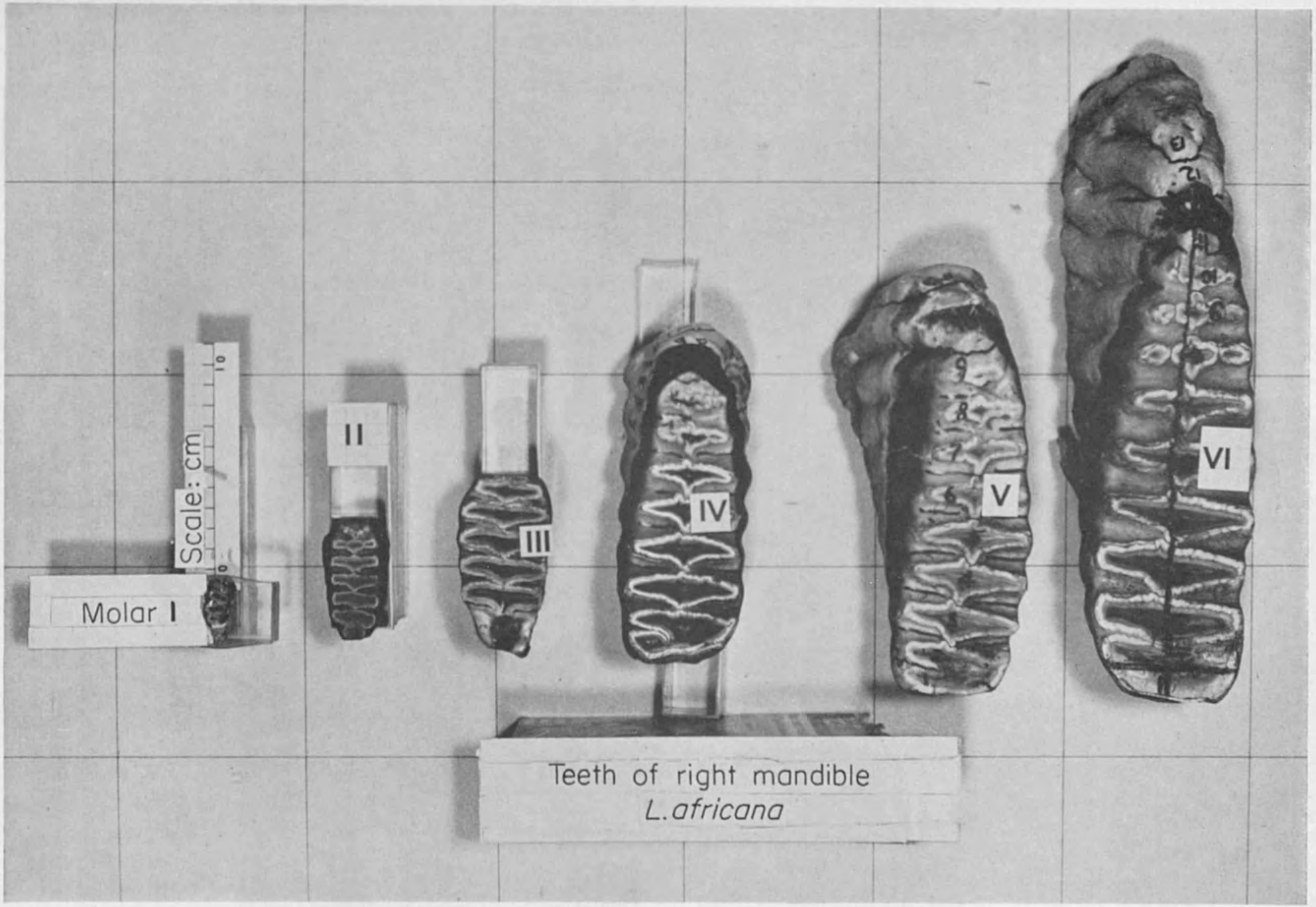
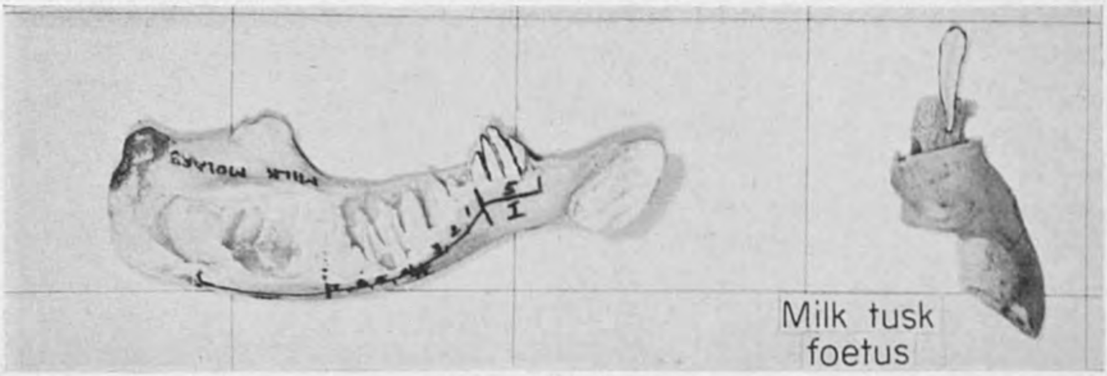
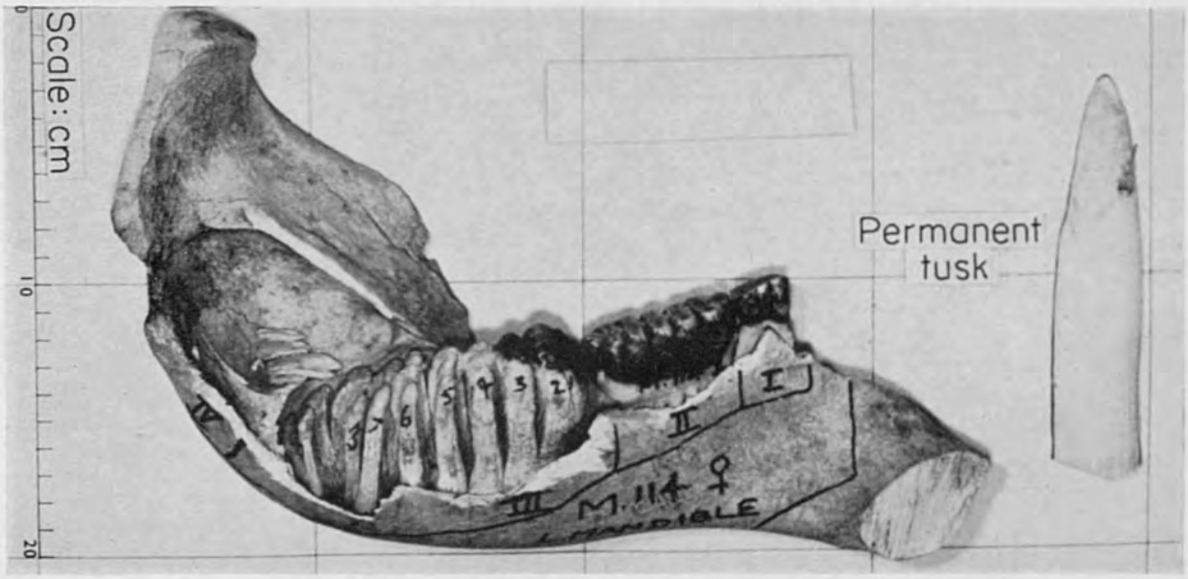


PLATE II. (b) Molars of the right mandible (crown view).



L. mandible, foetus

L. mandible, M 135



L. mandible, M 114

PLATE III. (a) Left mandibles, with molars exposed on the medial aspect, of a near-term foetus (154), a young calf (135) and a yearling calf (114). The left tusk of each of these specimens is also shown: no. 154 with the milk tusk; no. 135 with both the milk tusk and the permanent tusk *in situ* in the premaxilla; no. 114 with the developing permanent tusk only, the milk tusk having been shed.

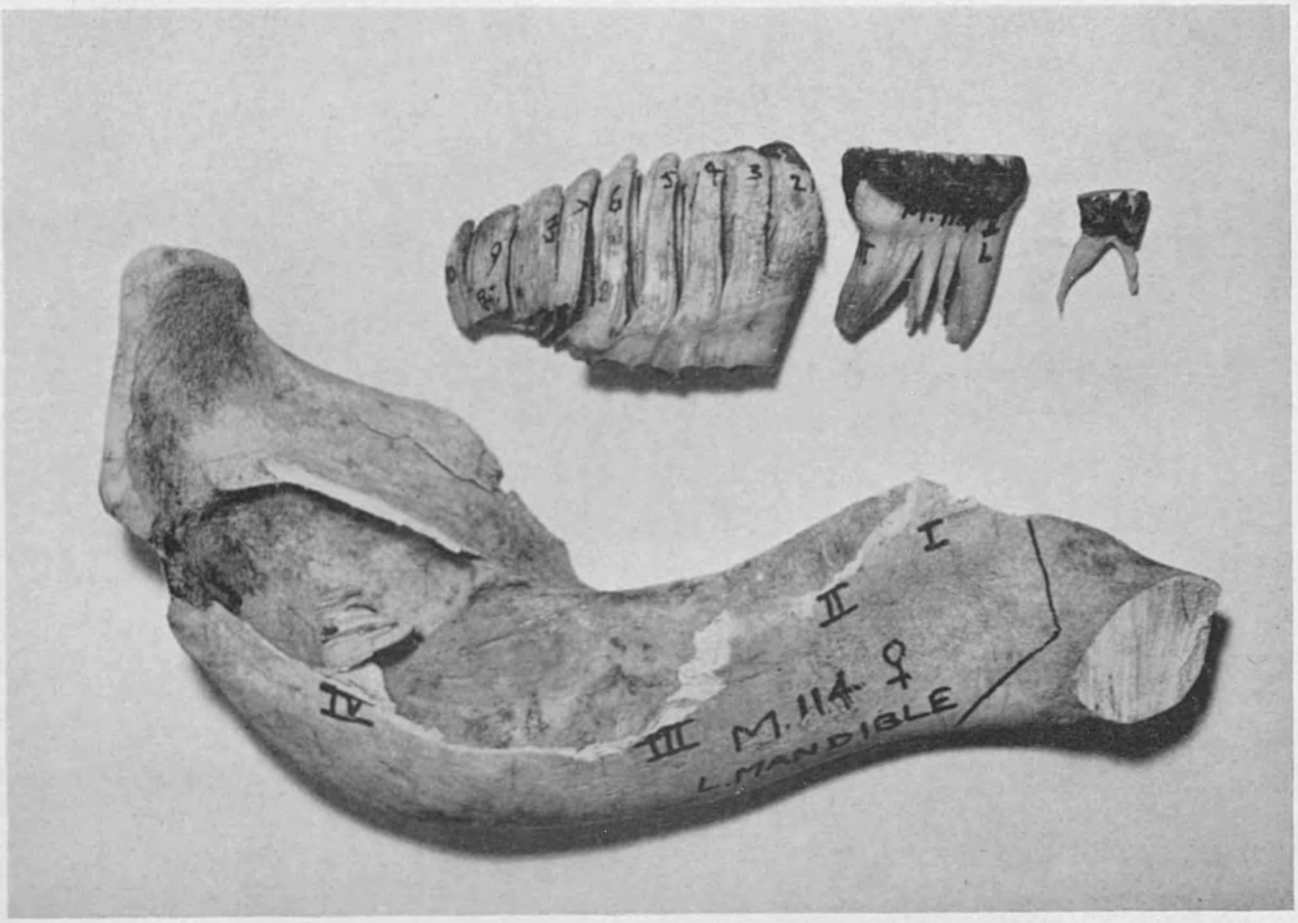
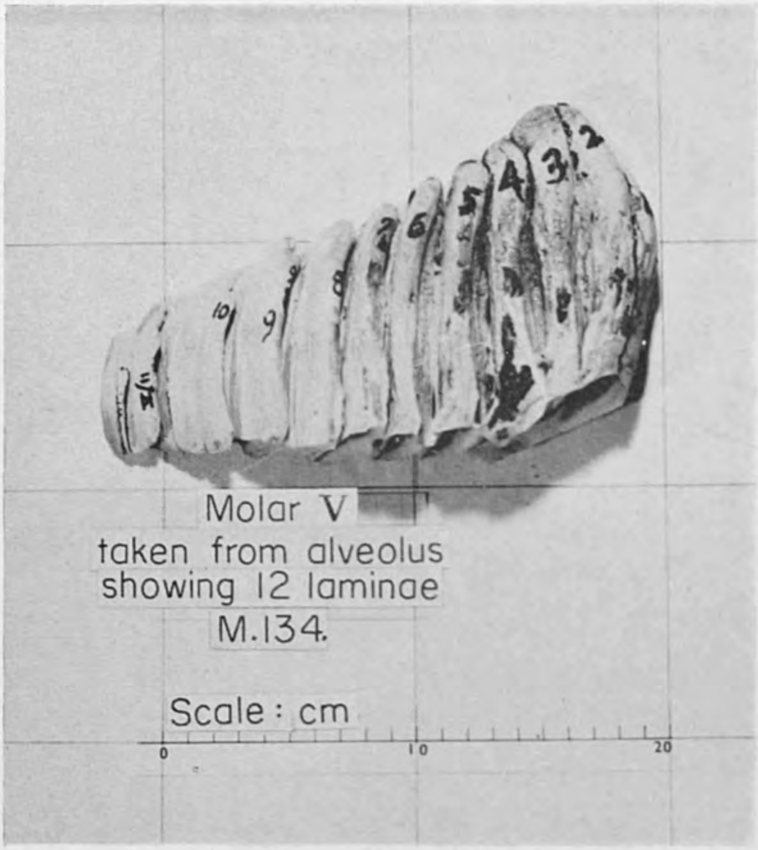
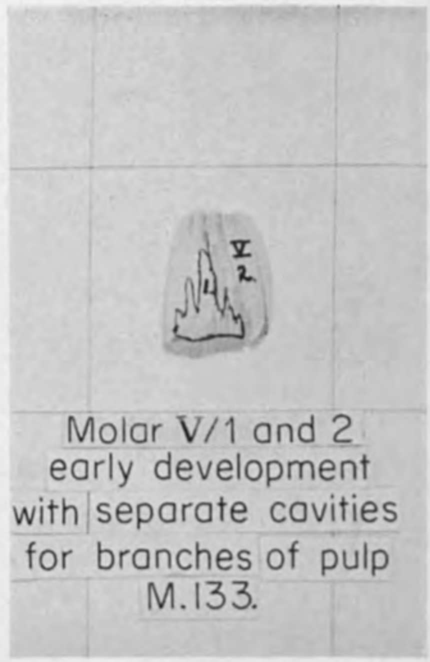


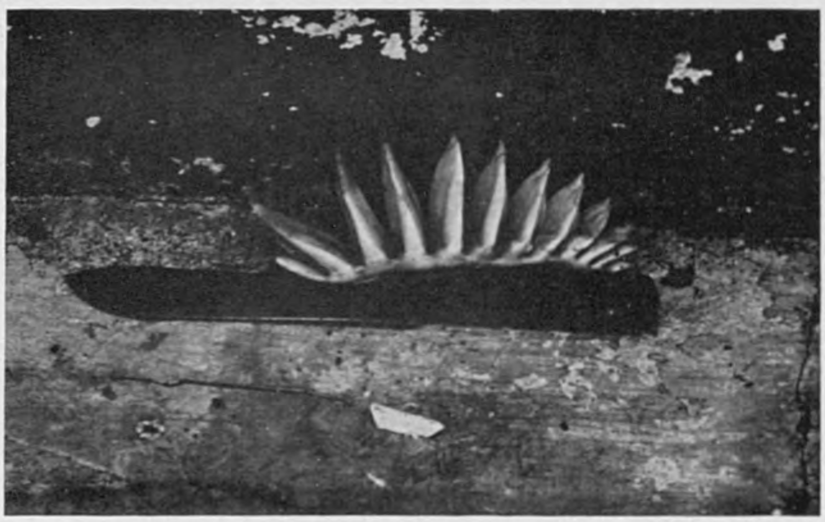
PLATE III. (b) Left mandible of specimen 114 showing the first four molars present, of which I to III are simultaneously in wear. No. IV is incomplete, only four laminae having been partially calcified at this stage of development. Ten quite distinct laminae are seen in the developing molar III.



(a)



(b)



(c)

PLATE IV. (a) Molar V, taken from the alveolar pocket of specimen 134. Twelve distinct developing laminae were found, of which no. 12 formed a tiny leaf on the proximal face of no. 11.

(b) Molar V, laminae 1 and 2 are always fused during development but have distinct pulp branch cavities. Specimen 133.

(c) Molar V, the complete pulp, extracted from the developing fifth molar of specimen 132, showing 12 distinct parallel branches which carry the 12 laminae of the tooth.

(a)

distal

proximal

(b)

Plate V. (a) Right mandible, medial aspect, of the very elderly female specimen 107. The sixth molar is already declining, its fangs bent and already largely resorbed, and the alveolar pocket fully invaded with diffuse bone.

(b) Upper jaws with remains of sixth molars of specimen 107, showing that only 3·5 enamel loops remain, severely limiting mastication.

PLATE VI. (a) Medial aspect of the left mandible of specimen 116, showing the initial invasion of the alveolar pocket, proximal to the sixth molar, by bone. Only laminae 2 to 13 are visible on the medial aspect, lamina no. VI/1 lying as a pillar at the distal end of the cheek side of the molar.

PLATE VI. (b) Medial aspect of the right mandible of specimen 121 after removal of the sixth molar, showing the build-up of bone on the proximal side of each lamina, thus exerting pressure on the laminae, and tending to force the molar in an anterior direction, the roots being simultaneously bent and resorbed.

Lens weights

The lenses (preserved in Richardson's Fluid for a period of not less than 2 months in every case) were dried to constant weight. The results shown in Table I, strongly suggest a possible correlation with the laminary age sequence obtained from the molars. Although lenses were obtained from only 26 of the specimens, there is sufficient indication of a parallel lens age sequence to warrant further close study if more material can be obtained by future investigators. Lens weights have been found to be very useful indicators of age in other species—of which examples include the racoon (Sanderson, 1961) the Gray fox (Lord, 1961), the Cottontail rabbit (Lord, 1959; Edwards, 1962) and the Pronghorn antelope (Kolenosky & Miller, 1962).

The molar progression and identification of the molars

It is well established that the African elephant, during its life, normally has a course of six molars in each half-jaw, upper and lower, which move forward by linear progression towards the distal end of the jaw, where small fragments break off during wear and are lost. Each of these molars arises proximally as a complex unit in an alveolar pocket. A great deal of unnecessary confusion has arisen as to the precise number of laminae which belong to each individual molar. Unless these are examined at an early stage of development, as well as at more advanced stages, confusion is inevitable, and unless a complete age-sequence is available it is difficult to trace the stages through which each lamina must pass during its functional existence. Moreover, some authors have described the laminae from the medial aspect and some from the cheek, while some have used upper teeth and some lower.

To avoid confusion, all the molars used here have been described from the medial and crown aspects only, and all have been taken from the right mandible. Checks against abnormalities have been made by comparison with duplicate molars from the left mandible and the photographs of the upper molars, and although a slight difference occasionally occurs, it is usually insignificant or only affects the fragmenting portions, distal to the foramen mentale (see Plate I(b)).

It is not relevant here to refer to the tusk development except in the early stages, in the foetus and calf. Aichel (1918), Eales (1926), Schaub (1948), Hill (1953) and other authors have referred to the milk tusk in the elephant, Lang (1965), however, disputes its existence.

Specimen 154 in the present series, a near-term foetus, possessed a pair of deciduous or milk tusks. The permanent tusk buds could not be identified with certainty in the premaxillae, although a series of thin sections of approximately 2 mm thickness were cut through it. Specimen 135 was a female calf of probably under six months old and still possessed a pair of milk tusks, as well as a distinct pair of permanent tusks developing behind them in the premaxillae. Specimen 114 was a larger calf, which had already lost the milk tusks and possessed permanent tusks, 15 cm long, which were still subcutaneous, although they protruded just beyond the anterior edge of the premaxillae (Plate III(a)). It is probable that specimen 135 was younger than any of the collection at Basle at the time of their arrival there, hence their milk tusks could no longer be observed, having already been shed.

Thus, the dental formula for the African elephant must include both an upper, deciduous, or milk tusk and an upper, permanent tusk on each side as well as six molars in each half-jaw, upper and lower.

TABLE I

Measurements of 40 elephants, arranged in laminary age order

Males

Spec. no.	F.M. laminary age	Lens wt (g)	Grinding length (cm)	Maximum grinding width (cm)	Wt distal molar in wear (g)	Wt proximal molar in wear (g)	Body wt (kg)	Height withers (cm)	Girth (cm)	Circumference of fore-foot (cm)
154*	I/0	0·09	—	—	—	—	61	74	173	32
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
113*	III/3	0·39	12·5	4·4	252	83	1389	200	259	81
—	—	—	—	—	—	—	—	—	—	—
103*	III/7	0·41	13·8	5·4	172	125	2480	221	274	107
—	—	—	—	—	—	—	—	—	—	—
134*	IV/2	0·48	13·5	5·2	765	—	—	277	335	104
110*	IV/2	0·45	13·2	5·2	950	—	2580	250	320	112
—	—	—	—	—	—	—	—	—	—	—
83	IV/5	0·51	—	—	—	—	2665	264	356	106
99*	IV/6	0·50	13·8	4·9	330	1500	—	290	350	107
132*	IV/7–8	—	16·4	5·2	180	1865	—	312	422	125
85*	IV/7–8	0·52	18·6	5·5	241	1925	—	295	384	124
87*	IV/8–9	0·59	18·4	5·4	144	1810	—	269	356	114
149*	IV/8–9	0·61	18·6	5·5	190	1900	—	280	326	124
150*	IV/9	0·61	18·4	5·9	57	2440	—	274	366	117
118*	IV/9	0·62	18·8	5·7	115	2320	—	277	378	122
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
19	V/2	—	—	—	—	—	4100	322	396	134
152	V/2	—	—	—	—	—	—	330	452	142
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
84*	V/6	0·71	24·8	7·4	990	2598	—	335	450	144
93*	V/7	0·71	22·0	6·6	680	2785	2870	262	340	99
119*	V/7	—	22·5	7·0	710	2610	—	300	400	132
120*	V/7	0·72	22·2	6·6	736	2720	—	322	419	140
108*	V/7	—	26·8	7·5	652	3170	5550	350	436	147
—	—	—	—	—	—	—	—	—	—	—
18	V/9	—	—	—	—	—	5400	335	414	137
116*	V/9–10	—	23·3	7·0	652	3570	—	325	406	140
117*	V/11	—	24·3	7·2	418	3910	6070	346	426	140
86*	VI/1	0·83	21·0	7·0	3440	—	—	340	420	150
121*	VI/1–2	0·88	21·0	7·2	3740	—	—	312	427	137
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—

TABLE I (continued)

Females

Spec. no.	F.M. laminary age	Lens wt (g)	Grinding length (cm)	Maximum grinding width (cm)	Wt distal molar in wear (g)	Wt proximal molar in wear (g)	Body wt (kg)	Height withers (cm)	Girth (cm)	Circumference of fore-foot (cm)
—	—	—	—	—	—	—	—	—	—	—
135*	I/0–1	0·18	6·5	1·8	—	—	212	114	137	56
114*	I/1	0·21	9·8	2·5	68	73	369	137	157	66
—	—	—	—	—	—	—	—	—	—	—
133*	III/4	0·30	12·6	4·3	69	74	—	213	287	88
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
23	IV/2	—	—	—	—	—	2130	252	302	104
100*	IV/2	0·48	14·2	5·3	680	708	—	234	294	107
25	IV/2	—	—	—	—	—	2080	256	287	97
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
112*	IV/7–8	0·51	15·9	5·6	129	1670	2380	246	335	107
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
22	V/1	—	—	—	—	—	2438	282	264	102
24	V/1	—	—	—	—	—	2620	284	336	109
88*	V/2	0·60	17·0	5·4	1710	—	—	259	366	114
—	—	—	—	—	—	—	—	—	—	—
131*	V/5	—	17·6	6·2	820	1500	—	252	350	114
127*	V/5	0·60	22·2	6·5	850	2160	—	262	332	107
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
21	V/8	—	—	—	—	—	2770	270	353	109
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
122*	VI/4	0·87	20·0	6·5	1530	—	2920	280	366	112
107*	VI/8	0·93	13·0	6·2	510	—	2537	259	322	125

* Indicates specimens whose right mandibles were available for detailed study and which have also been used in Table II.

Using the same numbering of the molars as used by Morrison-Scott (1947) Nos I to VI (I being the earliest, most anterior in development in each half-jaw), it now appears, from Lang's data (Lang, 1965) that molars I and II are lost at the ages of about two years and four to five years respectively. Weaning usually takes place at about two years old, but occasionally sporadic suckling in the wild state continues until two subsequent calves have been born to the dam (i.e. four to five years later). Molars I and II differ very considerably in the arrangement of the roots from molars III to VI (Plate II (a) and (b)). The roots remain "open" until the molar approaches the foramen mentale when they close and become bent towards the posterior as "fangs" (Verheyen, 1960).

Molar I

The first molar is very small and although it is lost at about two years old, it is not at present clear whether it has already been cut at the time of birth. Browsing begins at a very early age, but so far, reliable data as to exactly what this age may be have not been available.

In the near-term foetus, specimen 154, there were five quite distinct laminae. In specimen 135, all five were clearly distinguishable on the grinding surface, and the root had divided into distinct distal and proximal parts. Specimen 114 showed that the fifth lamina had been lost through wear and was no longer visible on the grinding surface. The other four were indistinct, but could just be identified. The maximum grinding width was 1·1 cm and the maximum weight 9·6 g maximum grinding length 2·4 cm (Plates II(a) and (b)).

Molar II

This molar apparently comes into wear simultaneously with molar I but is not lost until about four to five years old. Seven distinct developing laminae, all already partly calcified, were found in the foetus, specimen 154. All seven were also distinct in specimen 135. Out of these, only laminae 1 to 4 (inclusive) had come into wear (Plate III(a)). In specimen 114 the second molar was complete, the seven laminae being easily distinguishable on the crown and all in wear, while erosion was just beginning on the anterior face of the distal root. By comparison with details quoted by Lang (1965) and with the records kept of the development of "Diksie" and "Toto" at the Gardens of the Zoological Society of London, the loss of molar I usually seems to occur at about two years old, and of molar II at between four and five years old.

In the foetus, the foramen mentale lay distal to molar I, in specimen 135 it lay just under the anterior edge of the first lamina of molar I. The laminary age of 135 may thus be described as FM: 1/0–1. In specimen 114 it was below the first lamina, thus giving a laminary age of FM:1/1. The maximum grinding width found in molar II was 2·5 cm, the maximum weight 73·3 g and the maximum grinding length 5·5 cm.

Molar III

"Toto", the young cow in London, is at the time of writing (Feb. 1966) just over five years old and has her third molar fully in wear. Apparently her molar IV has not yet started to come into wear, although it is not very easy to see right to the back of the mouth with absolute certainty. By comparison with Table II, her laminary age is probably FM:

III/2. Three specimens taken in the present study had molar III in wear, and it was also present in specimens 154 and 135, in the alveolar pocket, while in 114, the first three laminae had come into wear, so that 114 actually had three molars, I, II and III, in wear simultaneously. In specimens 135 and 114, ten distinct laminae could be counted, these being fully calcified in 114 (Plate III(b)). Thus, molar III has ten potential laminae. Examination of the whole molar, however, after it has come into wear suggests that the tenth lamina never reaches full wear, although in two cases, 113 and 133, it was distinguishable as a buttress on the proximal face of lamina 9. As molar IV begins to come into wear, friction of IV/1 against III/9 occurs in some cases, e.g. specimen 103. It may wear away III/9 completely so that only eight laminae are distinguishable as ridges on the crown. The maximum grinding width found was 4·3 cm. It is not possible to measure the full grinding length in "Toto's" mouth, and unfortunately no specimen was collected on the present project possessing a complete molar III in wear. Thus, neither maximum grinding length nor weight are available, although probably about 9·5 cm is the maximum grinding length attainable by this tooth.

Molar IV

Molar IV begins to come into wear at about four years old and is fully in wear at about 10 to 11 years old—i.e. at the beginning of the sub-adult or "teenage" period. This molar has ten distinct potential laminae. These were all present in the alveolar pocket, prior to the growth of laminae 1 and 2 into wear. In 103 and 134, the tenth lamina was distinguishable only as a buttress on the proximal face of the ninth lamina. Thereafter it apparently disappears as the tooth develops. Lamina 9 also is frequently worn down at crown level by friction against V/1, as molar V comes into wear, e.g. specimens 112, 132 and 149. Thus, previous investigators have thought, for example, that molar IV had only seven (Falconer, 1868) or, others, nine laminae (Ward, 1935). The maximum grinding width found was 5·5 cm, maximum grinding length 13·5 cm, the weight of the complete tooth (♂) 950 g, (♀) 680 g. It should be noted that as wear and fragmentation progresses, lamina 4 marks the division between the distal and proximal root complexes, itself having a divided root. In molars IV, V and VI, laminae proximal to no. 4 may thus be counted with accuracy, even after the loss of the first three laminae (Plate II(a) and (b)).

Molar V

The first laminae of the fifth molar move into wear at about 13 or 14 years old, and the tooth is probably fully in wear by about the 23rd to 25th year of age. It has 12 potential laminae (Plate IV(a) and (c)) of which nos 1 and 2 arise united at the base, no. 1 being the smaller (Plate IV(b)). Both, however, contain distinct pulp-branch cavities and must be regarded as distinct laminae. During development, no. 1 reaches the level of the crown and comes into wear, but usually (though not always) only as a pillar on the cheek side of the molar (Plate II(b)). Sometimes it develops symmetrically but it is always less easily distinguished from no. 2 than no. 2 from no. 3. Number 12 appears as a very small leaf on the proximal face of No. 11 (Plate IV(a)). It also has its own pulp-branch cavity, but apparently it never comes into full wear, although in specimens 131 and 119 it could be identified as an indistinct buttress on the proximal face of no. 11. As in molar IV, the penultimate lamina of molar V may be worn away by friction against the distal end of molar VI, as this comes into wear, e.g. specimens 108 and 120. The maximum grinding width of molar V was found to be 7·5 cm, maximum grinding length approximately 17·5 cm and weight of the complete tooth 2440 g.

Molar VI

It is likely that the sixth, and largest molar, does not begin to come into wear until after the 28th to 30th year of age. No evidence has been available on which to base a suggested age at which it attains full wear, nor how many years it takes for all of its laminae to move past the foramen mentale. Undoubtedly this covers a considerably greater period of years than molar V since its laminae are not only more numerous but also thicker and heavier. Molar VI has 13 potential laminae, all of which may come into wear (Plate VI(a)), although sometimes no. 13 apparently forms a buttress against the proximal face of no. 12 without reaching the crown. As in the previous teeth, lamina no. 1 often arises asymmetrically, forming a pillar on the cheek side only of the tooth and it may also be rapidly worn away by friction against molar V/11. As the sixth molar moves anteriorly along the mandible, bone tissue invades the alveolar space and becomes increasingly dense (Plate V(a)). Bony tissue is also laid down in the mandible, proximal to each lamina edge, apparently forcing it to move forwards continuously (Plate VI(b)). The mechanism for this process has been discussed by Heuvelmans (1941*a*,*b*,*c*, 1942, 1943), Aichel (1918) and Verheyen (1960). It is quite evident, in the present series, that there is an actual elongation of the molar-bearing portion of the mandibular ramus. It is also clear that molar movement is not entirely dependent upon pressures exerted by the growing proximal molars, the dynamic and constantly self-adjusting bone formation within the mandible undoubtedly contributing to the molar movement in an anterior direction. It seems unlikely that mastication provides the only stimulus, or that it is dependent on environmental factors causing greater or lesser wear on the grinding surfaces. One is inclined to the view that the process is an intrinsic one. The sixth molar becomes very large and heavy at the point of maximum growth—i.e. when 12 laminae are fully and simultaneously in wear. Maximum grinding width found was 7·2 cm, grinding length 21 cm, weight 3740 g.

Thereafter the weight and length decrease as anterior fragmentation takes place and the roots are eroded, resorbed and no more replacement teeth are available proximally. The oldest elephant taken, laminary age FM: VI/8, was a cow. It showed all signs of senility and—a most unusual situation for a cow—had left its association with a herd with which it could presumably no longer keep up, and was obviously limited to feeding solely upon the softer shoots and leaves of the vegetation. The fangs of the remaining molars were severely eroded and the molars themselves found to be loose in the jaws, when it was shot. It is evident that the maximum age of an elephant is absolutely limited by the time when mastication is not longer possible, due to the decline and loss of the final laminae of the sixth molars (Plate V(a) and (b)).

Proposed laminary age standard

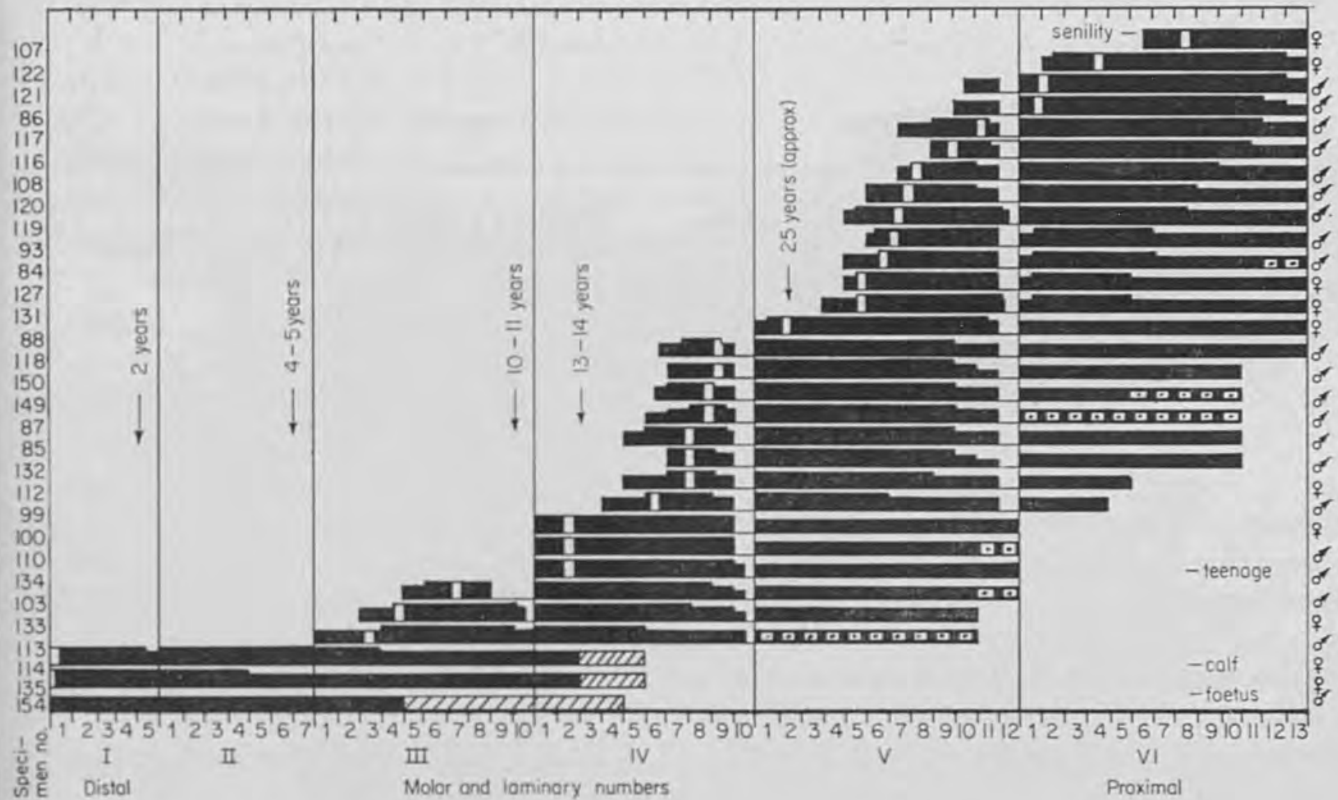
Table II is an attempt to represent graphically the molar sequence, showing the potential life-span of an elephant as the period covered by the progression of a total of 57 laminae anteriorly past the foramen mentale of the mandible.

Thus the laminary age sequence runs through molar laminae: I/1–5; II/1–7; III/1–10; IV/1–10; V/1–12 and VI/1–13, i.e. a total of 57 laminary increments.

The complete molar situation in the right mandible is represented by the shaded bars on the table, the maximum elevation in each case representing laminae in wear, the first level of decreased elevation representing laminae which have either been worn down to a lower level or which have not yet come into wear. The second level of decreased elevation represents laminae which never come into wear, terminating as mere buttresses on the

TABLE II

Laminary age sequence in 31 African elephants, ♂ and ♀
Right molars, medial aspect



proximal face of the tooth. Molar and laminary numbers are indicated along the base line, and the position of the foramen mentale in each specimen by a gap in the shading of the bar. In cases where laminae from the alveolar pockets were lost or damaged, this has been indicated by dots, and in specimens 154, 134 and 114, where portions of the developing molars were not yet calcified, the laminae being present as fibrous sheets only, the position is indicated by diagonal shading.

It should be noted that Table II, and indeed the whole concept of molar laminary age is based on a numbered laminary progression, not upon laminary or molar size. The measurements of molar length, width and weight are given only as a guide to the identification of the molar, or molars, currently in wear.

Having identified the molar, or molars, in wear and the lamina directly over the foramen mentale, the laminary age of the specimen in question may now be stated. Plate I(a) illustrates the procedure in the case of specimen 121.

For comparative purposes, indications of year-ages have been entered on the table, derived from data obtained from living captive animals of known laminary and year-age now at the Zoological Gardens of Basle and London.

Lens weights

Having determined the laminary age sequence of the 31 specimens whose mandibles and molars were available for detailed study, the available lens weights were entered on Table I for comparison and some degree of correlation was found. Unfortunately, insufficient lens weights were obtained in the present study to use as a sample from which to construct a meaningful curve.

TABLE III

Measurements of complete lower right molars

No.	Maximum grinding length (cm)	Maximum grinding width (enamel loop) (cm)	Maximum weight (g)
I	2·4	1·1	9·6
II	5·5	2·5	73·3
III	(approx.) 9·5	4·3	(approx.) 180–190
IV	13·5	5·5	950
V	17·5	7·5	2440
VI	21·0	7·2	3740

The remaining nine specimens of the field collection were also entered in Table I, being placed on the basis of laminary age estimations derived from field photographs of the molars, a method which, if used by itself for a large number of animals for which no additional data are available, might lead to error over the identification of molars III, IV, V and VI. In the case of the specimens used here, sufficient additional data were also available to confirm the first arbitrary placings made on the basis of the photographs of the molars.

The value of body measurements in age estimation

The value of the body measurements in age estimation is limited and really only offers a broad guide in the field. Knowledge of the normal measurements is useful when studying live, wild elephants for the purpose of herd composition counts and selection for "cropping" or for research purposes. The most meaningful for these purposes are withers (or shoulder) height and forefoot circumference.

Broadly speaking, a calf of under 140 cm at the withers indicates a laminary age of less than II/1 (under two years); from 140 to 200 cm indicates a calf of laminary age II/1 to III/1 (between two and five years). A height of 200 to 250 cm indicates a laminary age of III/1 to IV/1 (five to ten years). Above this, bulls grow more quickly than cows: 250 to 320 cm in a bull indicates that the laminary age is on the fourth molar (abour 10 to 25 years); 320 cm and over indicates that the laminary age is on the fifth or sixth molar (over 25 years).

No cow was taken in the present series above 284 cm at the withers, although several were outstanding members of their herds. Forefoot circumference is very variable, but in the bull 100 cm or less indicates a calf (under five years); 100 to 125 cm indicates laminary ages III/1 to V/1 (five to 25 years) and above 125 cm laminary ages of V/1 and over (over 25 years). The maximum forefoot circumference of any cow in the series was 125 cm, that of the very elderly specimen no. 107. Generally this measurement seems to be very variable in the cow, and therefore of little value for age assessments on the basis of the spoor alone. This maximum for a cow is much smaller than the maximum forefoot circumference of 150 cm of bull 86 taken in the present study, and of 155 cm found by measuring the spoor of a very large bull elephant seen and photographed (but not collected) in the Amboseli National Park, Kenya.

Measurements of body weight and girth are also of importance as a guide to the general physical condition of the elephant in relation to food and water availability, to stress, and in some cases to pathological, congenital or traumatic causes, since inconsistencies in these measurements are usually indicative of some abnormality. This is particularly evident in specimens 86, 87, 93 and 107, which may be contrasted to the measurements of 152, a bull in magnificent condition (laminary age FM: V/2) which was collected on Kinangop Mountain, Kenya. No lesions or parasites were seen in this specimen; a fistula near the trunk tip, probably due to piercing by a bamboo in early life, had healed and was apparently of no importance to the animal.

Specimen 86 was an elderly bull (laminary age VI/1), collected in North Uganda. It was lop-eared and maintained the "drooping-head" posture typical of an elephant with chronic ill-health. It was also sluggish, anaemic and had suppurating lesions on the trunk and in the buccal cavity. The sixth molar was lighter in weight than the sixth molars of comparable age from other specimens. The circumference of each of the forefeet was also rather larger than that of others in proportion to shoulder height, each forefoot having a soft, swollen appearance.

Specimen 87, from the same location as 86, had, at some time, lost the distal third of its trunk. It is of note that its molar weights, grinding width and length, and its shoulder height are rather less than should be expected. Its survival up to the time it was collected in this project was, in itself, remarkable, as the trunk stump had healed. Nevertheless, the elephant must have been greatly restricted in its ability to feed and drink and was probably capable of utilizing only softer, more readily accessible foodstuffs, and had thus become impaired in its molar and body growth rate.

Specimen 93, from West Uganda, was a very small elephant for the laminary age finding. It had advanced aortic and coronary atherosclerosis and was reported by the people of the locality, where it was collected, to be very inactive and to live within a small circumscribed area. Again it seems probable that the laminary formula gives a reasonably correct estimation of its age, as the molar dimensions and weights seem normal, but that possibly through ill-health or some other cause it failed to grow to the normal size and achieve the activity necessary to full physical development.

Specimen 107, a cow from the coastal region of Kenya, was obviously a very elderly elephant, as mentioned previously, and its shoulder as well as its head "drooped", as in specimens 86 and 93. It had extensive atherosclerotic plaques in the aorta, as well as a heavy parasitic infestation of the liver. Its body weight was apparently declining, 2537 kg being low for a cow elephant of its shoulder height (259 cm). The forefoot circumference is also rather large for a cow, and as in 86 the sole appeared unusually soft and swollen.

Conclusions

Owing to the inadequacy of reliable data on estimating the age of the African elephant (*Loxodonta africana*) on the basis of annual increments, it is suggested that a technique of estimating and describing the molar laminary age would be a simple and meaningful alternative for use in the field.

The potential life-span of an African elephant is limited by the character of the forward linear progression of the six molars located in each half-jaw. During the entire progression in the mandible a total of 57 molar laminae move past the foramen mentale, at which point erosion of the roots begins. Thence only the thin remnant of the grinding surface moves forward beyond this point and breaks away in irregular fragments.

The full number of 57 molar laminae may be identified during the development of the six molars, the laminae being grouped as follows: molar I/1–5; II/1–7; III/1–10; IV/1–10; V/1–12; VI/1–13. As the molars move into wear, surface irregularities occur, but these may be interpreted without undue difficulty by reference to direct measurements of the total grinding length of the molar or molars in wear, maximum grinding width of the outer edge of the enamel loops in wear, the weights of the molar or molars in wear, and an examination of any developing molars in the alveolar pockets. Comparison of these with the age reference Tables I and II, constructed from the 40 elephants used in the present study, will, it is believed, enable a worker in the field, collecting elephants in Kenya or Uganda, to identify the molars of the normal right mandible of any given specimen, and to describe the laminary age by the laminary standard as given in the second column of Table I. As many other specimens as possible, including those from other areas, have been tested against these Tables, and no difficulty has been found in placing them, provided the prescribed data have been available.

The grant by which the cardiovascular research project (of which this study has formed a fundamental part) was financed, was given by the British Heart Foundation, and the project carried out under the auspices of the Pathology Department, Nuffield Institute of Comparative Medicine, The Zoological Society of London. This assistance is gratefully acknowledged, as is also the invaluable assistance given by the Game Departments of Kenya and Uganda, in permitting the author personally to collect specimens representative of the complete age range from carefully selected, contrasted habitats.

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APPENDIX 7.

(*Rev. Zool. Bot. Afr., LXXIV, 3-4*). (*A paru le 30 décembre 1966*).

The African Elephant : the background to its present-day ecological status in the Murchison Falls (Uganda) and Tsavo (Kenya) National Parks, and environs.

BY

SYLVIA K. SIKES

I. WHY SO MANY ELEPHANTS ?

One of the most important problems of wildlife management confronting conservationists in Africa at the present time concerns the African elephant, *Loxodonta africana*. The problem is particularly acute in parts of East Africa, notably in the Murchison Falls and Tsavo National Parks, where over-concentration of elephants is associated with limited stock-carrying habitat capacity.

Elephant Physique, Habits and Distribution Have Altered Significantly in East Africa.

While it is most improbable that the overall elephant population in the whole of Africa today is anywhere near the tremendous number which must have existed in former centuries, certain physical characteristics, habits, and the distribution of the species have altered significantly. As will be shown, in East Africa the primary stimulus for this change was the construction of the main railroads from the coast to the hinterlands. Not only has this stimulus operated directly upon the elephants through the introduction of piped water supplies to formerly waterless areas, but also indirectly through pressures on natural wiedlife habitats resulting from colonial economic development programmes.

(« Royal Holloway College, University of London »).

Probably no other species of mammal has been ecologically affected in this way as dramatically as the elephant, for its demands for food, water and shade have, in tracts which include areas of low nutritional potential, necessitated extensive migratory movements during transitional seasons and climatic crises. In the past, in some regions, these almost certainly involved treks of up to several hundred miles extent.

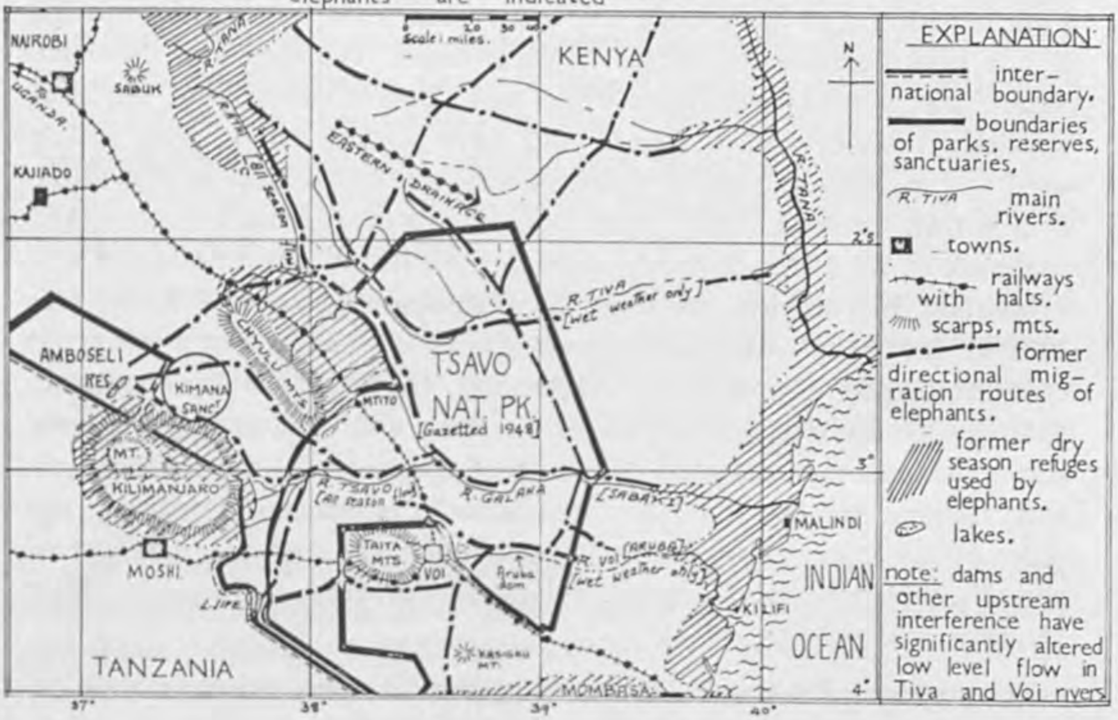
Since the impact of these changes in physique, habits and distribution has only taken effect comparatively recently, the underlying causes have sometimes been everlooked by conservationists and scientists, other than ecologists, whose experience of the African environment may be limited to the period following World War II. Consequently somewhat misleading comments are sometimes made, bedevilling not only the primary ecological study of the problem, but also the formulation or realistic long-term policies of elephant management. For example, a conservationist from the United Kingdom visiting Africa recently, has series recommended the management of African National Parks according to a « British pro forma » (BOYD, 1965). He apparently overlooked both the complexity of the dynamics of the African environment and the fact that most types of European « pro forma » which have been tried in Africa, have all too frequently been demonstrated in the past to be ill-suited to that continent. Another wrote recently: « We really know nothing about the Tsavo elephants » (HARTHOORN, 1965), a statement perhaps reiterating the need for further research, but unfortunately overlooking the wealth of relevant ecological data which already exists, and in which may be traced clues to the correction of the present ecological imbalance in the Tsavo National Park.

In the Report of the Kenya National Parks, 1962-63, the question is raised as to why so many elephants occur nowadays in the Tsavo National Park, and whence they originally came (Anon., 1963). I am currently engaged on a research project on the ecology of cardiovascular disease in East African wild animals, with particular reference to elephants *), occurring both in the semi-restricted habitats mentioned above and in free-range habitats. The answers to these questions on the origin of the present distribution and habits of these elephants are therefore most relevant in seeking an explanation of the disease patterns I have recently found in East African elephants. As the combined field experience of my father and myself in

*) (Financed by the British Heart Foundation).

the areas concerned extends back to the time of the construction of the Mombasa-Uganda railway, it seems useful to use this experience in considering some of the more obvious factors which have brought about today's « elephant problem » in Tsavo and its environs, and to compare it with the similar problem encountered in the Murchison Falls Park. In addition, I have drawn not only upon my own recent extensive observations on living elephants and their habitat, and the

MAP SHOWING MAIN EASTERN DRAINAGE AREA OF KENYA
Former dry season refuges and directional migration routes used by elephants are indicated



detailed examination, *post mortem*, of forty elephants representative of both sexes and all age groups, but also upon scientific, hunting, and historical literature and legend, government ivory licence books and reports, and also upon my own knowledge of African lore and language. Moreover, the freedom permitted me in the past three years by the Game and National Parks Departments of Kenya and Uganda**), to travel widely within controlled areas and parks, observing, photographing, and collecting data and specimens, has been fundamental to this attempt to evaluate certain aspects of elephant ecology in the areas studied.

**) (The co-operation accorded me by the Directors of these Departments is gratefully acknowledged).

The Environment: Geological and Hydrographical Factors.

Basic determinants of the character of any particular natural environment are the structure of the earth's crust in that area, the availability of water, and the prevailing climate. For example, the plateau lavas of those parts of Kenya characterised by grasslands are ideally suited to the existence of grazing animals. These plateau lavas mostly originated from centres of extrusion situated along the outer boundary faults of the Rift Valley, whence they spread out in flattish gradients over hundreds of square miles. The plateaux occur at fairly high elevations of 5,000-9,000 feet above sea level, with good rainfall but a high surface discharge. Subsoil water supplies are therefore small, but considerable quantities exist below older land surfaces between successive lava sheets and have consequently been widely used in the construction of borehole supplies for ranching. The situation within the Rift Valley itself differs, however, from the grassland plateaux in its irregularity through modifications due to erosion and volcanism. In contrast, the main Eastern drainage zone of Kenya lies east of the Rift Valley and slopes gradually towards the coast. It consists largely of exposed metamorphic rocks of the Pre-Cambrian period with various extrusions of Tertiary and Quaternary volcanic rocks, which have assumed the form of characterful mounds, ridges, and ranges. In the Eastern coastlands themselves, however, the older rocks are overlain by various sedimentary rocks as a fringe of variable width, formerly characteristically forested, and mostly about 35 miles wide (SIKES, 1934).

The exposed Pre-Cambrian rocks of the Eastern drainage zone typically carry sparse scrubland vegetation, but the weathered neighbourhoods of volcanic extrusions are sometimes lightly forested, especially in the region of springs and seepages. Almost all of the Tsavo National Park lies in this area, and possesses a flora and fauna typical of this arid scrubland type. For this reason we can be certain that the area now covered by the Tsavo National Park probably never consisted of extensive grassland of the type found around Nairobi or Arusha, and is probably incapable, even with first-class habitat management, of continuously carrying a similar biomass. Moreover, the effect of repeated firing of the area, simultaneously with its continuous use by large numbers of animals, must inevitably cause a degree of vegetation destruction exceeding its attainable regenerative powers.

It has been suggested that the Galla pastoralists used the area in the past, but if this was so, they would only have used it transitorily (as do the other pastoral tribes who use arid semi-desert and marginal lands, for example the Fulani of Northern Nigeria) during their migrations with large congregations of cattle in the transitional and rainy seasons. That this was so, probably from very early times, is also evident in the development of definite migratory routes, used also by slavers, hunters, and explorers, which were dependent upon the location of reliable water holes. In the years prior to the advent to East Africa of the benefits of veterinary medicine, even the comparatively large migratory congregations of cattle which were sometimes formed certainly never attained numbers comparable with those which may occasionally be seen nowadays in the few cases of pastoral tribes which still migrate. It is also most unlikely that they would have kept cattle in these areas for prolonged periods in view of the prevalence in the past of tsetse fly.

The Eastern coastland fringe, composed of various types of weathered sedimentary rocks, previously carried a thick cover of tropical coastland gallery forest. Its progressive destruction has also involved the destruction of a rich natural fauna, of which but limited samples remain now. It also constituted one of the main dry-weather forest refuges for mixed herds of elephant in the calving season.

The main natural surface drainage system of Eastern Kenya consisted of the Northern Uaso Nyiro, Tana and Sabaki (Galana) Rivers. All these originate in and receive tributaries from springs and seepages from the volcanic rocks. These all become severely reduced in flow as they pass through the Pre-Cambrian rocks of the Basement Complex, while additions from local springs and seepages along their course are negligible. During the rainy seasons, however, surface run-off through tributary valleys, which are otherwise absolutely dry, is considerable and appreciably supplements the flow. In addition, small dry-season discharges occur where mountain masses with a fair rainfall have gentle enough slopes to allow soil and vegetation to obtain a footing. On steep slopes, and places where vegetation has been destroyed, the discharge is rapidly lost through evaporation, especially where valleys debauch on the lower plateaux. In a few cases, however, springs of greater magnitude occur, some discharging at ground surface (Tsavo River), and others passing below impervious lava streams or the sediments of weathered valleys to re-appear lower down as seepages and springs.

The importance of these features within the area now occupied by the Tsavo National Park will at once be evident. In the past, prior to the construction of the railroad, constant surface water supplies were only available to wild animals in the Tsavo and Sabaki (Galana) rivers, and in the occasional springs and seepages emanating from the gentler slopes and foothills of the larger volcanic masses, such as Mt. Kilimanjaro, the Chyulu, Ngulia and Taita ranges, Mt. Kasigau, and the various ridges such as Maungu Hill, Mudanda Rock, and similar small outcrops. In the earlier part of each dry season, a certain amount of water was obtained by elephants digging in sand-river beds, but this would have been of limited quantity depending on influences higher upstream. Examples of this are the Voi (Aruba) and Tiva rivers. The latter also carries a certain amount of various salts which are valuable to wild animals.

In the past, any wild animals with regular requirements for large quantities of water (for example between 20 and 30 gals are needed per fully-grown adult male elephant per 24 hours) would remain within range of adequate water, food, and shade for their requirements. Since during the dry seasons, water, food and shade were, however, all inadequate in most of the plateaux areas in the Tsavo environs, the elephants then withdrew to the forested areas of the slopes of Kilimanjaro, the Chyulu Range, parts of the lower Sabaki (Galana) and Tana River valleys, and the Coastal forests both north and south of Mombasa. In the past, there was free access by the elephants to extensive unspoiled forests in all these areas. It is only since the advent of the railway that hundreds of square miles of coastland and mountain forests have been cut away and replaced by the vast sisal and coconut plantations of the coastland, Voi, and the Kibwezi areas, and the fenced ranches and settlements north of the Chyulu Range and on the lower slopes of Mt. Kilimanjaro. The Map indicates the former forest dry-season refuges used by elephant prior to the completion of the Mombasa-Uganda Railway. Confirmation of the regular presence of elephants in those forests in the past has been obtained by reference to missionaries formerly resident there, and from the reports of forest officers, surveyors and hunters. I personally recall vividly the activities of elephants in a private compound at Kilifi for example, even as late as the year 1931, when they broke down the branches of baobabs and other trees and shrubs. It is of note that of those baobabs, the ones still standing today show few identifiable scars made by the elephants, an indication not only of how effective bark regeneration can be, but also of the fact that elephants apparently caused less extensive bark damage there than that seen nowadays in Tsavo National Park.

Migration in Relation to Requirements for Food, Water, Shade and Herd Regrouping.

Previously, African elephants characteristically migrated over vast distances, thus ensuring their finding adequate shade cover, nutritional variety, and salt and water supplies. In addition, the opportunity was provided for herd regrouping, and large congregations were sometimes formed, numbering up to 100 animals or more, by the temporary amalgamation of smaller, mixed herds or clans. These migrations were apparently of two types; firstly, there were longdistance directional migrations, which took place in the transitional seasons - *i.e.* in the period following leaf-fall and the first sprouting of scrub vegetation, just prior to the onset of the rainy seasons, and again at the end of the rains, when mud-holes were drying up and their water becoming foul. Secondly, there were localised wet-season meanderings. There is abundant evidence that the long-distance directional migrations in certain cases actually covered several hundred miles per annum. This is not surprising to anyone familiar with elephants. I have personally observed, with binoculars from a hill top, a herd which covered thirty miles in one morning. A good working pack or ranch horse can manage fifty miles in a day without excessive exhaustion, so under migratory pressure it seems not unlikely that adult elephants could manage up to a hundred miles in one day. I also checked the speed of three bulls « marching » across bush, parallel to a road, and found that they were progressing at a steady 10 m.p.h. Any hunter knows all too well how difficult it is to follow up a « marching » (*i.e.* a non-browsing) herd.

One of the main effects of progressive colonial economy, resulting from development policies consequent upon the construction of the Kenya-Uganda Railway, has been expanding land usage by rapidly increasing human populations. The effect of this, from the point of view of elephants, has been (on the negative side) the closure of migration routes by the establishment of villages, towns, fenced agricultural projects; the replacement of large areas formerly covered with natural forest, by plantations (with consequent surface-water loss at seepages and springs); and the opening up of natural thickets by lumber-jacks for the timber trade. In some areas, total destruction of forests for purposes of tsetse fly control has also been carried out. On the positive side, a few wildlife and nature reserves, sanctuaries and parks have been demarcated in wilderness and agriculturally non-productive areas. The Tsavo and Murchison Falls National Parks are among these.

II. A COMPARISON OF THE PRESENT SITUATION IN THE TSAVO AND MURCHISON FALLS NATIONAL PARKS.

Murchison Falls National Park.

In the case of the Murchison Falls National Park, Uganda, the effect on the elephants of the closure of migration routes and non-availability of forest refuges has led to an over-concentration of elephants within the Park, with an overflow into the reserves to the north. At the time of demarcation as a national park, however, the area already consisted ecologically almost entirely of degenerate woodland, in which but few limited forest stands still remained amid the undulating grass-covered plains. Surface water is abundant at all seasons in the Murchison Falls National Park, through which the Victoria Nile flows, and along one side of which also runs the Albert Nile. Wallows, swamps and tributary streams of the Nile are also numerous and adequate for the needs at all seasons even of large mammal populations.

In contrast, however, the vegetation offers litle arboreal food for elephants, and recent studies have indicated that those elephants have adopted a diet of 88 % grass fodder (BUSS, 1961). Moreover, in their frustrating search for fruit, they have destroyed most of the undergrowth and the lower branches of trees in the remaining forest stands, have ring-barked some of the largest trees and pushed others over. Since fire is not totally prevented in this particular park, the damaged trees are rapidly burnt out by bush fires, and low-level growth repeatedly seared. Roots of dead and ring-barked trees are also rapidly destroyed underground by termites (BUECHNER and DAWKINS 1961). The destructive cycle has steadily gathered momentum, and one of the worst resultant features is the almost total lack of shade.

Indian elephants are unable to tolerate much direct tropical sunshine. Their ears offer a less efficient temperature-control mechanism than those of the African elephant, but even the latter species, although tolerant of considerable periods of exposure to direct tropical sunlight, does not thrive if continuously exposed to the unmitigated rays of the sun. On the other hand, inadequate exposure to heat may also be detrimental. In an abnormal condition frequently seen in captive, non-working elephants, the upper border of the ear bends forwards over the scaphoid surface, whereas in natural conditions, it normally bends backwards over the dorsum of the ear in a medial position. It is interesting that the ratio of turn-over to total ear depth normally increases with age in African elephants. It seems likely that the ear turn-over assumes the abnormal, scaphoid position in conditions where too equable a temperature, or too inactive a life, make demands on the ears too low for their vigorous « punkah » action to be necessary. The regular heating of elephant stalls in Zoos for about 4 hours daily, to approximately 100°F. while maintaining the normal chemical composition of the air, would possibly prevent the appearance, especially in elephants under 20 years old, of this condition. In wild elephants, the appearance of lop-ears is seen from time to time and may possibly arise from injury, but in some cases may be due to sclerosis of the peripheral arteries. It does not appear to be a condition necessarily associated with reversed ear turn-over as described above.

One effect of excessive exposure to continuous, direct tropical sunshine is for the skin to become over-dry, causing irritation. This increases the desire to scratch against tree trunks, with resultant damage to the bark, and often the subsequent death of the tree itself. This desire to scratch is not evident to any significant degree in wild elephants with ready access during the heat of the day to extensive, humid, shady forest habitats. It is possible that the lack of a variety of vitamin-containing fruit in the diet also results in ill-heath and associated disorders of the skin. Thus the result of the combined extrinsic factors operating on the Murchison Falls elephant populations has been to produce a heavy overconcentration of non-migratory, mainly grass-eating elephants, many of which show signs of malnutrition, a heavy parasite burden, an alarmingly high incidence of a distinctive type of cardiovascular disease pattern (Sikes: in press) an unusually high non-seasonal breeding rate, and a noticeable relative lack of mobility.

Tsavo National Park.

The situation regarding the elephant population in and around the Tsavo National Park nowadays differs in its basic causes, and is not as far advanced, as that in the Murchison Falls National Park, but the general trend seems to be progressing towards a similar end-point. As explained in Part I, the area covered by the Tsavo National Park is naturally non-productive scrubland, with surface water restricted to isolated areas possessed of limited vegetational cover, due to its foundation geologically on a Pre-Cambrian Basement Complex, with a few scenically interesting, recent volcanic extrusions. It would be difficult, by any stretch of the imagination, for an ecologist to regard such an environment *per se* as a promising area for demarcation as a permanent large-mammal sanctuary. One might therefore wonder why the area was ever chosen.

Needless to say, it was chosen with very good reason. Firstly, it contained, at the time of demarcation, an abundance of large vertebrates; secondly, it comprised a large area (about 8,000 sq. miles) and thirdly, it was agriculturally non-productive and therefore available. Some of the difficulties experienced in obtaining the necessary legislation to have the area gazetted as a National Park, and subsequently to ensure its protection from poachers and other would-be claimants is described in the reports of the Royal National Parks of Kenya (Anon. 1946-1950). What has not been explained, however, in those reports, in why those large vertebrates became so noticeably abundant in this non-productive area of some 8,000 square miles, in the years following the Second World War (an area where previously they had only put in sporadic appearances), and where they came from (Anon. 1963). If these questions had been faced at the very start, and the population dynamics of those mammals studied immediately the legislation was passed, the present pressing problem of how to cope with the inevitable ecological imbalance, which today threatens the very *raison d'être* of the park, would have been monitored, and long-term corrective action could have been initiated at least some fifteen or sixteen years ago.

What then was the reason for the presence of so many large vertebrates in the Tsavo environs at that time? The situation will be most readily appreciated if surface water requirements of the larger land mammals associated with arid areas are understood. Broadly speaking, they fall into three categories: - firstly, water-dependent resident types; secondly, arid-adapted, resident types; and thirdly, water-dependent, migratory and semi-migratory types.

The first category includes the hippopotamus, which is restricted constantly to areas containing permanent, comparatively abundant surface water. This restriction does not, however, prevent it from making the occasional long cross-country trek from one river to another, but this is a risky business and apparently only occurs due to pressures from local drought or overpopulation. A comparatively small number of this species occur within the Tsavo National Park.

The second category, the arid-adapted, resident species, vary in the degree of their arid-adaptation, but characteristically all have a built-in physiological, water-conservation mechanism, which ensures minimal body water loss. They can use surface water either by drinking in the normal way, or by utilising the water obtainable both from succulent, and from deep-rooted plants. As long as at least one of these sources of water is available, all is well; but if both fail simultaneously, even arid-adapted species cannot survive. Thus, if surface or sub-surface water supplies are exploited or exposed higher up, in or near water catchment areas, deep-rooted plants on the lower plateaux may fail, with resulting disaster to the animals dependent upon them in the dry seasons.

Rhino are partially arid-adapted, non- migratory mammals. Their survival usually depends upon the existence of thickets which both contain succulents and supply shade, and within which the rhinos themselves can lie up, thereby reducing their own water loss to a minimum. In extreme conditions they also depend to a considerable extent upon the digging activities of certain other mammals, notably elephant, to expose sub-surface water in sand-river beds and impervious shaded wallows. Here too, interference with the source and transit courses of sub-surface water by tapping it near its source, or damming it at intermediate levels, is liable to be disastrous to rhino. How strange it is that those in charge of the Tsavo National Park clearly recognised the effect of this type of interference in the Taita Hills near the source of the Voi (Aruba) River, yet nevertheless proceeded to dam it again themselves lower down in the Park, first at Kandetcha and then, in 1952-53, at Aruba (Anon. 1953).

The Tiva is another river, whose character in its lower reaches, has been noticeably altered since the first quarter of this century, due to up-stream demands for water for settlement schemes. Formerly, numerous elephant dug successfully along its sand bed for salt and water for their own use, incidentally also exposing them for the use of rhino and other mammals. The combined failure of surface and subsurface water, as well as of vegetational thicket-type cover, may cause excessive body dehydration in rhinos, due to their being only partially arid-adapted and non-migratory. The occurrence of rhinos dying in this condition, typified by a dark, blotched, appearance of the skin, has been described on various occasions, and is always associated with periods of excessive drought, of which the most recent occurred in Kenya in 1961. In certain cases of extreme dehydration, rhino have been known to stagger into a flooded river or pool after a sudden downpour, following a period of prolonged drought, only to drown in the water they so desperately sought.

Many animals which are actually water-dependent, but are also migratory or partially migratory, make part-time use of arid areas. These constitute the third category. The most important among the species belonging to this category are elephants, and to a lesser degree buffalo. To some extent, predators (such as lion, cheetah, hunting dogs, hyena) and insectivorous animals (such as aardwolf, ratel, and bat-eared fox) may sometimes become partial migrants and sometimes come into this category.

It was the members of this latter group, and in particular the elephant, which soon noticed the introduction of new watering points in the Tsavo environs, in their migration transit area, when the railway was built. During its actual construction, with all the human activity in its neighbourhood in a period when the scent of humans still spelled only « danger » to elephants, they did not linger in the vicinity. Later on, however, as the constructional activity died down, and trains passed only infrequently, the elephants became « squatters » and even took up dry-season « residence » in the vicinity, coming in at night, to drink at the spillage areas near the tanks and sleeves at each halt. In an area of limited natural watering points, water becomes an ecological factor assuming precedence over even food supplies and salt for elephants. At such places, they come in silently during darkness, drink, bathe and leave again without a sound. If aware of danger, near the water hole, they do not even defaecate in its vicinity and may have travelled as much as 20 miles away by dawn. It is not surprising therefore that, when only foot and mule transport was available for cross-country travel, elephants were but rarely actually seen in the Tsavo area near the railway, and in the hinterland only by hunters, and the occasional surveyor, geologist, or explorer.

During this period, changes were occurring in the coastlands, and encroachment on the forests was beginning. At first, only dry-weather tracks were available for vehicles going northwards to Malindi or southwards to Tanga. From just prior to World War II and up to the present, however, coastal development surged ahead. Sisal and copra estates were extended, a network of roads and tracks opened up, holiday resorts developed, and the forests reduced. Most of the elephants abandoned their former dry-season refuges and became irrevocably tied to the artificial supplies associated with the railway (Anon., 1958), the boreholes drilled for villages, and the permanent naturally flowing rivers: Tsavo, Galana and Tana. The introduction of water holes by Kenya National Parks authorities in the area by now demarcated as the Royal Tsavo National Park anchored them even more firmly in the areas of minimum vegetational productivity, such as Kandetcha, Aruba and Kilaguni (Anon.: 1956, 1957, 1958). Today the extreme vegetational destruction resulting from the installation and retention of these water holes is tragic.

It was absolutely inevitable that the migratory, water-dependent animals, of which the greatest biomass consisted of elephants, should now proceed to over-browse the local vegetation, which, due to the underlying nature of the soil and water, was inadequate in quantity or variety to their needs. In the process, they also uprooted succulents and pushed over the deep-rooted species of plants so essential for the continued existence of the arid-adapted non-migratory species.

Reading the Reports of the Royal National Parks of Kenya, it again and again strikes the reader that, if only the personnel in charge of the parks had had among them people qualified in the appropriate biological fields, they could have prevented the extreme ecological imbalance evident today in the Tsavo National Park. In one report it is stated *inter alia*: « It is conceivable that by maintaining water in the pool (Mudanda) for longer than normal periods (by a small pipe from the main Mzima/Mombasa water supply) it will result in concentrating large numbers of elephants in the vicinity of the rock, but it may easily lead to a situation where there is no feed in easy reach of the water » (p. 30, 1953). In the same report, the writer came very near to anticipating the present disastrous results of introducing artificial water supplies, when writing of the Aruba Dam: « The Aruba Dam... was completed in 1953, and... formed a wonderful sheet of water, and soon attracted large numbers of animals coming to drink and bathe. Here again I had some misgivings on the wisdom or justification of creating artificial watering places... ». Mistaken as to basic principles determining habitat character, however, he continued « ... the eastern section of the Tsavo Park... is a large portion of Africa almost waterless and incapable of holding any reasonable quantity of game, *unless water can be provided* » (Anon. 1953). It is clear from the writer's own uncertainty that the advice given to him by those working in the Tsavo area itself was ill-informed and unsound, since the rôle of surface and sub-surface water in country with this type of geological history, is to affect closely not only the movements of wildlife, but, equally important, to determine and limit the vegetational cover, and the productivity potential of the area as a whole. Moreover, the long-term hydrological cycles (major and minor) which have been observed to occur in East Africa since the turn of the century, have also apparently affected the migrations and distribution of the larger animals. In referring to the Reports quoted above, it is impossible to overlook the persistent, albeit long unsuccessful, pleas over a period of some 16 years for funds for ecological research to be carried out within the Parks (Anon., 1955; 1961). It is a matter of great satisfaction that funds for this purpose were recently made available by the Ford Foundation (Hayes, 1965).

The Effects of Fire

Since many of the animals which occur in a given tropical ecosystem are heavily dependent upon the existence of shade, it must also be appreciated that destruction of vegetation of low regenerative power by fire gravely affects not only the higher-level canopies, but also the shade in both the intermediate habitats and the micro-habitats at soil level. The humidity maintained by the shrub and grass cover at soil-surface level is of tremendous importance to the dry-season survival of smaller resident mammals in preventing their dehydration, while in the wet seasons, of course, it retains soil in the event of flooding.

Every time vegetation of low regenerative potential is burned-whether early or late — it radically affects the soil surface ecology. In areas of high regenerative potential, arguments have sometimes been successfully advanced in favour of burning bush, but even there the idea is notoriously unpopular among farmers who look for high stock yields on African ranches of limited size, and in fruit plantations, where arboreal productivity is carefully evaluated. It is impossible to overlook the fact that bush-burning is the technique favoured primarily by those who own exceedingly large areas of land carrying little stock or who make no serious attempt at obtaining long-term high productivity yields from stock. Some argue that insect vectors and parasites occur in greater numbers in unburned areas. This certainly appears frequently to be true in cattle-grazing areas, but it is noticeable that where cattle are excluded or their parasites controlled, wild animals appear to achieve a tolerable vector and parasite balance with themselves and their habitat.

It has been recommended that exclosures in the Tsavo National Park could be made in which controlled experiments should be carried out on the independent and combined effects of fire and elephants (HARTHOORN, 1966). Such experiments might prove valuable and interesting, but it is questionable if they are really necessary. Exclosures made for a variety of reasons already exist, in which the required controls have been applied over considerable periods — homesteads, air-strips, railway stations, mission stations, and wilderness pockets within fenced farmlands. What the natural vegetation can achieve if unspoiled by fire and/or elephants can be observed at any time by anyone who wishes to do so within the Eastern Pre-Cambrian drainage area under consideration, and only one conclusion can be drawn: fire is the most devastating single influence in that area, and is the first and most fundamental factor requiring urgent correction within the whole Tsavo National Park. Only if fire is totally prevented, can a proportion of the elephants now circumstantially « resident » in the area obtain, on the spot, shade, surface water, and fodder appropriate to their need.

In certain other, similar parts of Africa, where fire is effectively excluded and elephants occur, the elephants themselves carry out any « ploughing », « harrowing » and « rolling » activities necessary to aerate the undergrowth, yet without destroying it. References to this activity and its value to natural habitats have been made in the past (DARLING 1960; SIKES 1964).

Summary

The Tsavo Park must be regarded ecologically as presenting a basically different problem from, for example, the Murchison Falls Park, and the explanation of the apparent mystery as to why so many elephants occur in Tsavo today, where they came from, which seems to have so disastrously puzzled those in charge for so long, is really a comparatively simple one, if examined on the basis of the peculiar geological and hydrographical nature of the area.

Comparing the situation in Murchison and Tsavo, it is clear that in Murchison the elephant populations have increased in an area of abundant natural surface water, and considerable vegetational potential, and have remained partially confined there due to human encroachment on their migration routes and alternative refuges. Within the area, the combined effects of elephants and fire on the habitat are progressively to reduce the vegetation cover, with direct results upon the physical character, behaviour and health patterns of the elephants themselves. (SIKES, in press). The situation can be partially controlled by the total elimination of fire and by the reduction of the elephant population by cropping and culling, according to a policy of positive selective husbandry. An approach to this method of control has been discussed elsewhere (SIKES, 1966).

In the Tsavo National Park, on the other hand, the elephant populations have increased in an area of limited and isolated surface-water discharges, and very low vegetational potential due to the underlying geological and hydro-graphical nature of the area. They have remained within a partially confined area, as in Murchison, due to human encroachment on their migration routes and alternative refuges. As in Murchison, the combined effects of elephant and fire on the habitat have progressively reduced the already limited vegetational cover with direct results on the elephants themselves, producing new behaviour and health patterns, related characteristically to this habitat and differing slightly from those in Murchison. This situation was initially stimulated by the construction of the Mombasa-Uganda Railway at the turn of the century, with the introduction of its associated artificial surface-water supplies, and subsequently severely aggravated by the introduction of permanent artificial water holes by the Parks authorities themselves.

Here again, the situation is not irremediable, but for its successful control requires a combination of methods: attempted total control of fire; total closure or draining of uncovered, artificial water supplies within the Park in all normal dry-season periods (and possibly also closure to the public of the areas concerned for certain periods of the year), with the intention of driving the elephants from the Park at those seasons (Anon. 1952, 1955), while selective reduction of the elephant populations (by co-ordinated professional cropping and culling, and supervised amateur hunting on licences available at reduced prices), is operated outside the Park boundaries.

In the context of the changing habits, breeding cycles, and responses to the intrinsic urge to migrate by major seasonal, directional movements, or by minor meanderings, clearly the method of assessing the actual elephant populations is of great importance. Occasional irregular counts, disregarding the sex and age composition of herds, can have little real meaning in planned elephant husbandry. Only regular, frequent analytical counts can be expected to provide a reliable basis for effective elephant management in a given area.

The combined methods suggested above may seem drastic. Unfortunately, in both the Murchison Falls National Park and the Tsavo National Park the elephant problem has become critical, and failure to adjust it effectively and realistically could all to easily cause such permanent alteration in the habitat as to render large areas useless for the larger vertebrates. The situation demands drastic, but carefully planned, action, and if this is applied to the elephant populations according to principles of positive pasture, forest and wildlife husbandry, then both the environment and its whole fauna could be redeemed as a vital asset of very great value.

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