OBSERVATIONS ON THE CARDIOVASCULAR SYSTEM OF CATTLE

by

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I N D E X

1. Introduction

The function of the cardiovascular system of any species may be defined as a means of transporting to the cells of the body essential substances and of carrying away from them their excretory products. By means of this system, the cells of the body have access to the organs of absorption and excretion although situated within the body at some distance from these organs. Because of the continual circulation of intravascular fluid, the continuous exchanges between it and extracellular fluid, and the regulating effects of the organs of absorption and excretion, the relatively constant environment of the cells is maintained.

The cardiovascular system consists of three separate parts each of which has controlling mechanisms. The three parts are firstly the heart for impelling the intravascular fluid around the second part, the blood vessels, which are arranged in a series of parallel circuits. The third part consists of the intravascular fluid filling these channels, that is the blood.

The regulating mechanisms of these three parts are coordinated so that changes in one are compensated by changes in the other two parts. This coordinating mechanism functions in health and in disease up to a limit. When this limit is reached a state of failure exists which is known as circulatory failure.

Domestic cattle as a species have evolved from the wild ruminants whose safety and survival depend in part upon an efficient cardiovascular

system. Apart from the fighting bulls of Spain the process of selection in European cattle has not been concerned with safety and survival by speed and an athletic type of circulatory system. It is possible that in the selection of cattle for other characteristics such as body shape and milk yield the circulatory system may have been neglected. The selection process has also led to the appearance in European cattle of two conditions in which the primary deficiency is not within the cardiovascular system, and yet the cardiovascular system is implicated. These two conditions do not normally occur in Britain and do not appear in the studies presented herein. The conditions are High Altitude disease (a right sided heart failure) and Heat stress (the inability to survive in tropical environments).

Nevertheless, the cardiovascular system of European cattle is worthy of study in Scotland despite the fact that these two conditions do not occur. Little attention has been paid to the normal cardiovascular system of cattle, most physiological studies in this species having been concerned with the obviously different digestive system. Yet because of this digestive system, consisting as it does of large volumes of fluid carried within the body, it is possible that certain cardiovascular adjustments have to be made. Slaughterhouse surveys and experience in the University Veterinary Hospital suggest that much cardiovascular disease exists in cattle, so that in studying abnormalities there is no dearth of material. Finally with a large cattle population, studies both in health and disease can add to the whole field of comparative studies. Cattle being large animals with large organs and volumes of body fluids, lend themselves to analytical procedures possible with greater difficulty in smaller species.

A study of the cardiovascular system of cattle can involve the whole system in either health and/or disease, or it can involve just part of the system. The study presented here evolved from a desire to ascertain the functional disturbances of diseases and conditions manifest in cattle as circulatory failure. In order to proceed with this study it was necessary in the first instance to evolve methods of examination, methods of manipulation and procurement of samples, modify some analytical methods and develop others. Having methods evolved, it was then necessary to determine and define the normal.

Finally, abnormal states could be and were studied.

The Literature concerning the Cardiovascular System of Cattle

A mass of literature has accumulated concerning the cardiovascular system of cattle. It would serve little purpose to write a concise review of this literature, covering separately as it does anatomy, physiology, pathology, microbiology, medicine and surgery. Much of the literature about the abnormalities and diseases of the cardiovascular system of cattle has very little connection with the present study, since it deals with anatomical and pathological description with no reference to the functional disturbance.

Instead of such a review, within this study, where it has relevance, published work is discussed.

2. Methods

A. Blood Samples from Cattle

In cardiovascular investigations it is necessary to obtain venous blood samples from many veins, mixed venous samples and arterial blood samples.

(i) Percutaneous venipunctures

The usual vessels from which blood samples are obtained from cattle are the jugular vein and the subcutaneous abdominal vein (the mammary vein). No new techniques were evolved in procedures procuring blood samples from these vessels. In order to eliminate the formation of haematomata, small bore needles (18" or 19 British Wire Gauge) were used in preference to the larger needles often used by others.

(ii) Mixed Venous Samples

Mixed venous samples were obtained from the right ventricle or pulmonary artery by the process of cardiac catheterisation. By means of a manometer the site of the catheter tip was determined from the examination of the oscilloscope record of the pressure curve from this point.

(iii) Venous Catheterisation in Cattle

The usual method of catheterisation of the jugular vein in cattle involves percutaneous puncture with a wide bore (9 BWG) needle and the insertion of a catheter down this needle. This technique has obvious disadvantages due to the size of the needle. The production of large haematoma occurs frequently and more serious damage to the vessel can take place particularly in very young calves. A method of catheterisation of the jugular vein has been evolved, whereby short catheters of similar diameter to the catheters mentioned above can be inserted after the insertion of a 14 BWG needle through the skin into the jugular vein.

The method is adapted from a technique used in the human subject for arterial catheterisation (Seldinger, 1957).

The skin over the jugular vein in the upper third of the neck is clipped, sterilised, and infiltrated with a solution of Xylocaine hydrochloride. The jugular vein is raised by digital pressure below this point, and a 14 BWG needle is inserted through the skin into the vein in the anaesthetised area. A nylon rod 1 mm. in diameter and about 5 centimetres longer than the intended catheter is introduced into the vein through the needle. The needle is withdrawn leaving the rod partly in the vein and partly to the exterior. The exposed rod is then cleaned with sterile saline to remove any blood. A catheter is then inserted over the rod into the vein and the rod is withdrawn. In this manner a wide catheter is introduced into the jugular vein through a skin wound and a wound in the jugular vein both of which are the same diameter as the external diameter of the catheter. Thus the catheter is held tightly by the skin and leakage, even with elevated jugular venous pressure, is negligible.

If this catheter is used for the injection of substances, a short length of drainage tubing and a Leuer lock needle are attached, the catheter is filled with heparinised saline and closed with a Mohrs clip on the drainage tubing. The small length of drainage tubing allows slight movement of the head and neck during any injections without either involuntary removal or kinking of the catheter. Figure 1 illustrates needle, catheters and nylon rod.

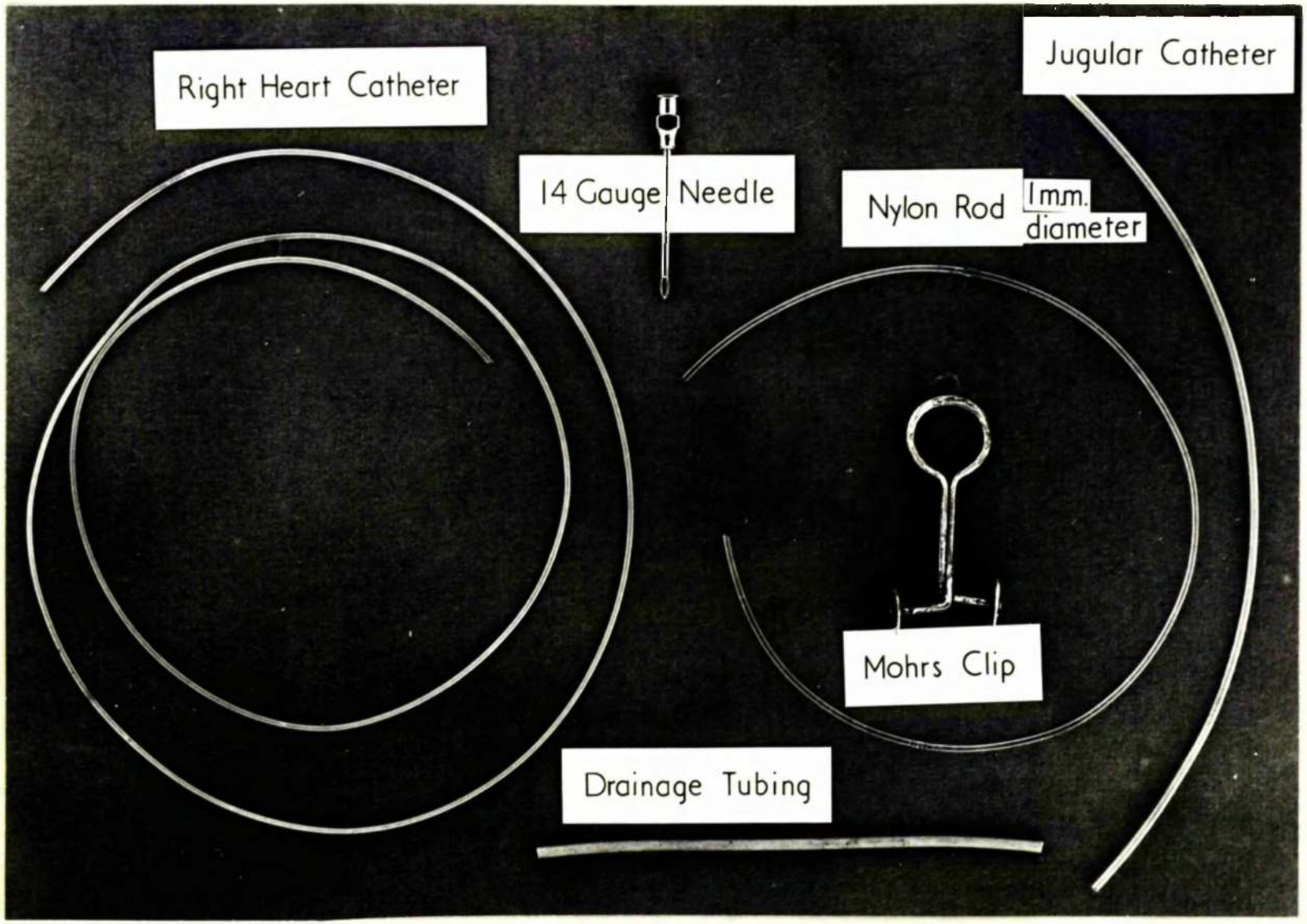


Figure 1 Catheters, needle and nylon rod for venous catheterisation

(iv) Catheterisation of the right heart and pulmonary artery

A long catheter (30-40 cm) is required to record pressures in the right heart and pulmonary artery and to obtain blood samples from these sites. A thinner catheter is inserted through the catheter previously described.

For short catheters in the jugular vein both nylon and polythene were found to be satisfactory, but for passage through the right heart the use of nylon catheters was avoided after two sudden deaths during catheterisation of calves with such catheters. These deaths were thought to be due to ventricular fibrillation as a result of stiff nylon catheters bombarding the ventricular wall. Ventricular extrasystoles produced by similar bombardment of the ventricular wall with polythene catheters has never caused death or collapse.

(v) Arterial Puncture in Cattle

Arterial blood samples have been obtained from cattle in many ways. Van Leersum (1911) described how in dogs it was possible by surgical intervention, to bring the carotid arteries into a superficial position enclosed in a roll of skin. Recently this procedure has been claimed to have been successfully adopted in cattle (Robertshaw, 1963). It has the disadvantage of being suitable for use in experimental animals only.

Radial artery puncture was used by Blackwood and Stirling (1932) to obtain arterial blood but difficulties arose in unanaesthetised cattle.

Arterial blood has also been obtained from cattle by percutaneous puncture of the brachial artery in the middle third of the neck (Sellers and Hemingway, 1951). They infiltrated the subcutaneous tissue with

procaine hydrochloride and inserted the needle above the jugular vein and into the artery. However, when this method was repeated by the author it was found that considerable restraint was necessary, and that slight movements of the neck withdrew the needle from the artery.

Swedish workers (Hamnson and Obel, 1958) have described how they effected entrance into the abdominal aorta. They used a special needle 80 cm. in length, the last 8 cm. of which was curved and of 1.7 mm. external diameter for actual insertion into the artery, while the remainder of the shaft was of 10 mm. diameter. With the tip of the needle protected by a rubber finger shield, the needle was inserted into the rectum, through the abdominal wall into the aorta. This method was not used in the present study.

Another method of obtaining arterial blood has been described by Stowe and Good (1960). Entrance to the abdominal aorta was effected percutaneously in the lumbar region just behind the last rib. Some years previously a few attempts at using this method on calves in Glasgow led to a mortality of 25% as a result of massive haemorrhage, so that it was not pursued.

In their cardiac output determinations Doyle, Warren, Patterson and Detweiler (1960) using local anaesthesia dissected out the carotid artery of cattle in order to obtain arterial blood samples. This method has been used on occasion by the author on very young calves.

A method of obtaining blood from the middle coxygeal artery of cattle has been described by Saarinen (1938) and by Campbell, Merilan and Carshaw (1961). This method has been repeated successfully in Glasgow (Anderson, 1962).

Percutaneous puncture of the brachio-cephalic trunk

The method described below has been in use for a number of years. It was evolved from the method of percutaneous puncture of the brachial artery which has been published (Fisher 1956). It had the advantage of experience, repeatability and the site was such that all instruments used for dye dilution curves and blood pressure recording could be concentrated at the head of the animal.

Percutaneous puncture of the brachiocephalic trunk was effected at the root of the neck. The animal was tethered by means of a halter so that its head was held slightly upward and away from the operator. The hand was placed under the point of the shoulder as shown (fig. 2) and the brachial artery was palpated at the point where it crossed the first rib. In thin cattle the brachial artery was easily found and rolled between the fingers and the first rib, but in fat, thick-necked animals it was not possible even to feel the pulse at this point.

The proposed puncture site was infiltrated with a sterile solution of 5% xylocaine hydrochloride, this having been found superior to 5% procaine hydrochloride for cutaneous local anaesthesia in cattle. An eight inch 15 British Wire Gauge needle was directed into the animal at a point just medial to the second finger shown in figure 2, at an angle of about 15° to the horizontal and 5° from the long axis of the cow. The needle was inserted to a depth of four to six inches in order to effect entrance to the artery.

This method enjoyed advantages over the previously published method of brachial artery puncture. Being inserted into a larger artery and

Figure 2

Site of Percutaneous Puncture of the
Brachio-cephalic trunk of cattle

being held by the mass of tissue at the root of the neck, the needle did not have to be held manually while collection of samples took place and considerable movements of the cow were possible without disturbing the needle. Figure 3 illustrates a successful arterial puncture.

B. The determination of the Bovine Haematocrit (a) Methods

Definitive standards have not been laid down for the centrifugation of bovine blood in order to determine the haematocrit. In some investigations in which use has been made of the haematocrit, no statements of either time or force of centrifugation have been given (Doyle, Patterson, Warren and Detweiler, 1961; Stowe and Good, 1961). Evidence was obtained by Jennings, Mulligan and Lauder (1954), that in order to obtain packing of bovine erythrocytes it was necessary to centrifuge at a force of 1600g for a period of three hours when determining the haematocrit.

This problem was re-investigated using a high speed microhaematocrit centrifuge. An evaluation was made of the accuracy of this centrifuge and comparisons were made with two standard centrifuges. The study was extended to discover other variables affecting the haematocrits which might lead to errors in the determinations of cardiac output, blood and plasma volumes if the haematocrit were used to convert plasma volumes and flows to blood volumes and flows.

Blood samples were taken from a number of healthy lactating and non-lactating cows.

(i) Analysis of the micro-haematocrit centrifuge*

* Hawksley Ltd., London, England

Figure 3

Successful Entry into the
Brachio-cephalic Trunk of Cattle

a) Error of reading the haematocrit of a single blood sample

A total of 36 microhaematocrit tubes were prepared from the same blood sample, 12 being prepared by each of three persons. These tubes were centrifuges at an R.C.F. of 12000g for a period of six minutes and all the haematocrits were read by each of the three persons.

b) Effect of time of centrifugation on the microhaematocrit

Six microhaematocrit tubes were prepared from each of four blood samples and these were centrifuged for a total time of 150 minutes. They were read at two minutes and then at 30 minute intervals. The experiment was repeated with four other blood samples; in this the total time was 30 minutes and readings were taken at two minute intervals.

(ii) Comparison of the microhaematocrit centrifuge with two standard centrifuges B & C*

Six haematocrits were prepared from each blood sample for each of the centrifuges. In the standard centrifuges, centrifugation was at an R.C.F. of 1600g for a total time of 180 minutes. Readings were made at 30 minute intervals and the temperatures within these centrifuges were recorded. In the microhaematocrit centrifuge, centrifugation was at a force of 12000g for a total time of ten minutes, readings being made at two, three, six and ten minutes.

(iii) Effects of Variations in sampling techniques and the handling of blood samples

a) Vessel sampled

A comparison was made between the haematocrits of blood samples taken at the same time from the jugular and mammary veins of individual cows.

* M.S.E. minor centrifuges, M.S.E. Ltd., England

Five microhaematocrits were prepared from each blood sample.

b) Effect of stasis

It is usual practice to place a choke rope around the neck of a cow in order to raise the jugular vein. If this rope were left for some time it might, due to transudation above the choke, affect the haematocrit. The effect was studied by removing samples from five cows before, after 2 minutes, and after 5 minutes application of the choke rope.

c) Effect of carbon dioxide loss from blood sample on the haematocrit

The chloride shift or carbon dioxide loss from erythrocytes would decrease cell volume and it might have been possible to demonstrate this.

From five animals blood samples were collected, exposed to air, and also collected under a layer of liquid paraffin. The microhaematocrits were determined.

d) Hourly variations in the haematocrit

Samples were taken at hourly intervals from the same vessel of individual cows and the microhaematocrit was determined.

e) Effect of overnight storage of blood on haematocrit

Haematocrits were determined on a number of blood samples before and after storage overnight in stoppered bottles in a refrigerator at $4^{o}C$.

B. Determination of the Bovine Haematocrit (b) Results

(1) Analysis of the micro-haematocrit centrifuge

a) Error of reading the haematocrit of a single blood sample

Table 1 The variation in reading the haematocrit of a single blood sample

	Mean	S.D.
Individual A (36 haematocrits)	31.1	±0.6
Individual B (36 haematocrits)	30.8	±0.5
Individual C (36 haematocrits)	31.3	±0.5
Total (108 readings)	31.1	±0.5

b) Effect of time of centrifugation on the micro-haematocrit

Table 2 Readings at 2 and then 30 minute intervals

Time(Min)	Sample A	Sample B	Sample C	Sample D
2	27.2	16.2	31.7	25.6
30	26.7	16.1	31.1	25.0
60	26.7	16.1	31.1	25.0
90	26.7	16.1	31.1	25.0
120	26.7	16.1	31.1	25.0
150	26.7	16.1	31.1	25.0

Table 3 Readings at 2 minute intervals for 30 minutes

Time(min)	Sample E	Sample F	Sample G	Sample H
2	29.7	38.2	26.7	22.5
4	28.5	36.6	26.1	22.2
6	28.2	36.3	26.1	22.1
8	28.2	36.2	26.0	22.0
10	28.1	36.2	26.0	22.0
12	28.1	36.2	26.0	21.9
14	28.1	36.2	26.0	21.9
16	28.1	36.2	26.0	21.9
18	28.1	36.2	26.0	21.9
20	28.1	36.2	26.0	21.9
22	28.1	36.2	26.0	21.9
24	28.1	36.2	26.0	21.9
26	28.1	36.2	26.0	21.9
28	28.1	36.2	26.0	21.9
30	28.1	36.2	26.0	21.9

(ii) Comparison of the microhaematocrit centrifuge with two standard centrifuges, B & C

Table 4 Comparison of Centrifuges

	Times of Readings (minutes)									
	2	3	6	10	30	60	90	120	150	180
Micro-haematocrit	31.0 ±2.82	30.5 ±2.79	30.3 ±2.87	30.1 ±2.82						
Centrifuge B Temp. 35°C					35.6 ±3.34	33.4 ±3.05	32.4 ±3.05	32.1 ±3.05	32.1 ±3.05	32.1 ±3.05
Centrifuge C Temp. 20°C					32.8 ±3.04	32.1 ±2.85	31.7 ±2.83	31.6 ±2.76	31.5 ±2.74	31.5 ±2.74

(iii) Effects of Variations in sampling techniques and the handling of blood samples

(a) Vessel sampled

Table 5 Difference between mammary and jugular vein haematocrits (non-lactating cows)

Cow	Mammary	Jugular	Difference
14949	30.9	34.9	4.0
12916	32.8	34.1	1.3
14711	36.3	37.5	1.2
Utmost	30.8	34.9	4.1
Wood	30.8	32.0	1.2
Risk	31.7	32.9	1.2
Sheppy	29.5	32.0	2.5
V.12.	32.3	33.3	1.0
N.N.	30.8	32.7	1.9
Mean	31.8	33.8	2.0
S.D.	±1.95	±1.76	±1.22

Table 6 Difference between mammary and jugular vein haematocrits (lactating cows)

Cow	Mammary	Jugular	Difference
Harebell	31.0	33.1	2.1
Fanny	32.7	36.7	4.0
Jersey	33.5	37.5	4.0
Rosa	28.1	30.0	2.0
Stella	33.0	33.0	0.0
Bantam	30.3	39.8	9.5
Daisy	33.2	37.8	5.6
Asta	33.6	40.7	7.1
Dora	28.5	34.3	5.8
Megan	30.7	33.9	3.2
Mean	31.5	35.7	4.2
S.D.	±2.15	±3.35	±2.8

b) The effect of stasis on the haematocrit

Table 7 The effect of stasis on the haematocrit of jugular blood

Cow	Before Choke	2 min Choke	5 min Choke
J	18.5	19.5	19.5
K	29.0	29.8	30.2
L	38.8	39.8	41.3
M	20.7	22.8	23.6
N	19.3	19.5	21.5
Mean	25.3	26.3	27.2
S.D.	±8.65	±8.65	±8.82

c) The effect of carbon dioxide loss on the haematocrit

Table 8 Difference between aerobic and anaerobic samples (collected from the mammary vein)

Cow	Aerobic	Anaerobic
W	35.20	33.16
X	39.50	41.33
Y	33.16	34.33
Z	32.00	32.50
V	22.90	23.60
Mean	32.01	33.00
S.D.	±5.93	±6.35

d) Hourly variation in the haematocrit

Table 9 Variations in the haematocrit of blood samples taken from individual cows at hourly intervals

Time		11.00	12.00	13.00	14.00	15.00	16.00
a. Heifers	1.	26.5	26.7	27.5	26.3	28.0	27.0
	2.	32.0	30.5	33.3	31.0	30.0	30.0
	3.	30.0	28.5	30.0	27.3	26.5	28.0
	4.	27.3	27.0	28.7	28.0	28.3	26.0
	5.	26.0	26.0	27.5	27.0	27.7	27.3
b. Lactating Cows	1.	31.3	34.0	35.3	33.5	34.5	34.0
	2.	33.0	33.0	36.3	33.5	35.0	35.3
	3.	34.0	34.0	33.7	34.7	37.5	32.5
	4.	34.5	33.7	35.0	34.7	34.0	34.0
	5.	34.2	36.8	33.7	32.8	33.2	32.0
c. Dry Cows	1.	32.0	33.0	34.7	33.5	33.0	33.0
	2.	28.3	27.2	26.0	27.0	27.2	28.0
	3.	29.3	26.8	26.6	27.5	27.8	27.5
	4.	32.0	32.5	32.0	32.7	25.4	34.2

e) Effect of storage of blood overnight

Table 10

Sample	A	B	C	D	E	F	G	H
4 P.M.	35.3	37.8	32.6	32.6	15.5	28.0	34.2	29.3
10 A.M.	35.8	38.0	32.6	32.5	15.6	28.2	24.5	29.6

The determination of the Bovine Haematocrit (c) Discussion

It was obvious from the results in Table 1 that the microhaematocrit centrifuge gave results for the bovine haematocrit comparable in repeatability with the best results obtained for the human haematocrit with standard centrifuges, that is, a variation of ±0.5 mm. (Gregerson, 1951). Variations in the different individuals preparing and reading these microhaematocrits were of little consequence despite the fact that two of the individuals had very little experience in these techniques. Slight differences which were observed in the bore in the capillary tubes made no difference to the haematocrit reading.

The results given in Table 4 confirmed the observations of Jennings et al. (1954) that centrifugation of cattle blood at 1,600 g for 30 minutes was not sufficient to obtain adequate packing of the red cells. The microhaematocrit centrifuge after ten minutes gave better packing than either of the two standard centrifuges after three hours. The differences between each of the standard centrifuges were probably due to differences in the temperatures of the centrifugation resulting in evaporation in centrifuge B, which regularly overheated due to old bearings. There was no significant difference between the haematocrits when read after 3 hours in the standard centrifuges and after ten minutes in the microhaematocrit centrifuge.

The significantly higher jugular haematocrits ($p<0.02$) shown in Table 5 may have indicated a loss of fluid to the saliva. The highly significant elevation of jugular haematocrits in lactating cows (Table 6) ($p<0.001$), may have indicated an even greater loss of fluid due to increased salivation as a result of increased food intake during

lactation. This phenomenon can be further emphasised by comparing the mean jugular haematocrits of lactating and non-lactating cows where it can be shown that the samples from lactating cows are significantly higher ($p<0.02$). There was no significant difference between mammary vein haematocrits of lactating and non-lactating cows.

The differences due to choking and to collection with carbon dioxide loss were not significant (Table 9).

No explanation could be found for the hourly variations in haematocrit observed (Table 10). It was not considered to be due to variations of the reservoir function of the spleen for red cells, as had been shown to occur in sheep by Turner and Hodgetts (1959).

All the variations observed and demonstrated served to emphasise in this study the errors possible in the use of the haematocrit to convert plasma flow to blood flow, particularly if jugular blood were used to obtain this haematocrit. Further errors also arise if factors allowing for trapped plasma are included in the calculations. These factors are obviously dependent on the degree of cell packing and in the literature, values for bovine trapped plasma vary between a minimum of 3.2% (Jennings et al. 1954), and a maximum of 7% (McLain and Ruhe, 1949).

C. Plasma Electrolytes (a) Methods

Standard biochemical methods were used to define the normal parameters of the more important plasma electrolytes of healthy adult cattle and calves.

Sodium and Potassium

Flame photometry was used for the determination of the concentrations of these electrolytes. Mixed standards of 120 m.eq/litre Sodium and 3 m.eq/litre Potassium, 140 m.eq/litre Sodium and 4 m.eq/litre Potassium, 150 m.eq/litre Sodium and 5 m.eq/litre Potassium were made up into 1 in 100 dilutions, as were plasma samples, and direct comparisons were made. Each plasma dilution was bracketed between two standards.

Calcium

Plasma calcium was determined by the method of Clark and Collip (1925).

Magnesium

Plasma magnesium was determined by the Titan Yellow Method as modified by Neely and Neil (1956).

Chloride

Plasma chloride was determined by the method of Schales and Schales (1941).

Plasma Electrolytes (b) Results

The following results were obtained for the concentration of plasma electrolytes (Fisher, 1960).

Table 11 The concentration of electrolytes in the plasma of cattle

Constituent	No.	Concentration m.eq/litre	No.	Concentration m.eq/litre
Sodium	94	142.2±2.0	65	141.8±3.5
Potassium	92	4.0±0.3	59	5.1±0.4
Calcium	94	5.0±0.6	22	4.9±0.2
Magnesium	57	1.46±0.4	29	1.14±0.3
Chloride	140	103.3±5.0	59	100.3±3.5

These results were used as a reference standard for plasma electrolyte concentrations.

There was a significant difference between the chloride and potassium concentrations of cows and calves ($p<0.05$). There was a highly significant difference between magnesium concentrations of the plasma of cows and calves ($p<0.01$).

In Table 12 are given the normal concentrations of plasma and serum constituents which were obtained by other authors.

Table 12

Summary of the results of other authors for the concentrations in m-equiv./l. of some of the inorganic constituents in the plasma of cattle

Reference	Cl^-	Na^+	K^+	Ca^{++}	Mg^{++}	Total cation
Anderson, Gayley & Pratt (1930)	-	-	-	6.3s (5-8)	-	-
Brown (1946)	108s	-	-	-	-	-
Craige (1947)	99s (90-109)	-	-	4.5s (3.6-5.1)	-	-
Craige, Johnson & Blackburn (1949)	108-89p	-	-	-	-	-
	104-96p	-	-	-	-	-
(three cows studied over parturition)	100-95p	-	-	-	-	-
Dale, Goberdhan & Brody (1954)	-	162p	5.1p	7.5p	3.2p	177.8
Dukes (1947)	-	-	-	4.5-6s	-	-
Duncan, Huffman & Tobin (1939)	97.3p (93-105)	-	-	5.3p (4.7-5.9)	2.4p (1.6-3.1)	-
		-	-			
Evans & Phillipson (1957)	-	140p (139-144)	4.5p (4.2-4.6)	-	-	-
Godden & Allcroft (1932)	93s (85-98)	-	-	5.0s (4.0-5.8)	-	-
Lengemann, Aines & Smith (1952)	104.2p (96.6-110)	-	-	-	-	-
McSherry & Grinyer (1954)						
Eighty-six adults	103.7±3.5s	142±5.0s	4.85±0.47s	5.42±0.34s	-	-
Twenty calves	103.0±2.5s	142±4.0s	5.25±0.54s	5.08±0.22s	-	-
Reihart (1939)	-	155s (151-165)	6.3s (6.1-6.4)	5.7s (5.5-5.8)	1.6s (1.5-1.8)	-
Sampson & Hayden (1935)	-	-	-	5.6s (4.6-6.2)	-	-
Sellers & Roepke (1951a,b)	103p	144p (139-146)	4.0p (3.9-4.4)	4.9p	1.8p	154.7
Spector (1958)	104s (97-111)	142s (132-152)	4.8s (3.9-5.8)	5.4s (4.7-6.1)	2.0s (0.8-2.4)	154.2
Ward, Blosser, Adams & Crilly (1953)	98s (90-107)	-	-	4.7s (3.8-5.3)	-	-

s = serum
p = plasma

D. The determination of the Cardiac Output of Cattle by the Injection Method (a) Methods

The determination of the cardiac output gives a direct indication of the ability of the heart to maintain the circulation. A number of methods have been devised to make this critical determination, some, such as the thermostromuhr and the cardiometer, being applicable to experimental animals only, while others have been devised for use on the intact unanaesthetised subject. These latter methods include the use of X-rays and the measurement of heart size in systole and diastole, ballistocardiography, the Fick Method and the Injection method. Of all these methods only the Fick Method and the Injection method have been used in cattle.

The Fick method, whereby the cardiac output is determined from the amount of oxygen absorbed or carbon dioxide excreted by the lungs per unit time, requires the measurement of ventilation rate and the measurement of the concentration of oxygen or carbon dioxide in arterial and in mixed venous blood at the time that the ventilation rate is being measured. This method is unsuitable for use in adult cattle if face masks are used to measure ventilation rate. A number of animals would resent the continued application of face masks, thus invalidating as normal their cardiac outputs if they were reacting to the restraint. Furthermore, Dougherty (1960) demonstrated that ruminant animals may inhale eructated rumen gases and absorb them in the lungs. Thus measurements with a face mask would be in error, transfers from the rumen to the lungs via the pharynx being unrecorded. The difficulty can be overcome by tracheotomizing and recording ventilation through a tracheotomy tube, but this procedure would limit the number of animals on which studies could be made.

The Injection method on the other hand requires only the injection of a suitable, non diffusible intravascular indicator into the venous circulation and the collection of serial arterial blood samples for a short period afterwards in order to follow the passage of the indicator through the heart.

The cardiac output is calculated from the equation:

$$\text{Cardiac Output} = \frac{60 \times I}{ct}$$

Where I = amount of dye injected
c = mean concentration of dye
t = time for one passage of dye through the heart

Derivation of Equation

Consider water flowing from a pipe at a constant rate. To find the rate of flow it is necessary to collect and measure the outflow for a time

$$\text{Flow per minute} = \frac{\text{Volume of outflow} \times 60}{t \text{ seconds}}$$

If no accurate method is available for measuring this volume (v) it is possible to determine it by adding to it a known amount (I) of a substance which will mix completely with this volume of water, and, after they have mixed, finding the concentration of this substance. The volume can then be determined from the equation:

$$V = \frac{I}{c}$$

Where V = volume
I = amount of substance added
c = concentration of substance in volume v

Substituting in the flow equation:

$$\text{Flow per minute} = \frac{I \times 60}{ct}$$

Considering the pipe again, if a known amount of an indicator is injected into the flow and the passage of the indicator (I) is followed at some point distal to the injection site by the removal of serial samples, then it will be found that the mean concentration passing this point will be the same as the mean concentration in the collected volume (V).

Furthermore, the time taken for the indicator (I) to pass this point will be the same as the time taken to fill the volume (V) containing the indicator at concentration (c). By constructing a graph of serial indicator concentrations against time on semi-logarithmic paper it is possible to find the mean concentration c and the time t for the passage of the indicator. Thus by serial sampling it is possible to find V from $\frac{I}{c}$ and, therefore, flow from

$$F = \frac{I \times 60}{ct}$$

Within the circulation it is not possible to measure the volume of outflow from the heart directly, but the passage of an indicator can be followed by adopting a procedure analogous to the pipe described above by taking serial arterial samples, studying the time course of the passage of indicator past the sampling point and from this finding the mean concentration 'c' and the time 't' for one circulation of the indicator through the heart. If the amount of intra-vascular indicator is known, the cardiac output per minute can be calculated:

$$\text{Cardiac Output} = \frac{60I}{ct}$$

Many intravascular indicators have been used for the determination of cardiac output by the injection method including sodium chloride, fluoresceine, cardio-green, Evans blue and albumin labelled with (I^{131}). Evans Blue has been used to a greater extent than others, but in the human subject suffers from the disadvantage of "blueing" the patient. In recent years, too, many dye dilution recorders have been developed to facilitate the determination of cardiac output, and, in the human subject, earpiece oximeters have been used to eliminate arterial puncture.

However, there are divided opinions on the value of various dye dilution recorders and ear piece oximeters (Dow 1956). In the study reported, Evans Blue (T 1824) was used as the intravascular indicator for the determination of the cardiac output of cattle. Dye dilution recorders and ear piece oximeters were not used, partly because of the controversy surrounding them and partly because it would have been necessary to carry out additional development procedures in order to use them in cattle.

Cattle have been a neglected species in the determination of their cardiac outputs. This study reported here was one of the first to appear (Fisher and Dalton 1959). Since that time more investigators have reported cardiac output determinations in cattle (Doyle, Patterson, Warren and Detweiler 1961, Stowe and Good 1961, Reeves, Grover, Alexander & Will, 1962, Kuida, Brown, Lange and Hecht, 1961).

This study reported is the only one in which determinations were made on a large number of animals.

Procedure Adopted

All these normal animals had as far as could be ascertained clinically and electrocardiographically no abnormalities of their cardiovascular systems, or diseases liable to cause alterations in cardiac output. The body weights varied between 100Kg and 600Kg and their ages from 9 months

to adult dairy cows over 3 years.

It was realised that it was not possible to carry out the determinations in cattle under the same basal conditions described for such determinations in the human subject. However, a standard procedure was adopted so that the animal was as close to the resting condition as possible. Animals which were brought to the Veterinary Hospital for cardiac output determinations were allowed to settle down after their journey for at least 24 hours and often for two to three days. Determinations were carried out in a quiet room with as few persons as possible present. Each animal was in stocks while the injections and collections of serial arterial samples took place, but these stocks merely prevented excessive backward, forward and sideways movement. The animals were haltered and the halter was held by a quiet and experienced attendant. Any animal which was disturbed by these minimal restraints was rejected as unsuitable.

In order to facilitate the injection of Evans Blue, the jugular vein was catheterised as described previously. The subcutaneous tissues through which entrance to the brachio-cephalic trunk was effected was infiltrated with Xylocaine Hydrochloride at this time. The animal was left undisturbed for about an hour.

Just prior to the injection of Evans Blue entrance to the brachiocephalic trunk was effected as described earlier. Attached to the needle was a 30 cm length of flexible vinyl tubing. The purpose of this tubing was to lead the blood from the needle to the serial collector. Flexibility

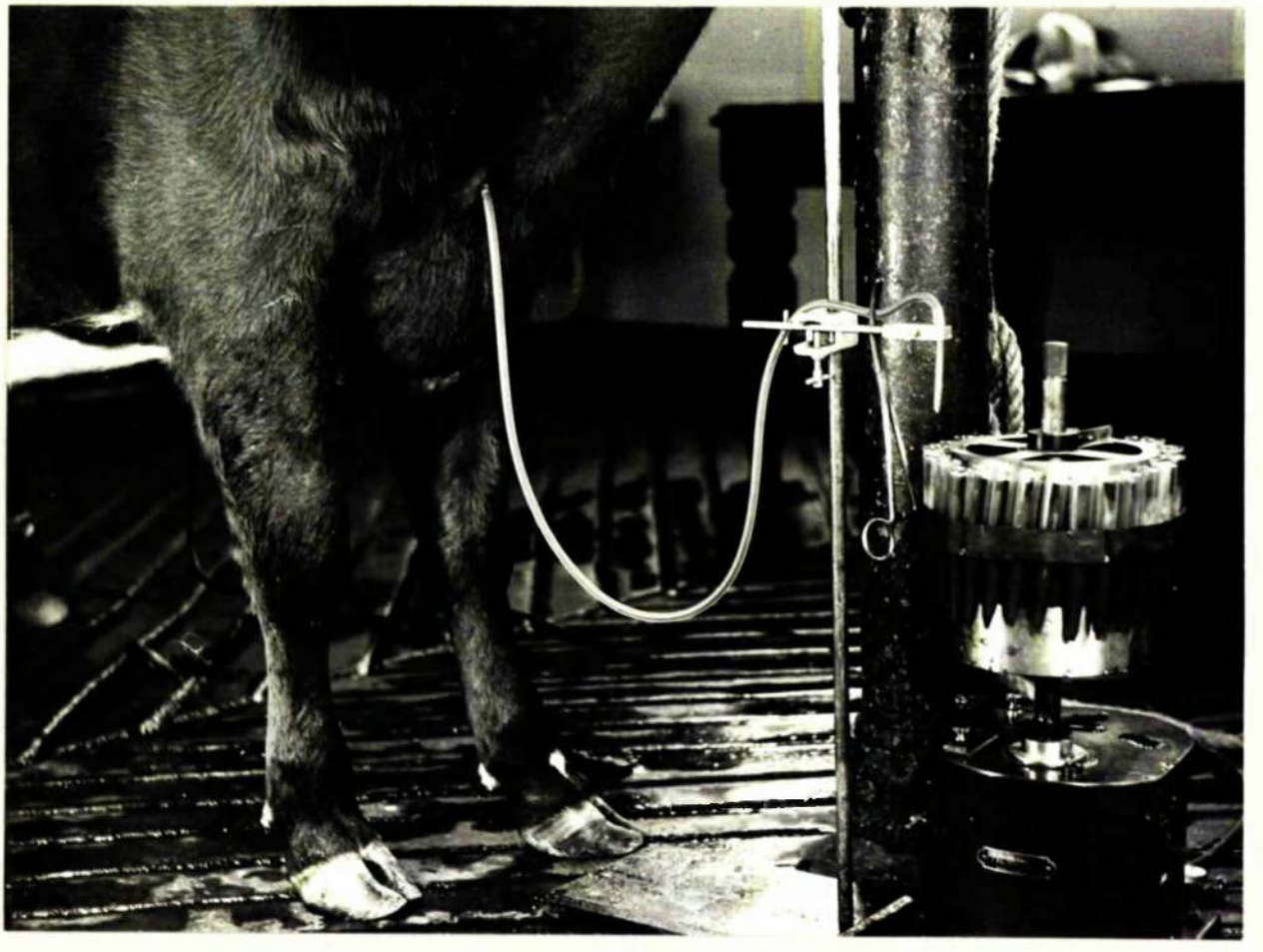
of this tubing allowed slight movements of the animal and tended to iron out the pulsations in the blood flow. About 40-60 millilitres of blood was collected for the preparation of dye-blood and dye plasma standards.

The Evans Blue solution was of a concentration of 20 mg/ml in normal physiological saline. The amount injected varied with the body weight but was of the order of 1 ml/50Kg body weight. The amount of dye was accurately determined by weighing the syringe containing it immediately before and after injection. The dye was injected into the jugular vein through the nylon catheter and the catheter was cleared with normal physiological saline so that all the dye entered the circulation. This double injection procedure was carried out in less than four seconds using a special Y piece with Luer-Lock connections and minimal dead space. Checks on this Y piece showed that after the injection of dye and the succeeding wash through with saline, less than 0.1 mg of dye remained in the Y piece.

Collection of the serial arterial samples was started immediately after the dye was injected. These samples were collected into a number of heparinised centrifuge tubes which were arranged round the rim of a 6 inch diameter kymograph drum. The speed of the kymograph was regulated so that each centrifuge tube collected blood for one second. Such a collection is illustrated (fig. 4). After all the tubes had collected blood, the arterial flow was stopped and the needle was removed from the artery. Pressure was often applied to the point of removal of the arterial needle by means of a pack and hand pressure to minimise possible haematoma formation.

Figure 4

Collection of Serial Arterial Samples



During injection and collection, the pulse rate was recorded. About half an hour after injection and collection the animal was taken back to its loose box or stall.

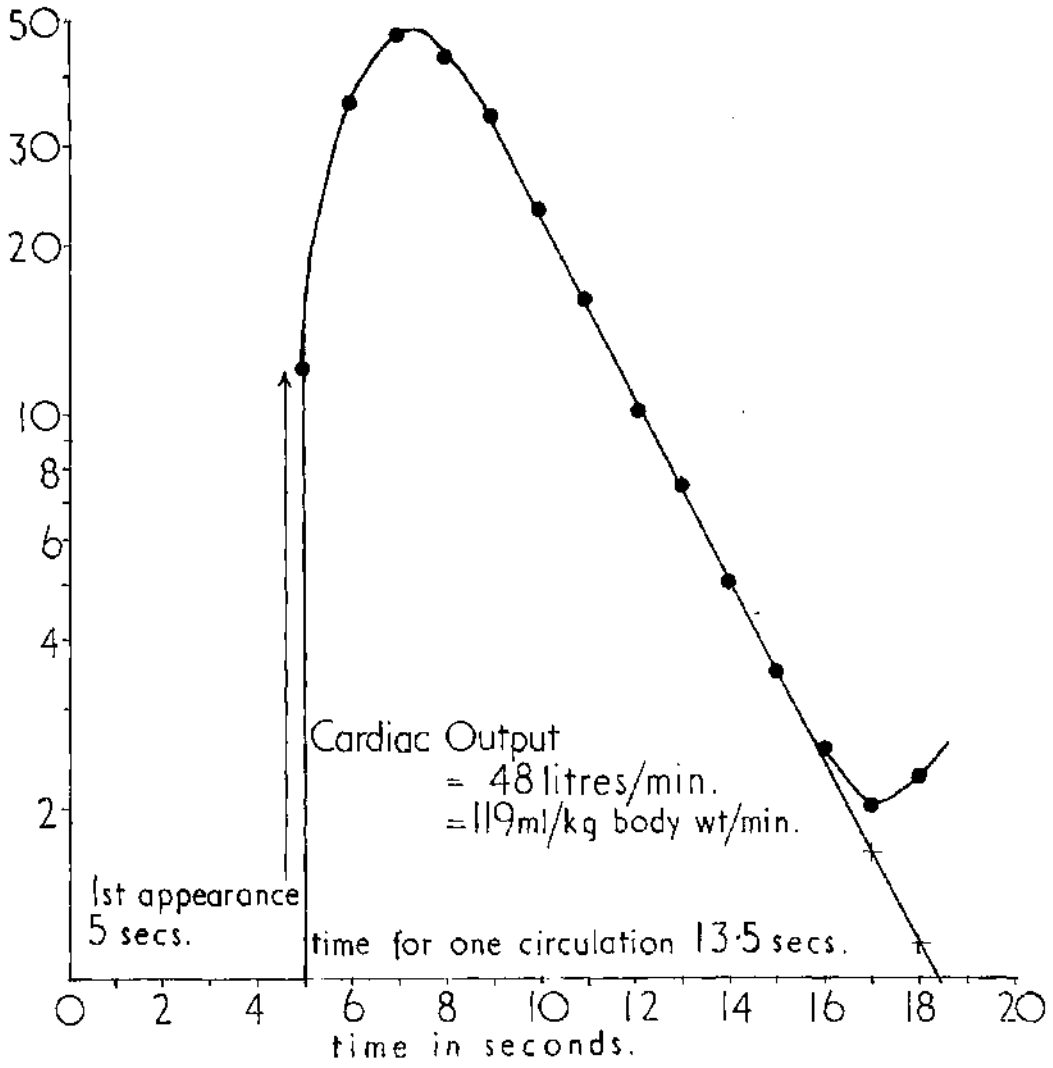
The serial arterial blood samples were numbered, centrifuged and the plasma was separated. From the blood collected prior to injection, 20 millilitre volumes were accurately measured and to each volume was added by means of a micrometer syringe or by microsyringe sufficient of the 20 mg/ml Evans Blue solution in order to make standards in which the dye concentration was 20 mg per litre of blood. These were then mixed thoroughly, centrifuged and the plasma separated.

Such standards made from blood collected immediately prior to injection and collection would thus be of blood of the same cell/plasma ratio as in the serial arterial samples. By making a standard in this blood, the Evans Blue would distribute in the same relative volume of plasma as in the serial samples. Thus it was unnecessary to determine haematocrits to convert plasma flow to blood flow. The time of the first appearance of the dye in the arterial blood was noted.

Comparisons were made between the readings of the plasma of the serial arterial samples and the plasma of the standards using an E.E.L. photo-electric colorimeter with a No. 607 Ilford Filter. A graph was plotted on semi-logarithmic paper of the colorimeter readings of the serial arterial blood samples against time. The descending limb of the dye dilution curve so obtained was extrapolated to the base line as shown in figure 5.

Figure 5

Dye Dilution Curve from a Normal Cow



It has been shown that the curve so produced is what would be expected if there were no recirculation of dye as occurred in the body and which produced the secondary rise shown.

From this extrapolated curve was found the time for one complete circulation of the dye and the mean concentration of the dye. The cardiac output was calculated from the equation:

$$\text{Cardiac Output} = \frac{60I}{ct}$$

Where I = amount of dye injected
c = mean concentration of dye
t = time for one circulation

The Determination of the Cardiac Output of Cattle (b) Results

The results of thirty cardiac output determinations on twenty four cows and heifers in Glasgow, and three determinations carried out on three cows in Philadelphia, U.S.A., are given in Table 13.

The calculations are given as litres per minute and also as millilitres per kilogram body weight. Some duplicate determinations were separated by considerable intervals, so that marked differences were observed in body weight.

Table 13

Cardiac Output Determinations in Cattle

Expt. No.	Cow No.	Body weight Kg	Cardiac Output Litres/min	Cardiac Output ml/Kg body weight/min
1	1	111	12.3	111
2 a	2	201	22.0	110
b	2	201	26.0	129
3	3	209	25.0	121
4	4	314	32.0	102
5 a	5	330	40.0	121
b	5	350	37.0	106
6	6	342	39.0	114
7	7	344	42.0	122
8	8	360	48.0	133
9	9	361	34.0	94
10	10	365	43.0	115
11	11	371	40.0	108
12	12	380	44.0	116
13	13	387	37.0	96
14	14	392	48.0	122
15	15	404	48.05	119
16	16	420	56.0	133
17 a	17	424	52.0	123
b	17	433	48.0	111
18	18	472	48.0	102
19 a	19	482	53.0	110
b	19	482	60.0	124
20	20	486	62.0	128
21	21	495	58.0	117
22 a	22	505	51.0	101
b	22	515	49.0	95
23 a	23	528	55.0	104
b	23	534	67.0	125
24	24	595	58.0	97
25	F1	650	65.0	100
26	F2	514	54.0	105
27	F3	500	60.0	120
Mean		407.7	45.8	113 ±11.33

The results obtained in this study are compared in Table 14 below with the results of other workers.

Table 14 Comparison of Cardiac Outputs of Cattle

Authors	Cattle	No.	Method	Cardiac Output ml/kg body wt/min.
Doyle, Patterson, Warren & Detweiler, 1961	cows	5	Dye Dilution	99
Stowe & Good, 1960	calves	15	Dye Dilution	123
Kuida, Brown, Lange & Hecht, 1961	calves	15	Dye Dilution	142
Reeves, Grover, Will & Alexander, 1962	steers	10	Fick	117
Present study	heifers cows	4 25	Dye Dilution	113±11

There is a close correlation in all the studies made except those of Kuida et al. (1961). Their high value for the cardiac output may be explained by the fact that they used tranquillizers and then restrained animals in lateral recumbency. They quoted a mean heart rate of 100 beats per minute, which suggested some excitement and thus a high cardiac output. All the other workers carried out determinations with their subjects standing. Reeves et al. (1962) compared cardiac outputs in cattle before and after tranquillization with chlorpromazine hydrochloride. Although the mean value reported was higher after tranquillization, the difference between this and the values determined before tranquillization was not significant.

If comparisons are made on a bodyweight basis between cattle, other species of domestic animals, and the human subject, it is noted that cattle, sheep, goats and humans in a non basal state have similar cardiac outputs, horses have lower cardiac outputs and dogs have higher cardiac outputs. No reasons have been suggested for these differences. Further comparative studies would be necessary to explain these differences. In Table 15 a comparison is given of cardiac outputs of the different species.

Table 15 Species Differences in Cardiac Output

Species	Cardiac Output ml/Kg body wt/min	Authors
Cattle	113 ± 11	Present Study
Sheep	113	Schambye, 1952
	100	Cross, Dawes & Mott, 1958
Goats	120	Barcroft, Boycott, Dunn & Peters, 1919
Horses	75	Fisher & Dalton, 1961
	75	Zuntz & Hagemann, 1898
Human (resting non-basal)	122	Wood, 1958
Dogs	138	Marshall, 1926

D. (c) Variations in cardiac output of cattle

Before correlated studies were made of cattle with cardiac disease a number of cardiac output determinations were made upon cattle either suffering from cardiac disease or affected with conditions liable to cause alterations in cardiac output.

(a) Excitement

Fear and excitement increase heart rate and cardiac output due to sympathetic discharge. A comparison was made of a normal curve and an excitement curve from the same young animal (Figure 6). While excited the pulse rate increased and there was a 50% increase in cardiac output.

(b) Anaemia

Anaemia has been stated to cause, in the human subject, an increase in cardiac output (Wood, 1958) and this would be an expected reaction of the heart in order to pump the same quantity of oxygen to the tissues. Below is illustrated a dye dilution curve of an anaemic cow (Figure 7).

The haematological data is given in Table 16. The cardiac output is above normal at 148 ml/kg body weight.

Table 16 Haematological Data 12416

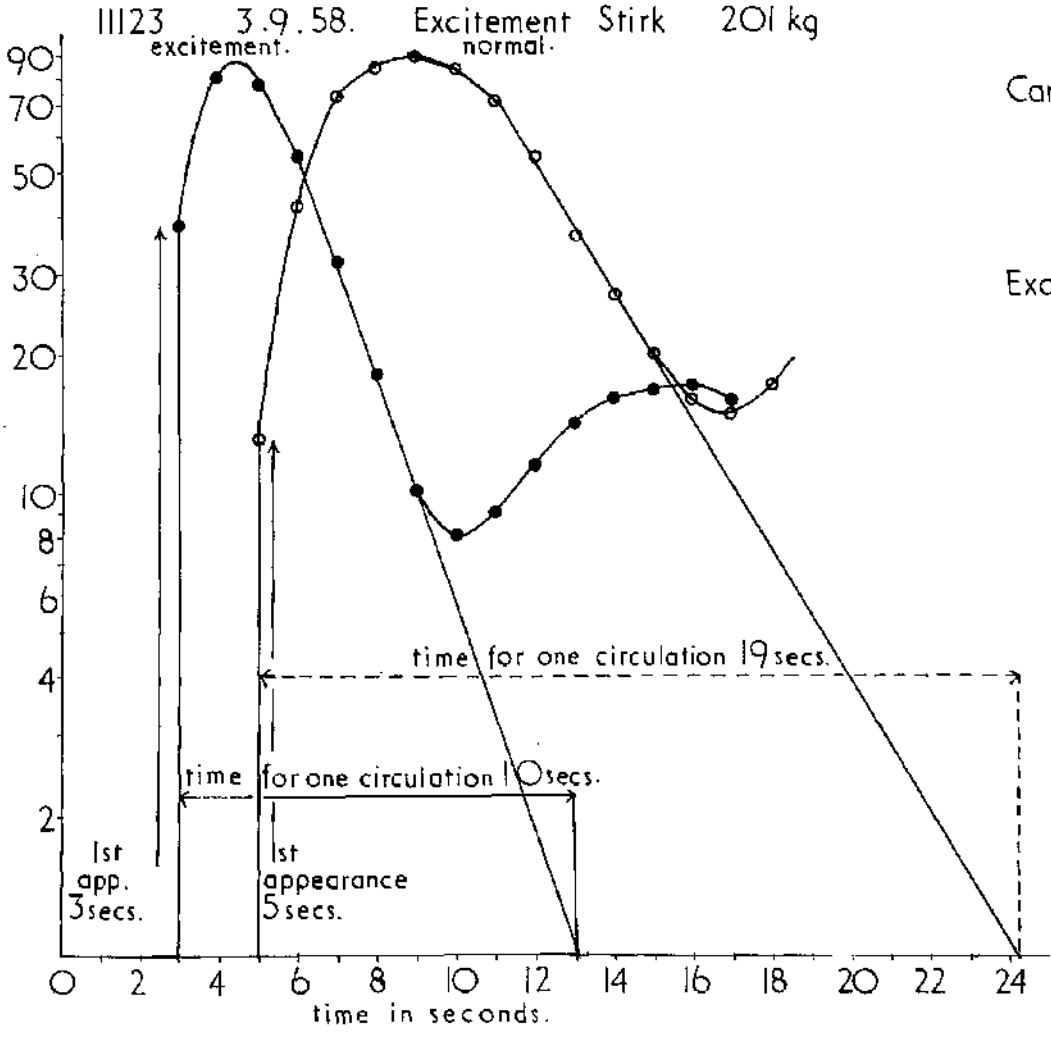
	Normal	12416	
Packed Cell Volume	30 ± 3	22	%
Haemoglobin	9 - 11	6.9	gms/100 ml
Erythrocytes	5 - 8	2.13	millions per cu.mm.

(c) Anaesthesia

Halothane anaesthesia has been shown to cause a decrease in cardiac output in dogs (Raventos, 1956) and in man (Kubota and Vandam, 1962).

This decrease in cardiac output was demonstrated in a cow. Below are illustrated dilution curves from the same normal cow before and during Halothane anaesthesia (Figure 8). A 14.6% decrease was demonstrated.

Figure 6



Cardiac Output:

Normal: 22 litres/min.
=110 ml/kg body wt/min.
Pulse 80 min.

Excitement: 34 litres/min.
=164 ml/kg body wt/min
Pulse 100 min.

Figure 7

12416 23.6.59. Anaemia (346kg)

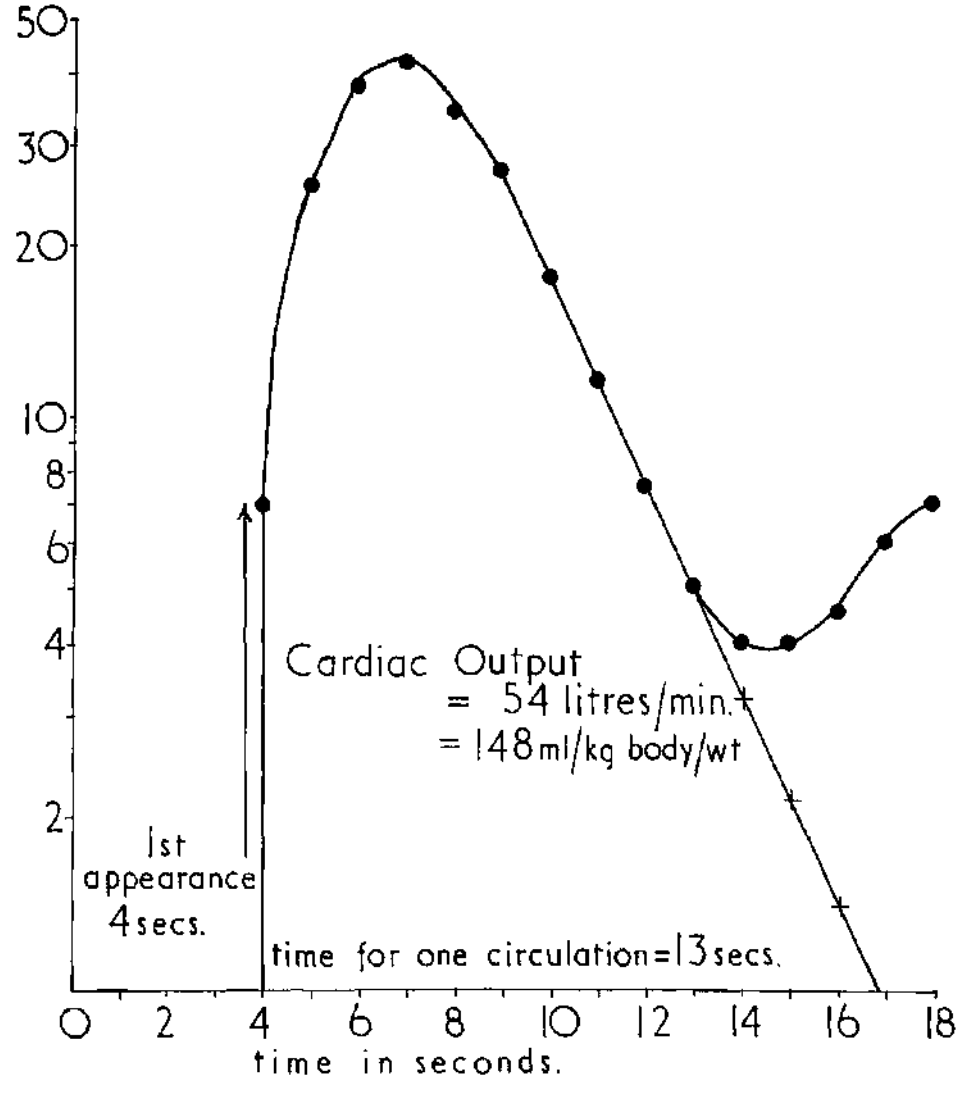
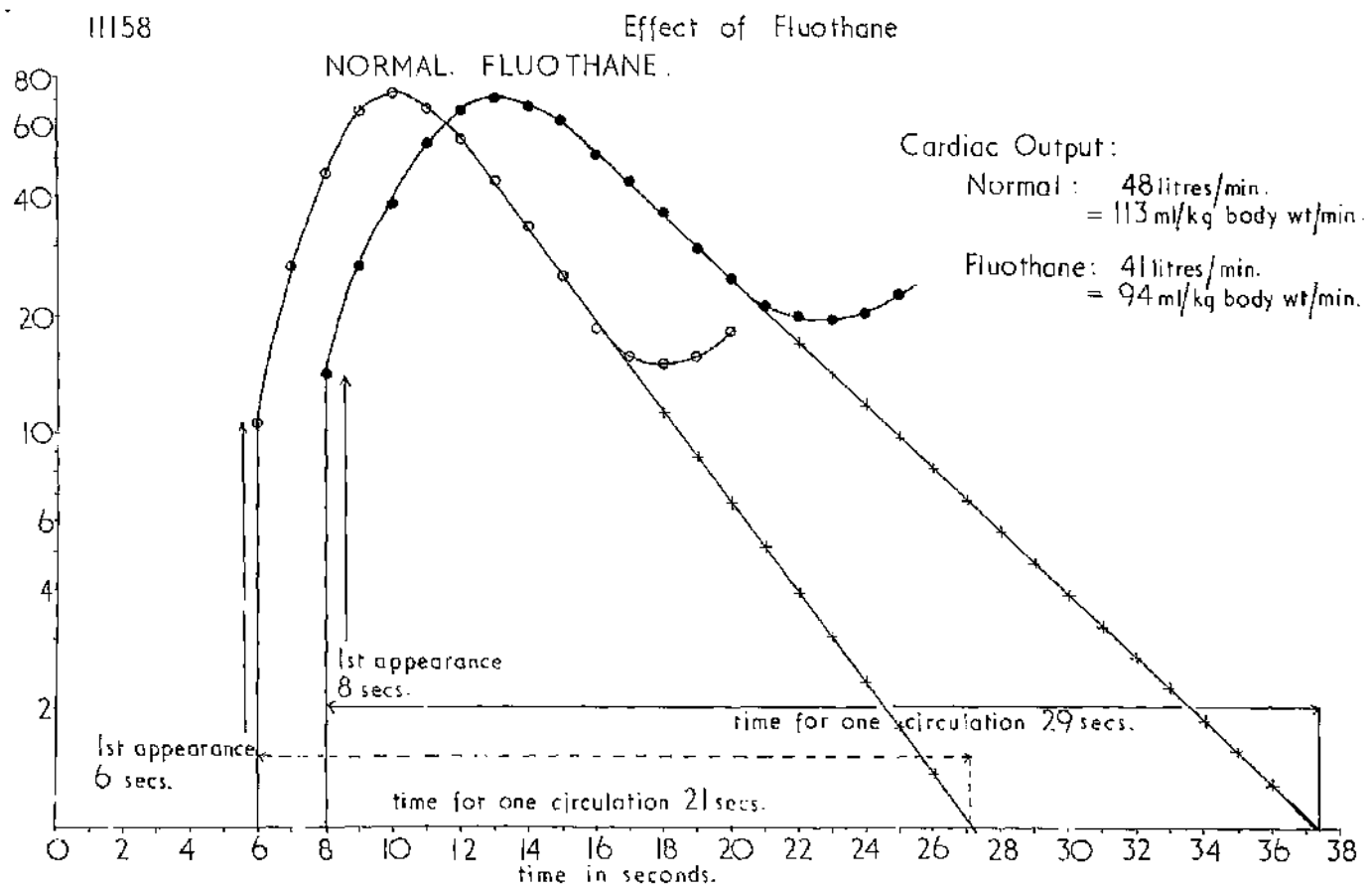


Figure 8


11158
Effect of Fluothane
NORMAL. FLUOTHANE.
Cardiac Output:
Normal: 48 litres/min.
= 113 ml/kg body wt/min.
Fluothane: 41 litres/min.
= 94 ml/kg body wt/min.
80
60
40
20
10
6
4
2
1st appearance
8 secs.
time for one circulation 29 secs.
1st appearance
6 secs.
time for one circulation 21 secs.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
time in seconds.

(d) Pneumonia

Due to interference with oxygen uptake and carbon dioxide excretion an increase in cardiac output might be expected in the early stages of pneumonia. At a later stage the decrease in myocardial oxygenation would cause a decrease in cardiac output.

Physiological studies of parasitic pneumonia and the effects of anoxia in cattle have suggested that the initial stimulus to respiration from pneumonia may be from the lung (Fisher 1962). As a result of pneumonia, pulmonary ventilation is increased to a greater extent than in experimental anoxia. Thus at the early stages of pneumonia a marked increase in cardiac output due to anoxia is unlikely, and measurements of cardiac output in cattle in the early stages of pneumonia failed to show a significant departure from normality. However, the determination of cardiac output in a moribund pneumonic animal illustrated in Figure 9 demonstrated a marked decrease in cardiac output.

(e) Circulatory failure due to dehydration

A cause of death in cattle is circulatory failure as a result of the dehydration caused by the chronic diarrhoea of Johne's disease. The decrease in cardiac output was demonstrated in two cases. In one case it was possible to follow the animal from before the development of circulatory failure (Figure 10), after the development of circulatory failure (Figure 11), and finally when the cardiac output was about one half normal (Figure 12). A few minutes after the determination the cow collapsed and died. Dye dilution curves from these animals are illustrated below.

Figure 9

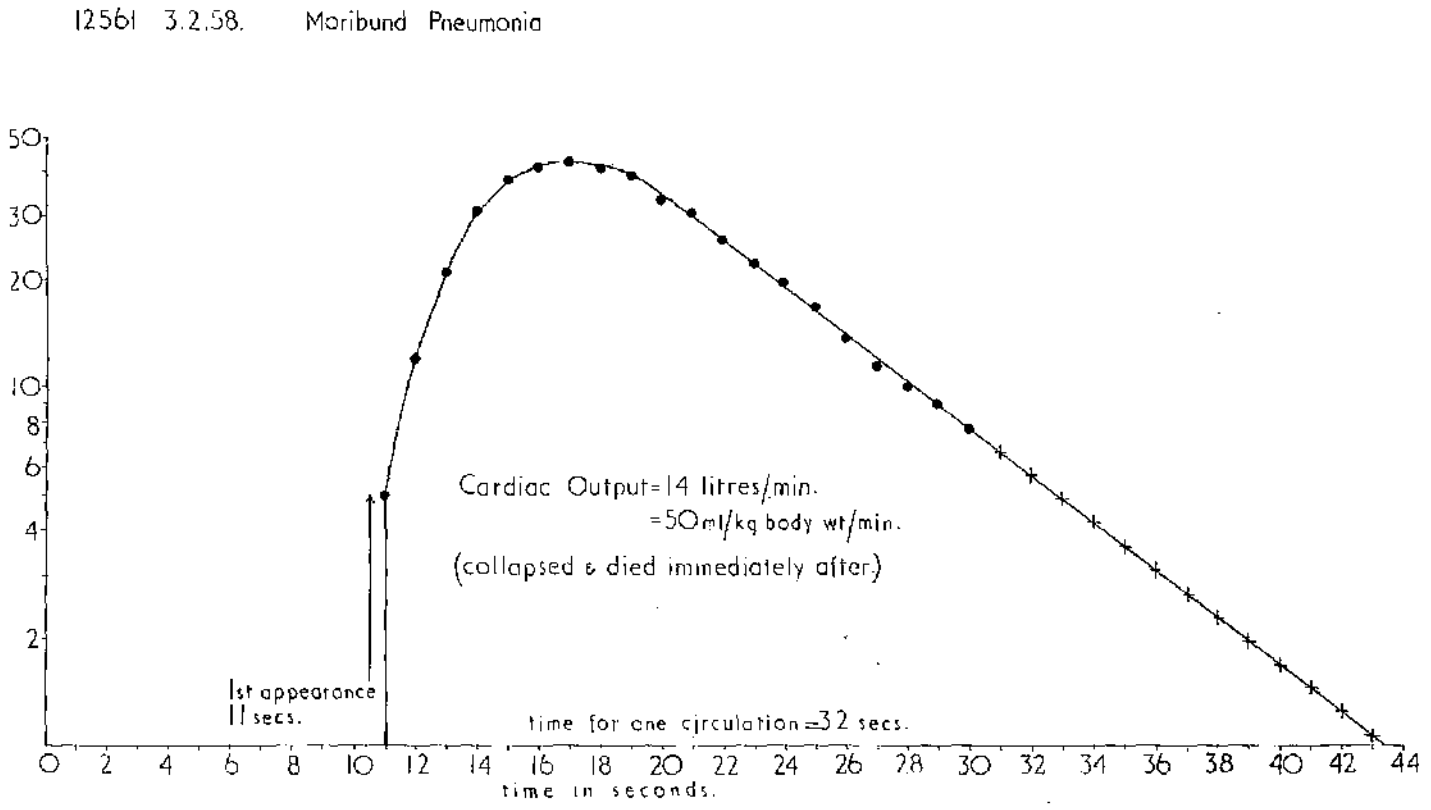

12561 3.2.58. Moribund Pneumonia
50
30
20
10
8
6
4
2
Cardiac Output=14 litres/min.
=50ml/kg body wt/min.
(collapsed & died immediately after)
1st appearance
11 secs.
time for one circulation=32 secs.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
time in seconds.

Figure 10

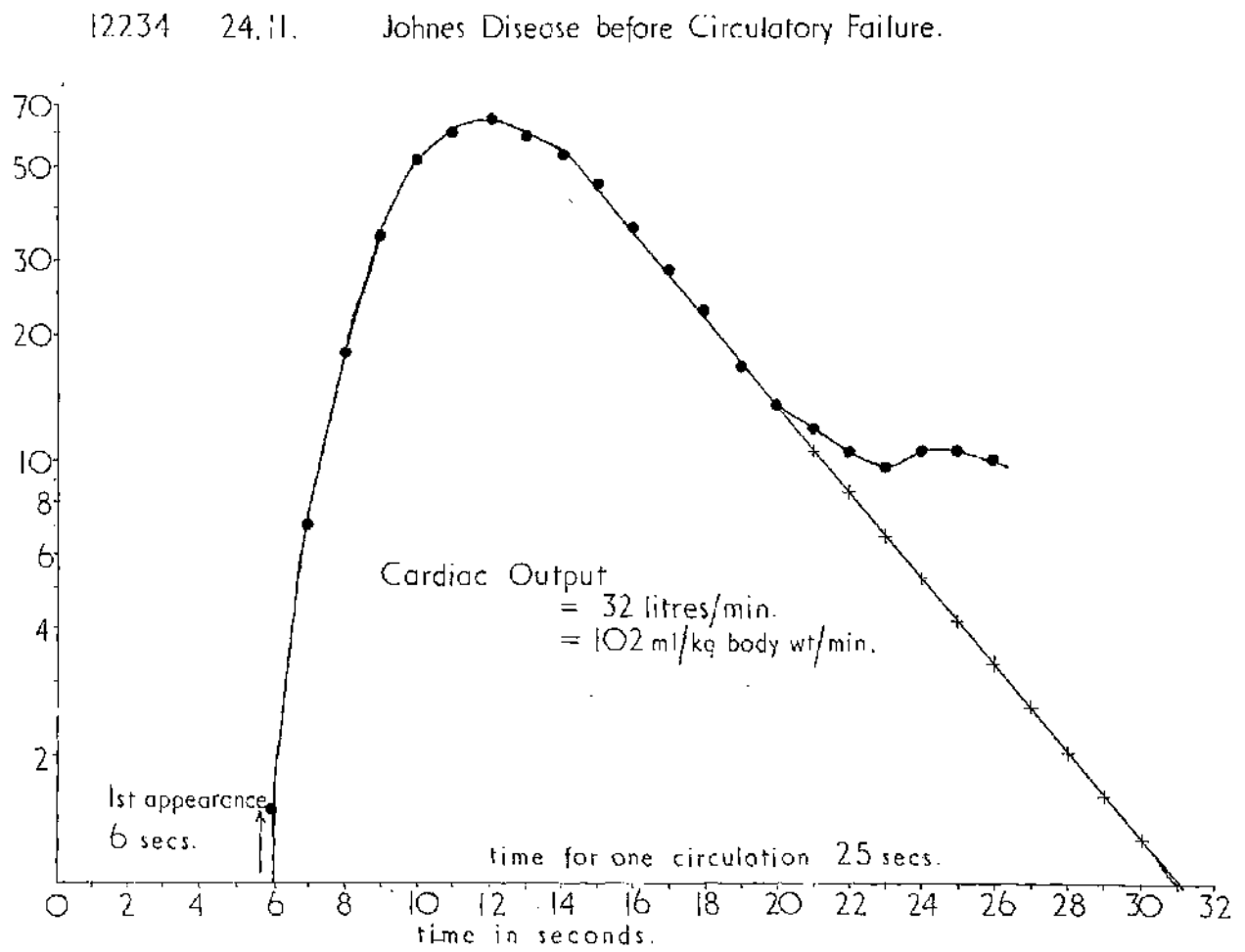

12234 24.11. Johnes Disease before Circulatory Failure.
70
50
30
20
10
8
6
4
2
Cardiac Output
= 32 litres/min.
= 102 ml/kg body wt/min.
1st appearance
6 secs.
time for one circulation 25 secs.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32
time in seconds.

Figure 11

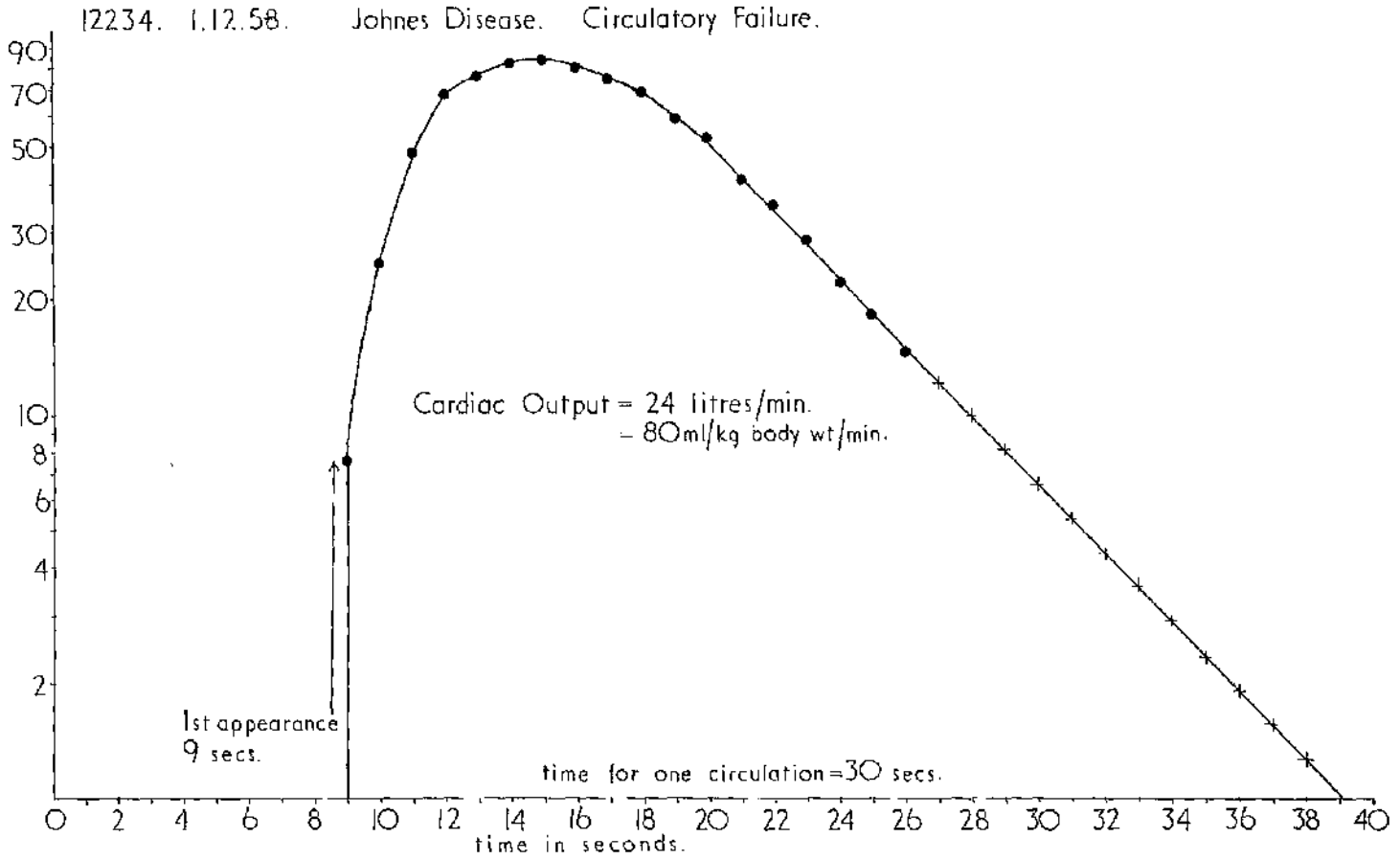
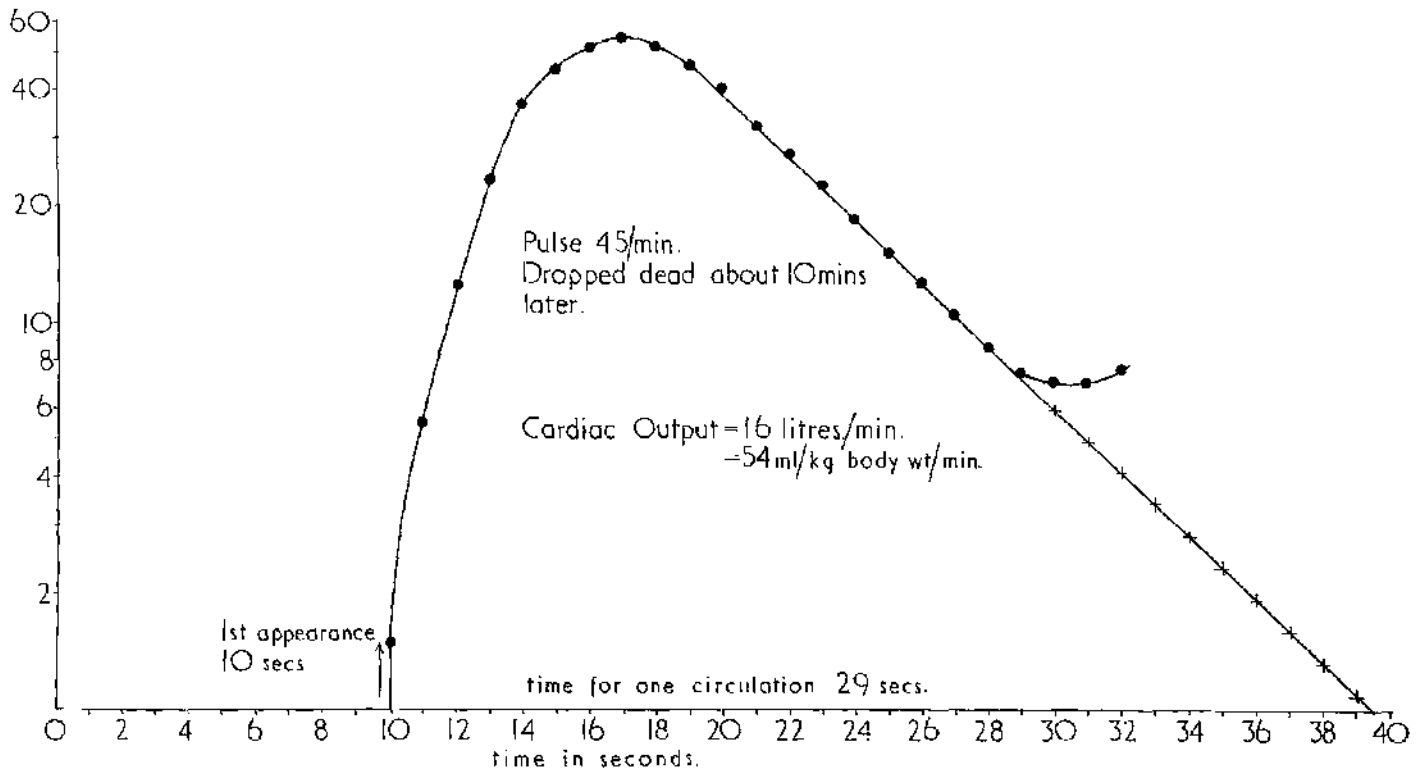

12234. 1.12.58. Johnes Disease. Circulatory Failure.
90
70
50
30
20
10
8
6
4
2
Cardiac Output = 24 litres/min.
= 80ml/kg body wt/min.
1st appearance
9 secs.
time for one circulation = 30 secs.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
time in seconds.

Figure 12

12234 2.12.58. Johnes Disease.



In addition, in Table 17 are given the blood and plasma volumes of the animal on which determinations were made up to the point of death. There was a decrease in both as the circulatory failure progressed. If expressed on a body weight basis the values are not markedly abnormal since in this chronic condition it is attempted to maintain circulating volume while body tissues are disappearing. Therefore weight loss is greater than circulating volume loss. Studies presented later on neonatal diarrhoea in calves suggest that the primary failure in diarrhoea may be of the heart. Detailed biochemical and electrocardiographic evidence of such a failure in Johne's disease may indicate similar findings but in these cases herein presented such evidence was not sought.

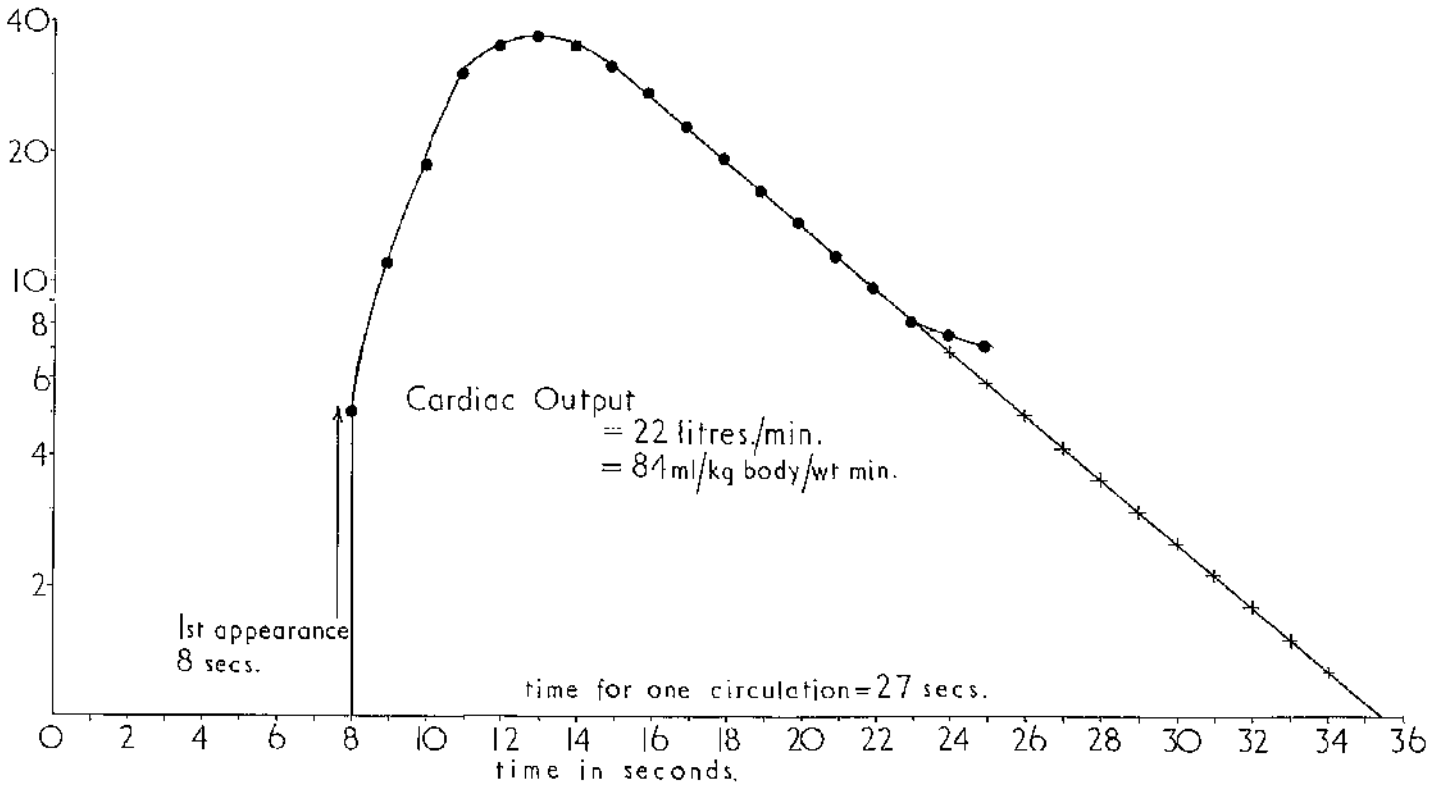
Figure 13 illustrates the cardiac output decrease in another cow with Johne's disease.

Table 17 12234 - Changes of cardiac output and circulating volume with dehydration

Date	Weight Kg.	Cardiac Output litres/min	Cardiac Output Ml/kg/min	Blood Volume litres	Blood Volume ml/kg	Plasma Volume litres	Plasma Volume ml/kg
26/11	314	32	102	27.5	87.6	20.1	64
1/12	299	24	80	20	66.9	13	43
2/12	295	16	54	15	50.8	11	37
Normal Cow			113±11		63±8		50±7

Figure 13

14083 Johnes Disease.



(f) Chronic Congestive Cardiac Failure

Many cardiac conditions cause chronic congestive cardiac failure in cattle. In this part of the study determinations were made on four cattle which exhibited clinical and pathological evidence of chronic congestive cardiac failure.

(i) Penn. I

In the correlated part of the study later, no opportunity arose to carry out fully correlated studies of cattle with lymphosarcoma.

It was possible for the author to determine, whilst in Philadelphia, the cardiac output of a cow with chronic congestive cardiac failure due to lymphoid infiltration of the cardiac muscle. The clinical signs in this animal were those of congestive cardiac failure. There was oedema of brisket and limbs, distension of jugular and mammary veins and a fast, weak pulse.

The dye dilution curve is illustrated below (Figure 14). This indicated a slowing of the circulation with a delayed first appearance time of the dye and prolonged circulation.

The cardiac output was reduced.

(ii) 12284

Determinations were carried out on this animal before the development of congestive cardiac failure.

As the curves (Figures 15, 16, 17) below illustrate, with the progression of the condition and decrease of cardiac output the first appearance time is increased and circulation time is prolonged.

Figure 14

28.6.60. Lymphosarcoma cow. Philadelphia. (655 kg.)

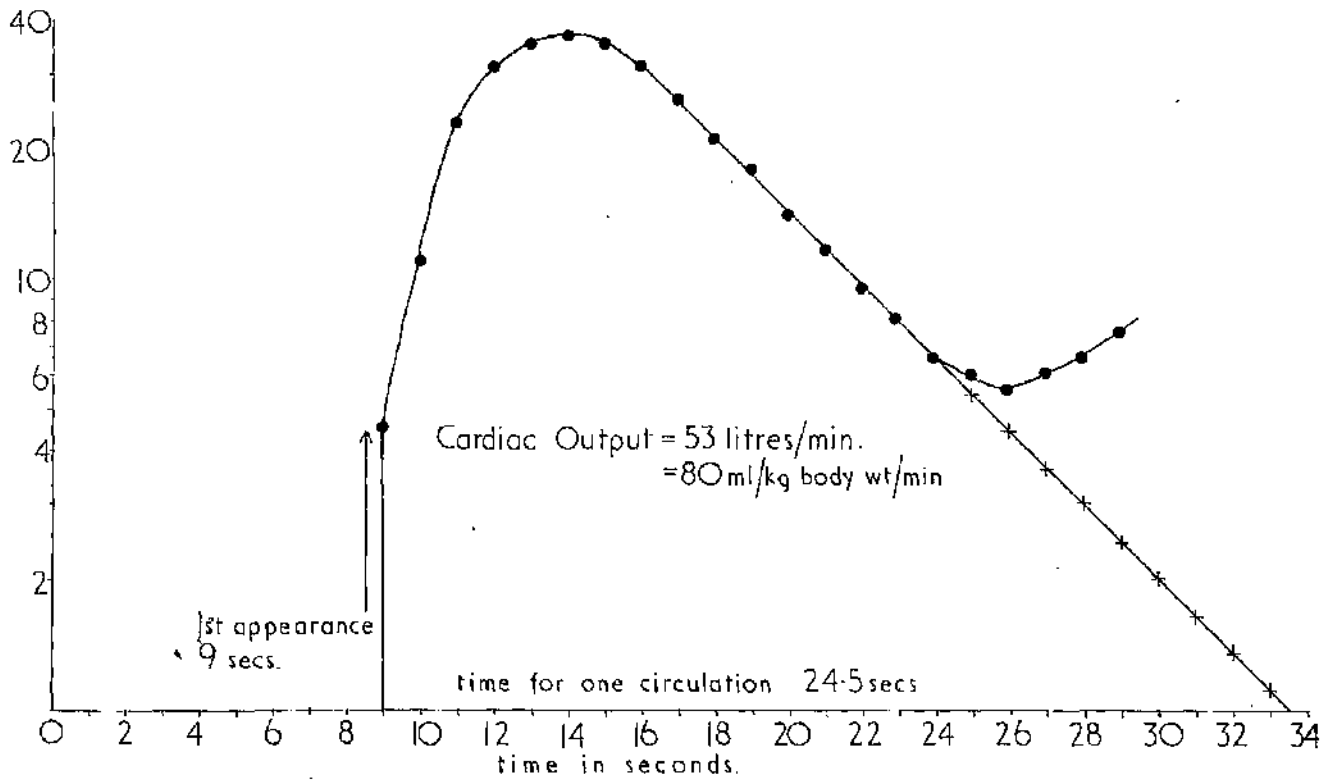


Figure 15

12284. 2.12. Before development of C.V.C.

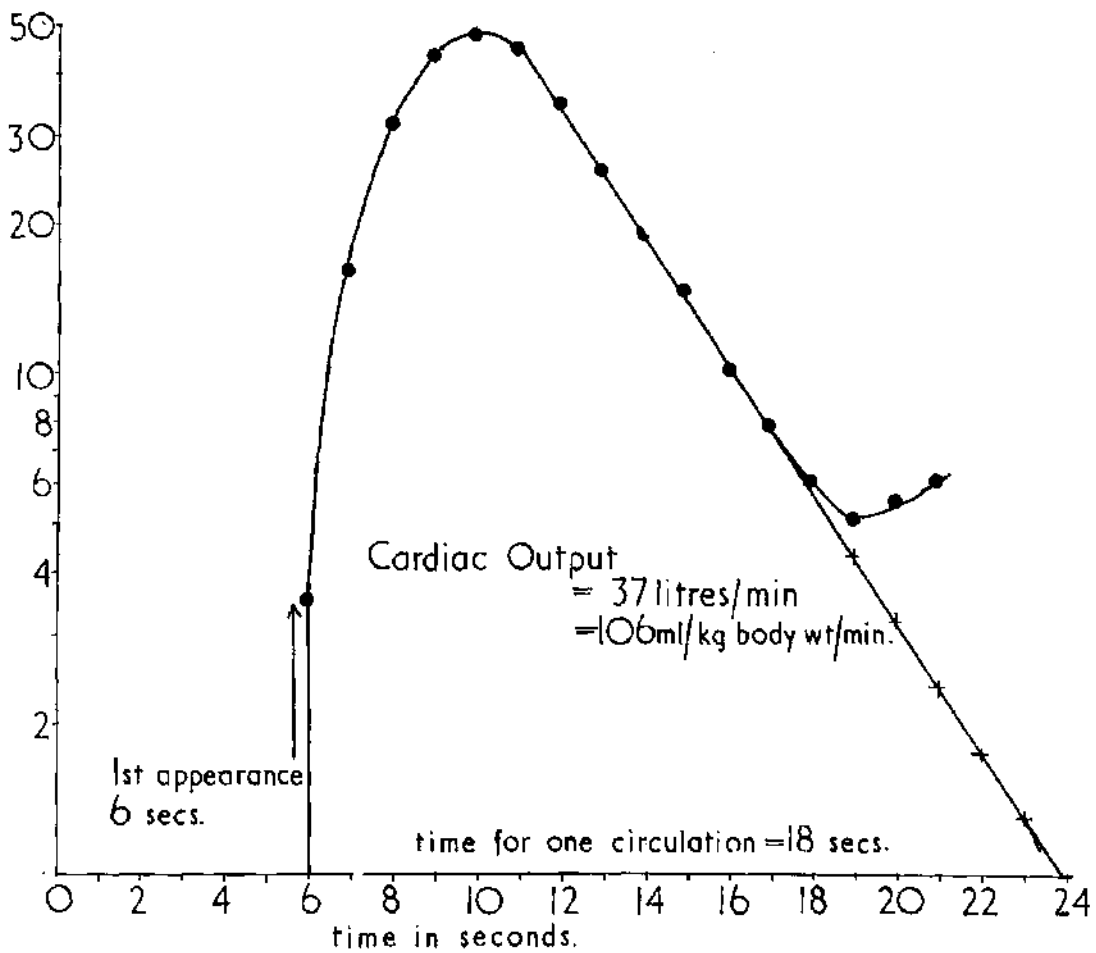


Figure 16

12284 8.12.58.

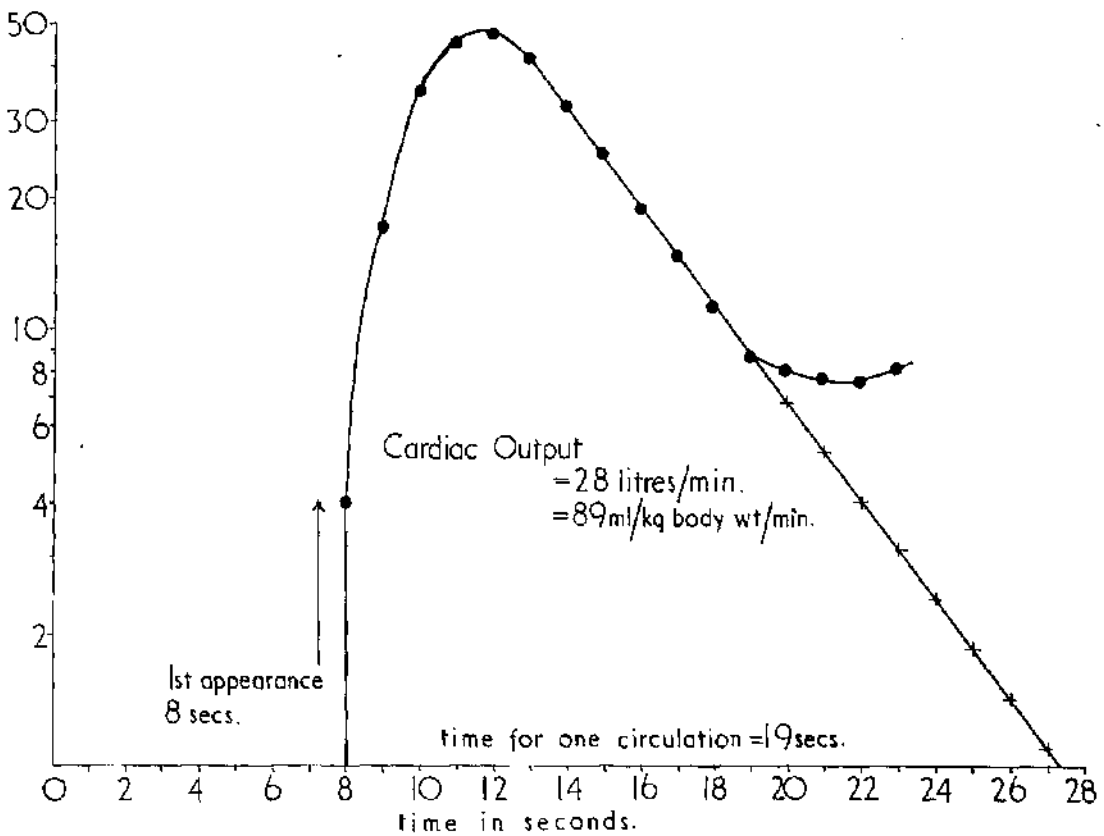
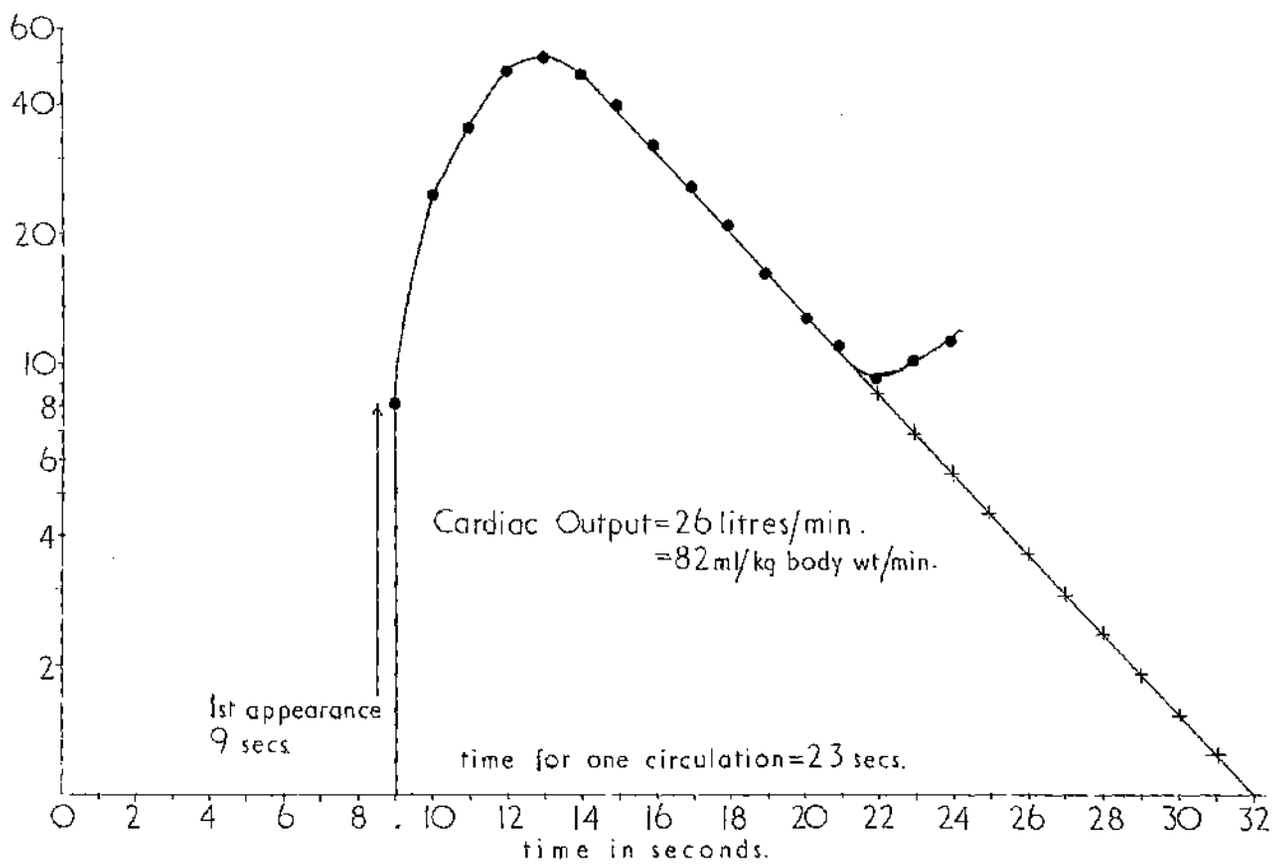


Figure 17

12284 12.12.58.



(iii) 12784

Determinations were carried out on this animal in a similar manner. The findings were essentially similar. The dye dilution curves are illustrated below (Figures 18, 19, 20).

(iv) 12084

When first studied this animal was already in chronic congestive cardiac failure with very marked subcutaneous oedema. The dye dilution curves illustrated below indicated that eventually it was impossible to determine the cardiac output because of the prolonged circulation time (Figures 21 and 22).

(g) Possible High Output Failure

No extensive opportunities arose to study high output failure in cattle but two cases presented themselves which suggested that this could occur.

Both cases were of Hydrops Amnii, that is there were excessive quantities of foetal fluids. Cardiac output determinations on both animals indicated that the hearts were maintaining a normal output if this excessive foetal fluid was included in their fluid dynamics. Thus, this fluid was causing an additional load upon the heart and could therefore cause a high output failure.

In one of these animals a Caesarian section was performed, after which a cardiac output determination was made. The decrease in cardiac output at this time illustrated the effect of the removal of a large viscus from the splanchnic area upon the circulation. A determination of cardiac output made four days later demonstrated the recovery of the circulation as evidenced by a normal cardiac output.

Figure 18

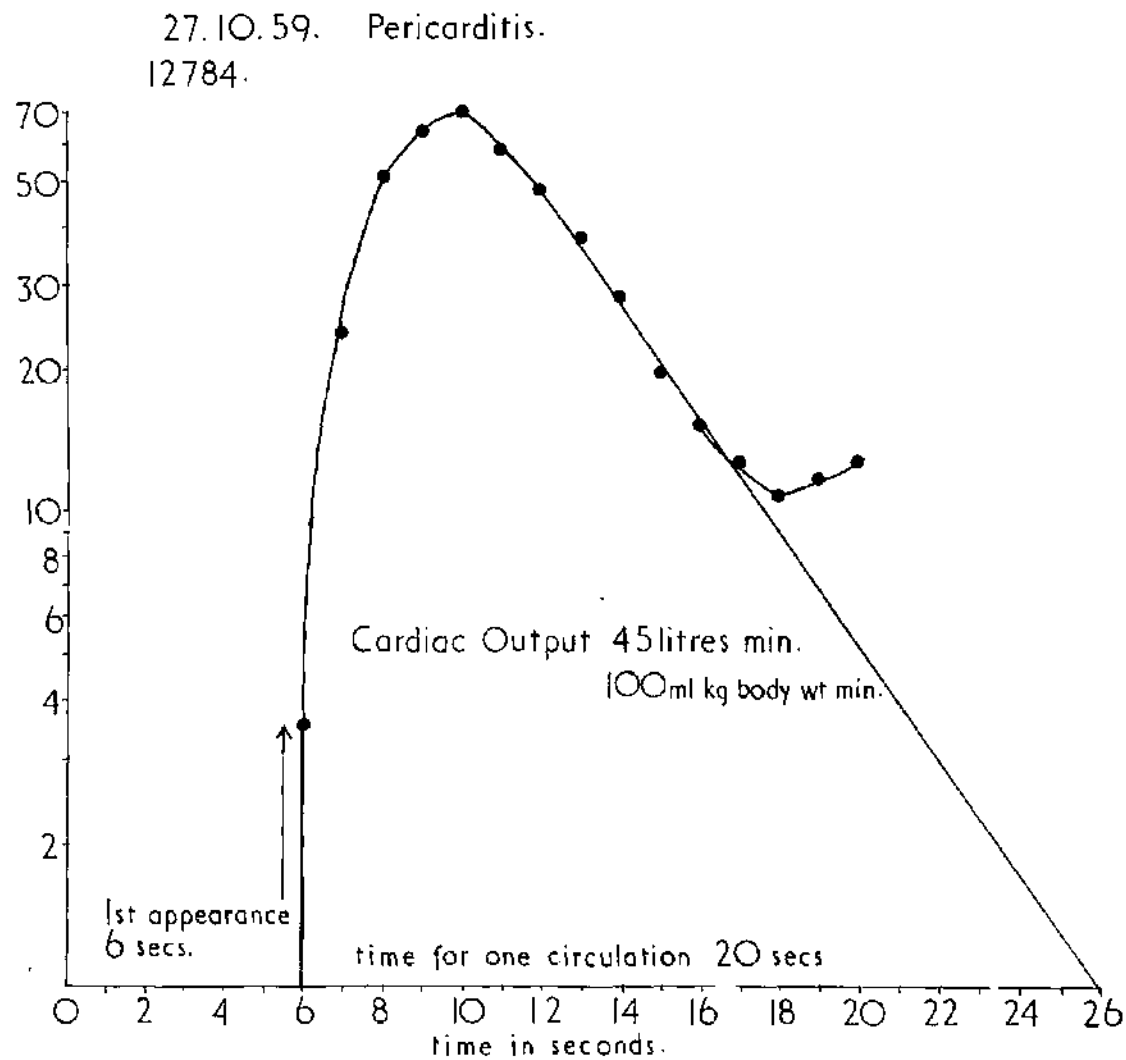

27.10.59. Pericarditis.
12784.
70
50
30
20
10
8
6
4
2
Cardiac Output 4.5 litres min.
100 ml kg body wt min.
1st appearance
6 secs.
time for one circulation 20 secs
0 2 4 6 8 10 12 14 16 18 20 22 24 26
time in seconds.

Figure 19

12784 3.3.59.

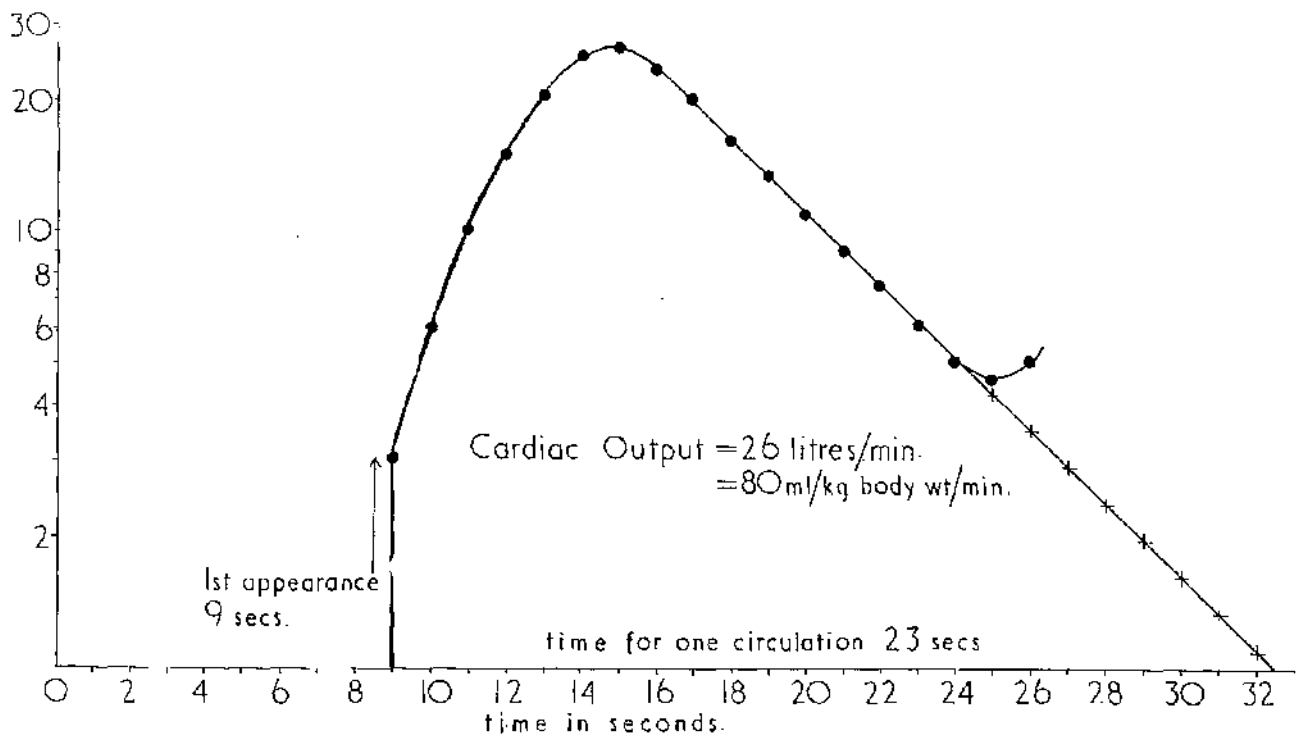


Figure 20

12784 10.3.59.

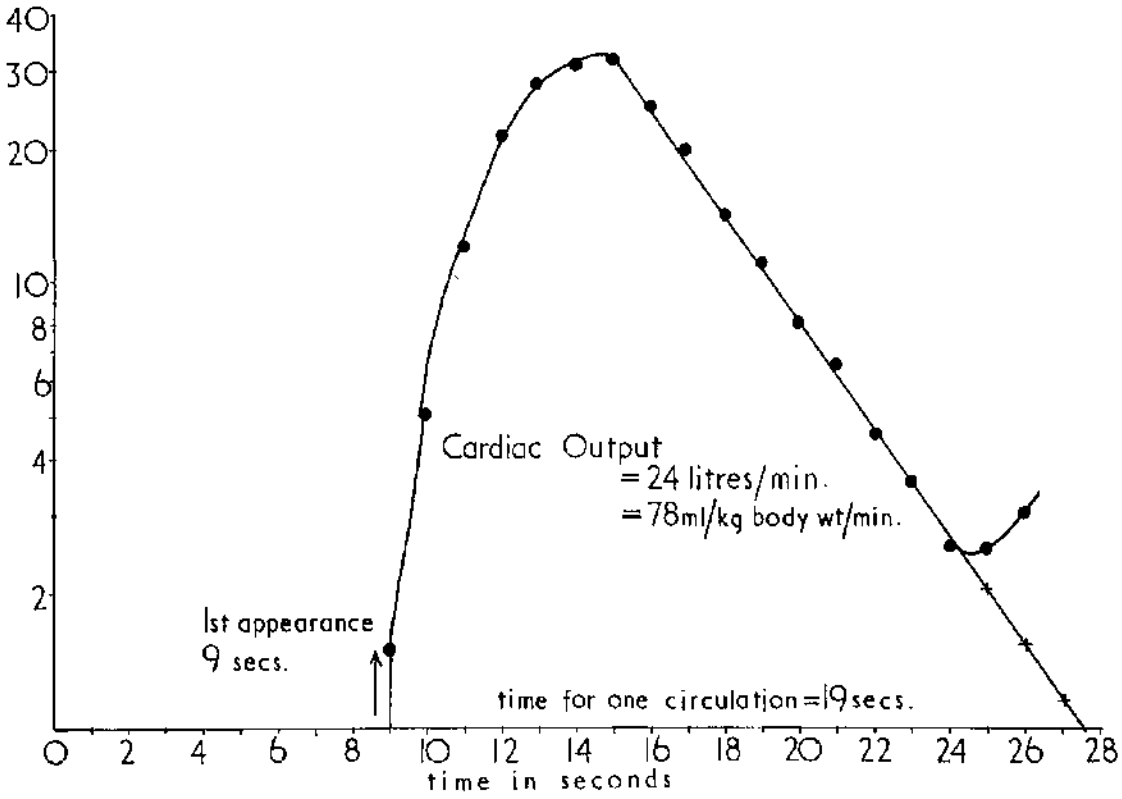


Figure 21

12084 Congestive Failure.

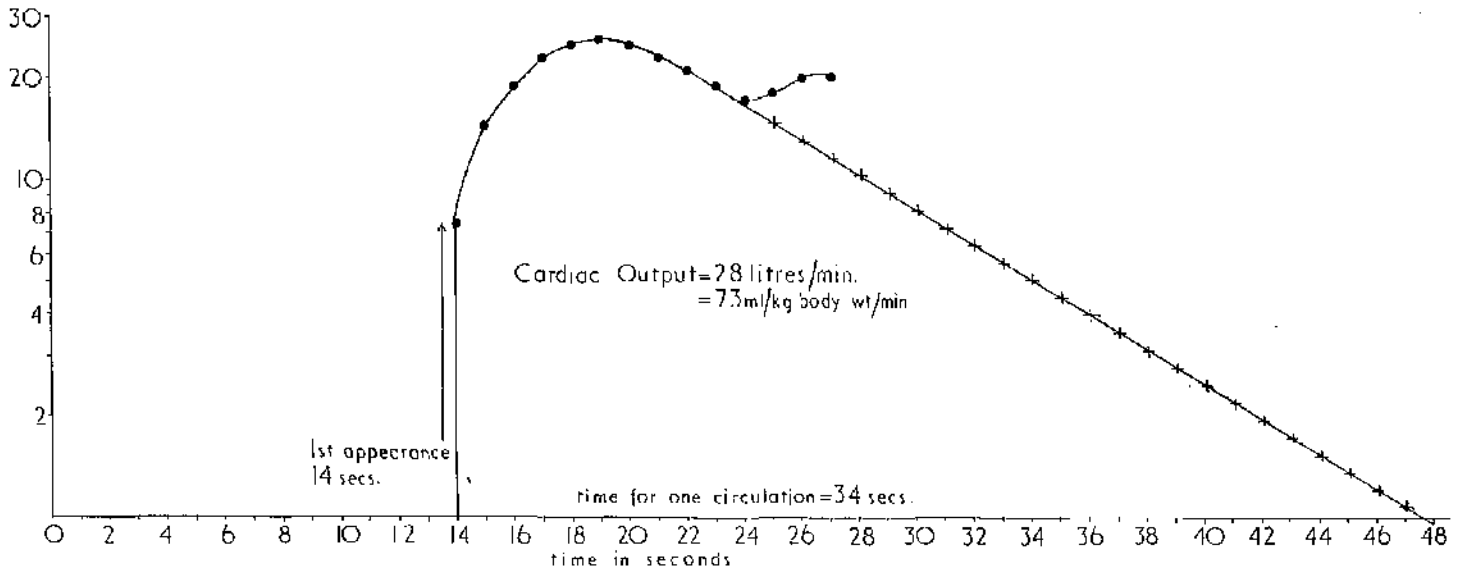
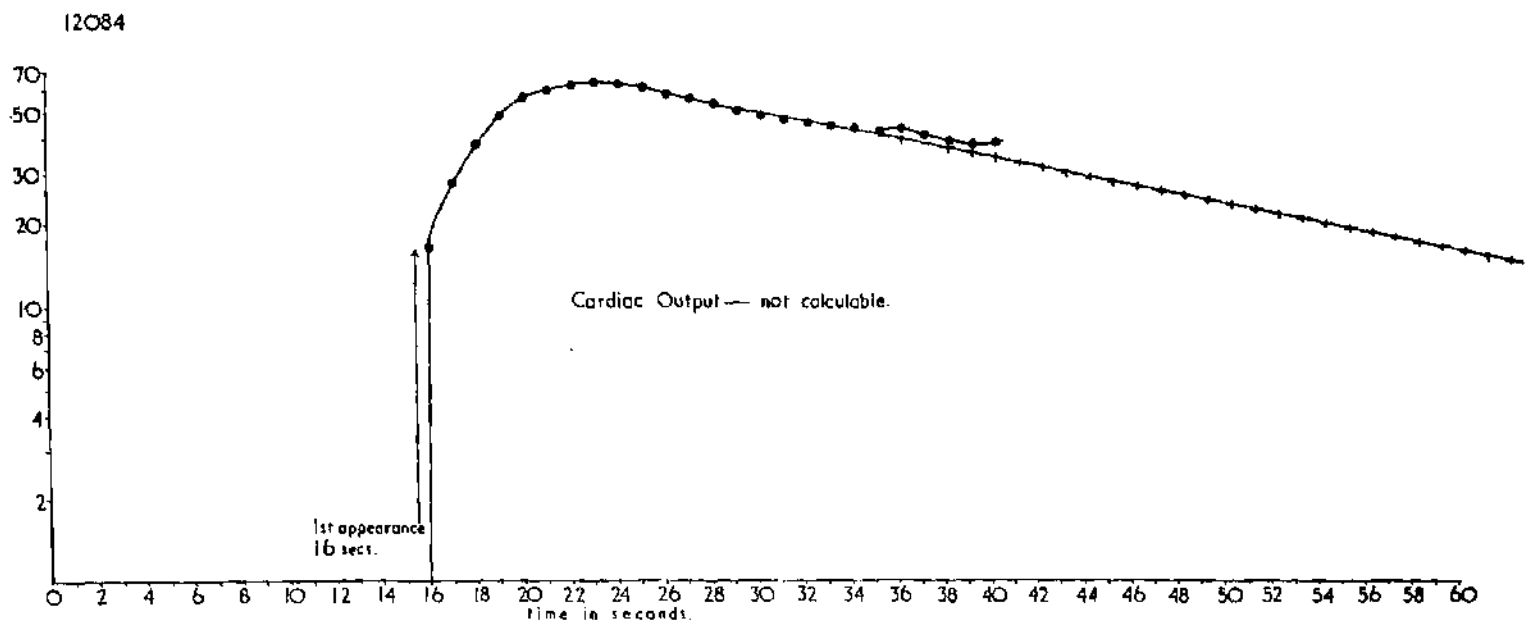


Figure 22


12084
70
50
30
20
10
8
6
4
2
1st appearance
16 secs.
Cardiac Output — not calculable.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60
Time in seconds.

The dye dilution curves from these animals are illustrated below (Figures 23 and 24a, b and c).

D. (d) Variations in Cardiac Output in Cattle - Discussion

The study of these variations in cardiac output demonstrated that the method as used was able to illustrate the alterations in circulatory dynamics by the changes in shape of the dye dilution curves. Marked increases in cardiac output and the increased speed of circulation was manifest by a shortening of the first appearance time to three or four seconds. Decreases in the speed of circulation associated with a lowering of cardiac output showed a lengthening of the first appearance time of the dye.

The limb of rising concentration of the dye dilution curve was steepest in those cases with an increased from normal cardiac output and flattest in those cases whose cardiac output was below normal.

The limbs of falling concentration of the dye dilution curves showed similar differences in shape as the limbs of rising concentration, but the differences were much more marked. Those animals with marked evidence of congestive cardiac failure showed very prolonged limbs of falling concentration.

From the dye dilution curves it was possible to calculate the actual increases and decreases in cardiac output.

In other species it is considered that a 50% decrease in cardiac output is incompatible with life (Guyton 1961) and it is of interest that the two animals in which such values were obtained died very shortly afterwards.

Figure 23

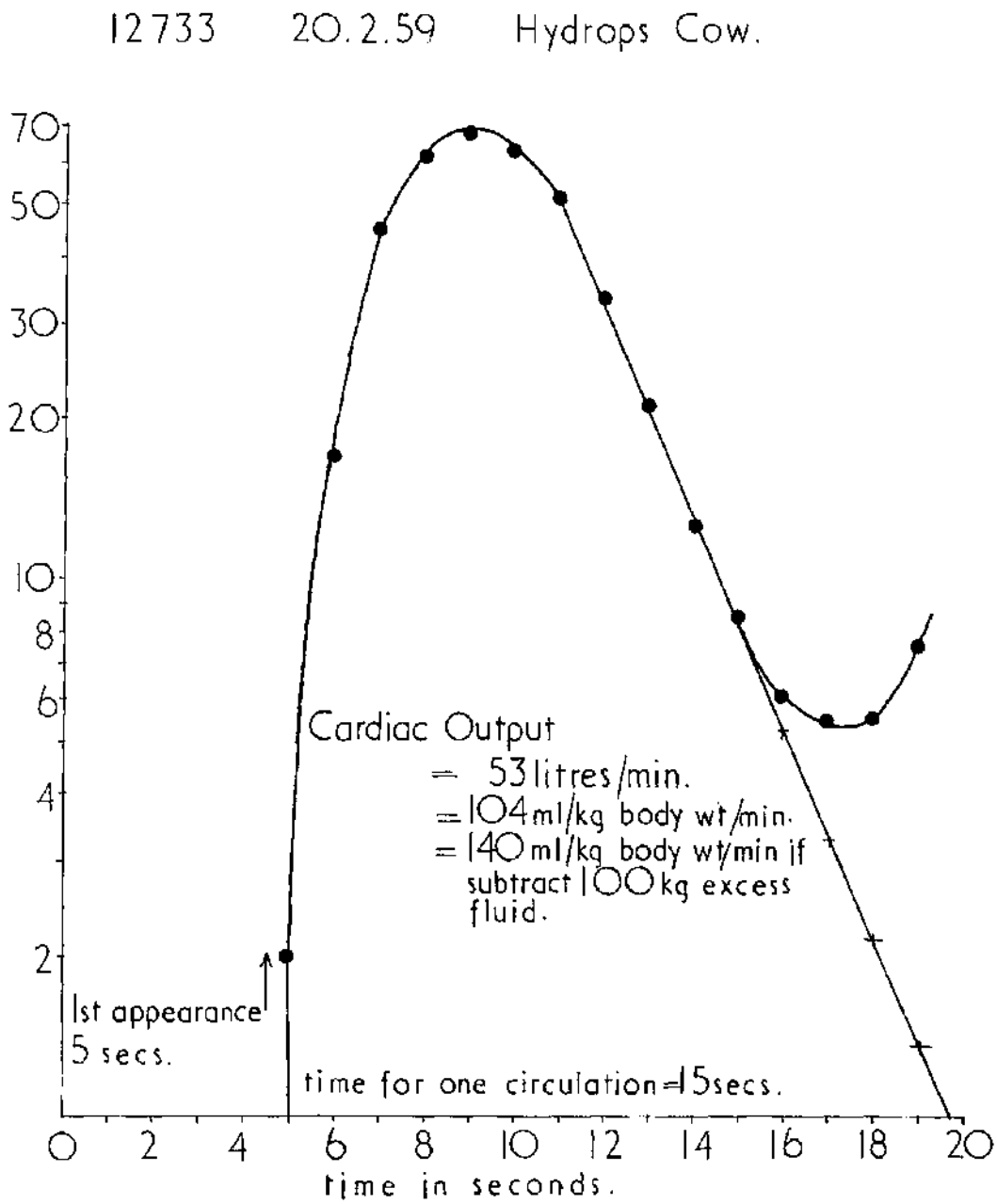

12733 20.2.59 Hydrops Cow.
70
50
30
20
10
8
6
4
2
Cardiac Output
= 53 litres/min.
= 104 ml/kg body wt/min.
= 140 ml/kg body wt/min if subtract 100 kg excess fluid.
1st appearance 5 secs.
time for one circulation = 15 secs.
0 2 4 6 8 10 12 14 16 18 20
time in seconds.

Figure 24a

12.2. Hydrops Amnii. (480 kg)

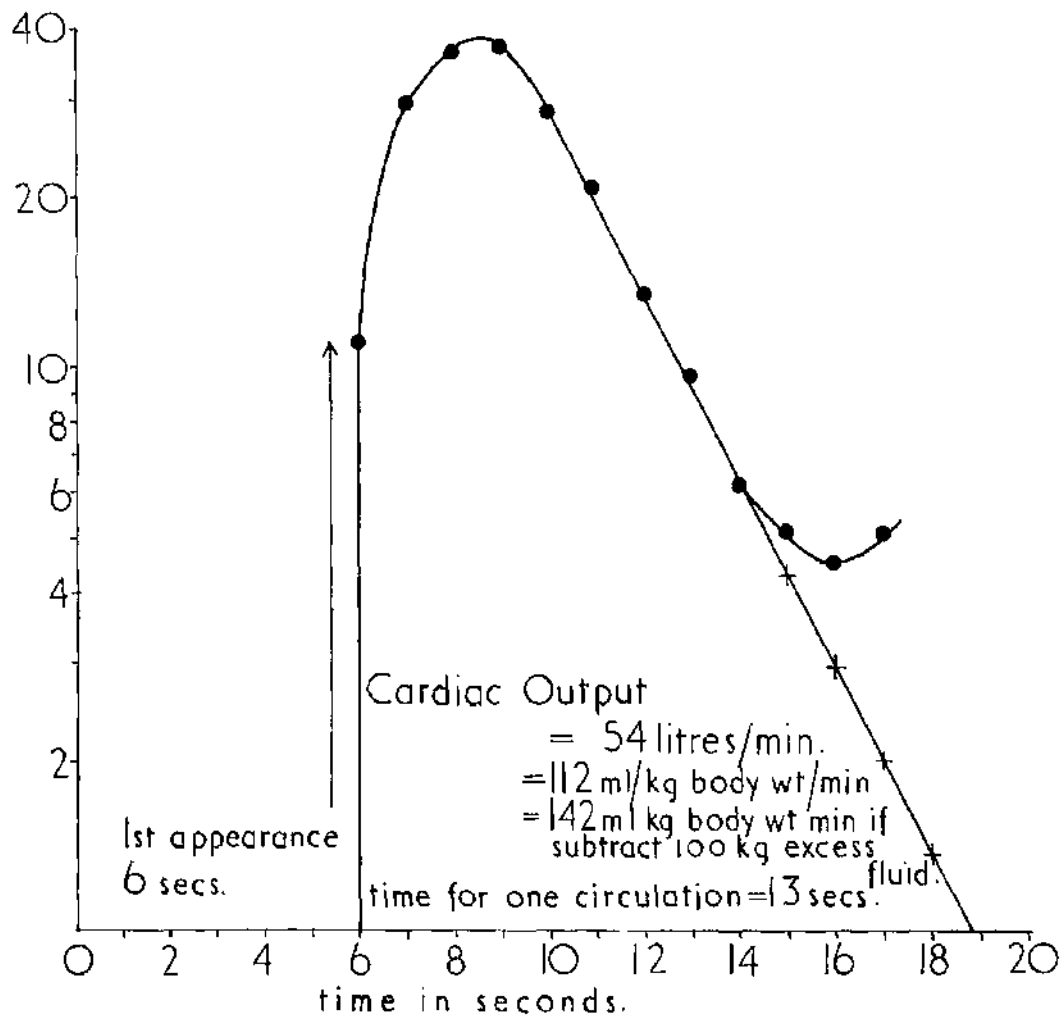


Figure 24b

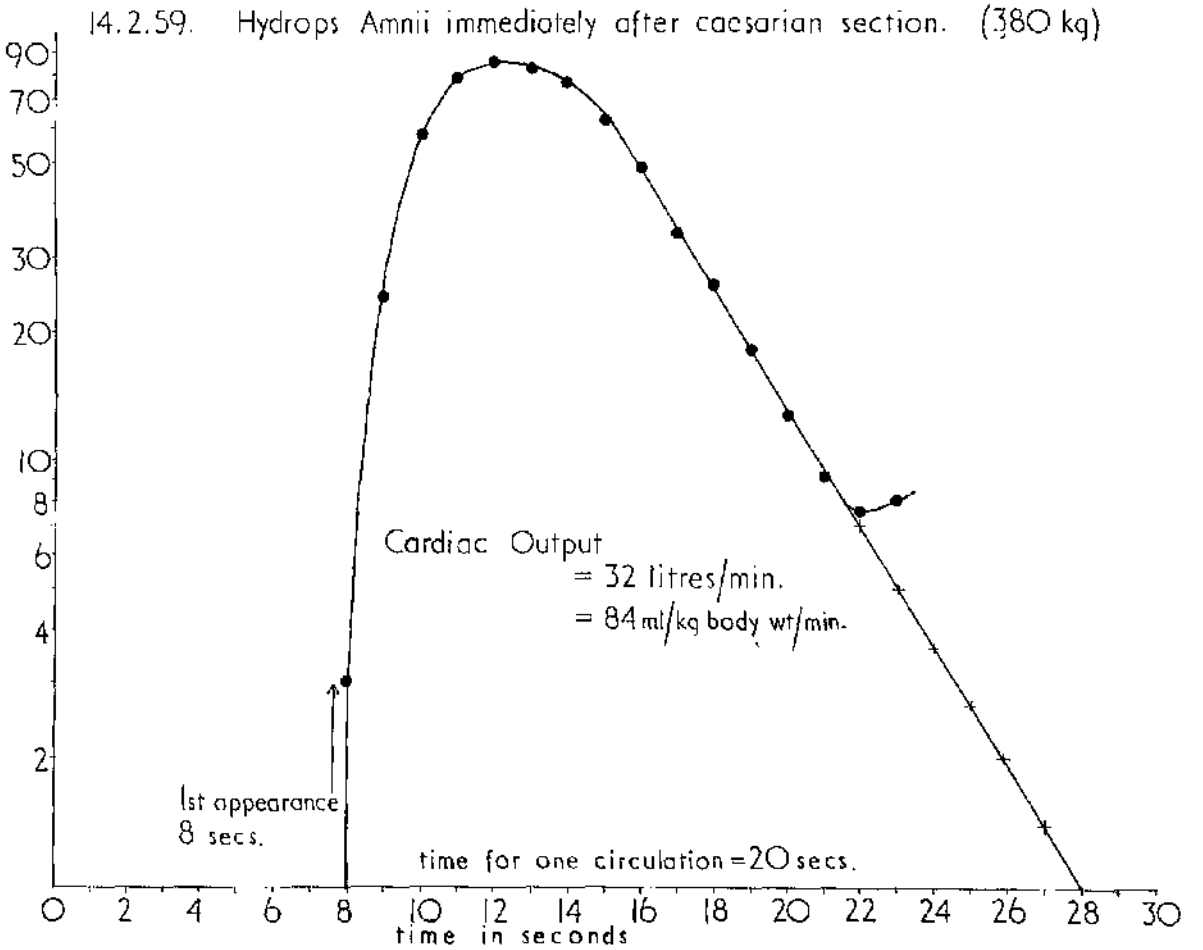
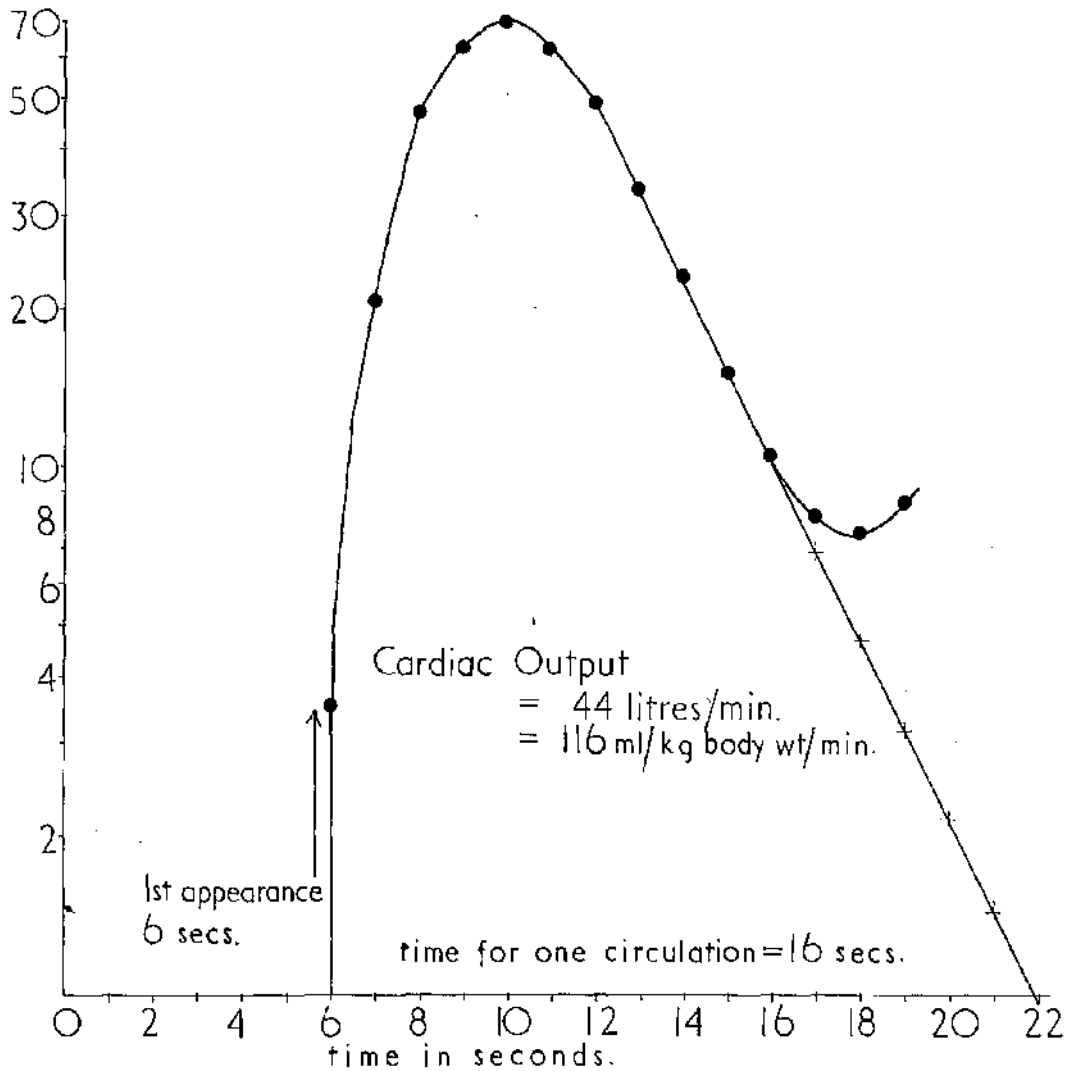

14.2.59. Hydrops Amnii immediately after caesarian section. (3.80 kg)
90
70
50
30
20
10
8
6
4
2
Cardiac Output
= 32 litres/min.
= 84 ml/kg body wt/min.
1st appearance
8 secs.
time for one circulation = 20 secs.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
time in seconds

Figure 24c

18.12 Hydrops Amnii recovered. (380 kg.)



From this series of animals it was concluded that cardiac output determinations were a valid method of measuring cardiac function in a number of conditions.

E. Determination of blood and plasma volumes of cattle (a) Methods

Blood and plasma volumes of cattle have been far more extensively studied than has the cardiac output. The results obtained and the methods used by different workers are given in Table 18.

One of the reasons for the continued use of Evans Blue as the intravascular indicator in this study was the fact that its slow excretion from the circulation meant that the quantity of dye injected for a cardiac output determination could be then used to determine blood and plasma volume. The optimum time to remove a single blood sample for the determination of plasma and blood volume had been shown to be 10 minutes in cattle (Dalton and Fisher 1961) and in the human subject (Gregersen 1951). This was again checked in healthy cows and Figure 25 illustrates an excretion curve in a cow.

Determination of blood and plasma volumes from the quantity of Evans Blue injected for a cardiac output determination

After an interval of 10 minutes from the determination of cardiac output a blood sample was removed from a subcutaneous abdominal vein, from the opposite jugular vein to that through which Evans Blue was injected into the circulation or from the brachiocephalic trunk. This sample was

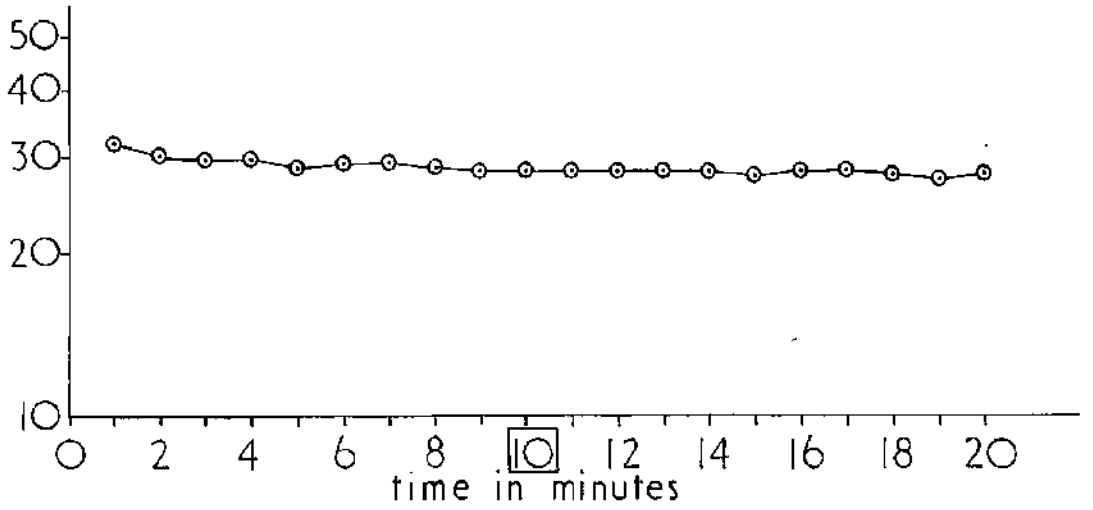
Table 18 Plasma and Blood Volumes in Cattle

Reference	Method	Animals	Plasma (ml/kg.)	Blood (ml/kg.)
Turner & Herman (1931)	Vital red	54 growing dairy cows	35.0	58.1
		24 non-lactating cows	37.8	63.8
		41 lactating cows	49.2	81.1
Miller (1932)	Vital red	19 animals 81 determinations Weight range 400-1,300 lb.		59.7
Hansard Butler Comar & Hobbs (1953)	Erythrocytes labelled with phosphorus-32	Hereford Cattle		
		2 2-6 weeks old		120
		1 3 weeks old		85
		3 2-3 months old		62
		5 6-8 months old		58
		3 14-15 months old		57
		4 8-12 years old		57
		Guernsey Cattle		
Reynolds (1953a)	T.1824	11 determinations on 10 non-pregnant and non-lactating animals	36.9±0.8	52.1±1.4
			38.8±1.4	57.4±2.1
Reynolds (1953b)	T.1824	20 pregnant animals	38.5±1.8	59.2±2.8
		7 lactating animals	44.1±1.7	64.1±2.7
Dale, Burge & Brody (1956)	T.1824	3 dry Jerseys	36.6±3.7	62.0±5.0
		3 lactating Jerseys	47.1±4.7	68.8±7.0
		3 lactating Holsteins	54.5±5.6	84.4±9.8
Bianca (1957)	T.1824	18 determinations on 6 Ayrshire calves aged 4 months	47.5±0.8	65.4±1.1
Mixner & Robertson (1957)	Bromosulph-ophthalein	Holstein cattle		
		5 lactating cows	38.1±6.5	57.2±9.6
		9 bull calves Mean weight 48.7 kg.	68.2±16.0	115.0±30.4

Figure 25

Excretion curve, Evans Blue - Adult Cow

Excretion Curve. Arterial samples at 1 min. intervals.



centrifuged. Using the E.E.L. colorimeter the concentration of dye in this sample was found by comparison with the blood standard plasma prepared for cardiac output determination. This gave the concentration of dye in blood (C_b). At the same time a comparison was also made against a standard made from plasma obtained before dye injection, to which had been added sufficient Evans Blue to produce a concentration of 20 mg per litre of plasma. This gave the concentration of dye in plasma (C_p).

If I was the amount of dye injected:

$$\text{Blood Volume} = \frac{\text{I in mg}}{C_b}$$

$$\text{Plasma Volume} = \frac{\text{I in mg}}{C_p}$$

Method used in neonatal calves

In experiments studying the dehydrating effects of diarrhoea in newborn calves, cardiac output determinations were not performed. To obtain blood and plasma volumes an accurately weighed amount of Evans blue was injected into one jugular vein and after 10 minutes equilibration a blood sample was withdrawn from the opposite jugular vein. Blood samples for making standards were taken from the first venipuncture prior to the dye injection. These samples were handled as previously, that is a standard was prepared and compared with the 10 minute sample. Since these calves were on a milk diet and were not ruminating it was considered that such jugular blood samples would accurately reflect changes without the effects of salivation which would be likely in older ruminating animals.

A number of determinations were made on normal cows and calves.

E. Determination of blood and plasma volumes (b) Results

These results are given in Table 19 as millilitres per kilogram body weight.

Table 19 Blood and Plasma Volumes in Healthy Cows and Neonatal Calves

Animals	No. of Animals	Blood volume ml/kg	Plasma volume ml/kg
Neonatal Calves 25 - 45 Kg	10	106±11	
	20		68 ±5
Adult Cows 300 - 600 Kg	18	62± 5	
	15		50.5±5

These results are similar to the results of other workers (Table 18), differences probably being due to the various intravascular indications used. The values in Table 19 are not significantly different from previously published results (Dalton and Fisher 1961). These results indicate that calves have significantly higher ($p<0.01$) blood and plasma volumes than adult cows. Similar findings are reported in the human subject (Wiggers, 1949).

E. (c) Variations in blood and plasma volume of cattle

In some of the cases where changes in cardiac output were studied blood and plasma volumes were also measured. The results obtained are given in Table 20.

Table 20 Blood volumes of animals with alterations in their cardiac output

No.	Condition	Blood volume litres	Blood volume ml/kg	Remarks
1158	Control	27	62	
	Fluothane Anaesthesia	28.8	68	
11123	Control	10.7	50	
	Excitement	11.1	55	
12234	Johne's Disease	27.5	87.5	
		20	66.9	Progressive dehydration
		15	50.8	
12071	Hydrops Amnii	27	56	Before Caesarian Section
		25	65	Immediately after operation
		24.3	64	4 days post operation
12084	Chronic Congestive Cardiac Failure	24	65	Before failure
12284	Chronic Congestive Cardiac Failure	22	63	
		19	61	
12784	Chronic Congestive Cardiac Failure	23	70	
12416	Anaemia	28	76	
14084	Johne's Disease	16	60	

As part of another experiment plasma volumes were measured in young calves before and during the dehydration caused by neonatal diarrhoea.

The results obtained in ten calves are given below in Table 21 to illustrate the changes taking place.

Table 21

Calf	Before diarrhoea			After 3 days moderate diarrhoea		
	Body Wt. Kg.	Plasma Vol. litres	ml/kg	Body Wt. Kg.	Plasma Vol. litres	ml/kg
17163	33.6	2.01	59.8	31.8	1.86	58.5
17167	32.7	2.06	63	30.0	1.82	60.7
17156	36.4	2.41	66.2	31.4	1.95	62.1
17159	33.6	2.15	64	30.9	1.99	64.4
17151	36.9	2.1	58.5	33.6	1.79	53.3
17482	35.9	2.3	64.1	34.0	2.11	62.1
17484	36.8	1.91	51.9	34.5	1.23	35.7
17469	32.3	2.15	66.6	31.4	1.92	61.1
17476	28.3	1.31	46.3	24.1	1.12	46.5
17481	34.1	1.9	55.7	30.0	1.32	44.0
Mean & S.D.	33.96±2.54	2.03±0.27	59.6±6.64	31.2±2.9	1.71±0.57	54.8±7.4

With the dehydration of diarrhoea there was a decrease in body weight and a decrease in plasma volume. There was no significant difference between plasma volumes before and after 3 days moderate diarrhoea.

E. (d) Variations in blood and plasma volumes of cattle - Discussion

These determinations of blood and plasma volumes were successful in illustrating decreases as a result of dehydration, but the few determinations attempted in congestive cardiac failure failed to illustrate hypervolaemia. Evidence of hypervolaemia is presented later in the more detailed studies of the heart failure due to traumatic pericarditis.

3. Discussion on the Methods

This initial part of the study has illustrated the feasibility of the utilisation of many techniques as part of a routine cardio-vascular examination of cattle when intact and unanaesthetised.

The determinations carried out demonstrated that cattle are similar to most other species with reference to their cardio-vascular parameters. The most noteworthy exception was in the haematocrit, which was found in adult cattle to be lower than in other species. This in itself is not an original observation, neither was the observation that variations in the haematocrit occur from vessel to vessel. It was of great interest to observe higher jugular than mammary haematocrits in both lactating and non-lactating cows. The loss of fluid to saliva could be predicted in cattle, as could the greater loss in lactating cattle who are eating more. A further interesting extension of this part of the study, which was not at this time pursued, would be a comparison between housed lactating cattle in winter and similar cattle in summer, particularly if the cattle were not being fed concentrates in summer.

A vessel with the name 'mammary' might be expected to play a large part in the drainage of the mammary gland. The evidence of haematocrits would suggest the contrary, since no significant differences could be found between lactating and dry cows. This particular aspect of the mammary gland of cattle would be worthy of further investigations,

although outwith the interest of the study herein presented. Some evidence on mammary blood flow has confirmed these observations (Reynolds 1963).

The variation in venous haematocrits emphasised the fallacy of the utilisation of peripheral venous samples in the determination of the concentration of certain blood constituents. A further observation which reinforced the above observation was made when long venous catheters have been used to obtain mixed venous blood samples. It is usual to insert these blind, without monitoring the pressure at the catheter tip. On many occasions in calves, difficulty has been encountered in entering the right ventricle, which fact was known only by pressure recording. Slaughter of some calves with catheters in situ revealed that the catheter tips were in the liver, not the right ventricle.

The use of Evan®s Blue as the intravascular indicator enabled the same dye injection to be used for blood volume, plasma volume and cardiac output determination. "Blueing" was not a problem in cattle but the persistance of dye in lymph glands, liver and kidney meant that after injection of Evans Blue at least one week had to elapse before slaughter if salvage of the carcase was required.

The preparation of both plasma and blood standards avoided calculations using a trapped plasma factor. It also avoided the errors if such calculations were made from results of haematocrits from peripheral veins. This was considered of crucial importance in the determination on diseased animals. A side determination often made and which was usually within 1 or 2 millimeters of the centrifuged haematocrit was the calculation of haematocrit from the plasma and blood volumes found.

The use of this calculation acted as a check to a limited extent on the validity of the 10 minute sample, but more on the accuracy of the standards made in blood and plasma.

The variations in cardiac output were not unexpected but served to illustrate graphically the changes in the functional ability of the heart as a result of various conditions. These variations are often quoted in textbooks but are seldom illustrated or given quantitatively.

Of the greatest interest were the very few observations made on the cattle with hydrops amnii, suggesting as they did high output failure as a possible cause of death in this disease. It is unfortunate that due to the gradual development of the many methods utilised over the whole of this present study, some were not available when the variations in cardiac output were studied. Later studies on abnormal animals were limited to conditions available in the greatest numbers. It must be emphasised that this study of variations was for the purpose of demonstrating that the Injection method of the determination of cardiac output could be utilised to quantitate and illustrate. It gave indications of possible investigations to be pursued at a later date.

In a similar manner the determinations of variations of blood and plasma volume, although in some ways less striking, also indicated further time of research, particularly with reference to dehydration. The changes of plasma volume in dehydration were less than expected and in the second part of this study evidence is presented that in one dehydrating or sodium-losing condition plasma volume decrease may not be the primary cause of death. The stimulus for this study arose from the observations in this first part.

4. Observations on abnormalities and disturbances of the cardiovascular system of cattle

The broad field of abnormalities and disturbances of the cardiovascular system obviously covers such a wide area of study that it would be impossible to cover completely in correlated clinical, physiological and pathological investigations. Moreover, as mentioned earlier, some important cardiovascular diseases of cattle do not occur in Scotland. Thus any reports of these would merely review the work of others. Studies were made on three conditions only in which numbers of animals were available and which presented distinctively different cardiovascular syndromes. These were:-

(b) Anatomical cardiac abnormalities (Malformations of the Ventricular Septal Complex).

(c) A common infectious cardiac disease of cattle in Britain (Traumatic Pericarditis).

(d) Primary cardiac failure as a result of neonatal calf diarrhoea.

Two of these conditions required intensive pathological studies but in the third, the pathological observations on the hearts revealed no distinctive lesion. However, before these studies are presented, descriptions are given of the additional methods (a) utilised in this part of the study.

a) Additional Methods

(1) Electrocardiography

Although some fairly extensive studies have been made of electrocardiograms of cattle (Alfredson and Sykes, 1942; Lank and Kingrey, 1959; Brooijmans, 1957; Sellers, Hemingway, Simonsen and Petersen, 1958) no definitive standards have been laid down. In fact both Brooijmans (1957) and Sellers et al. (1958) have stated that variations from animal to animal and in the same animal from time to time are present in the direction and shape of the usual complexes when electrocardiograms are taken using standard limb leads.

In the present study an extensive investigation of electrocardiography in normal cattle was not made.

Electrocardiograms were taken of standard limb leads of Einthoven and Unipolar limb leads with the left arm-electrode attached to the left forelimb at the level of the olecranon, the right arm-electrode attached to the right fore-leg at the level of the olecranon and the left leg-electrode attached to the left hind leg just in front of the patella.

The areas of attachment were thoroughly wetted with an electrolyte solution containing sodium chloride, alcohol and water. The electrodes were attached by means of nickel silver crocodile clips, it having been found that plated steel crocodile clips had too short a life due to corrosion.

The electrocardiograph used was in the first instance a single channel heated stylus apparatus*, but this was not satisfactory at fast

* Cambridge Instrument Company Ltd., Cambridge, England

heart rates. A six channel direct writing jet recorder** was then obtained and was used continuously and with good results.

The electrocardiogram was used to find heart rate, to define arrhythmias, to determine whether complexes obtained were of normal size and to define exactly where murmurs recorded with the phonocardiogram were occurring in relation to the cardiac cycle.

** Siemens Cardirex 6. Supplied by Sierex Ltd., London, England

The results of other authors were confirmed and are summarised below (after Brooijmans 1957 and Lank and Kingrey 1959).

(a) The heart rate of the normal cow varied from 60-80 per minute with a mean of 72 beats per minute.

(b) The P-R interval varied between 0.1 seconds to 0.28 seconds with an average of 0.21 seconds. As the heart rate increased the P-R interval decreased.

(c) The QRS interval varied between 0.04 seconds and 0.11 seconds with an average of 0.08 seconds.

(d) The QT interval varied between 0.26 seconds to 0.5 seconds with an average of 0.4 seconds.

(e) The amplitudes of the P and the QRS waves of the bovine electrocardiogram were low but the T waves were often relatively high, particularly in calves. Below, in Table 22, are given published parameters.

Table 22

Deflection	Minimal mv	Maximal mv
P	0.03	0.18
Q	0.03	1.00
R	0.03	2.60
S	0.03	0.25
T	0.30	1.10

The smallest amplitude of any of the deflections of the electrocardiogram were always observed in lead I of the standard limb leads, while the largest deflects were observed in lead II.

(f) Considerable variability was present in the conformation of the QRS deflections of the standard limb leads. This variability existed between animals and in the same animal at different times

(ii) Phonocardiography

The heart sounds of cattle have been very infrequently recorded. As far as can be ascertained there are no published records of the heart sounds of cattle except those of the author (Fisher and Pirie 1964, a and b). The present study has to a large extent been confined to the recording of abnormal heart sounds, but to a limited extent normal sounds were first defined.

Sounds consist of the subjective impressions produced by vibrations reaching the auditory apparatus. Any apparatus recording heart sounds in a graphic manner can simulate the human auditory apparatus by recording the vibrations of a mass of air between the chest wall and the sensitive pick-up. Such an apparatus suffers from the disadvantage that it records all the vibrations of this air mass, for example those produced by extraneous objects unrelated to the heart sounds. For such a recording system absolute quiet is necessary, and thus recording in a sound-proof room with a complete quietness of all operators is obligatory.

The microphone used in the studies reported obviated all these precautions.

By means of a plastic feeler-pin the mechanical vibrations picked up at the chest wall over the heart were transformed into electrical signals. These signals were fed into a heart sound amplifier and a series of electrical filters. The output of amplifier and filters was then fed into galvanometers and thus it was possible to record graphically, in a series of frequency bands, the vibrations caused by the heart. By means of these filters it was also possible to record intensity or loudness as differences in amplitude.

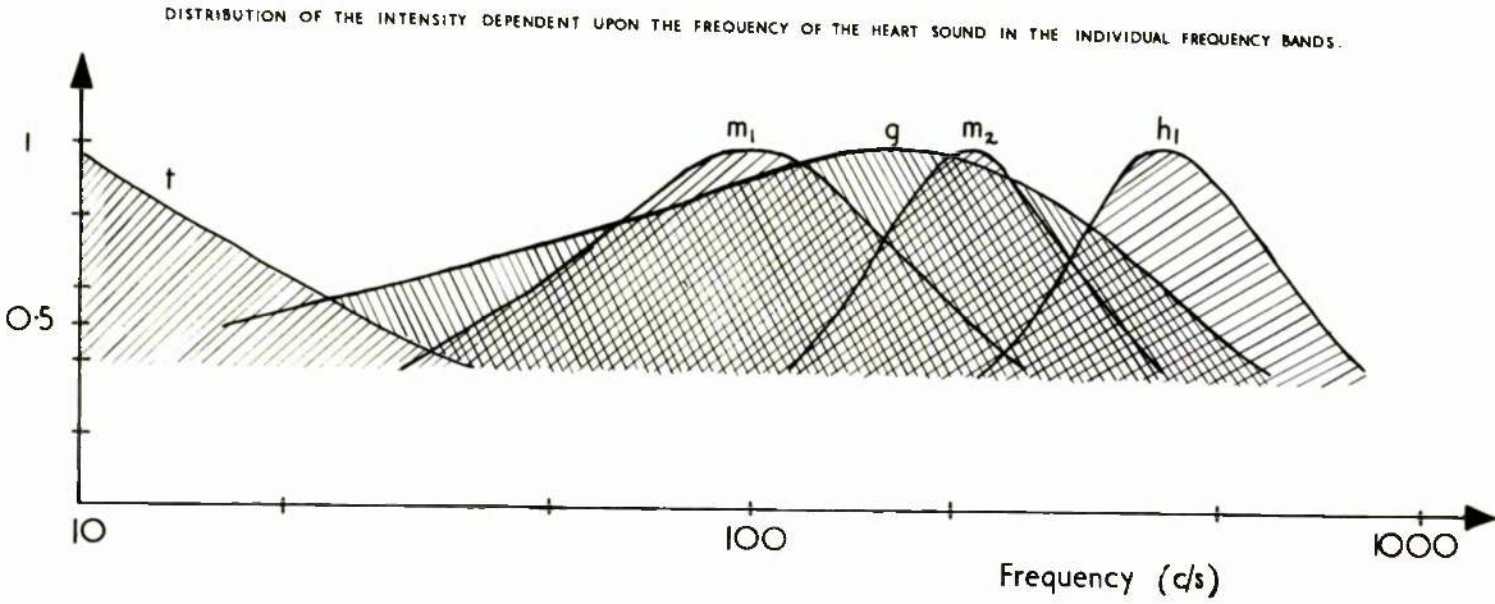
Graphic records in different frequency bands were obtained of heart sounds recorded at the chest wall without any extraneous sounds.

The distribution of the intensity depended upon the frequency of the heart sounds in the individual frequency bands as shown in figure 26.

The t frequency band records the low frequency heart sounds, the frequency bands m_1 and m_2 record the medium frequency sounds and the h_1 frequency heart sounds. The g frequency band records a wide range of sounds and is known as the stethoscopic frequency band, since it records graphically those sounds appreciated by the human ear when listening with a stethoscope.

The actual vibrations recorded from the chest wall depend on the thickness of the chest wall and the position of the microphone in relation to the heart. In the present study recordings have been made at the point on the chest wall where the greatest intensities of vibrations have been obtained. No attempt has been made to define

Figure 26


DISTRIBUTION OF THE INTENSITY DEPENDENT UPON THE FREQUENCY OF THE HEART SOUND IN THE INDIVIDUAL FREQUENCY BANDS.
1
0·5
t
m1
g
m2
h1
10
100
1000
Frequency (c/s)

specific valvular areas as has been done in the dog (Detweiler and Patterson 1962). The graphic recordings were made on the six channel jet recorder previously described, using a programme of 5 frequency band sound records, together with a lead II electrocardiogram for the purposes of timing.

On auscultation of the chest of the cow the heart sounds are heard most distinctly between the 3rd and 6th ribs on the left side and right side at a level of 5-10 cms above the olecranon. Heart sounds are usually more distinct on the left than on the right side of the chest. The first sound and the second heart sound have always been heard, but the third heart sound has not been appreciated. In adult cows the first sound was often 'split' and the second heart sound was occasionally also 'split'.

Some recordings of heart sounds of normal cattle are illustrated in figures 27, 28, 29 and 30.

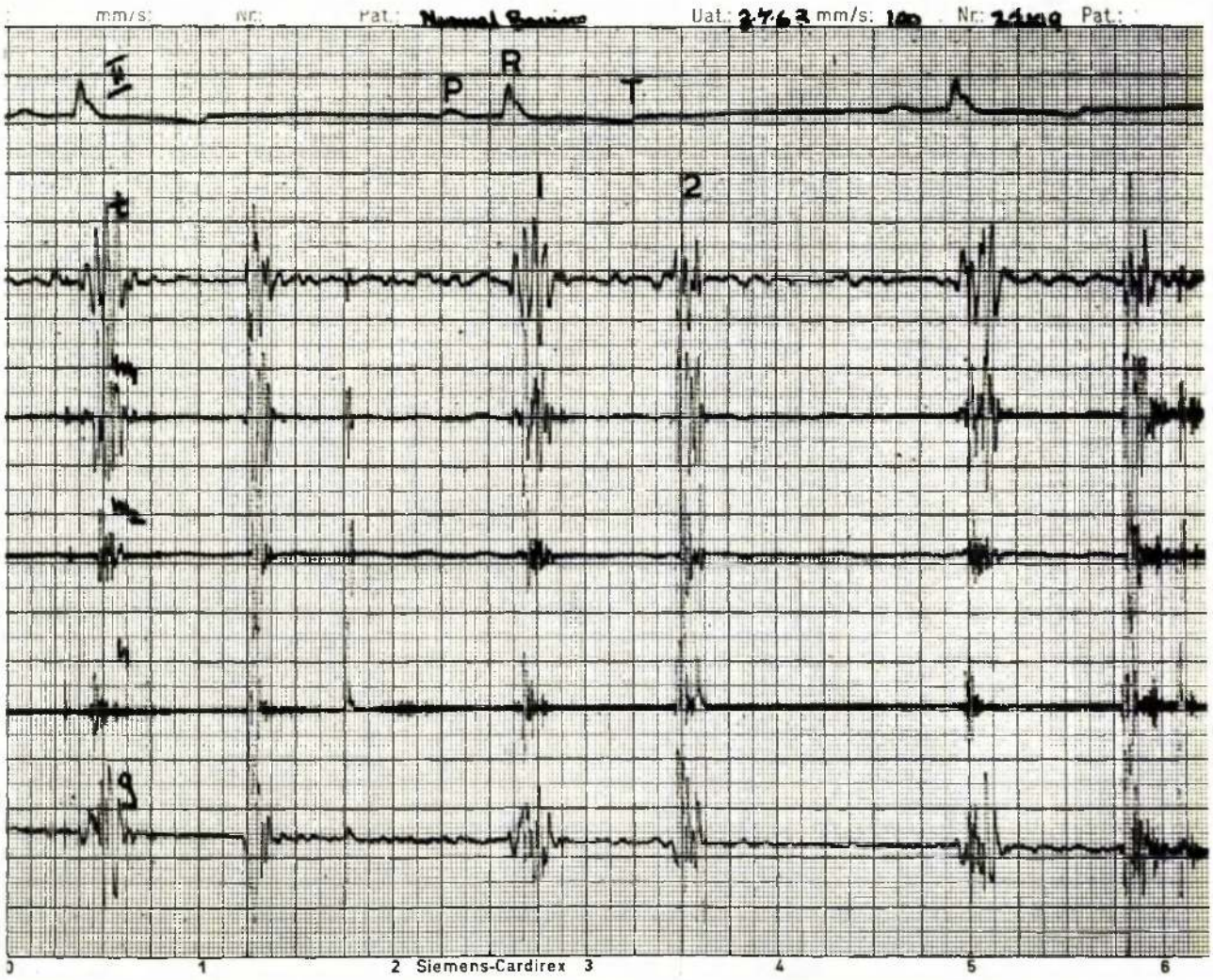
(iii) Intravascular Pressure Recording

Initially attempts to record the blood pressure of cattle were made with a capacitance manometer*. This instrument proved to be very unreliable and was abandoned. By the time that reliable manometers were obtained results of blood pressure measurements made by other workers had been published (Doyle, Patterson, Warren and Detweiler 1961, Reeves, Grover, Will and Alexander 1962, Sellers and Hemingway 1961,

* New Electronic Products Ltd.

Figure 27

Phonocardiogram of Normal Cow



II-ECG LEAD II

t-LOW FREQUENCY HEART SOUND

m_1-MEDIUM FREQUENCY HEART SOUND

m_2-MEDIUM FREQUENCY HEART SOUND

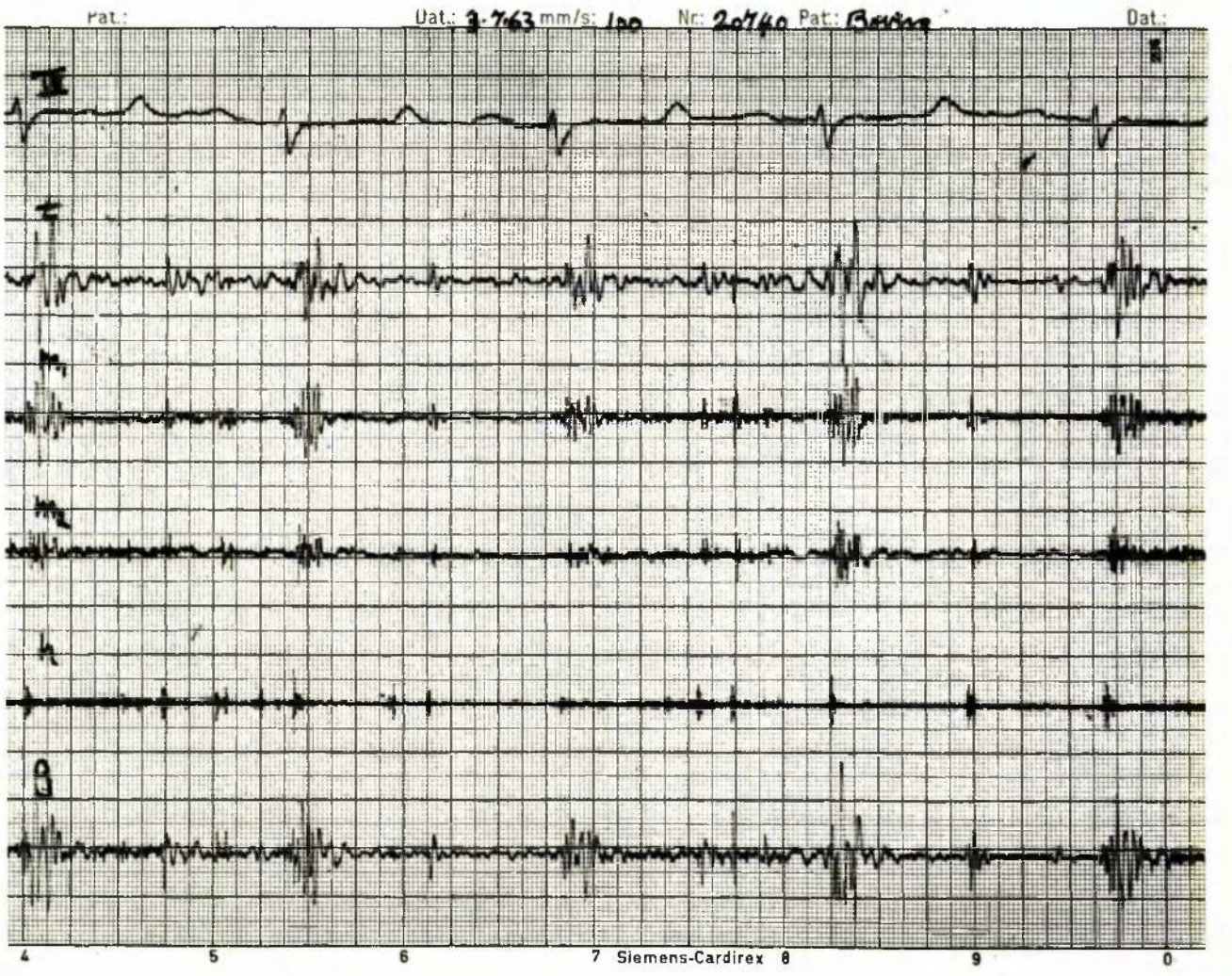
h-HIGH FREQUENCY HEART SOUND

g-STETHOSCOPIC HEART SOUND

1-1st HEART SOUND

2-2nd HEART SOUND

Figure 28



II – ecg lead II

t – low frequency heart sound

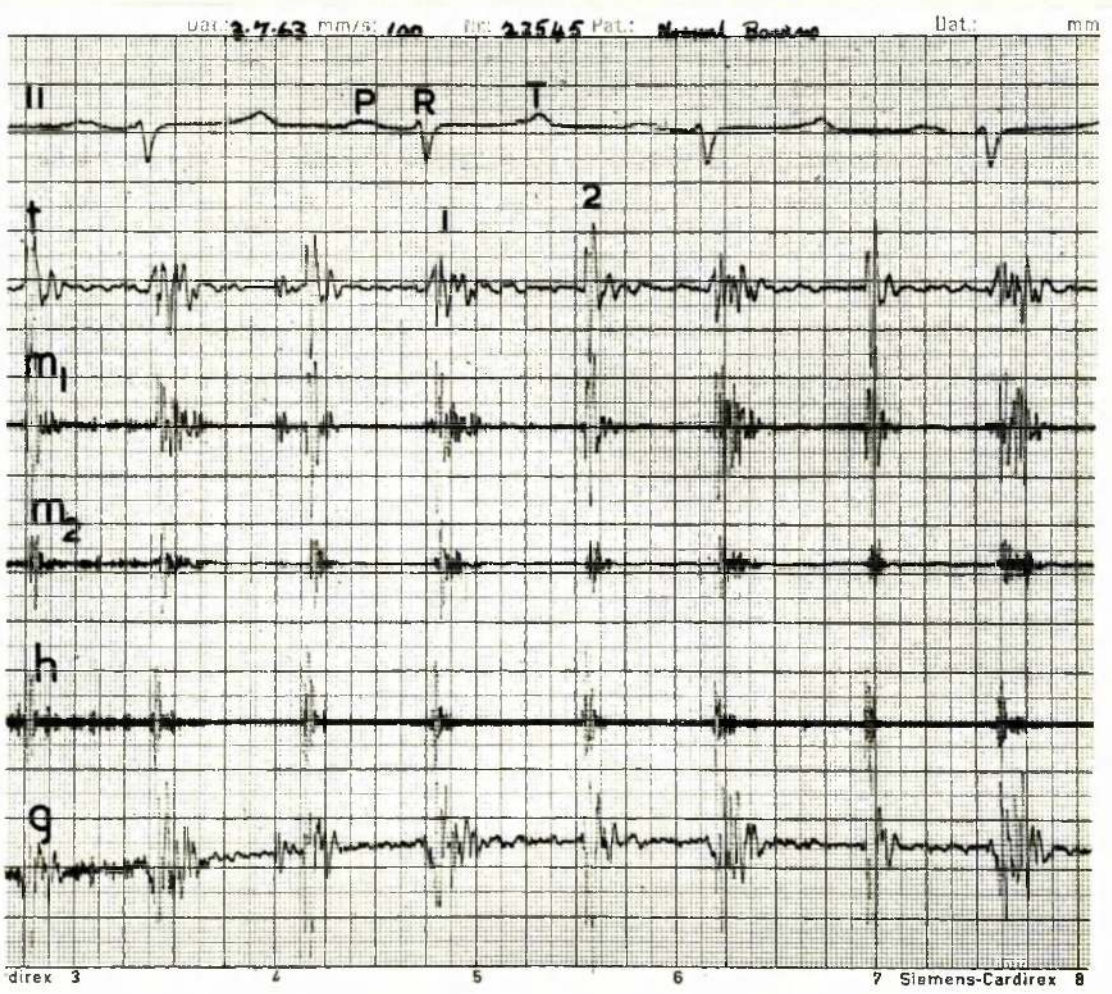
m_1 – medium frequency heart sound

m_2 – medium frequency heart sound

h – high frequency heart sound

g – stethescopic heart sound

Figure 29



II – ecg lead II

t – low frequency heart sound

m_1 – medium frequency heart sound

m_2 – medium frequency heart sound

h – high frequency heart sound

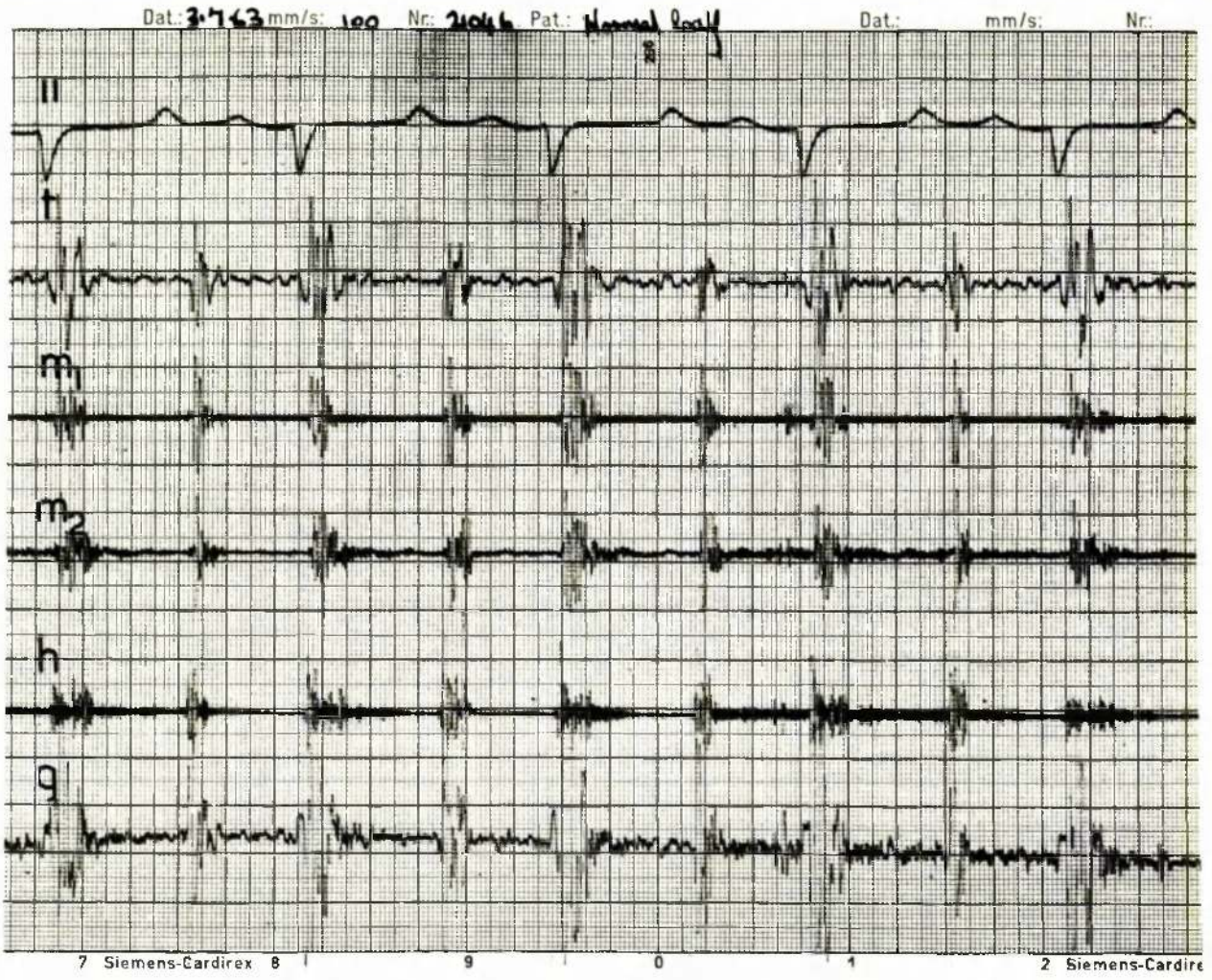
q – stethoscopic heart sound

1 – 1st heart sound

2 – 2nd heart sound

Figure 30

Phonocardiogram of Normal Calf



II - ecg lead II

t - low frequency heart sound

m_1 - medium frequency heart sound

m_2 - medium frequency heart sound

h - high frequency heart sound

q - stethoscopic heart sound

Kuida, Brown, Lange and Hecht 1961) so that no attempt was made to obtain a series of normal readings.

Methods were checked to ensure that readings obtained in normal cattle compared with those of other workers.

Pressures from the jugular vein, the right side of the heart, the pulmonary artery and the brachial artery, brachio-cephalic trunk and carotid artery were measured by inductance manometers**, the output of which was fed into the six channel jet recorder for graphic recording.

In cattle it was not possible by radiography to obtain evidence that a catheter tip was at a particular point in the right side of the heart or pulmonary artery so that the pressure recorded was the pressure at the site claimed. From the shape of the pressure curves obtained, reference to published pressure curves (Doyle et al. 1961) and reference to the curves obtained from other species it was possible to state with reasonable certainty that pressure curves obtained were from the sites claimed. In addition to confirm these claims, a small series of experiments were performed whereby catheters were inserted immediately before slaughter, pressure curves obtained and, after fixing the catheters, postmortem examination determined the site.

The results of Doyle et al. (1961) were taken as a standard. It was found that pressure recordings obtained were in agreement with these results. Their reference standards are given in Table 23.

** Siemens - Elema

Table 23 Intra-vascular pressures
(after Doyle et al., 1961)

	Pressures in mm.Hg.	
	Systolic	Diastolic
Right Atrium	5	0
Right Ventricle	53	0
Pulmonary Artery	45	19
Jugular Vein	0	0
Carotid Artery	100	130

(iv) Biochemistry

The biochemical results presented in this part of the study were obtained in part from a routine hospital service.

Before this service was instituted the normal values for plasma electrolyte concentrations were obtained in the author's laboratory (Fisher, 1960). These are given in Table 24.

Table 24 The concentration of electrolytes in the plasma of cattle

Constituent	Cows No.	Cows Concentration m.eq/litre	Calves No.	Calves Concentration m.eq/litre
Sodium	94	142.2±2.0	65	141.8±3.5
Potassium	92	4.0±0.3	59	5.1±0.4
Calcium	94	5.0±0.6	22	4.9±0.2
Magnesium	57	1.46±0.4	29	1.14±0.3
Chloride	140	103.3±3.0	59	100.3±3.5

When individual determinations were made in the author's laboratory and by the routine hospital service a close correlation existed between the results.

In Table 25 are given other biochemical parameters used in this study.

Table 25 — Normal Values of other Blood and Urine Parameters

Total Protein gms/100 ml.	5.7-8.3
Albumin/globulin ratio	0.7-0.8
Alkaline Phosphatase King Armstrong units	<12
S.G.O.T. S/F units	40±10
S.G.P.T. S/F units	20±10
Urea mg/100 ml.	<30
Urine Urea gm/100 ml.	< 1
Urine Protein mg/100 ml.	Nil

(v) Haematology

No specific determinations were made of normal animals (with the exception of bovine haematocrit) but the following table gives the values used as standards in cattle.

Table 26 — Normal Haematological Data of Cattle

Packed Cell Volume	=	30±3%
Erythrocyte count	=	5 - 8 million per cu. mm.
Leucocyte count	=	9 - 11 thousands per cu. mm.
Differential count		
Neutrophils	=	40 - 45%
Lymphocytes	=	60 - 65%
Basophils	=	1 - 2%
Eosinophils	=	1 - 2%

(vi) Pathology

The results of the pathological findings presented in this fourth part of the study were obtained by a colleague, H.M. Pirie, as part of the correlated study of cardiac disease.

Autopsy

The hearts were weighed after they had been opened, emptied of blood, and the major vessels trimmed off. In the case of veins this was done at their junction with the atria and in the case of arteries at the level of the semi-lunar valves.

The thickness of the right ventricle was measured at a point on the wall adjacent to the insertion of the moderator band. The thickness of the left ventricle was measured at the level of the insertion of the chordae tendineae into the papillary muscles, on the line of an incision, made so that it would pass between the anterior and posterior papillary muscles but not involve either of them.

The circumferences of the aorta and pulmonary arteries were measured and abnormalities noted in valve cusps. Blocks of tissue for histological examination were taken from the heart, lung, liver, spleen and kidney of each animal. The tissues were fixed in corrosive formol or 10% formalin and, after dehydrating and embedding, stained with haematoxylin and eosin, picro-Mallory, Van Gieson and Weigert elastica.

In order to establish normal parameters for cattle hearts, a number of such hearts were examined. The parameters are given in Table 27 below.

Table 27 Parameters, cattle hearts

	$\frac{H.W.}{B} \times 100$	$\frac{lv}{rv}$	$\frac{p}{a}$	$\frac{r\text{-}av}{l\text{-}av}$
Adult Cattle (15)	0.46±.05	1.85±.37	0.95±.04	1.05±.25
	n.s.	n.s.	n.s.	n.s.
Calves (8-12 weeks) (5)	0.47±.04	1.80±.26	1.06±.06	1.09±.09
	p<.001	p<.01	p<.05	p<.001
Calves (less than 7 days) (10)	0.70±.03	1.06±.07	1.01±.001	1.04±.04

Where H.W. = heart weight B = body weight
lv = left ventricular thickness
rv = right ventricular thickness
p = pulmonary valve circumference
a = aortic valve circumference
r-av = tricuspid valve circumference
l-av = mitral valve circumference

The significantly higher heart weight on a body weight basis of very young calves is probably a manifestation of low body fat and an empty, non-functional rumen when compared to older calves and adult cattle. The other significant differences in parameters indicated the relatively larger right side of the heart in the young calf.

It was found that a number of adult cattle had functionally competent but anatomically patent foramina ovales. This was considered to be a normal finding in cattle, since it was found in 6 out of 31 hearts from animals over 1 year of age with no evidence of cardiac disease, and in 4 out of 30 hearts of animals over 1 year of age with cardiac disease. Similar findings have been reported in the human subject (Edwards, 1960).

b) Malformations of the ventricular septal complex in cattle

In a study of cardiovascular disease in cattle, several congenital cardiac anomalies have been observed. The highest proportion of these have involved the ventricular septum. In the human subject, the term "ventricular septal complex" was used by Edwards (1960) to classify congenital cardiac anomalies in which a ventricular septal defect was present either alone or associated with other cardiac anomalies. Such anomalies have been described in many species. Figures for the incidence in man indicate that 25 per cent of cases of congenital heart disease have defects of the ventricular septum (Wood, 1958), and in the dog 15 per cent of cases of congenital heart disease have shown involvement of the ventricular septum (Detweiler, Patterson, Hubben and Botts, 1961). In a survey of 3,000 calf hearts two defects of the ventricular septum were discovered (Rupperts, 1961). Other investigators have reported finding 15 cases out of 4,500 cattle necropsies (Olafson, 1939) and six cases out of 2,000 cattle necropsies (Cordy and Ribbelin, 1950). Many individual cases have been reported (Blood and Steel, 1946; Blood, 1960; Dison, 1958; Hahn, 1908; Lilleengeen, 1934; Misdorp, Noordijk and Rook, 1959; Monti, 1934; Sheather, 1911). These individual reports have been mainly of limited clinical observations. In the present series, 16 anomalies out of a total of 19 have involved the ventricular septum. The other three cases were two ectopia cordis and one complete transposition of the great vessels. The cattle were of the common breeds found in the West of Scotland, all under three years of age, and included apparently healthy animals as well as those obviously diseased.

These cases have been classified into three groups on the basis of their pathological anatomy. These are: Group I, ventricular septal defects; Group II, ventricular septal defects with pulmonary stenosis (Tetralogy of Fallot); Group III, ventricular septal defects with dextroposed aorta but no pulmonary stenosis (Eisenmenger complex).

Group I

Eight animals which had ventricular septal defects as the primary lesion were seen in this group (Table 28).

Table 28 Group I: Ventricular Septal Defects

Case No.	Age at Autopsy	Sex	V.S.D.* Aortic circum-ference	Qualitative Assessment	Ultimate fate of animal
19738	6 weeks	Female	1.1	Large	Died
20510	3 weeks	Male	0.9	Large	Destroyed
21342	4 weeks	Male	0.8	Large	Died
20123	6 weeks	Female	0.63	Medium	Destroyed (moribund)
18633	2 years 6 months	Female	0.59	Medium	Destroyed
19151	2 years 6 months	Female	0.36	Small	Destroyed
18961**	2 years 6 months	Female	0.31	Small	Destroyed
17736	3 months	Male	0.25	Small	Destroyed

** Septum not perforated * Ventricular septal defect

The size of the defect varied and, using the circumference of the aorta as a standard, the defects were classified as large, medium and small. Details of the individual cases are given below.

Case No. 19738: 6 week-old cross-bred Aberdeen Angus, female

This calf was admitted to the Veterinary Hospital with a gross cardiac murmur and respiratory disturbance. The animal was dull, in fair bodily condition, and on inspection had an increased respiratory rate of 60/min. Palpation of the chest revealed a precordial thrill at the 4th intercostal space on both sides. Percussion of the chest gave an increased area of

cardiac dullness. Auscultation of the lungs revealed bronchial inspiration and bronchovesicular expiration. When the heart was auscultated at the 6th intercostal space, the heart sounds were detected, but they were partially obscured by a gross murmur. This murmur was best heard at the 3rd intercostal space on the left side, at a point 5 cm. above the elbow. In character it was continuous and of the machinery type, the systolic portion ending in a distinct squeak. The heart rate was 120/minute and the pulse volume was fair. The jugular veins were distended right up to the mandible.

No cyanosis was evident at rest or on exercising. Haematological examination indicated no polycythaemia. Electrocardiographic examination showed no distinctive abnormality. X-ray of the chest showed a much enlarged cardiac shadow, particularly of the left ventricle, and the trachea was displaced upwards. There was radiographic evidence of pulmonary oedema.

In view of the machinery murmur, the cardiac enlargement - particularly of the left ventricle - and the respiratory disturbance, a diagnosis was made of a primarily left-sided heart failure, probably due to a large left to right shunt through a patent ductus arteriosus.

The animal survived only three days.

Autopsy

There was a moderately severe fibrinous pericarditis and the pericardial sac contained 100 ml. of serosanguinous fluid. The heart was grossly enlarged and weighed 660 g. The heart weight/body weight ratio was 1:26. The right ventricle was 1 cm. and the left 1.1 cm. thick. External examination of the heart showed that the apex was rounded.

In the anteroventral part of the fossa ovalis there was a small atrial septal defect, 0.8 cm. in diameter. The right ventricle, which was grossly dilated, had a hypertrophied wall, and the pulmonary artery and valve were slightly dilated. The left atrium was dilated and the wall was hypertrophied. A large ventricular septal defect which was triangular in outline, with rounded corners, was found. The triangle measured 3 cm. x 2.5 cm. x 2.5 cm. and when viewed from the left ventricle the lesion was high in the interventricular septum with the apex of the triangle between the anterior and right cusps of the aortic valve. In the right ventricle the defect appeared posterior to the crista supraventricularis and extended slightly behind the septal cusp of the tricuspid valve, posterior to its most anteriorly situated chorda tendinae.

There was slight subcutaneous oedema along the floor of the abdomen, and the thorax contained 300 ml. of serosanguinous fluid. The trachea and large bronchi were full of frothy oedema fluid, while the lungs were dark red and heavy, due to pulmonary oedema; when the lobes were sectioned, oedema fluid exuded freely from the cut surface. The liver was pale yellow and had a nutmeg appearance. Histological examination confirmed the presence of early chronic venous congestion.

Case No. 20510: 3 week old Ayrshire, male

This calf was admitted as a possible case of a cardiac defect, since a gross systolic murmur had been detected on auscultation of the chest.

When examined the calf was bright and in good condition. The pulse rate was 120/minute and of good volume. On palpation of the chest a precordial thrill could be felt at the 3rd intercostal space on the left,

where it was most intense, and at the 5th intercostal space on the right. Percussion of the chest revealed a loss of resonance over the lower third. Auscultation of the chest confirmed the presence of the gross systolic murmur which was most intense at the 3rd intercostal space on the left and the 6th intercostal space on the right. There was no respiratory disturbance and no cyanosis or other evidence of heart failure.

Haematological and biochemical examinations revealed no abnormalities.

The electrocardiogram suggested left ventricular hypertrophy (Figure 31) and the phonocardiogram demonstrated the systolic murmur (Figure 32).

The calf was then slaughtered.

Autopsy

The heart was enlarged and weighed 598 g. The heart weight/body weight ratio was 0.99. The right ventricle was 1.3 cm. and the left 1.5 cm. thick. The pericardial cavity contained 30 ml. of serous fluid. The foramen ovale was patent but probably had been functionally competent. The right ventricle was dilated and hypertrophied. A triangular-shaped ventricular septal defect with sides 2 cm. x 2 cm. x 2 cm. was present high in the interventricular septum with the apex of the triangle dorsally. In the right ventricle it was posterior to the crista supraventricularis; in the left ventricle, whose wall was not hypertrophied, the apex of the triangle lay immediately below the anterior cusp and the right cusp of the aortic valve. The edges of the defect were rounded, thick and composed of muscle tissue. The ductus arteriosus was probe-patent. No other lesions were found.

Figure 31

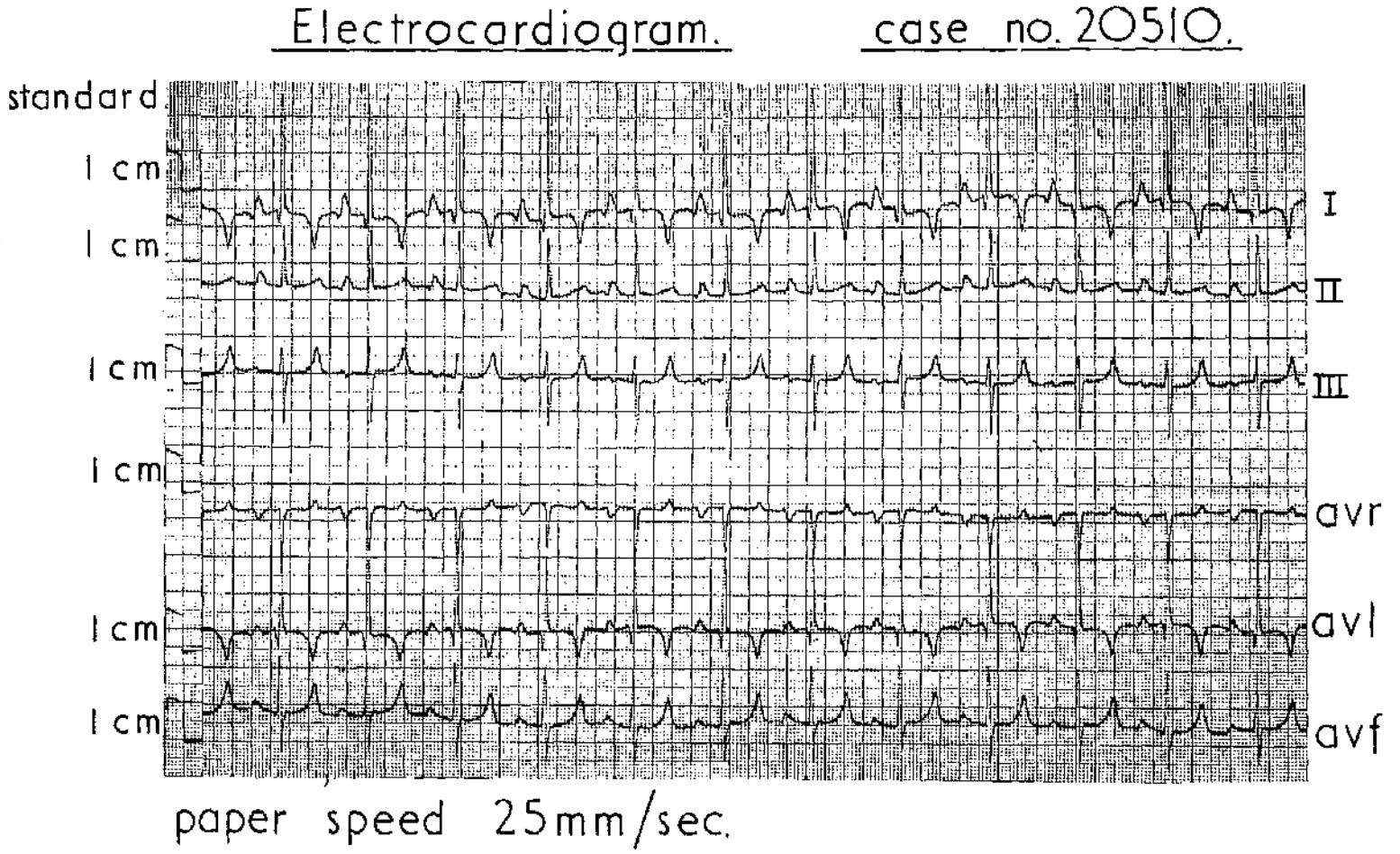
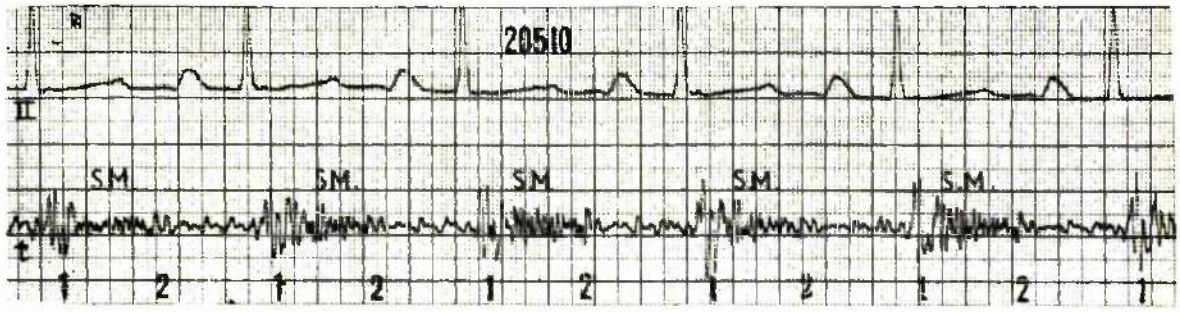

Electrocardiogram.
case no. 20510.
standard
1 cm
1 cm
1 cm
1 cm
1 cm
1 cm
I
II
III
avr
avl
avf
paper speed 25mm/sec.

Figure 32

Heart Sounds. case no. 20510.



S M —SYSTOLIC MURMUR

1 — FIRST HEART SOUND

2 —SECOND HEART SOUND

II - ECG LEAD II

t - LOW FREQUENCY HEART SOUND

Case No. 21342: 4 week-old Friesian, male

This calf was admitted with a history of not thriving. When examined it was dull and in poor condition, and it was noticed that the neck was very short. The respiratory rate was 30/minute and there were no adventitious sounds. A precordial thrill could be felt on the left side of the chest but not on the right, although the apex beat was felt on the right. On auscultation an atrial 4th heart sound was heard, followed by a gross systolic murmur (Figure 33). This murmur was heard all over the chest but was most intense at the 5th intercostal space on the left and the 4th intercostal space on the right. The pulse rate was 100/minute and the volume was good. Cyanosis was not evident, neither was jugular distension. The condition of the calf did not change until about ten days had elapsed. The animal was then found collapsed, with a subnormal temperature, and died three hours later.

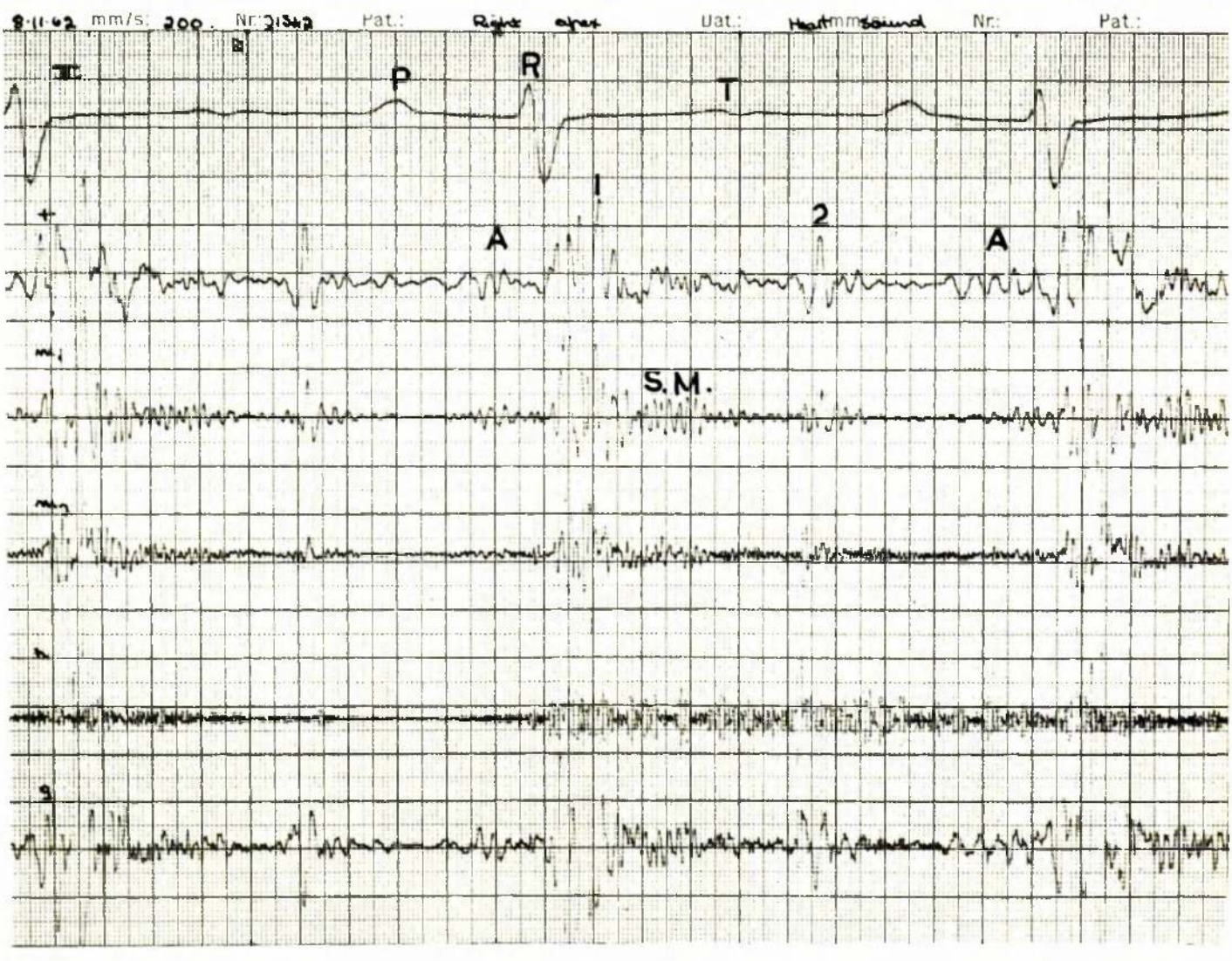
There were no biochemical or haematological abnormalities initially. The electrocardiogram suggested cardiac hypertrophy, while the phonocardiogram demonstrated the atrial sound and the systolic murmur.

An initial diagnosis of a ventricular septal defect was made.

Autopsy

The heart appeared larger than normal and weighed 378 g. The heart weight/body weight ratio was 0.62. The walls of the right and left ventricles measured respectively 1.5 cm. and 1.7 cm. The right atrium was dilated and although the foramen ovale was patent it appeared to have been functionally competent. As a result of dilatation, the lumen of the right ventricle extended further to the apex of the heart than normal, and

Figure 33



II – ECG LEAD II

f – LOW FREQUENCY HEART SOUND

m_1 – MEDIUM FREQUENCY HEART SOUND

m_2 – MEDIUM FREQUENCY HEART SOUND

h – HIGH FREQUENCY HEART SOUND

g – STETHOSCOPIC HEART SOUND

1 – 1ST HEART SOUND

2 – 2ND HEART SOUND

S.M. – SYSTOLIC MURMUR

A – ATRIAL SOUND

in addition the wall was grossly hypertrophied. High in the ventricular septum there was an elongated triangular defect with rounded corners whose apex was situated ventrally (Figure 34). The width at the dorsal part was 1.5 cm., ventrally it was 0.5 cm., and it was 3 cm. long. In the right ventricle the lesion appeared posterior to the crista supraventricularis and in the left below the anterior and right cusps of the aortic valve in the outflow tract of the ventricle (Figure 35). The moderator band was displaced ventrally and to the left of the apex of the defect. The pulmonary valve and the pulmonary trunk were dilated. The left atrium was dilated and the left ventricle was also dilated and hypertrophied.

In the trachea and bronchi there was a large amount of pale yellow foam and fluid. The lungs, which were oedematous and congested, were heavy and dark red, and when they were cut the surface exuded copious amounts of fluid.

There were 11 thoracic vertebrae, 11 right ribs and 12 left ribs. The eighth thoracic vertebra, which was wedge-shaped, articulated with three ribs on its left side. In addition, although the vertebral arches were normal, the bodies of the sixth and seventh cervical and the first and second thoracic vertebrae were smaller than normal, distorted, and fused together, there being no proper intervertebral disc formation. The body of the 4th cervical vertebra was also shortened.

Case No. 20123: 6 week-old Ayrshire, female

This calf was admitted to the Veterinary Hospital because a systolic murmur had been detected and the calf was not thriving.

Figure 34

Ventricular Septal Defect
viewed from Right Ventricle

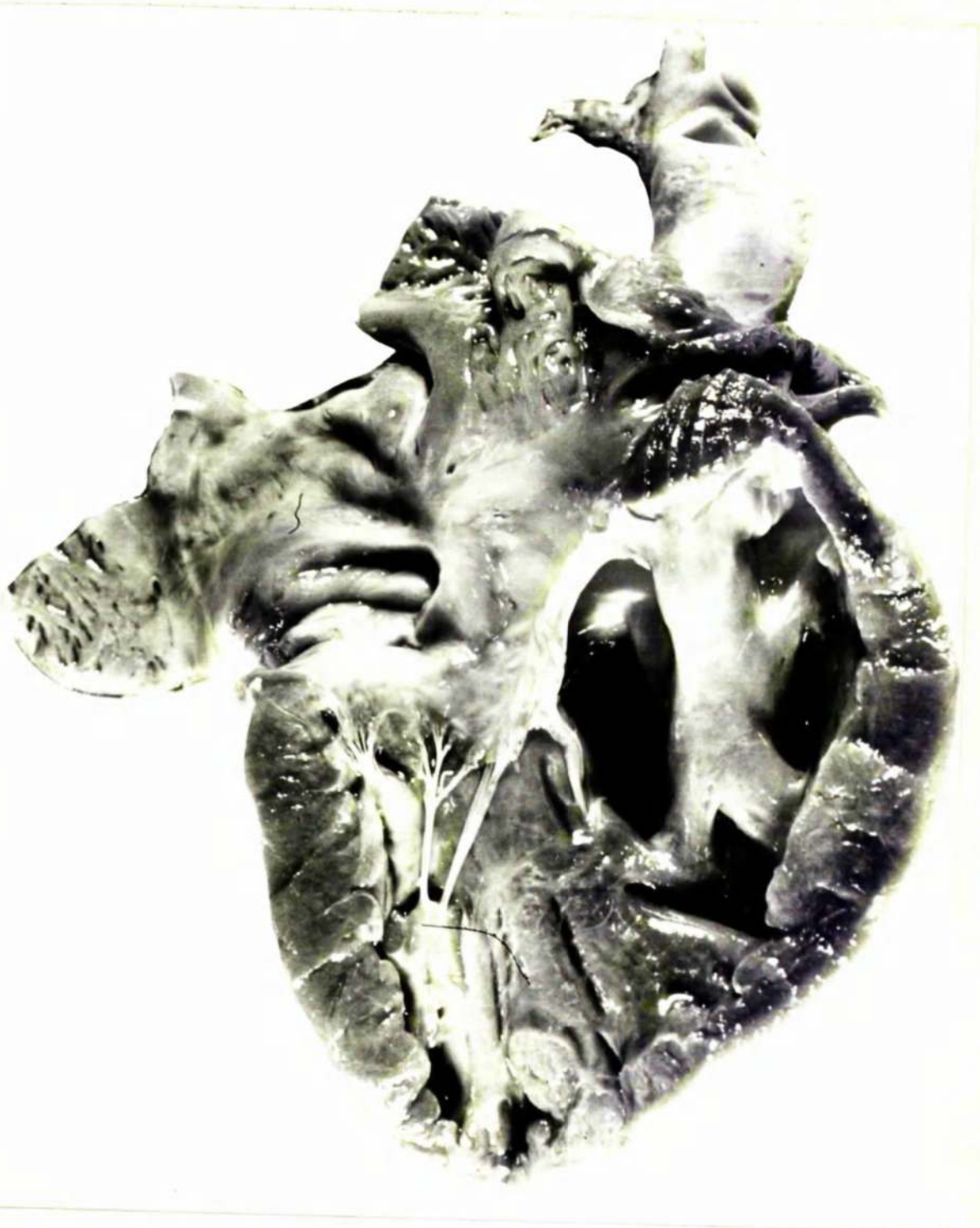


Figure 35 Ventricular Septal Defect viewed from Left Ventricle

On clinical examination, the calf was in poor condition, with a markedly pendulous abdomen. The respiratory rate was 60 per minute and on auscultation bronchial inspiration and bronchovesicular expiration were heard. There was no loss of resonance on percussion of the chest, but on palpation a precordial thrill could be detected on the left at the 4th intercostal space and on the right at the 3rd intercostal space. The thrill on the right was very pronounced.

Auscultation revealed a gross systolic murmur, most intense at the 4th intercostal space on the left and at the 3rd intercostal space on the right side of the chest. Pulse volume was good and the rate was 90/minute.

There was no obvious jugular distension and no oedema. The mucosae were pale pink, and showed no evidence of cyanosis.

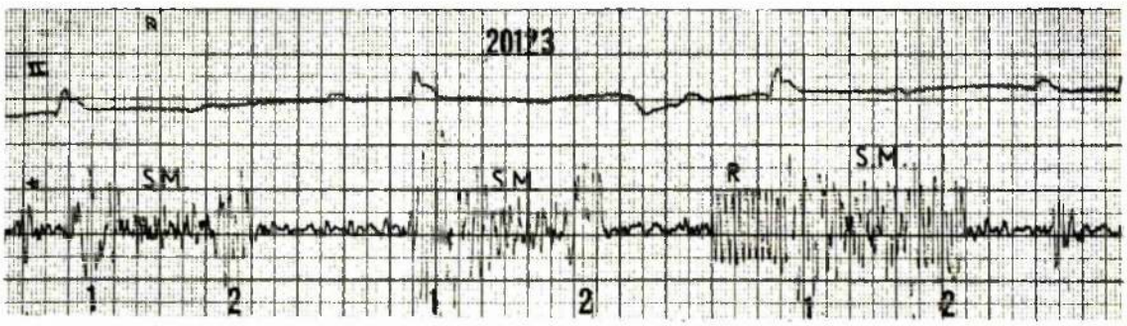
Haematological and biochemical examinations revealed no abnormality. Electrocardiographic examination likewise revealed no abnormality. Phonocardiographic recordings taken at the 4th left intercostal space demonstrated the pan-systolic murmur (Figure 36).

Autopsy

The heart was slightly enlarged, weighing 479 g. The heart weight/body weight ratio was 0.79. The right ventricle was 0.6 cm. thick and the left 1.4 cm. thick. The right ventricle was dilated and the wall was slightly hypertrophied. High in the interventricular septum a circular defect 1.2 cm. in diameter opened into the right ventricle posterior to the crista supraventricularis. This defect appeared in the left ventricle,

Figure 36

Heart Sounds. case no. 20123.



S.M.—SYSTOLIC MURMUR

R.— RESPIRATORY SOUND

1 — FIRST HEART SOUND

2 — SECOND HEART SOUND

II— ECG LEAD II

t — LOW FREQUENCY HEART SOUND

immediately below the junction of the anterior cusp and the right cusp of the aortic valve. The edges of the lesion were composed of white fibrous tissue. Instead of the usual brachiocephalic trunk arising from the aortic arch there was a brachiocephalic artery 0.9 cm. in diameter, and just dorsal to this, arising independently from the aortic arch, was the left brachial artery, 0.7 cm. in diameter

In the apical lobe of the right lung there was a greyish-yellow patch of consolidation which proved on histological examination to be "cuffing" pneumonia.

Case No. 18633: 2½ year-old Ayrshire, female

This cow was admitted to the Hospital suffering from hydrops amnii. No cardiac examination was carried out, and in life she suffered from no apparent cardiac dysfunction.

Autopsy

The heart weighed 1,850 g. The right ventricle was 1 cm. thick and the left ventricle was 2.1 cm. thick. After the right ventricle was opened a circular ventricular septal defect 2.2 cm. in diameter with firm, white, fibrous edges was seen high in the interventricular septum behind the crista supraventricularis and anterior to the anterior cusp of the tricuspid valve. When the defect was examined from the left ventricle its dorsal edge was seen to lie 0.8 cm. ventral to the right half of the anterior cusp of the aorta. The other lesions found in this animal were those associated with hydramnios.

Case No. 19151: 2½ year-old Ayrshire, female

This animal was bright in demeanour, in poor bodily condition and had a reduced food and water intake. Clinical examination showed that all mucosae were pale with a yellowish tinge. There was subcutaneous oedema present just in front of the udder and under the jaw. The liver could be palpated behind the last rib on the right side. A precordial thrill could be palpated on both sides of the thorax at the 5th intercostal space.

The pulse was irregular but of good volume.

On auscultation, the respiratory rate was not elevated at 30 respirations per minute, but there was slight hyperpnoea and a slight increase in normal respiratory sounds. Percussion of the thorax revealed no loss of resonance. Auscultation of the heart confirmed the irregularity of the heart rhythm, which took the form of single sounds and pauses suggestive of extrasystoles. A gross systolic murmur could be detected on both sides of the thorax.

Both jugular veins were distended the whole way up the neck but no marked pulsations were detected. A pulse was palpated in the mammary vein.

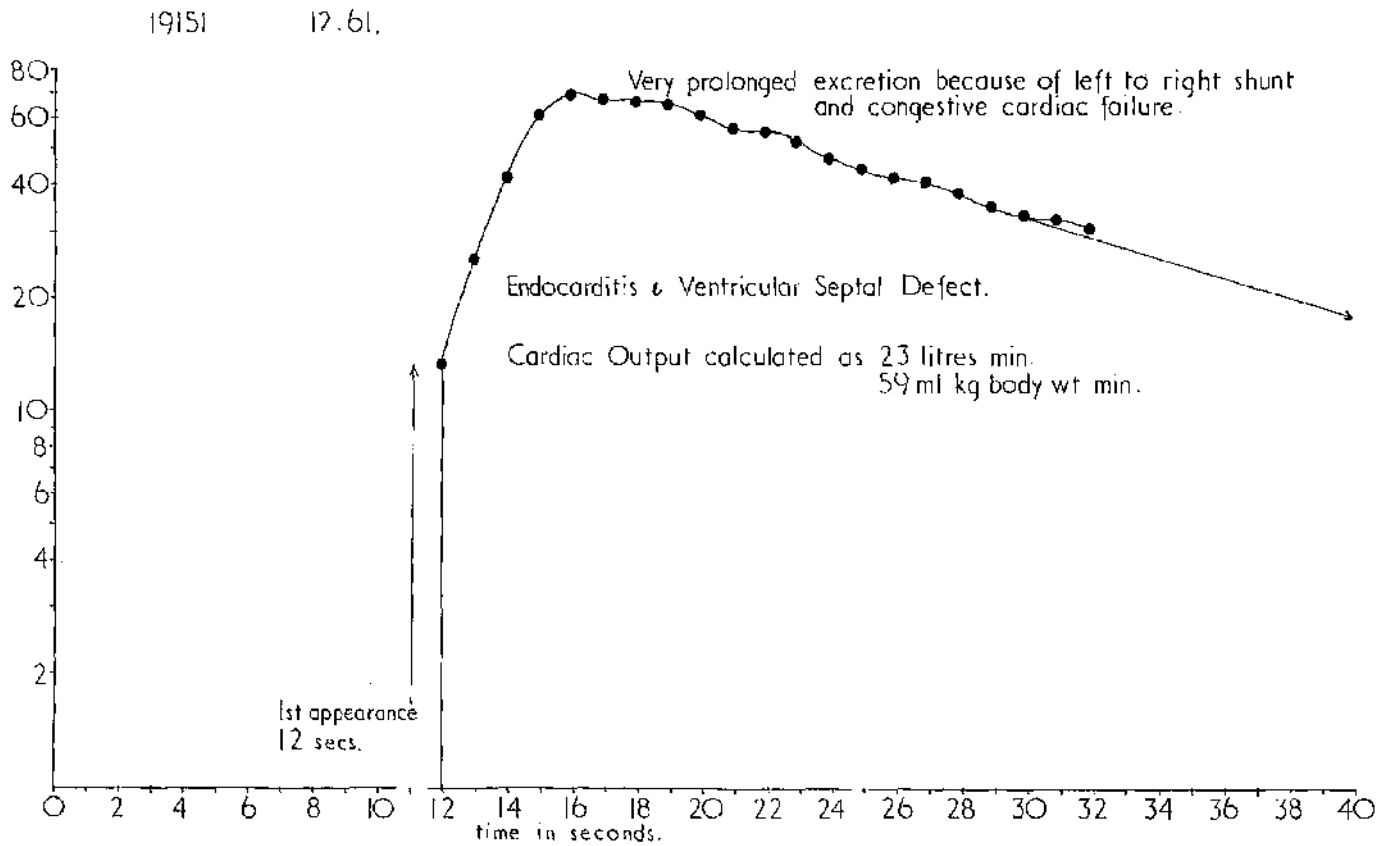
Haematological examination indicated some anaemia or haemodilution, with a packed cell volume of 25 per cent and a haemoglobin of 8 gms. per 100 ml of blood. There was no leucocytosis, the white cell count being 7,400/cu.mm., but there were 74 per cent neutrophils and 25 per cent lymphocytes. The biochemical abnormalities detected were elevated serum transaminases and increased urine urea only.

Electrocardiographic examination confirmed the presence of ventricular extra systoles. Cardiac output determination gave a subnormal cardiac output with a much prolonged clearance time of dye (Figure 37). Cardiac catheterization showed some elevation of right atrial and right ventricular pressure but normal pulmonary and brachial arterial pressures. The final ante-mortem diagnosis was of a bacterial endocarditis with reservations in that the dye-dilution curve showed a degree of failure not manifest in the animal clinically.

Autopsy

The heart weighed 2,690 g. The heart weight/body weight ratio was 0.69. The right ventricle was 1.5 cm. thick and the left ventricle was 2.5 cm. thick. The valve of the foramen ovale had not been closed completely and in the anterior part of the fossa ovalis there was a small defect, 0.4 cm. in diameter. A large mass of yellow vegetation with an irregular surface blocked the anterior part of the tricuspid valve, reducing its effective orifice by about half. The vegetation was almost completely organized and when cut into it could be seen that firm, white, fibrous connective tissue occupied most of the mass. Several small, yellow purulent foci were present in the fibrous connective tissue. The vegetation extended round the crista supraventricularis into the conus arteriosus of the right ventricle. This part of the vegetation was mostly composed of the thrombus material which had not organized. A small amount of vegetation was present on the pulmonary valve and a few similar

Figure 37


19151 12.61.
Very prolonged excretion because of left to right shunt and congestive cardiac failure.
Endocarditis & Ventricular Septal Defect.
Cardiac Output calculated as 23 litres min.
59 ml kg body wt min.
1st appearance 12 secs.
80
60
40
20
10
8
6
4
2
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
time in seconds.

lesions were found on the endocardium of the conus arteriosus. The main mass of the vegetation was dissected by several long, deep fissures which converged at a point posterior to the crista supraventricularis where there was a ventricular septal defect. The defect was most easily seen from the left ventricle (Figure 38). No vegetation was present around the edges of the ventricular septal defect in the left ventricle. The defect was situated high in the interventricular septum immediately below the anterior cusp and right cusp of the aortic valve. The diameter of the defect was 1.5 cm. and the edges were composed of white fibrous tissue. Ventral to the lesion there was a horizontal fibrous band, 4 cm. long, on the endocardium of the outflow tract of the left ventricle (Figure 38). In the branches of the pulmonary artery in the diaphragmatic lobe of each lung were several small emboli. Subcutaneous oedema was present to a moderate degree and in the abdominal cavity there was about 1 litre of serous fluid. The liver was grossly enlarged, weighed 10,399 g. and had the nutmeg appearance of chronic venous congestion. No other lesions were detected. nature of injection ? S. pyogenes

Case No. 18961: 2½ year-old Ayrshire, female

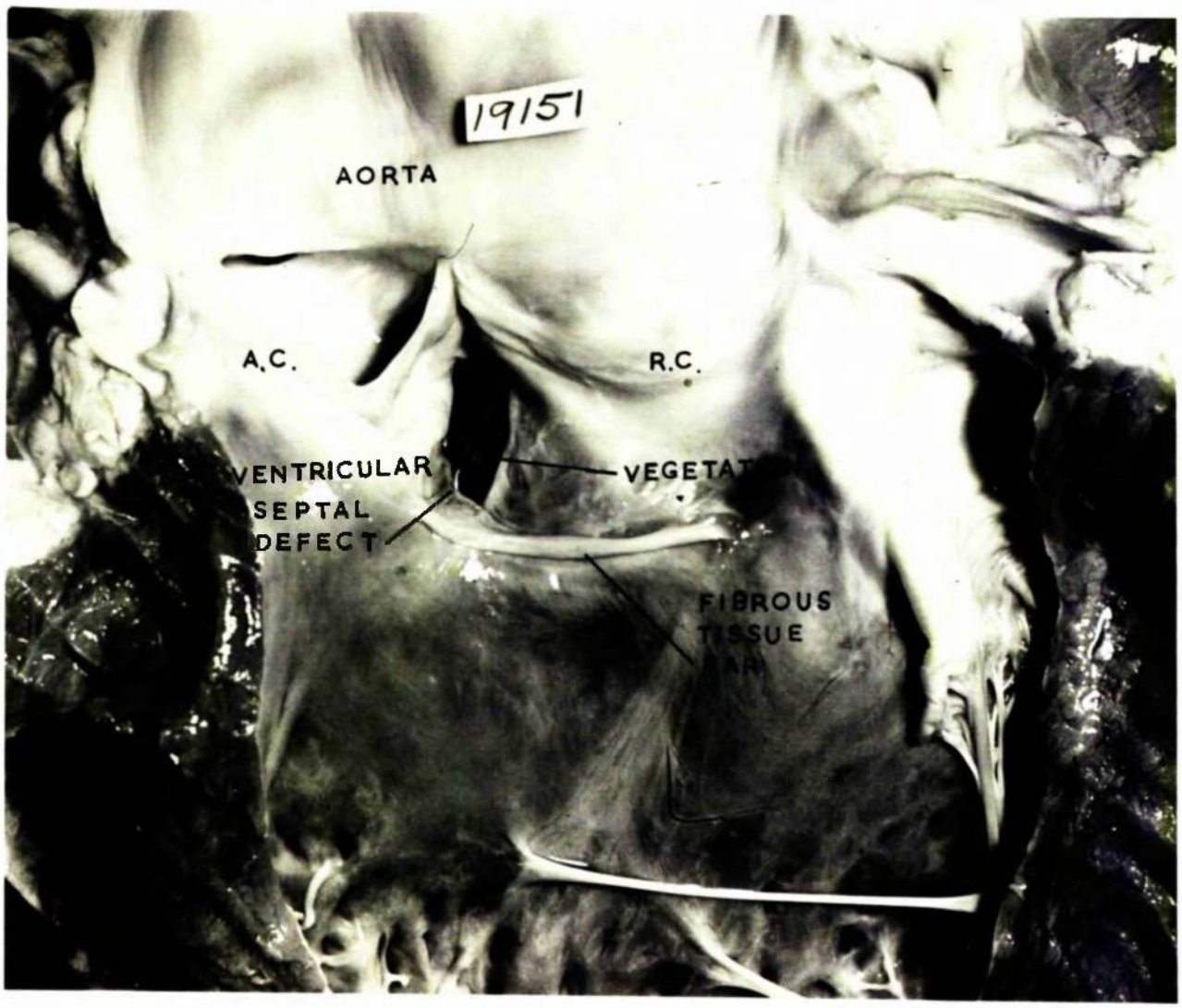
This animal was admitted with a history of recurrent bacterial pneumonia which responded to treatment with antibiotics. The owner complained that it had not been thriving.

Clinical examination showed an animal bright in demeanour and in fair condition. The mucosae were pink and moist and no oedema was present. Respiratory rate was 20/minute; there was hyperpnoea with a slight increase in respiratory sounds, but no adventitious sounds were heard. The pulse was 80/minute and of poor volume. There was no obvious jugular distension.

Figure 38

View into Outflow Tract of Left Ventricle

(19151)



A.C. = Anterior cusp of aortic valve

R.C. = Right cusp of aortic valve

On auscultation of the heart two clear heart sounds were heard at the 6th intercostal space on the left side, but further forward, under the elbow at the 4th intercostal space, a harsh systolic murmur was detected. A lower-pitched systolic murmur was heard in a similar area on the right side of the chest.

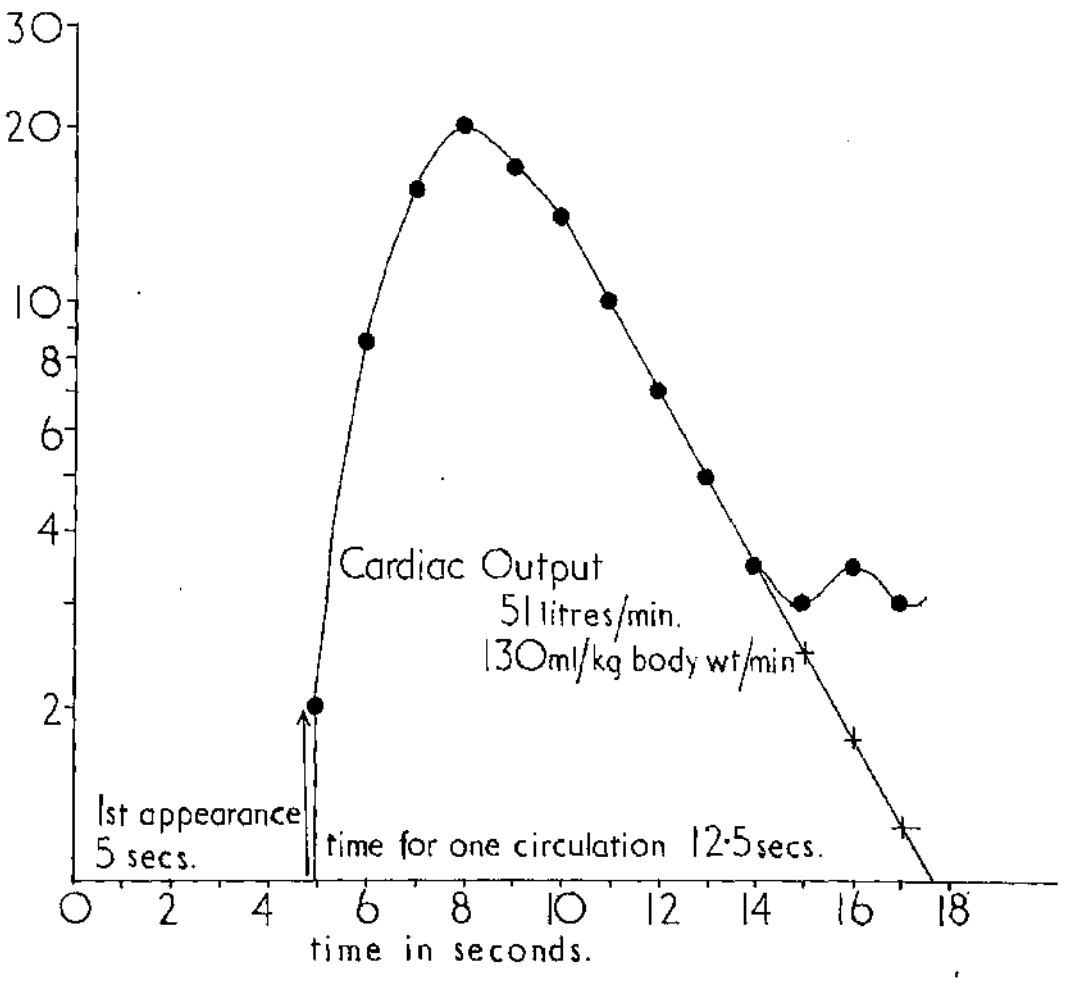
Haematological and biochemical examination revealed no abnormality. The dye-dilution curve of the cardiac output was normal (Figure 39). Cardiac catheterization revealed no abnormality. During its stay in hospital the animal ate normally, gained weight and continued to give about a gallon of milk per day. A provisional diagnosis of a mild degree of endocarditis was made, which proved to be incorrect on autopsy after slaughter two weeks later.

Autopsy

The heart weighed 2,030 g. The heart weight/body weight ratio was 0.52. The right ventricle was 1.4 cm. and the left 2.8 cm. thick. When the left ventricle was opened a defect was seen high in the interventricular septum in the form of a conical depression situated below the junction of the anterior and the right cusps of the aortic valve. The opening of the defect was 1.2 cm. broad and the defect narrowed as it penetrated the septum to a depth of 0.6 cm. The ventricular septum was not perforated by the defect and it was not possible to pass a probe through the ventricular septum into the right ventricle. About 1 cm. ventral to the lesion there was a transverse ridge of tissue 2 cm. long on the endocardium of the left ventricle. This ridge of tissue was white, firm and projected about 2 mm. from the endocardium. Histological examination of the left ventricle showed focal small areas of fibrosis in the myocardium.

Figure 39

18961 1.12.61.



Scattered in all the lobes of the lungs were a moderate number of small lobular areas of consolidation, which histologically were patches of necrotizing bronchopneumonia surrounded by a zone of fibroblasts, plasma cells and macrophages.

Case No. 17736: 3 month-old Ayrshire, male

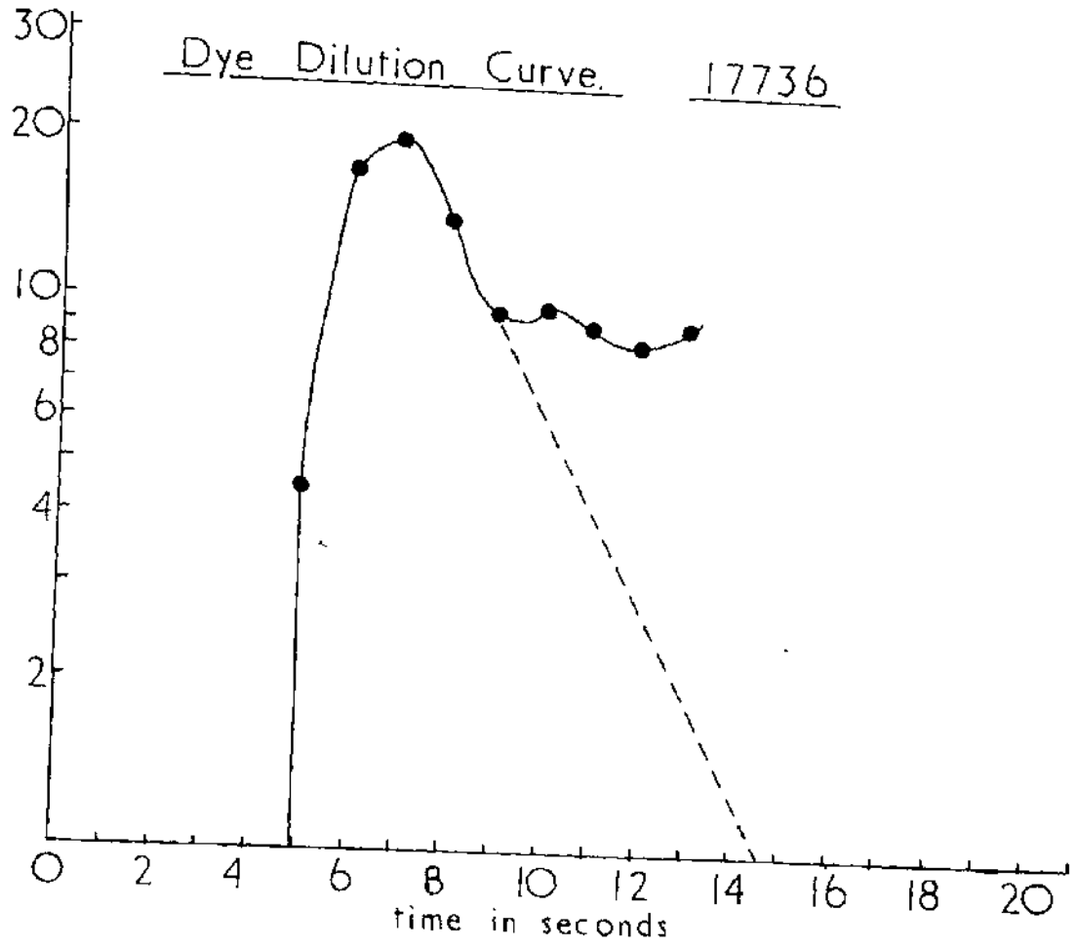
This calf was purchased as a healthy newborn animal in a local market. The calf was thin but bright. After a few days of diarrhoea in the first two weeks, it gained weight and behaved like a normal calf. There was no cyanosis or dyspnoea at rest or on exercise. A gross systolic murmur was heard equally loudly on both sides of the thorax, but there was no palpable thrill and no evidence of cardiac enlargement on percussion. The heart rate was normal and the pulse volume was good. The electrocardiogram showed no evidence of hypertrophy or other deviation from normal. The dye-dilution curve showed an early elevation on the downward limb, suggestive of a left-right shunt (Figure 40). Catheterization showed a slight elevation of right ventricular pressure but no other evidence of abnormality. Haematological and biochemical findings were normal.

The calf was slaughtered at three months of age.

Autopsy

The heart weighed 344 g. The heart weight/body weight ratio was 0.54. The right ventricle was 0.8 cm. thick, and the left ventricle was 1.5 cm. thick. When the right ventricle was opened, a defect could be seen high in the interventricular septum, posterior to the crista supraventricularis.

Figure 40


Dye Dilution Curve. 17736
30
20
10
8
6
4
2
0
2
4
6
8
10
12
14
16
18
20
time in seconds

The lesion was 0.6 cm. in diameter. In the left ventricle the defect could be seen to be immediately below the junction of the anterior and the right cusp of the aortic valve. The edges of the opening were formed of muscle tissue on all sides except dorsally, where there was a fibrous patch on its edge. No other lesions were found.

Group II

Table 29

Group II: Ventricular Septal Defects with Pulmonary Stenosis

(Tetralogy of Fallot)

Case No.	Age at Autopsy	Sex	Ultimate fate of animal
18633/1	7 months (foetus)	Female	Mother destroyed
20488	3 months	Male	Destroyed
18921	8 months	Female	Destroyed
19429	1 year 7 months	Female	Destroyed

This group consisted of four animals (Table 29) in which a ventricular septal defect was associated with pulmonary stenosis. These anomalies were of the classical Tetralogy of Fallot type, since the ventricular septal defect and pulmonary stenosis were accompanied by dextroposition of the aorta and right ventricular hypertrophy.

Case No. 18633/1: 7 month-old Ayrshire foetus, female

The foetus of cow 18633, referred to earlier, was examined postmortem and the following was found.

Autopsy

The heart weighed 212 g. The heart weight/body weight ratio was 1.06. The right ventricle was 1.2 cm. thick and the left 1.3 cm. thick.

The foramen ovale was patent but normal for a foetus at this stage of development. The right ventricular wall was slightly more hypertrophied than normal. The aorta was dextroposed. There was a moderate degree of pulmonary stenosis. High in the intraventricular septum there was a defect 1.6 cm. in diameter, which was situated below the aortic and pulmonic valves. No other lesions were found.

Case No. 20488: 3 month old cross-bred Hereford, male

This calf was admitted with a history of a respiratory disturbance and a failure to thrive. On inspection the animal was dull, in poor condition and had a slight increase in respiratory rate (40/minute). The mucosae were slightly cyanosed. There was no jugular oedema. The right knee was noticed to be swollen. The pulse volume was fair and the rate was 80 per minute.

On palpation the apex beat was felt strongly on both sides of the chest and there was a precordial thrill at the 4th intercostal space on the left. Percussion showed a loss of resonance over the lower half of the chest.

On auscultation the respiratory sounds were increased with bronchial inspiration and bronchovesicular expiration. The heart sounds were clear at the 5th intercostal space on the right, but a systolic murmur could be detected at the 3rd intercostal space. On the left side a systolic murmur could be detected all over the cardiac area but this was most intense at the 4th intercostal space.

When the animal was exercised it became dyspnoeic and much more cyanosed. Haematological and biochemical examinations indicated an erythrocythaemia with a packed cell volume of 46 per cent, a haemoglobin concentration of 16 g./100 ml., an erythrocyte count of 12 million/cu.mm., and a plasma protein of 6.6g./100 ml.

Electrocardiographic examination showed electrical alternation (Figure 41). Phonocardiography confirmed the presence of the systolic murmur (Figure 42). Cardiac catheterization revealed an increased right ventricular pressure, but it was not possible to get the catheter into the pulmonary artery.

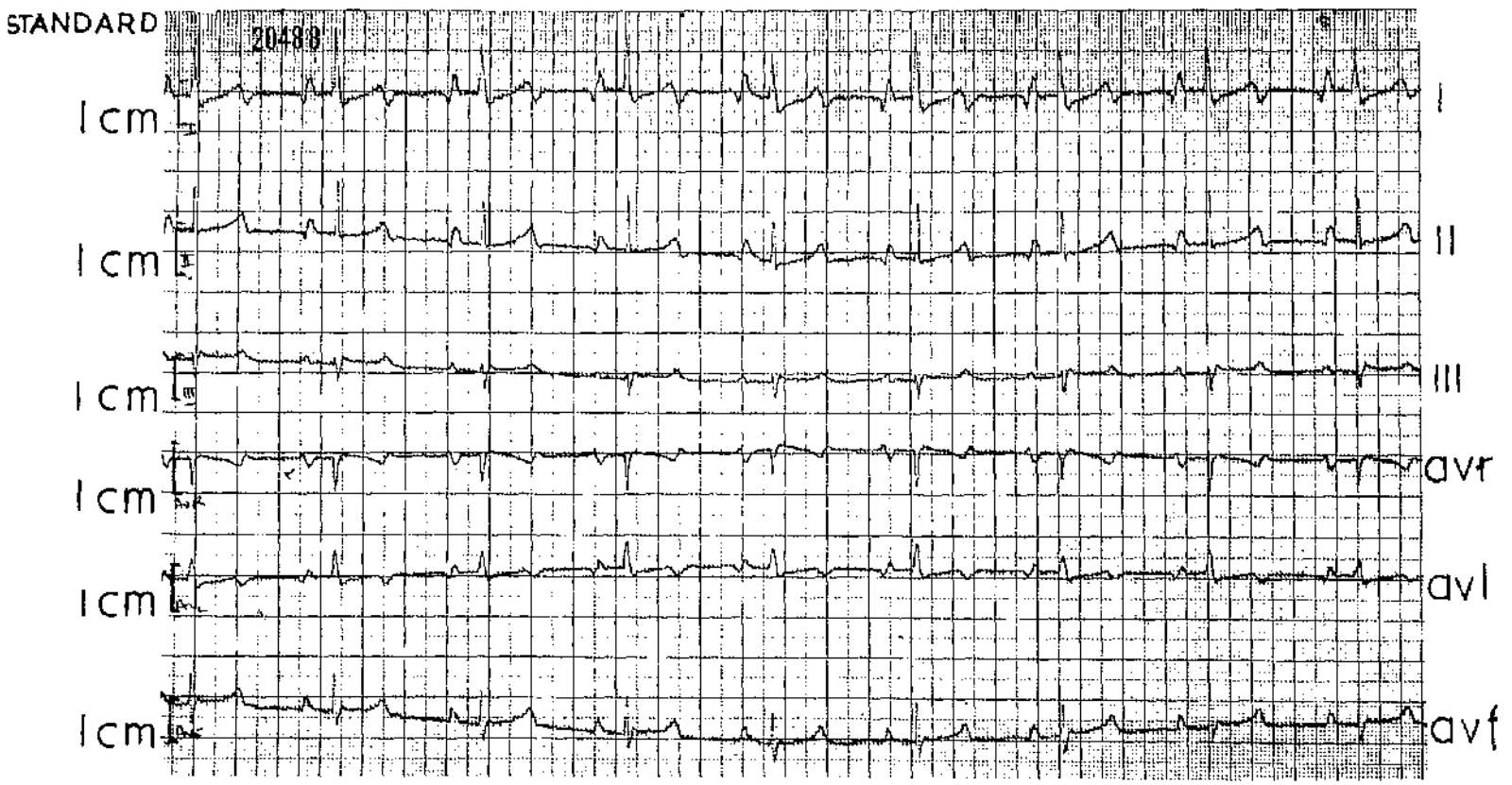
A complex defect of the Fallot type was diagnosed as a result of the clinical and specialized examinations and the animal was slaughtered.

Autopsy

The heart was enlarged, weighing 670 g. The heart weight/body weight ratio was 1.6. The right ventricle was 1.5 cm. thick, the left ventricle 1.7 cm. thick. When the heart was examined externally, owing to the right ventricular hypertrophy it appeared to have a double apex. It could also be seen that the pulmonary artery was very small and hypoplastic, with a thin wall, and that the ascending aorta and aortic arch were dilated. The change in the pulmonary trunk was present from the level of the pulmonary valve to the point where the vessel was joined by the ductus arteriosus, which was patent (Figure 43). After the junction of the ductus arteriosus and the pulmonary trunk the latter vessel and the right and left pulmonary arteries were wider in diameter and had thicker walls

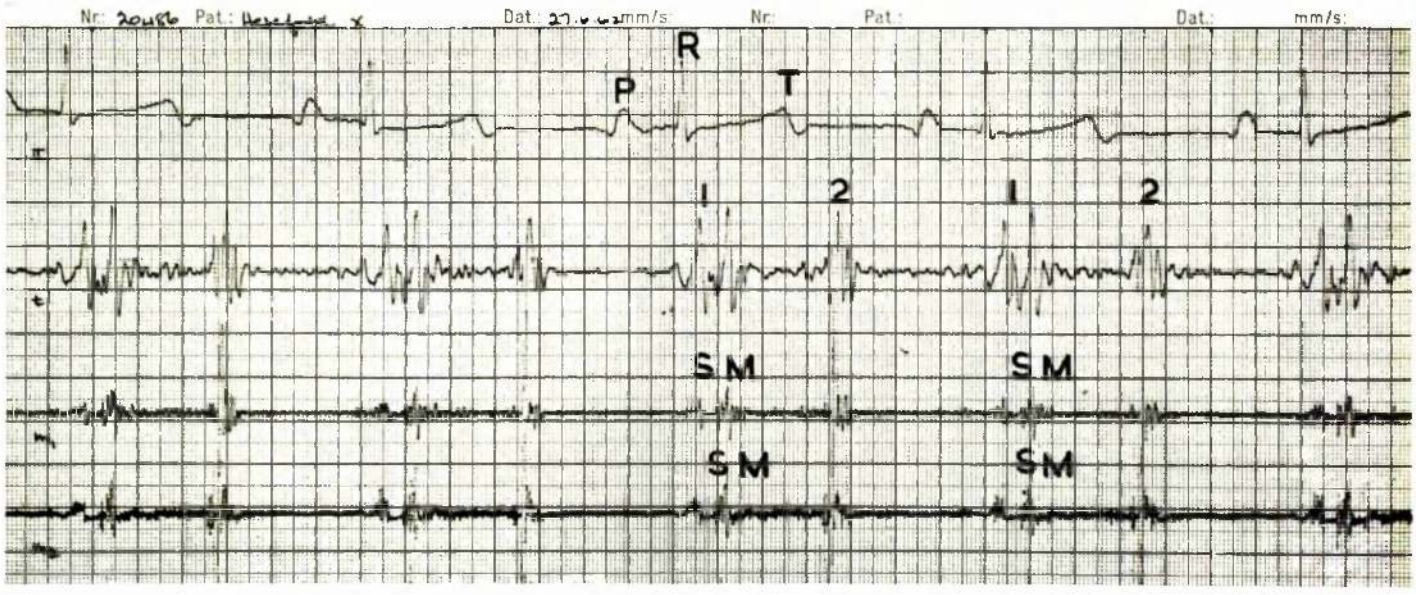
Figure 41

Electrocardiogram. case no. 20488.



paper speed 50mm/sec.

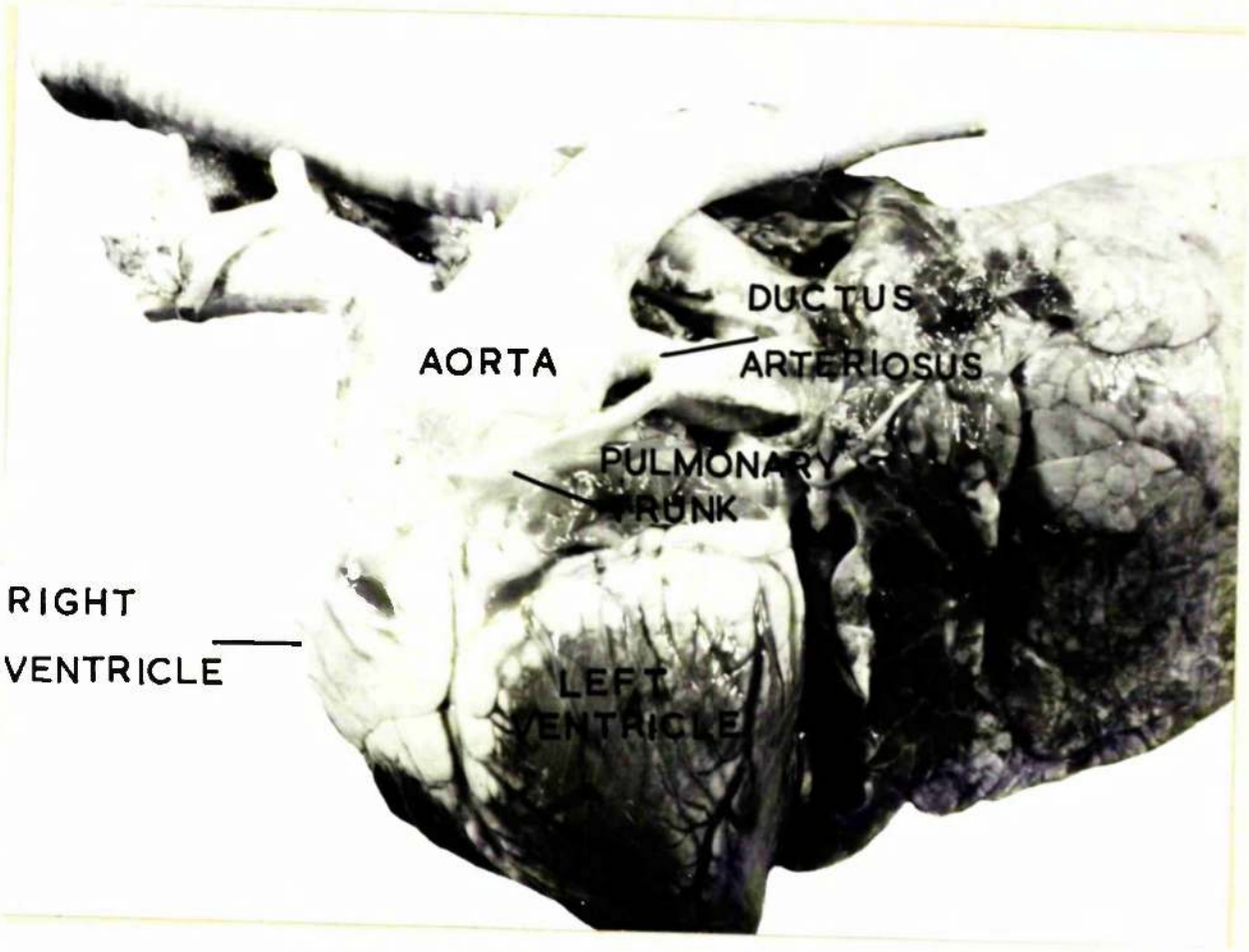
Figure 42 Heart Sounds (20488)



II	ECG Lead II	1	1st heart sound
t	low frequency heart sound	2	2nd heart sound
m_1	medium frequency heart sound	S.M.	systolic murmur
m_2	medium frequency heart sound		

Figure 43

Left Lateral View of Heart (20488)

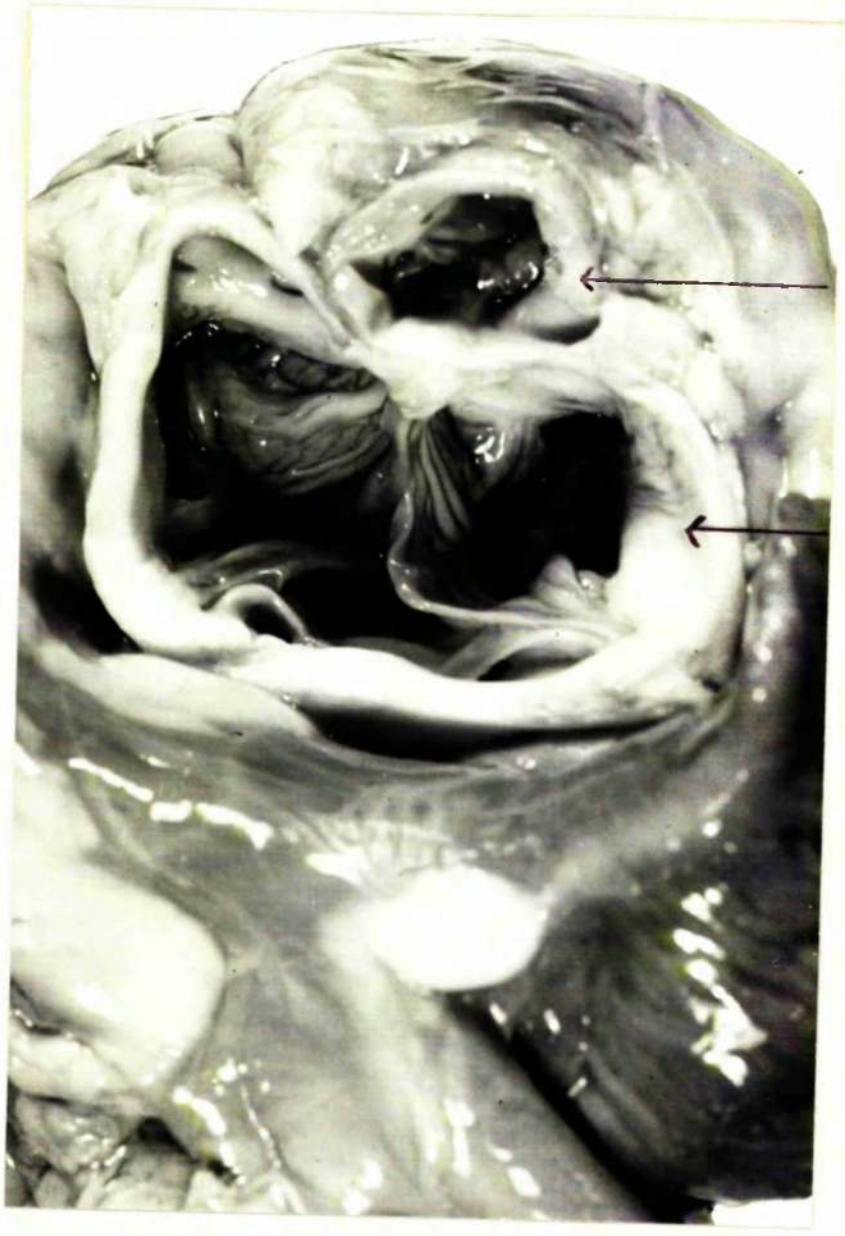


than the first part of the pulmonary trunk. The right atrium was slightly hypertrophied and the foramen ovale was patent but functionally competent. There was marked hypertrophy of the right ventricle and the lumen of this ventricle extended further to the apex of the heart than is normal. High in the interventricular septum there was a large defect, 2 cm. in diameter, with white fibrous edges (Figure 44). The aortic valve was immediately above the defect. The outflow tract of the right ventricle to the pulmonary trunk was stenotic. The stenosis was of the infundibular type and had resulted in a channel only 0.5 cm. in diameter leading to the pulmonary valve from the right ventricle. There was no ring of fibrous tissue at the entrance to the channel and the walls were composed of muscle. The pulmonary valve itself was small and only 1.3 cm. in diameter. It had only two cusps - a large one which appeared to consist of fused right and left anterior cusps, and a normal posterior cusp. The right coronary artery opened into the pulmonary trunk above the larger cusp. The left atrium and the left ventricle were normal. The aorta was dextroposed so that the anterior cusp was above the right ventricle. The aortic valve was dilated, being 3 cm. in diameter, and the cusps were larger than normal (Figure 45). The bronchial arteries were slightly enlarged and an extensive plexus of small vessels could be seen in the pleura of both lungs around the hilus. In the right carpal joint there was a fibrino-purulent arthritis.

Figure 44

View of Right Ventricle with Major Vessels Removed (20488)

Figure 45 Aortic and Pulmonary Valves (20488)



Case No. 18921: 8 month-old Friesian, female

This heifer was admitted with a history of dyspnoea when driven out to pasture in early summer and whenever chased in the field. After being housed for five months, when driven out to pasture the dyspnoea was again noticed, and at one stage the animal collapsed and lay gasping.

The animal was in poor condition and appeared slightly stunted. When examined at rest the respiratory rate was normal but the slightest exercise caused a rapid increase in rate to 70 per minute, and an increase in the respiratory sounds. Dyspnoea appeared when the animal was driven 100 yards. Slight cyanosis, which became much more pronounced on exercise, was evident in the mucosa of the mouth and vagina. There was slight distension of the jugular veins. On palpation of the chest the apex beat was felt on both sides, but no precordial thrill was detected. Percussion of the chest revealed no abnormality.

Auscultation of the heart revealed clear heart sounds all over the chest except at the 4th left intercostal space under the point of the shoulder, where a systolic murmur was heard. This murmur was obscured when the animal was exercised and dyspnoea produced increased respiratory sounds. The pulse volume was good and the rate was 100/minute.

Haematological and biochemical examination gave evidence of an erythrocythaemia with a packed cell volume of 50 per cent, a haemoglobin of 15 g./100 ml., an erythrocyte count of 7.2 million/cu.mm., and a plasma protein of 7 g./100 ml. Electrocardiography revealed no abnormality.

It was not possible to get a catheter into the right atrium or ventricle. Injection of Evans blue into the jugular vein (Figure 46) gave a curve suggesting a left to right and a right to left shunt. A diagnosis of a complex cardiac anomaly was made but this was not pursued further before slaughter.

Autopsy

The heart was enlarged and weighed 1,050 g. The heart weight/body weight ratio was 1.77. The right and left ventricles were each 2 cm. thick. The outline of the heart was altered because of the right ventricular hypertrophy which made this side of the heart bulkier than normal. The anterior part of the fossa ovalis contained a small circular atrial septal defect about 0.4 cm. in diameter. The right ventricle was grossly hypertrophied and so was the moderator band (Figure 47). About 2 cm. below the pulmonary valve, which was much smaller in diameter than normal and whose circumference was only one-third of the circumference of the aortic valve, there was a ring of fibrous tissue causing an infundibular stenosis in the outflow tract of the right ventricle. A high elliptical ventricular septal defect 2.5 cm. x 0.5 cm. dorsoventrally was present immediately below the aortic cusps. The aorta was dextroposed and the free edge of the left aortic cusp was over the ventricular septum. The valve was dilated and the cusps were larger than normal. The ostia of the left coronary artery was slightly displaced dorsally and the ostia of the right coronary artery was displaced to a similar extent dorsally, but it was also situated to the left of its normal

Figure 46

18921 Jugular Injection.

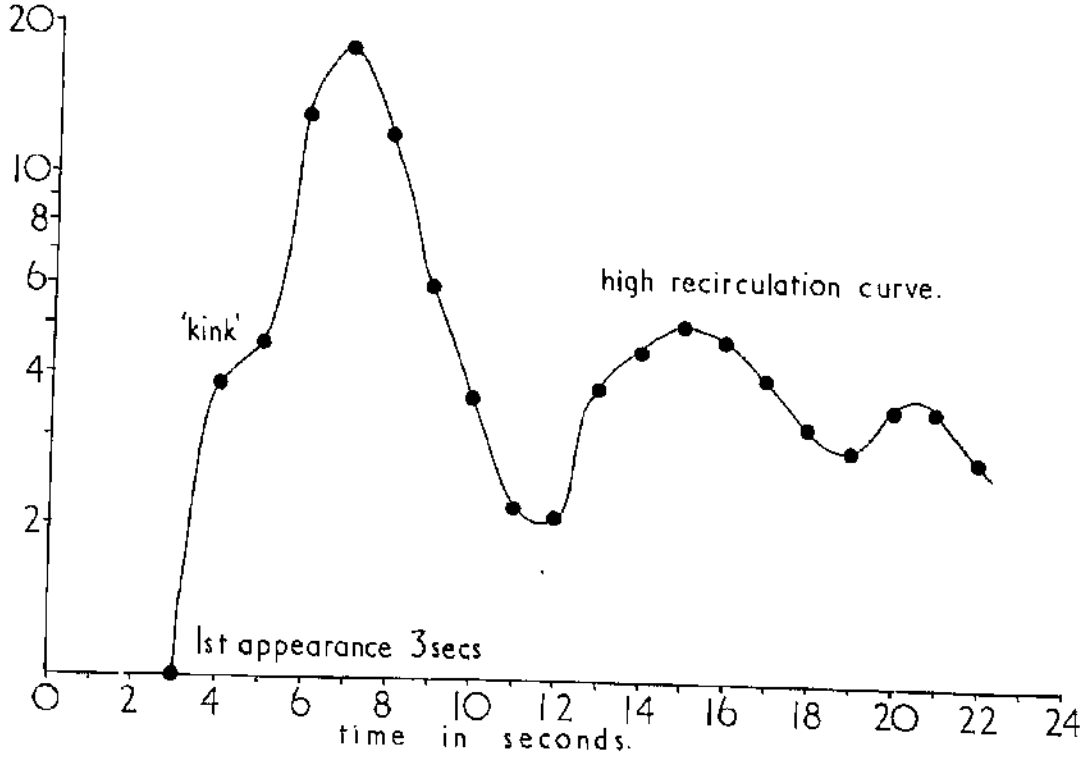
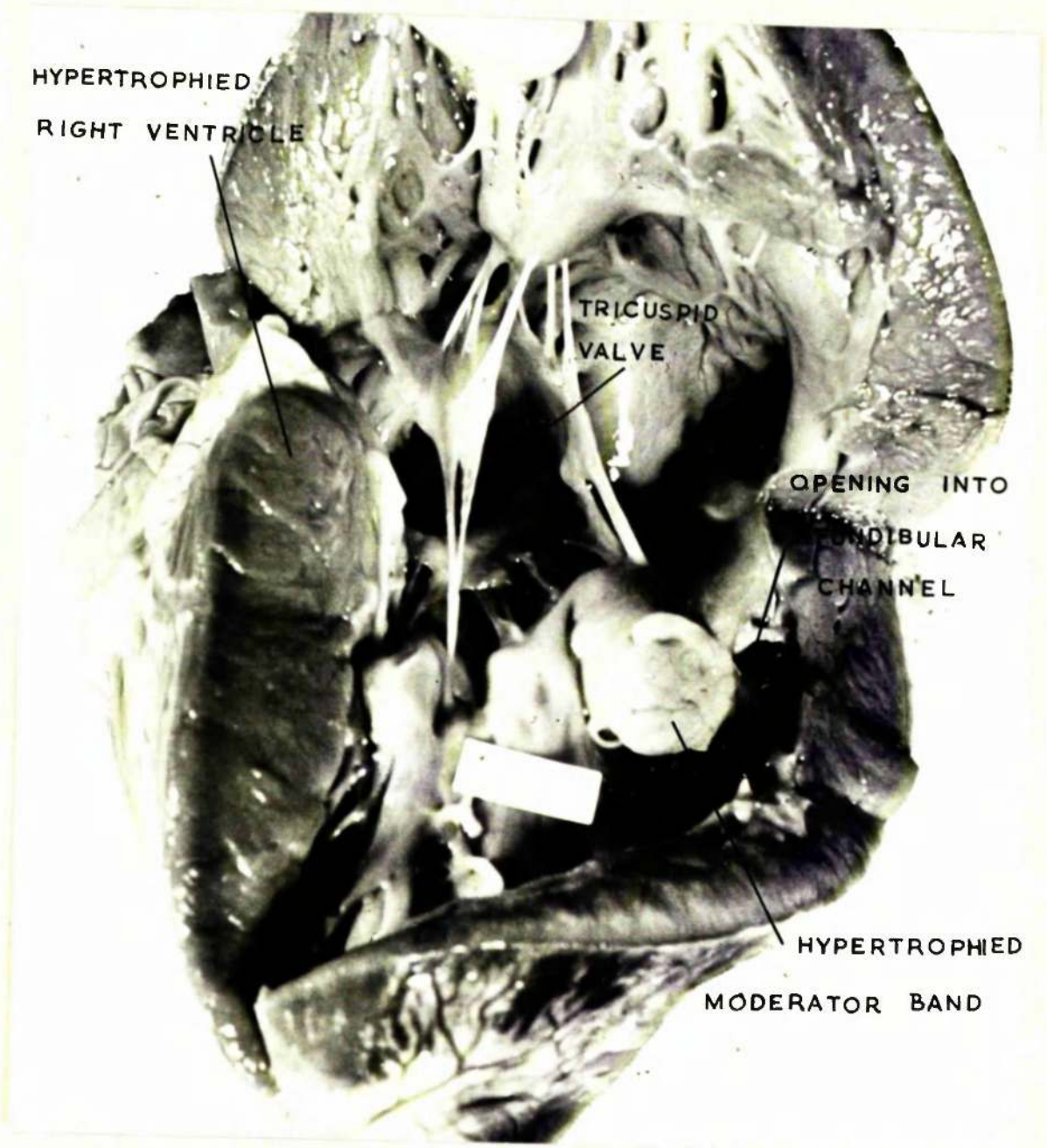


Figure 47

View into Right Ventricle (18921)



position, so that it was above the junction of the left and anterior cusps of the aortic valve. The pulmonary trunk was hypoplastic and had a thin wall. The ductus arteriosus was patent and also had a moderately thin wall. The ascending aorta was dilated to the origin of the brachiocephalic trunk. On the pleura around the hilus of the lungs there was a plexus of small vessels, probably representing collateral circulation developing from the bronchial arteries. No abnormality was detected in the other organs.

Case No. 19429: 19 month-old Friesian, female

The subject was admitted to the Veterinary Hospital at the age of 9 months with a history of not thriving. It was dull in demeanour, in poor condition, weighed 148 kg., and had large subcutaneous abscesses behind the left shoulder and upon the left patella. The feet were very overgrown. At rest the respiratory rate was 50 a minute and the heart rate was 100 a minute. On auscultation, bronchovesicular respiratory sounds were heard. Palpation of the chest revealed a precordial thrill on the left-hand side and a distinct apex beat on the right-hand side. On percussion there was an increased area of cardiac dullness on both sides of the chest.

The first heart sound was obscured by a gross systolic murmur which was most intense at the pulmonic area, that is under the elbow at the third intercostal space, about 5 cm. above the level of the olecranon. The pulse volume was very poor. Cyanosis was detectable at rest on the mucous membranes of the eyes, the mouth, and the vulva. When the animal was exercised by being run for a distance of 150 yards it became much more cyanotic and dyspnoea developed.

Haematological examination showed polycythaemia with a haemoglobin concentration of 20.6 g. (normal 9-11 g.) and a red blood cell count of 14.3 million (normal 5-8 million). The white blood cell count and the plasma protein concentration were normal.

The animal was kept for 10 months. During this time it showed no change in its cardiac condition. Body weight increased from 148 to 287 kg. when it was slaughtered.

Electrocardiograms The electrocardiogram (Figure 48) showed large complexes when compared with normal cattle, suggesting cardiac hypertrophy, while the direction of the QRS complexes in limb leads and unipolar leads suggested that this hypertrophy was on the right side of the heart.

Pressure Recordings The pressure recordings of the right side of the heart (Figure 49) showed a rise in right atrial pressure, an increased right ventricular pressure, and a lowered pulmonary arterial pressure. The values found are given in Table 30, where they are compared with a normal series of pressures found by Doyle et al. (1961). It will be observed that the arterial pressure was also below normal and that there was a low pulse pressure.

Table 30 Catheterization Data (mm.Hg)

	Normal Heifer		Fallot's Tetralogy 19249		19429
	Systolic	Diastolic	Systolic	Diastolic	
Right Atrium	5	0	19	5	
Right Ventricle	53	0	93	12	
Pulmonary Artery	45	19	23	16	
Carotid Artery	180	130	105	88	

Figure 48 **Electrocardiogram (19429)**

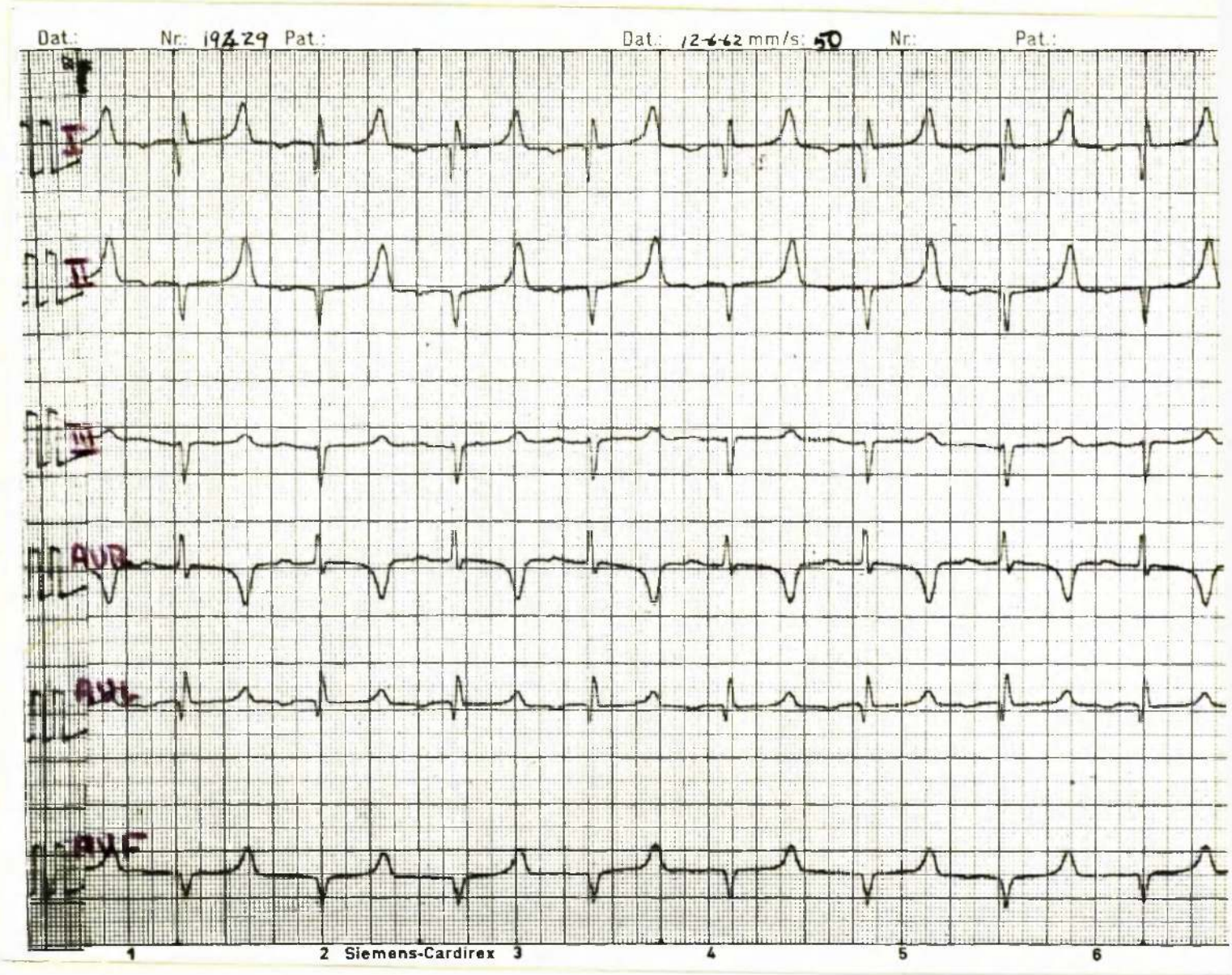


Figure 49

PRESSURE CURVES RIGHT HEART : 19429

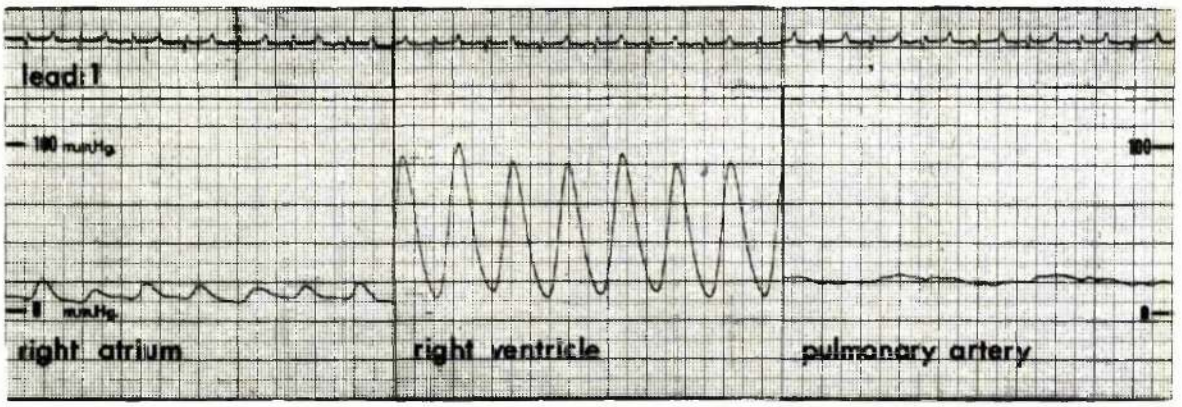
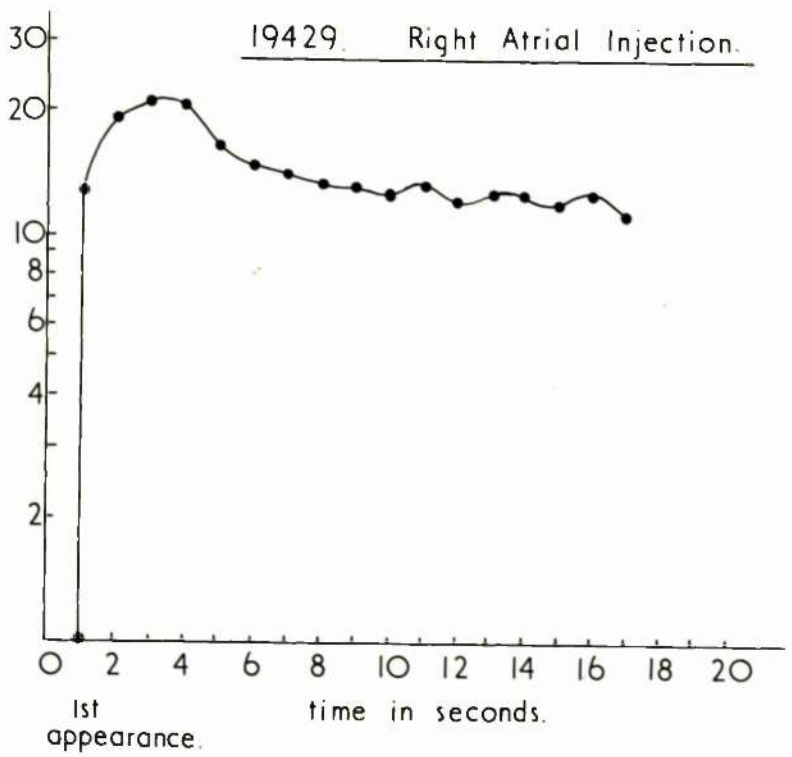


Figure 50a



Dye Dilution Recordings The dye dilution curves, which were obtained by plotting the varying concentrations of Evans Blue in plasma against the time of their appearance in the brachial artery, are shown in Figure 50a, b and c. The right atrial and right ventricular injections of dye produced curves indicating abnormal mixing of blood within the heart. Moreover, the time of first appearance of the dye was in each case more rapid than normal, suggesting a right to left shunt. The injection of dye into the pulmonary artery produced a dye dilution curve which was normal in shape except that the first recirculation was not so obvious as in a normal animal. The time of first appearance of dye from injection into the pulmonary artery was also normal. The delayed downstroke of the dye dilution curves suggested that in addition a left to right shunt also existed. Therefore, from these curves it was concluded that there was a gross abnormality of blood flow through the heart, which included a right to left shunt at the level of the ventricles and a left to right shunt at a higher level.

Heart Sound Recordings These recordings, which are illustrated in Figure 51, demonstrate the systolic murmur; and this was demonstrable at all frequencies.

Diagnosis In arriving at a diagnosis, the following facts were considered significant. In this young animal there was clinical evidence of cardiac hypertrophy, a loud systolic murmur most intense at the pulmonary area, in combination with tachypnoea and cyanosis at rest. These findings, together with electrocardiographic evidence of right ventricular hypertrophy, indicated the presence of a major congenital cardiac

Figure 50b

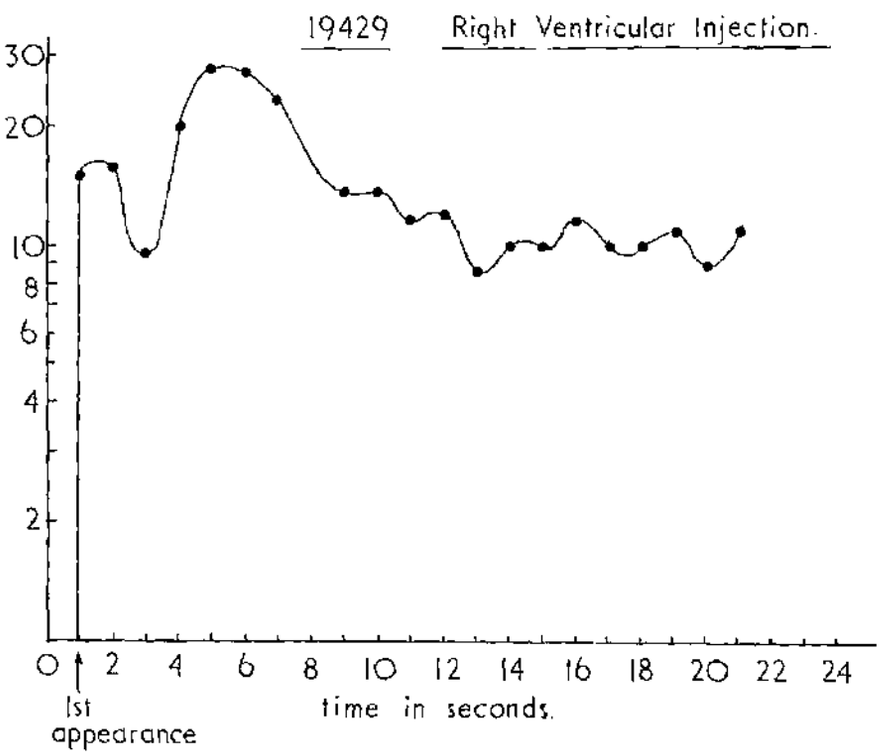


Figure 50c

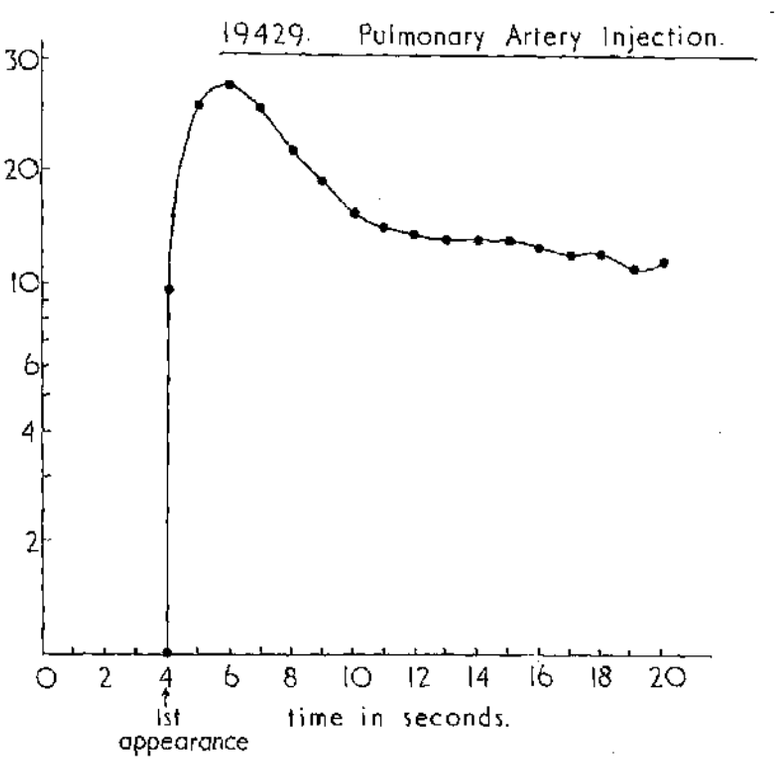
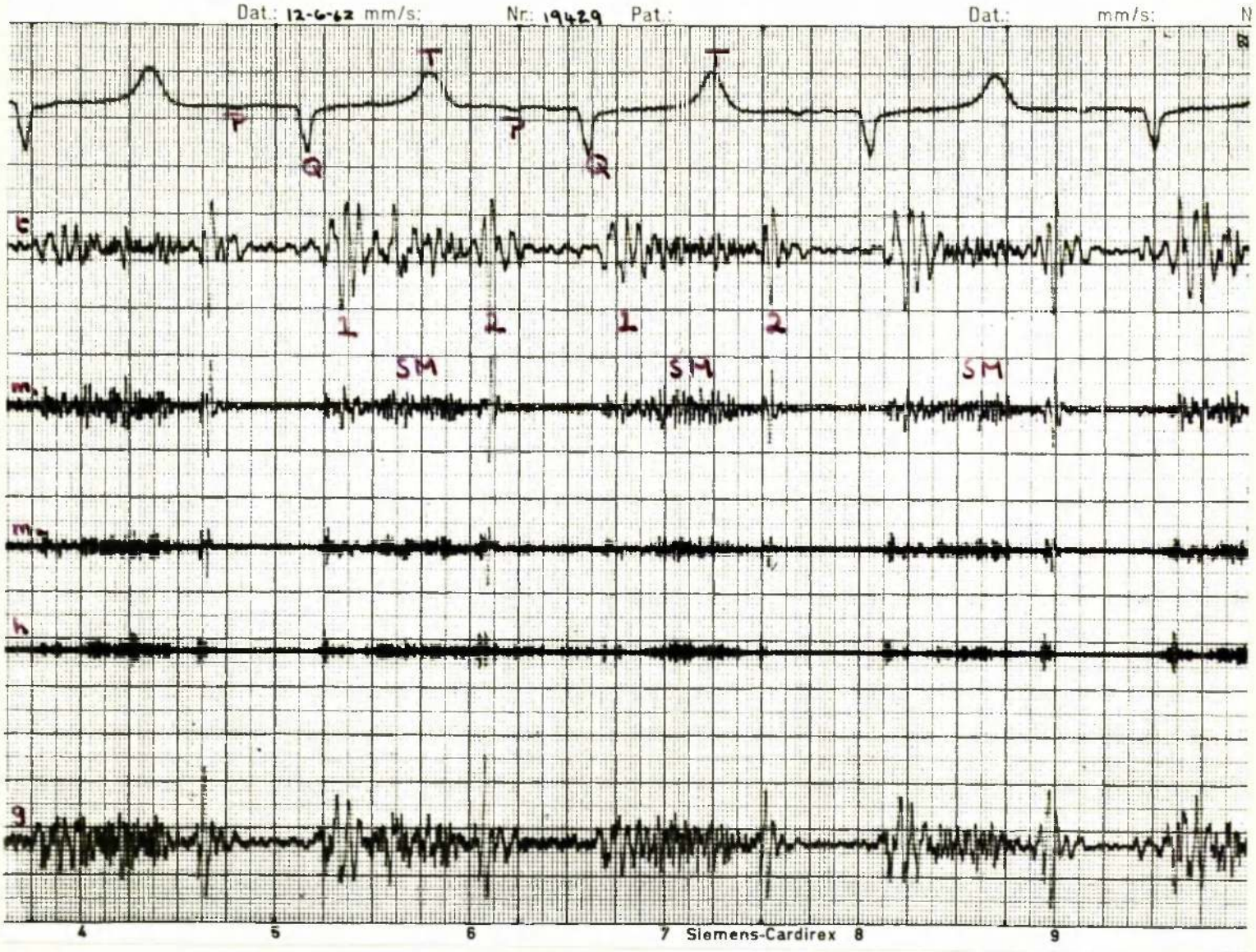


Figure 51 Tetralogy of Fallot in a Friesian Heifer



II: e.c.g. lead II t: low frequency heart sound
m_1: medium frequency heart sound m_2: medium frequency heart sound
h : high frequency heart sound g: stethoscopic heart sound
1: first heart sound 2: 2nd heart sound S.m: systolic murmur

anomaly. The dye dilution curves demonstrated a defect in the ventricular septum with a right to left shunt, while the pressure recordings from the right side of the heart showed the presence of pulmonary stenosis. Thus cyanosis, right ventricular hypertrophy, a right to left shunt in the ventricles, and pulmonary stenosis led to diagnosis of Tetralogy of Fallot.

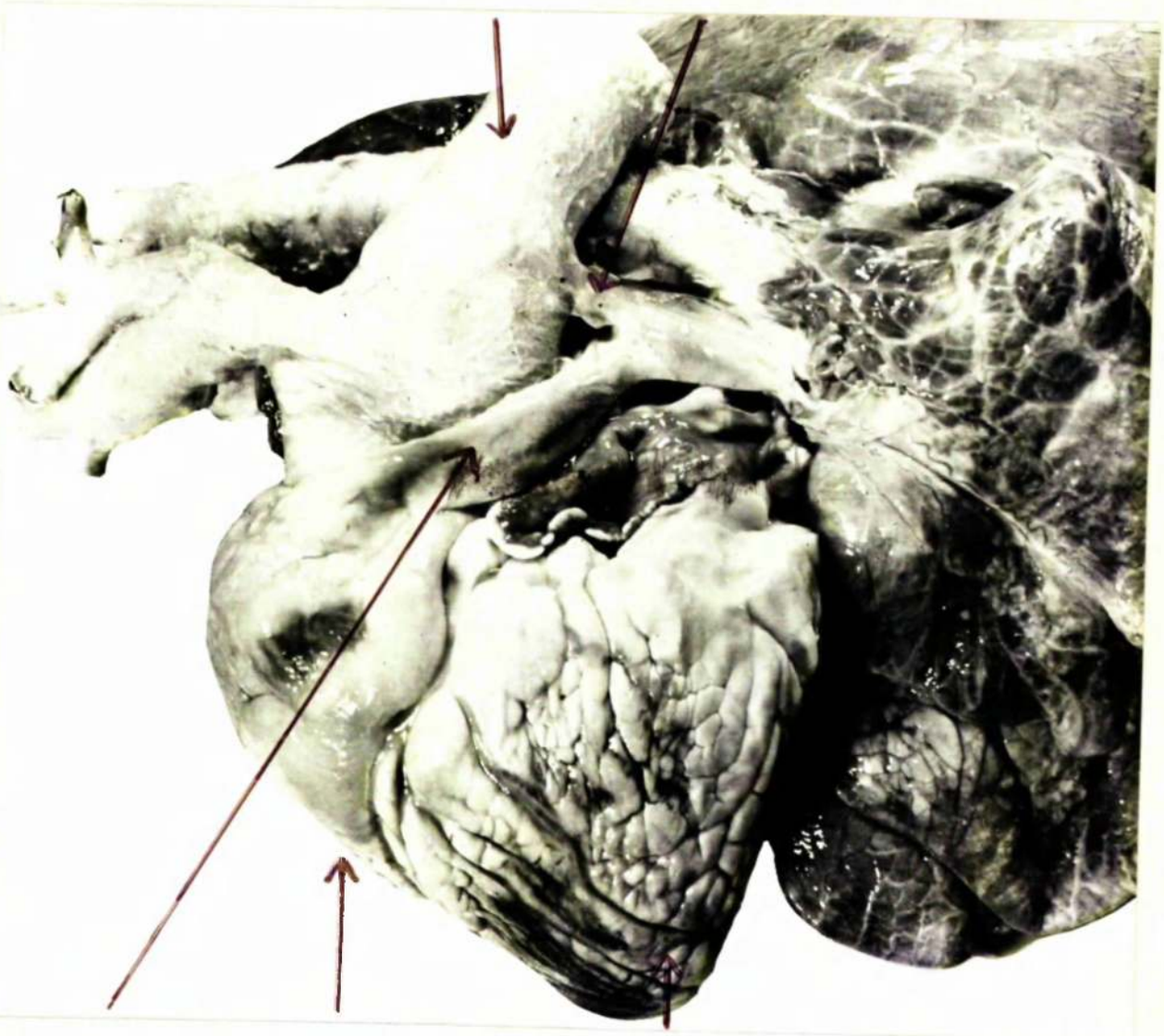
Autopsy

The heart was enlarged, weighed 1620 g., and when viewed anteriorly the apex was rounder than normal. The heart weight/body weight ratio was 0.56. The gross disproportion in size between the hypoplastic pulmonary trunk and the dilated ascending aorta was obvious (Figure 52). The wall of the pulmonary trunk was less than half the thickness of the wall of the aorta. The ductus arteriosus, which was patent, also had a thin wall and connected with the beginning of the left pulmonary artery (Figure 52). The dilated right atrium was slightly hypertrophied, and the foramen ovale, although functionally competent, was anatomically patent.

The wall of the right ventricle, which was grossly hypertrophied (Figure 53), was as thick as the left ventricle, and the lumen of the ventricle extended ventrally to the apex farther than normal. High in the ventricular septum was a large elliptical ventricular septal defect 3.5 cm. x 1.5 cm., with its long axis horizontally situated (Figure 53). Above the ventricular septal defect the aorta was dextroposed so that its anterior cusp was on the right side of the ventricular septum when viewed from above. In the left ventricle the ventricular septal defect appeared below the anterior cusp of the aorta. The aortic arch was on the left side.

Figure 52 Left lateral view of heart

Aorta Ductus Arteriosus



Pulmonary Trunk Right Ventricle Left Ventricle

Figure 53 View into right ventricle

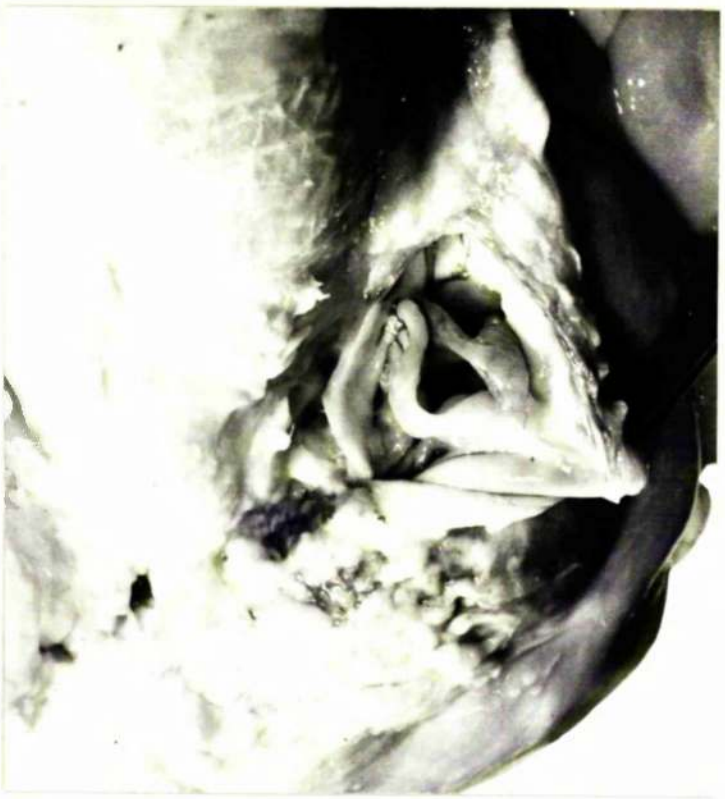
The aortic valve was dilated and had three cusps which were larger than normal. The bones of the heart were well developed and the coronary arteries were normal. The aorta itself was dilated to the origin of the ductus arteriosus and the proximal part of the brachiocephalic trunk was also dilated.

The pulmonary valve was less than half the diameter of the aortic valve and had only two large cusps (Figure 54) which were excessively large for the size of the valve and were anterior and posterior in position. Below the pulmonary valve there was an infundibular type of stenosis which had produced a narrow curving channel 5 cm. long, forming the outlet from the right ventricle to the pulmonary trunk (Figure 53). There was no ring of fibrous tissue at the proximal opening of the channel which had thick muscular walls and was dilated immediately below the pulmonary valve, forming an infundibular chamber.

The left atrium was normal and the wall of the left ventricle was not hypertrophied.

A large abscess 22 cm. x 22 cm. x 15 cm., involving the diaphragmatic surface of the liver in its dorsal half and the diaphragm itself was found. The diaphragmatic lobes of the lungs were adherent to the thoracic surface of the diaphragm over the abscess. Scattered throughout the liver were several smaller abscesses 2 cm. in diameter, either showing through the liver capsule as white circular convex areas or hidden in the liver parenchyma. No abscesses were found in the brain. The abscesses behind the left shoulder and upon the left patella had healed by the time the

Figure 54 Bicuspid pulmonary valve (19249)



animal came to autopsy, and only increased amounts of fibrous connective tissue at these sites indicated where the lesions had been.

A few small, pale, wedge-shaped areas were seen in the cortices of the kidneys, along with some moderately large haemorrhagic infarcts. The bone marrow in all of the vertebrae and sternebrae bodies was bright red and soft.

Histology Histological examination of the heart showed that although there was considerable variation in the width of the fibres in the right ventricle, some were wider than normal. Many fibres had large nuclei, and groups of three to four nuclei close together were frequently present. In the lungs there were several moderately heavy peribronchial accumulations of lymphocytes. Histological examination of the liver and the kidneys showed the usual changes associated with abscess formation and infarction. No significant lesions were seen in the other organs.

Group III

Table 31

Group III: Ventricular Septal Defect with Dextroposed Aorta but no Pulmonary Stenosis (Eisenmenger Complex)

Case No.	Age at Autopsy	Sex	Ultimate Fate of Animal
20127	3 weeks	Female	Died
21809	3 months	Female	Died
16040	1 year 9 months	Female	Destroyed
20536	2 years 6 months	Female	Died (Late pregnancy)

Four animals were seen in this group, which is rather heterogeneous anatomically. It is useful to classify them together, however, since all of them fit the title Eisenmenger Complex, because they have a ventricular septal defect associated with a dextroposed aorta, right

Case No. 20127: 3 week-old Ayrshire, female stenosis.

Case No. 20127: 3 week-old Ayrshire, female

This calf was admitted with a number of congenital anomalies. In addition to the cardiac defects described below, it was small, blind because of non-development of the eyes, had a very short tail, and had prognathus.

On inspection the animal was in fair condition, with a slight increase in the respiratory rate to 50 a minute. The pulse rate was rapid (120/min) but the volume was good. When the chest was palpated a precordial thrill

could be detected on both sides at the 4th intercostal space. Percussion revealed no abnormality. Auscultation revealed normal respiratory sounds but on both sides of the chest a continuous murmur of the machinery type could be heard all over the chest. There was no cyanosis evident in the mucosae. Exercise produced dyspnoea, but no cyanosis. Electrocardiography revealed no abnormality. Phonocardiography distinguished the murmur as occupying the latter part of the diastole and the whole of the systole,(Figure 55).

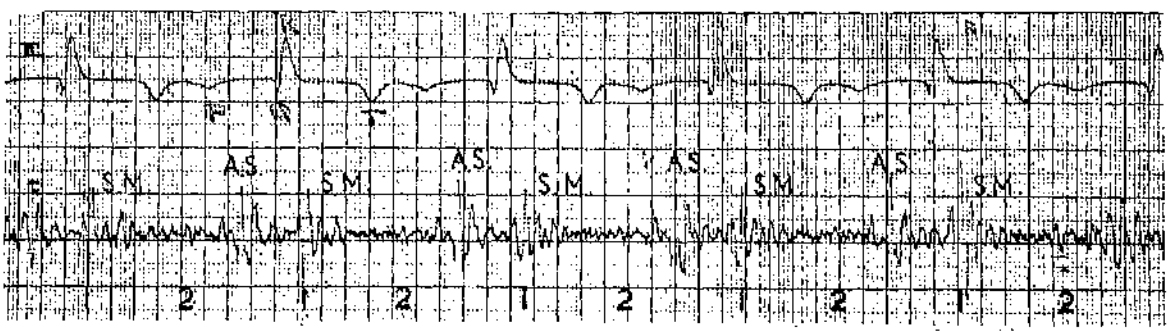
On the basis of the clinical signs and the character of the murmur a diagnosis of a widely patent ductus arteriosus was made, such signs in other species (dog and man) being pathognomic of this condition (Detweiler 1959; Wood, 1958).

The calf died after ten days.

Autopsy

The heart was larger than normal and weighed 260 g. The heart weight/body weight ratio was 0.87. The right ventricle was 1.2 cm. thick and the left ventricle was also 1.2 cm. thick. In the pericardial sac there was 15 ml. of serous fluid. The right atrium was dilated and in the region of the fossa ovalis there was a large atrial septal defect 2 cm. in diameter (Figure 56). The posterior edge of the defect was thin and membranous. The right ventricle was dilated and the wall hypertrophied. Close behind the septal cusp of the tricuspid valve there was a circular ventricular septal defect 2 cm. in diameter whose edges were formed by muscle tissue (Figure 56). In the position where one would normally expect to find the

Figure 55 Heart sounds - Case no. 20127



S.M.: Systolic murmur

A.S.: Atrial sound

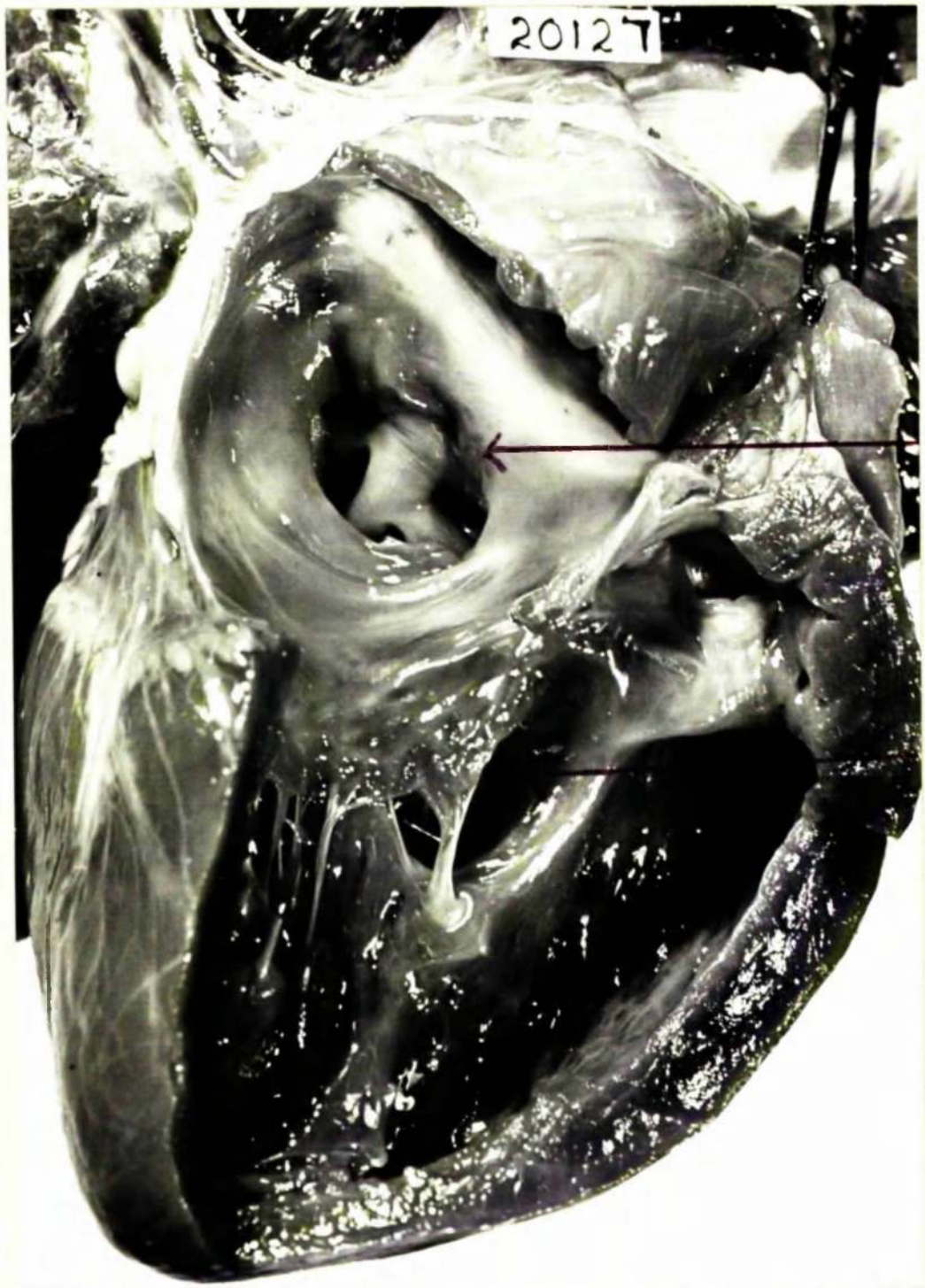
1 : First heart sound

2 : Second heart sound

II: e.c.g. Lead II

f: Low frequency heart sound

Figure 56 View into Right Atrium and Right Ventricle - 20127



crista supraventricularis, the aortic valve opened into the right ventricle (Figure 56). The aorta was completely dextroposed and arose solely from the right ventricle. The left ventricular wall was not hypertrophied and the only outlet for blood from the left ventricle was through the ventricular septal defect. The ductus arteriosus was probe-patent.

The lungs were heavy and dark red in colour. When the trachea and bronchi were opened they were seen to contain a large amount of frothy fluid. Owing to the severe pulmonary oedema, cutting the lungs allowed a large amount of fluid to exude from the surface.

Histological examination of the lungs confirmed the presence of pulmonary congestion and severe oedema with oedema fluid in the bronchi, bronchioles, alveolar ducts and alveoli.

There was anophthalmos. The palpebral fissures were small and no eyeball could be seen until the orbit was dissected, when a small vestigial structure was found on each side. The third eyelids were normal.

Case No. 21809: 3 month-old Ayrshire, female

This calf was submitted dead, thus no ante-mortem examination was carried out.

Autopsy

The heart was enlarged and weighed 740 g. The heart weight/body weight ratio was 0.74. The walls of the right and left ventricles measured 0.9 cm. and 1.3 cm. respectively. The pericardium contained 10 ml. of

yellowish fluid. The right atrium was dilated. The right ventricle was grossly dilated and hypertrophied, and the moderator band was thicker than normal. High in the ventricular septum and posterior to the crista supraventricularis there was a large circular defect 2 cm. in diameter with muscular edges. Above the defect the aorta was dextroposed. The pulmonary valve and the pulmonary trunk were dilated. The left ventricle was dilated and hypertrophied. The coronary ostia were dilated and the isthmus of the aortic arch was coarcted.

Congestion and oedema were present in the lungs in addition to severe pneumonic consolidation which affected the apical cardiac and anterior third of the diaphragmatic lobe.

Subcutaneous oedema was found, and the thorax and abdominal cavities each contained 1 litre of straw-coloured fluid. The liver was moderately enlarged and showed changes of chronic venous congestion.

Case No. 16040: 1 year 9 month-old Ayrshire, female

This animal was in good bodily condition and weighed 750 lb. It was eating 18 lb. of hay and 8 lb. of concentrates per day.

At rest its respiratory rate was 70 per minute and its heart rate 90 to 100 per minute. On auscultation a short broncho-vesicular respiratory sound was heard but there were no adventitious sounds present. On percussion of the pulmonary area resonance was good. Some degree of cyanosis was observed on the mucous membranes of the tongue, conjunctivae and vulva.

The heart sounds were readily audible on auscultation of the cardiac areas on both sides of the chest and a splitting of the first sound was detectable. No murmurs were heard on initial examination, but after 3 months it was possible to hear a slight diastolic murmur on some occasions when auscultating the left side of the chest just above the elbow. The pulse was almost undetectable in the median artery and in the iliac arteries it was of very poor volume. When the animal was subjected to the exercise of being run on a halter for 400 yards it became much more cyanotic and dyspnoea developed.

On haematological examination an erythrocytosis was demonstrated with an erythrocyte count of 11,000,000 cells per cu.mm. of blood, a packed cell volume of 61 per cent and a haemoglobin concentration of 18 grammes per 100 ml. The plasma protein concentration was 6.4 grammes per 100 ml.

During 3 months in hospital the animal's appetite was maintained and its weight increased by 100 lb. It also remained bright in general demeanour.

Electrocardiogram As illustrated in Figure 57, the electrocardiogram showed very large QRS complexes when compared with those of other cattle, suggesting that cardiac hypertrophy was present.

Dye Dilution Curves The curve produced by plotting the concentration of Evan[@]s Blue against the time of its appearance in the brachial artery is illustrated in Figure 58. It is obvious that in this animal passage of all the dye into the systemic circulation from the heart was delayed. This type of excretion curve in man is associated with gross cardiac defects which give rise to mixing of blood from both sides of the

Figure 57 E.C.G. of heifer 16040

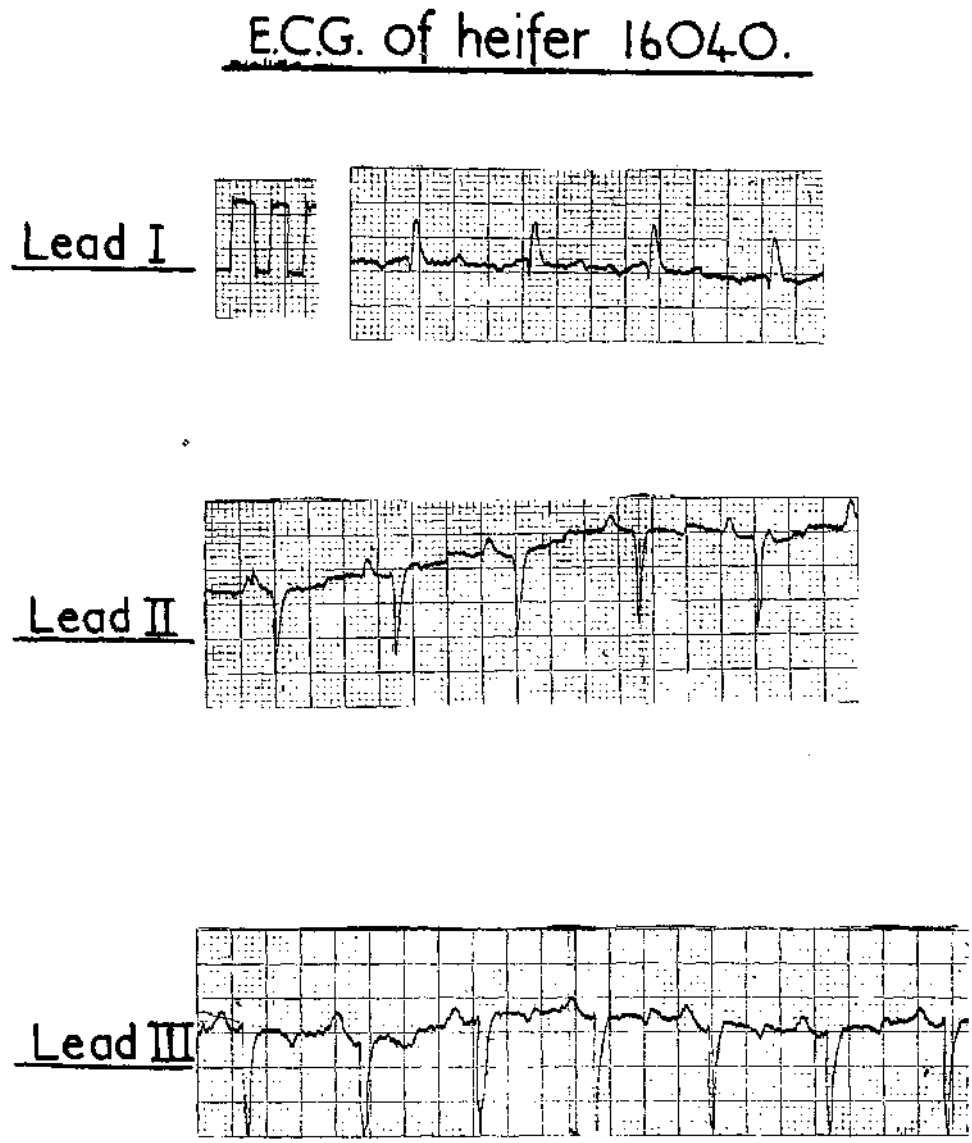


Figure 58 16040 - Jugular Injection

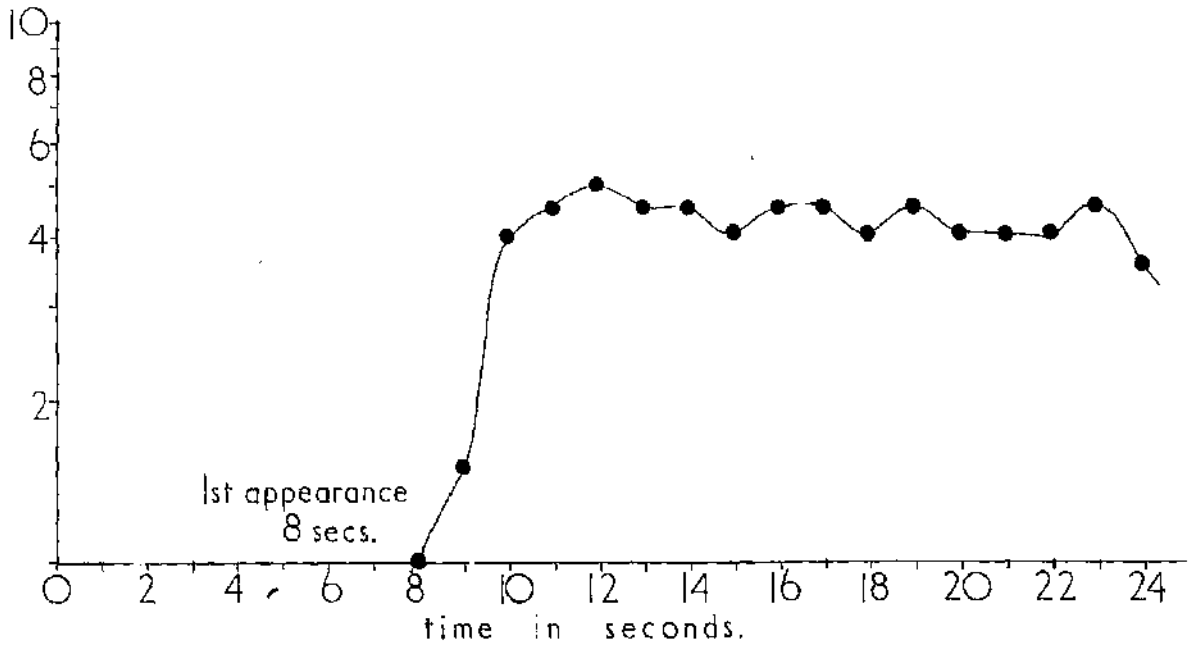
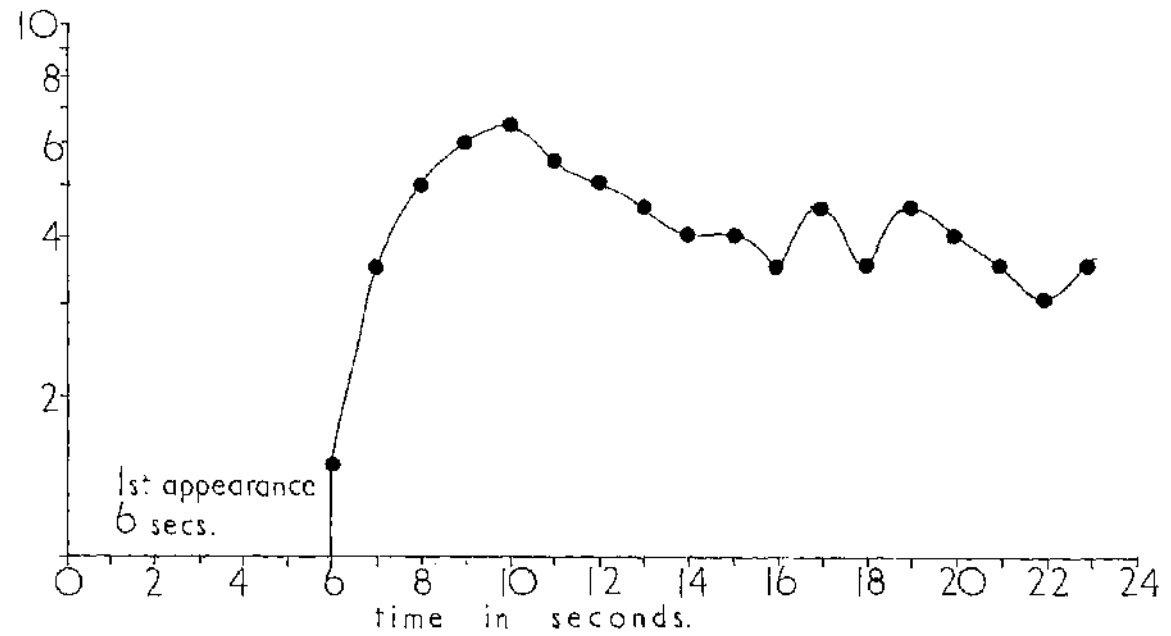


Figure 59 16040 - Right Atrial Injection



circulation within the heart or great vessels (Wood, Swan and Helmholz, 1957). Furthermore, by selective injections of dye it is possible to localise such lesions (Swan and Wood, 1957). If dye is injected into the circulation at a point beyond such a defect, a normal type of dye dilution curve is obtained, whereas injections before or at a defect give abnormal curves. In the animal under observation injections of Evan's Blue dye were made into the right atrium and right ventricle, by means of a polythene catheter (Figures 59 and 60). The excretion curves were similar to that produced by injection of dye into the jugular vein (Figure 58), indicating a major ventricular septal defect or a large persistent patent ductus arteriosus, or both.

Pressure Recordings Recordings of the pressure in the right atrium, the right ventricle and the pulmonary artery were made and these are shown in Figure 61. It can be seen that the right atrial pressure curve was normal in shape and that the pressure was not elevated. However, the pressure curves recorded from the right ventricle and pulmonary artery were abnormal in shape with marked splitting of the systolic peaks, and pressures in the right ventricle and the pulmonary artery were also elevated.

Diagnosis

In arriving at a diagnosis the following facts were considered to be significant. The cyanosis at rest which was readily exaggerated on moderate exercise and the dyspnoea produced by this exercise indicated that there was a considerable interference with oxygenation of the blood.

Figure 60 16040 - Right Ventricular Injection

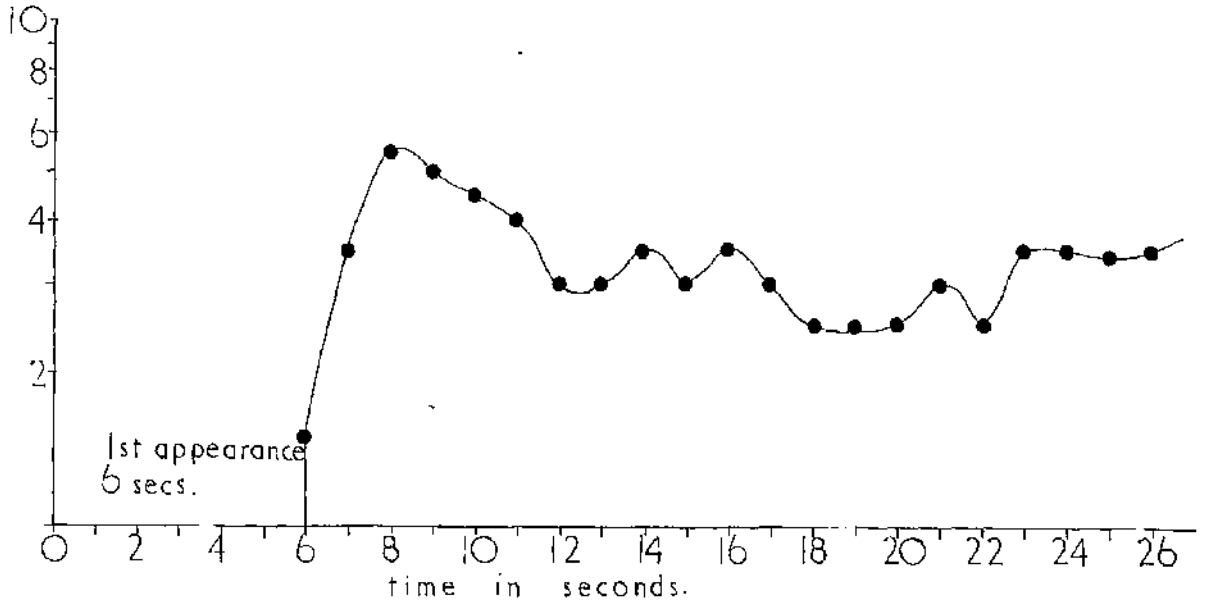
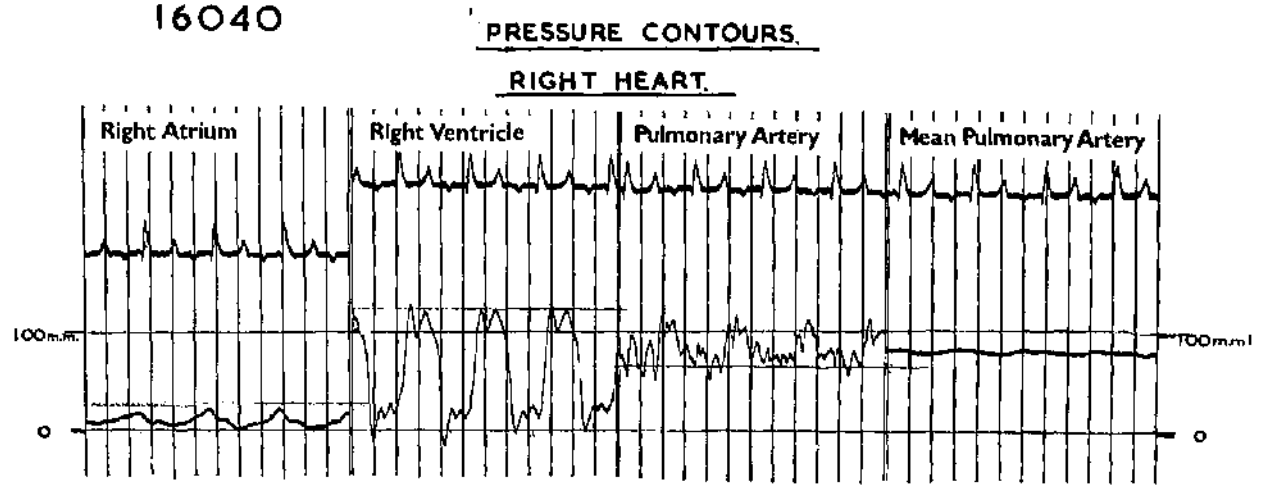


Figure 61 Pressure Contours - Right Heart



The erythrocytosis which persisted during the time the animal was in the hospital substantiated a long-standing anoxia. The hypertrophy suggested by electrocardiographic examination was in keeping with the possibility of a major cardiac defect. The selective dye injections showed that this defect was in the ventricular septum, in the persistence of a patent ductus arteriosus or both.

The abnormal shaped pressure pulse curves which were observed each time the animal was catheterised were unlike any pulse curve observed in other cattle and, for these reasons, were not considered to be artefacts. The elevated right ventricular pressure supported the presence of a major defect at the ventricular level while the elevated pulmonary arterial pressure suggested that this defect was probably of the type that is classified as an Eisenmenger Syndrome (Wood, 1958).

Autopsy

External examination of the heart showed that it was enlarged, the right ventricle being bulkier than normal and the apex rounded. The heart weight/body weight ratio was 0.71. In the atrial septum a small hole, 0.5 cm. in diameter, was present in the dorsal part of the fossa ovalis. The wall of the right ventricle was grossly hypertrophied, being 2.5 cm. thick, and the cavity of the right ventricle extended to the apex of the heart. The wall of the left ventricle was slightly hypertrophied and was 2.5 cm. thick. In the ventricular septum below the pulmonary valve, there was a large elliptical hole, 3 cm. long. The pulmonary valve and the

artery were dilated. The valve, which had 3 large cusps, was 5.5 cm. in diameter and the artery, which was dilated above the valve, was 15 cm. in circumference compared with a valve diameter of 4 cm. and a pulmonary artery circumference of 10 cm. in a normal animal of similar size.

The aorta was dextroposed and arose from opened into the right ventricle in a recess opposite the ventricular septal defect. The aortic valve had 3 cusps and was hypoplastic, measuring only 2.5 cm. in diameter, compared with a diameter of 4 cm. in the same normal animal as above. The left coronary artery passed anterior to the pulmonary artery instead of being in its usual position posterior to it.

The ossa cordis were not developed.

Above the aortic valve the ascending aorta was hypoplastic, being only 4 cm. in circumference. It was just 7 cm. long and terminated in a dilated portion of the brachiocephalic trunk about 3 cm. anterior to the point where this vessel had an anomalous origin from the pulmonary artery. When the dilated pulmonary artery was explored, the origin of the brachiocephalic trunk was found as a small elliptical opening 2 cm. x 0.5 cm. This opening was 7.5 cm. from the pulmonary valve. A pulmonic-aortic window, 5 cm. in circumference, was present a short distance dorsal to the opening of the brachiocephalic trunk. This opened into a dilated portion of the descending aorta, 10 cm. in circumference, and was the only communication between the descending aorta and the heart, since the aorta ended blindly proximal to this point.

The wall of this dilated region opposite the pulmonic-aortic window and also the wall of the dilated region of the brachiocephalic trunk opposite its slit-like origin in the pulmonary artery were rough in appearance. These were probably jet lesions which could be attributed to blood impinging on the wall of the vessels after being forced through the narrow apertures described (Robbins, 1957). All of these anomalies are illustrated in Figures 62, 63 and 64. When the large vessels were trimmed off the heart, it weighed 2,427 grammes.

Several small patches of pleurisy with adhesions were present on the dorsal borders of the posterior parts of the diaphragmatic lobes of the lungs.

On the anterior edge of the spleen, near its ventral tip, there was an abscess 2 cm. in diameter, containing thick yellow pus. Between the diaphragm and the liver in its dorsal half, there was another abscess, 4 cm. in diameter, causing an adhesion between the two organs. A third abscess, 1 cm. in diameter, was present in a kidney. The bodies of all the vertebrae and the sternum were packed with dark red marrow.

Histological examination of the right ventricle showed that the muscle fibres were increased in width, and that some of them had large nuclei, while others had groups of 2 to 4 overlapping nuclei. A few small accumulations of lymphocytes were present between the muscle fibres. The sections of lung tissue examined showed proliferative changes in the walls of the smaller arteries and arterioles adjacent to bronchioles, alveolar ducts, and in the septa, with narrowing of the lumina of these

Figure 62 Eisenmenger complex. View into right ventricle and pulmonary artery

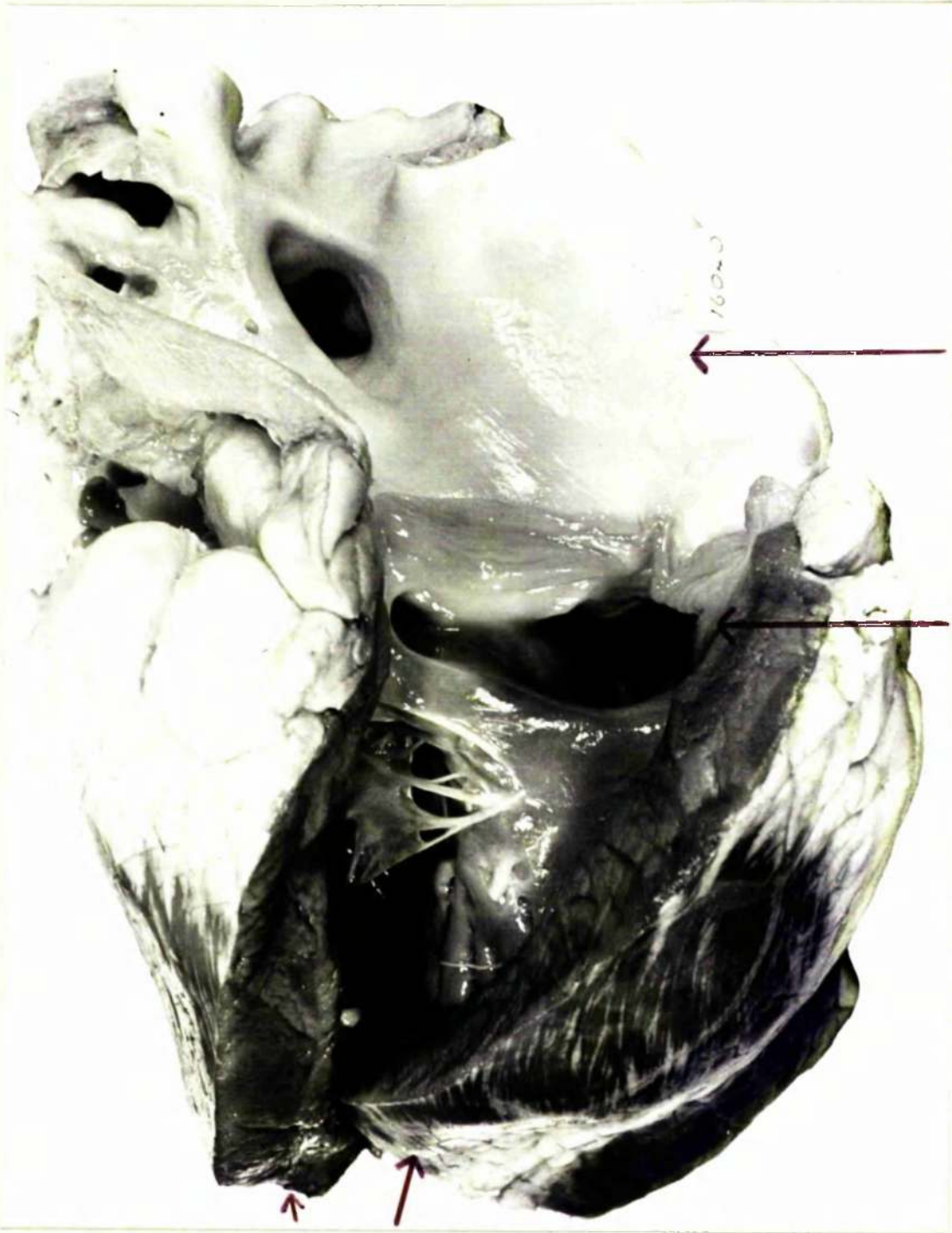
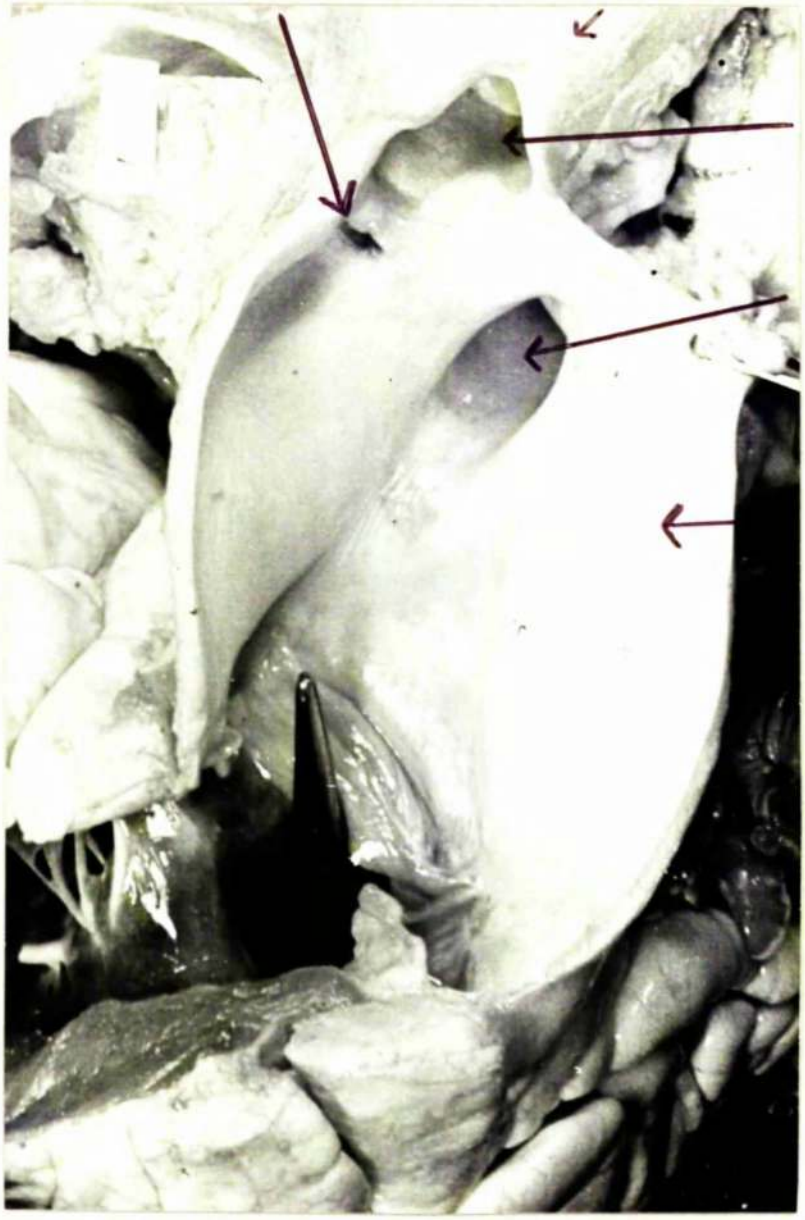


Figure 63 Eisenmenger complex. View into pulmonary artery

Connection between Pulmonary Artery and brachiocephalic trunk

Descending Aorta

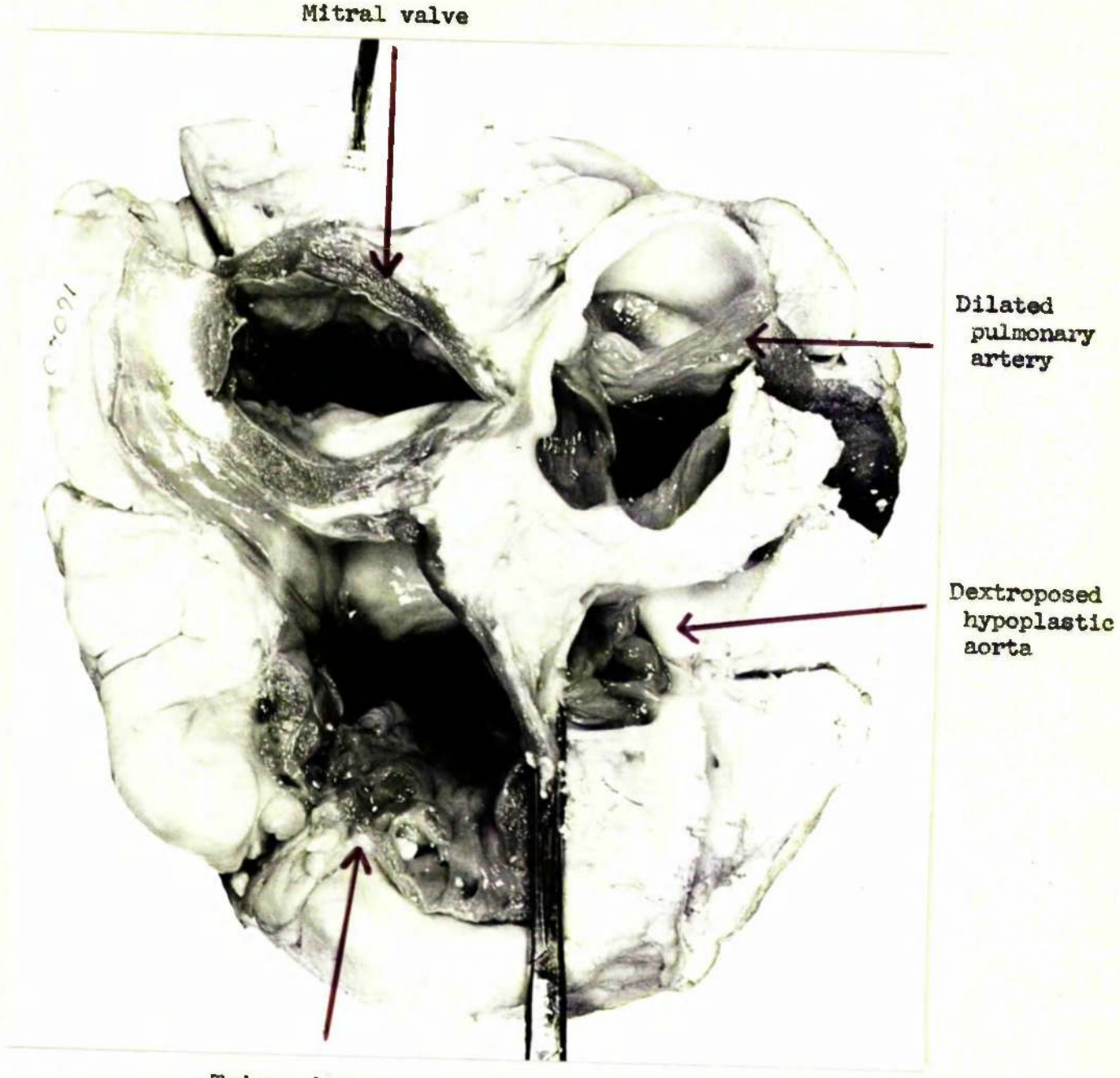


Pulmonic Aortic Window

Continuation of Pulmonary Artery

Pulmonary Artery

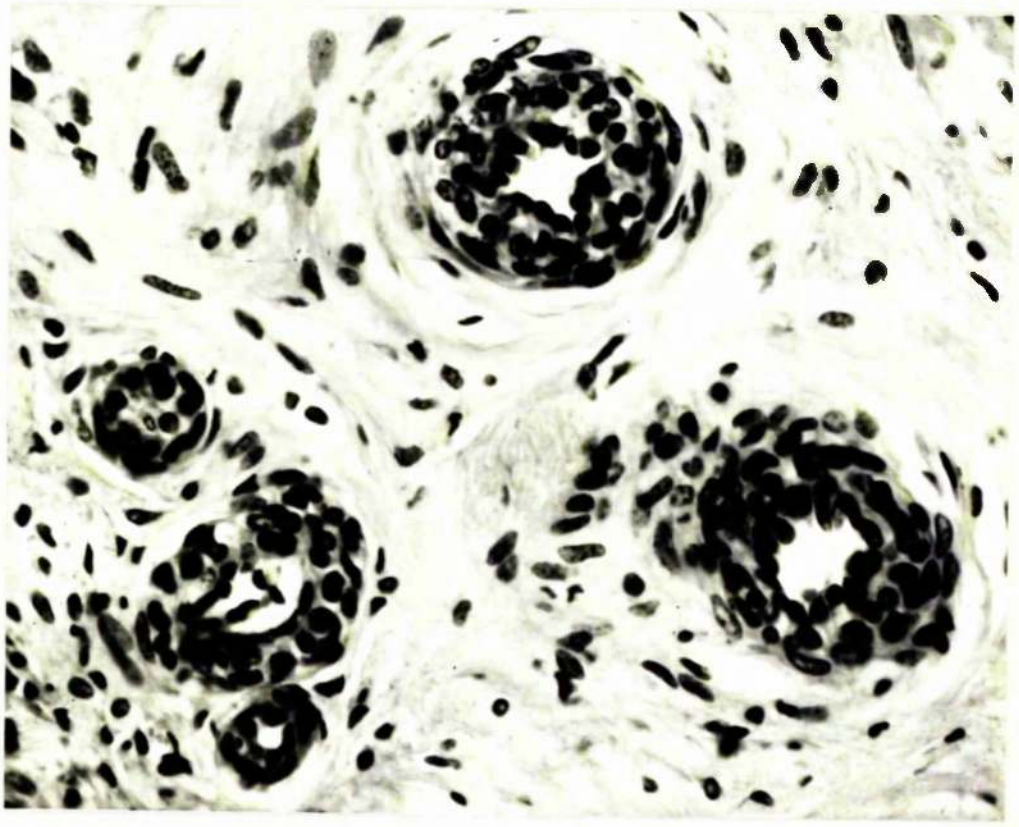
Figure 64 Eisenmenger complex: Base of Heart



vessels in proportion to the thickness of the wall. These changes are illustrated in Figure 65. There was also proliferation of the endothelium and, in a few instances, thickening of the intima. The most marked changes in these vessels were seen in the media and adventitia where the cells had proliferated, resulting in an increased thickness and increased cellularity of the vessel walls. There was also proliferation and condensation of the perivascular fibrous tissue in a concentric manner around the small vessels. In a few instances, reduplication of the internal elastic lamina was detected. These changes were present in all the lobes of the lungs. Peribronchial and peribronchiolar accumulations of lymphoid cells were also seen. Sections taken from the jet lesions in the aorta and brachiocephalic trunk showed that the rough appearance was due to the thickening of the intima by proliferation of the fibroblasts and the formation of many new elastic and collagen fibres. Below these lesions the internal elastic lamina was fragmented and could be seen to be splitting longitudinally. The abscesses had fairly thick fibrous connective tissue walls infiltrated on the inner parts by plasma cells, lymphocytes and mononuclear cells. Bacterial examination of the abscesses yielded C. pyogenes.

The Eisenmenger syndrome was defined by Wood (1958) as pulmonary hypertension with a reversed shunt which may occur through an atrial septal defect, a ventricular septal defect or through a patent ductus arteriosus.

Figure 65 Proliferative changes in lung arterioles due to pulmonary hypertension.



The term 'Eisenmenger Complex' is reserved for cases in which the shunt is through a ventricular septal defect. It was not possible to determine the exact position of the shunt in this animal while it was alive and so the clinical diagnosis had to remain an Eisnemenger syndrome. Postmortem examination, however, revealed that the animal did, in fact, have an Eisenmenger Complex.

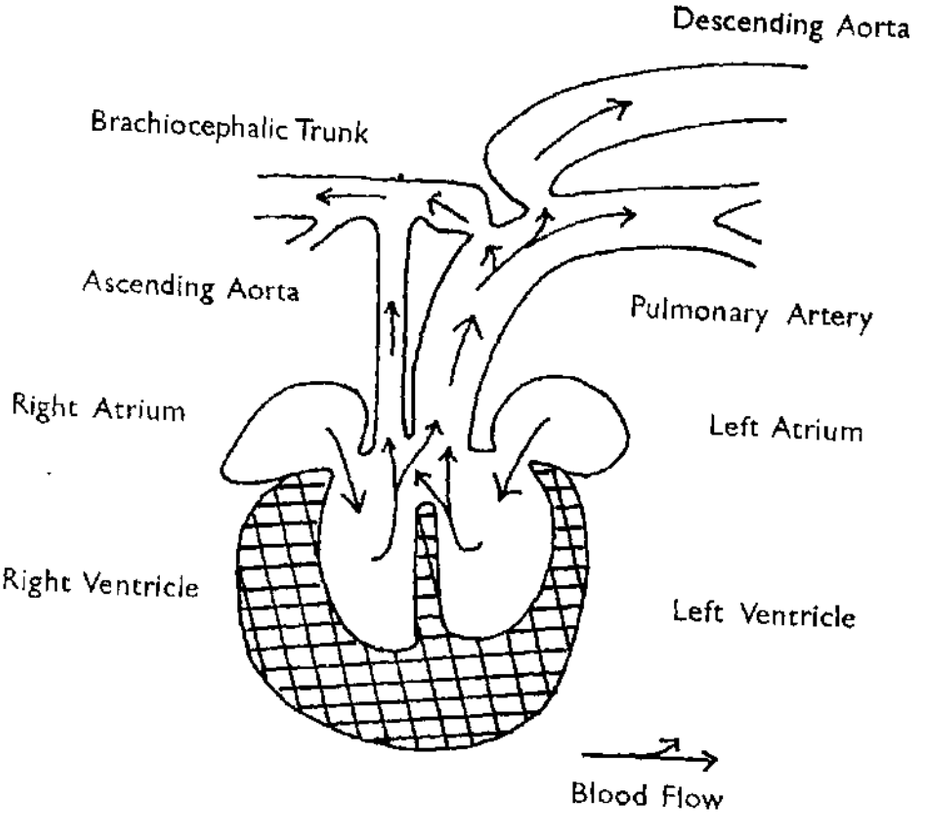
The pulmonic-aortic window present as an associated anomaly was the only route by which blood could pass from the heart to the parts of the body supplied by the descending aorta. The atrial septal defect was quite small and was regarded as a feature of no functional significance.

The hypertrophy of the right ventricle was so great that it was possible to appreciate an increase in the width of the individual myocardial fibres when compared with normal fibres without any measurements being made. The presence of large nuclei in hypertrophic cardiac muscle has been described previously (Robbins, 1957).

It is interesting to note that in this case vascular changes were present in all the lobes of the lungs. This is similar to the findings of Doyle, Goodwin, Harrison and Steiner (1957), who noticed that in man, cases of pulmonary hypertension due to congenital heart disease had changes in the vascular tree throughout the lungs, whereas in pulmonary hypertension due to mitral stenosis the changes did not affect the apical regions of the lungs. Abscesses in organs are a common finding in cases of congenital heart disease in man (Wood, 1958) and it is interesting to note their presence in this case.

Taking into consideration the lesions found in this heart and the slope of the pressure contours from the right ventricle, the circulation through the heart was probably as described below. Systemic venous blood entering the right ventricle was ejected into the hypoplastic dextroposed aorta and the pulmonary artery mixed with arterial blood which had passed through the ventricular septal defect from the left ventricle. The stenotic aortic valve ensured that most of the blood from the left ventricle passed into the pulmonary artery. The mixture of blood in the pulmonary artery passed to the lungs and through the pulmonic-aortic window into the descending aorta to supply the posterior part of the body. Mixed blood from the pulmonary artery would also pass into the brachiocephalic trunk through its small elliptical origin. Blood from the lungs returned to the left atrium and thence to the left ventricle. From the left ventricle some blood passed up the hypoplastic aorta but more probably passed through the ventricular septal defect into the right ventricle and then to the pulmonary artery, as previously described. The defects in this heart were such that gross mixing of blood from both ventricles contributed blood to the hypoplastic aorta and to the dilated pulmonary artery. This circulation is illustrated in Figure 66, which is a diagrammatic version of the heart and the vessels leading from it. The pulmonic-aortic window, by providing a circulation of oxygenated blood to the descending aorta, enabled life to be maintained and growth to take place within the sheltered environment of the hospital, but it is unlikely that such an animal would have survived in a commercial dairy herd.

Figure 66 Diagrammatic representation of circulation



Diagrammatic representation of circulation.

Case No. 20536: 2 years six month-old Ayrshire, female

This heifer was approximately five months pregnant when admitted to the Veterinary Hospital as a suspected case of traumatic pericarditis. She was dead on arrival and the following was found on autopsy.

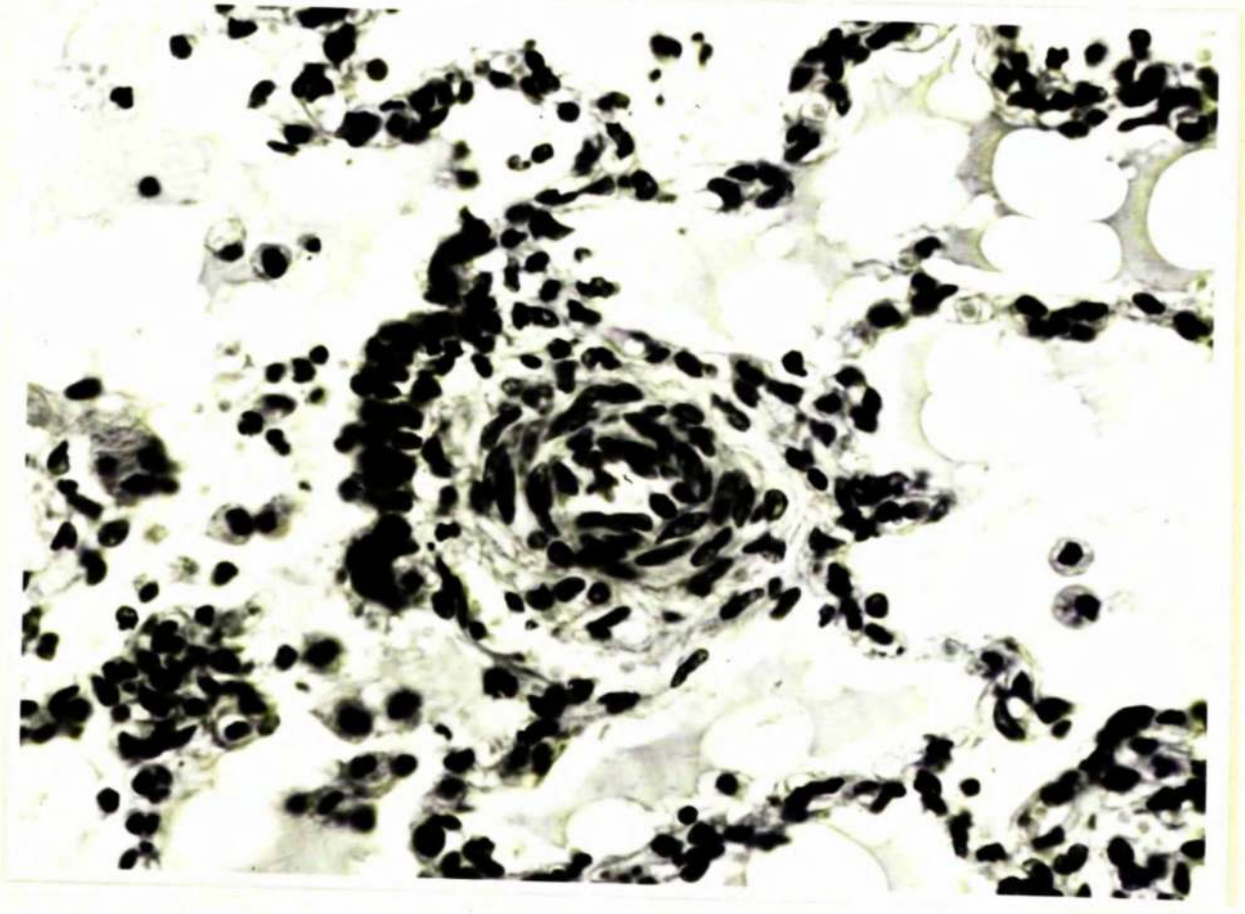
Autopsy

The heart was enlarged and weighed 3,028 g. The apex of the heart was rounded. The right ventricle was dilated and the wall grossly hypertrophied. The pulmonary valve was normal. High in the ventricular septum there was a large elliptical ventricular septal defect. The left ventricle was dilated and the wall was markedly hypertrophied. The ventricular septal defect was present immediately below the aortic valve, which was dextroposed, dilated, and had three large cusps. In the left ventricle at the ventral edge of the ventricular septal defect, a band of fibrous tissue extended out onto the ventricular surface of the anterior cusp of the mitral valve and formed a ring of fibrous tissue below the aortic valve giving rise to subaortic stenosis. The animal had died in congestive cardiac failure and there was subcutaneous oedema in the brisket region. In addition, a considerable amount of straw-coloured fluid was found in the thoracic and abdominal cavities, and there was oedema in the mesentary adjacent to the coils of the colon. The liver was enlarged and showed changes of chronic venous congestion.

Histological examination of the lungs showed proliferative changes in the arterioles attributable to pulmonary hypertension (Figure 67).

No abnormalities were found in the foetus.

Figure 67 Proliferative changes in Lung Arterioles and Pulmonary Oedema. (20536).



b) (ii) Malformations of the ventricular septal complex in cattle - Discussion

It is impossible to get the true incidence of congenital lesions in cattle from this series. Congenital lesions involving the ventricular septum in cattle have been found more frequently than lesions of the atrial septum, or of the pulmonary or aortic valves.

The initial detection of all cases seen alive has depended upon the use of the stethoscope. The stimulus for its use has been a respiratory disturbance. Random stethoscopic examinations of the chest of apparently normal calves also led to the detection of two cases. The primary cardiac finding was a loud systolic murmur; occasionally a diastolic murmur was also detected.

Cyanosis and polycythaemia were not observed in animals in Group I but were seen in cases in Groups II and III, being a constant feature in the animals whose lesions were classified as Tetralogy of Fallot. From the limited number of cases observed in Group III it appeared than when there was a dextroposed aorta but no pulmonary stenosis, cyanosis was not present early in life. Cyanosis is not a common clinical sign in cattle and, apart from congenital heart cases, has only been observed by us in dyspnoeic animals in the terminal stages of pneumonia.

Specialized techniques have aided the diagnosis of these anomalies.

Electrocardiography was often able to predict cardiac hypertrophy but was unable to predict which ventricle was involved to the greatest greater extent. Where pericarditis or pericardial effusions were present the QRS complexes were of normal size or smaller.

Pressure recordings from the right side of the heart detected right atrial and right ventricular hypertension in several cases, and proved the existence of pulmonary hypertension in one case and pulmonary hypotension due to pulmonary stenosis in another. Because of the size of the animals fluoroscopy was not employed, but the pressure records were identified from the shape of the pressure curves. As a result of previous experience and experiments, the shape of the curves was known to indicate that the catheter was in a particular site. In some cases, however, bizarre curves were obtained which could not be identified accurately. In the one case of a successful catheterization of a pulmonary stenosis, the serial dye-dilution curves proved that the pressures were from the sites stated.

Dye-dilution curves were used in a qualitative manner only to detect abnormal pathways of blood flow. They have demonstrated left to right shunts through ventricular septal defects and also right to left shunts in animals with complex anomalies. Analysis of the abnormal curves obtained from some cases was not always possible before death but correlation of the blood flow and the lesion found at autopsy could be made in retrospect.

Retardation of growth was apparent in all animals with a ventricular septal defect associated with other complex anomalies.

Skeletal abnormalities were seen in one animal in Group I, and one animal in Group III. In addition, in the latter animal there was anophthalmos and although it has been shown that vitamin A deficiency can

cause eye defects and cardiac deformities in experimental animals, there was no evidence that the dam of this animal had suffered from a deficiency of vitamin A.

Abscesses, which have been described as a frequent complication of some congenital cardiac anomalies of man, were present in two cases at several sites, but not in the brains.

Group I

All of the ventricular septal defects occurred in the outflow tracts of the ventricle and involved that part of the heart which is the pars membranacea. In the right ventricle they were posterior to the crista supraventricularis and in the left ventricle were found just below the junction of the anterior and right cusp of the aortic valve, or extending from this site ventrally. In case 18961, however, although the ventricular septum was not completely perforated, the deficiency of tissue was in exactly the same situation as in the other animals with complete defects.

The severity of the functional disturbance varied directly with the size of the defect, and duration of survival varied inversely.

Associated congenital lesions which were probably not functionally significant were found in four cases. There were small atrial septal defects in two animals, horizontal ridges of fibrous tissue on the endocardium of the left ventricle below the defect in two animals, and in one animal anomalous origin of the left brachial artery from the aortic arch.

Bacterial endocarditis of the tricuspid valve and the right ventricular side of the defect was a major complication in one case, since clinically the functional disturbance was of the type usually seen as bacterial endocarditis rather than that produced by a ventricular septal defect.

In our series, in one instance congenital cardiac lesions were found in a heifer and her foetus. It was not possible to demonstrate any other familial tendency, but a genetic factor has been suggested in one herd of Hereford cattle (Belling, 1962).

Group II

The ventricular septal defects were again large and high in the interventricular septum. The pulmonary valve was abnormal in all cases and, as well as being hypoplastic, in two instances only two cusps were present. In cases with Tetralogy of Fallot, pulmonary stenosis may be at the level of the pulmonary trunk, the pulmonary valve, or infundibulum. Three of the cases recorded here had infundibular stenosis and in one case stenosis was valvular. The ductus arteriosus was patent in all cases, but could only be definitely considered abnormal in the three seen alive. This is not a common feature of Tetralogy of Fallot in man (Edwards, 1960), and undoubtedly provides a useful collateral channel by which the pulmonary flow can be augmented. In addition to patency of the ductus arteriosus a small atrial septal defect was found in one animal, and abnormalities of the origin of the coronary arteries, in particular of the right coronary artery, were found in two cases.

Group III

All of the animals in this group had complicating lesions which were probably functionally significant. These were in case 20127, a large atrial septal defect; in case 21809, coarctation of the isthmus of the aorta; in case 16040, atresia of part of the aortic arch and the pulmonic-aortic window; and in case 20536, subaortic stenosis.

Cyanosis was not present in the calves, but they had marked exercise intolerance. If they had survived, cyanosis probably would have developed due to changes in lung vessels and subsequent pulmonary hypertension.

Although a functionally significant atrial septal defect was seen only once, small atrial septal defects in the fossa ovalis due to over-resorption of the septum primum were seen in four cases. Foramina ovales which are anatomically patent but functionally competent can be considered normal in cattle.

In the two animals which had survived for over 18 months, histological examination of the lungs showed proliferative changes in the pulmonary vasculature which were due to pulmonary hypertension.

c) (i) Traumatic Pericarditis in cattle - Case Reports

Metallic foreign bodies ingested by cattle tend to collect in the most anterior of the four stomachs, the reticulum. Thin, sharp objects such as nails or pieces of wire may be forced through the wall by contractions of this organ and an infective focus established. Figure 68 illustrates some of these objects. This focus may be in the peritoneal cavity, the liver, the lung, the pericardial sac and in rare cases may lead to a subcutaneous abscess perforating to the exterior. Because of the close proximity of the pericardial sac to the reticulum traumatic pericarditis occurs not infrequently (Figure 69).

Traumatic pericarditis is a well-recognised condition of cattle, which has been the subject of many clinical and pathological reports (Arthur, G.H., 1947, Blair,W.R. 1905, Holmes,J.R. 1960, Schleiter,H. 1958, and Stephens, T.K. 1944). One group of authors (Stowe,C.M. and Good, A.L., 1961) has reported on some physiological changes of one case of pericarditis in a cow.

Detailed studies were made of 13 cases.

Clinical Examinations

The clinical examinations of the animals in this study showed three distinct syndromes:

(i) Typical Traumatic Pericarditis which is well recognised. Subcutaneous oedema is usually a feature.

Figure 68 Objects removed from pericardium, mediastinum and reticulum of cattle.

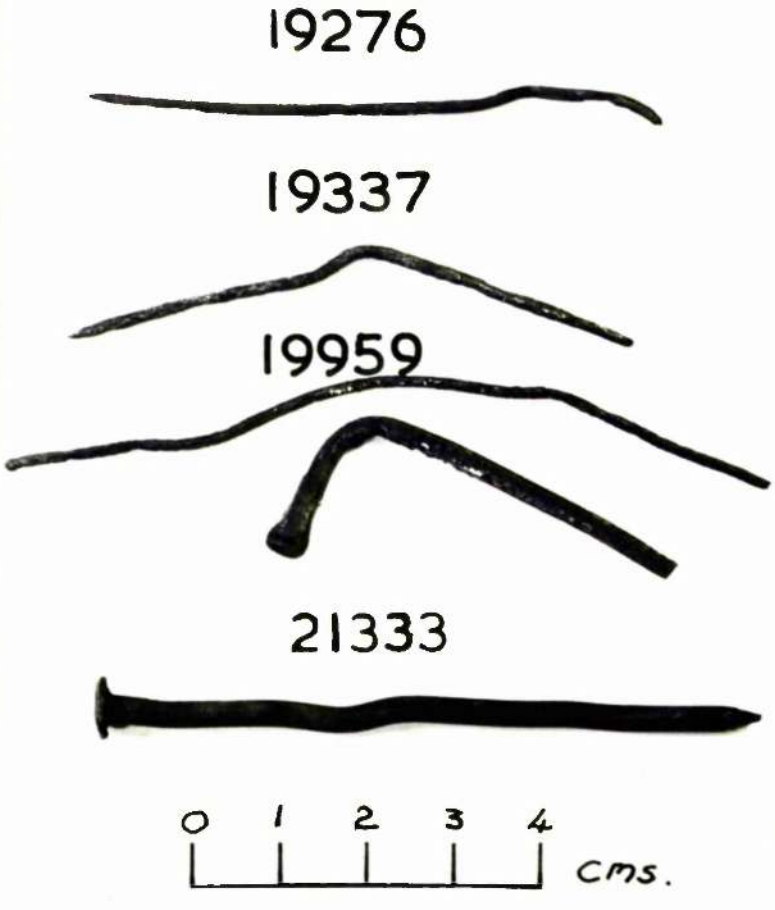
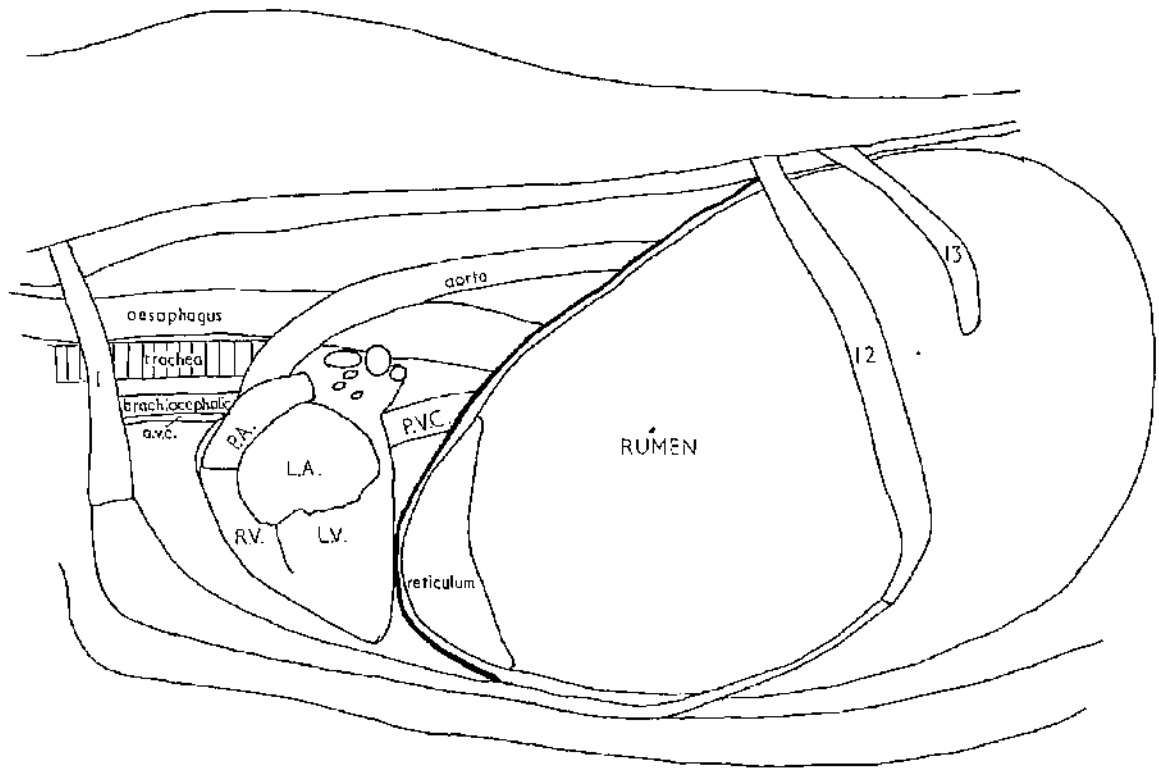


Figure 69 Sagittal section of bovine thorax and anterior abdomen



a.v.c. = Anterior vena cava

P.A. = Pulmonary artery

L.A. = Left atrium

R.V. = Right ventricle

L.V. = Left ventricle

P.V.C. = Posterior vena cava

12, 13 = ribs

(ii) Traumatic Pericarditis as a long-standing condition without oedema.

(iii) Traumatic Pericarditis manifest as an acute condition without oedema.

(i) Typical Traumatic Pericarditis

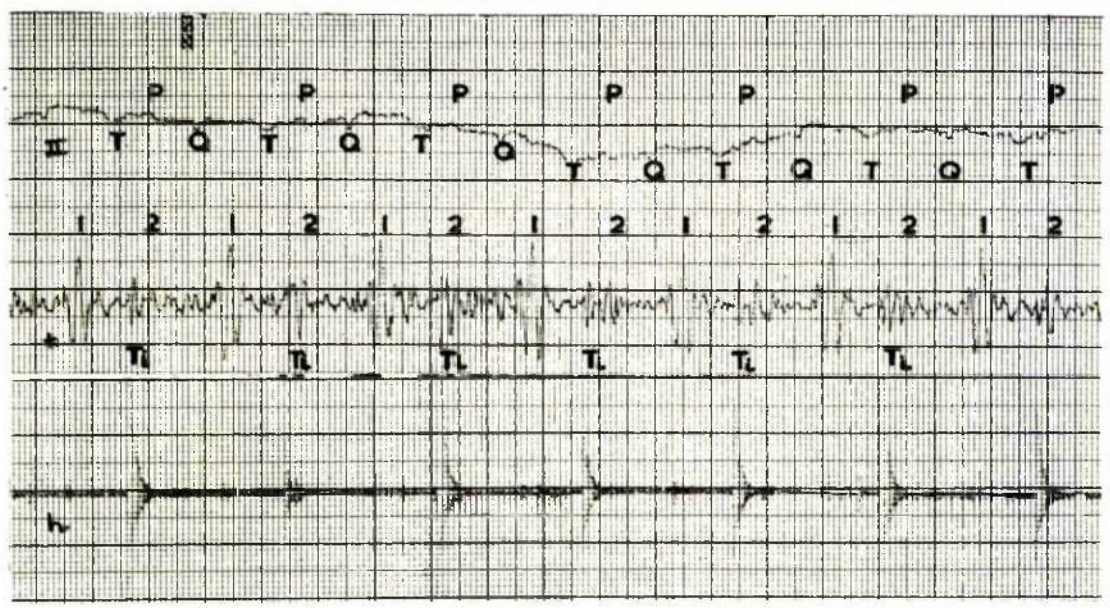
In the majority of cases the history indicated that the onset of clinical signs had begun about 12-14 days previously. The first sign noted was loss of, or the development of a capricious appetite. Following this there appeared the clinical signs described below.

The animals were dull, in poor bodily condition, standing with elbows abducted, and were unwilling to move. The jugular veins were visibly distended up to the mandible and there was a variable amount of oedema present in the submandibular space and brisket and, rarely, in the limbs. A slight pyrexia was usually present.

The respiratory rates were slightly increased from normal, with hyperpnoeic inspirations and often a double expiratory effort.

The pulse rate in all cases was increased from the normal of (72±10) per minute and the volume was fair or poor. On percussion of the chest there was a loss of resonance over the lower one third to a half. Auscultation of the thorax, in addition to indicating the abnormal respiratory movements described, demonstrated tachycardia, a muffling of heart sounds and occasionally the adventitious sounds described as 'tinkles' or splashing. Figure 70 illustrates the phonocardiographic record of a tinkling sound.

Figure 70 Heart sounds showing "tinkle" (22619)



1 = 1st. heart sound
2 = 2nd. heart sound
II = lead II electrocardiogram
t = low frequency sound
h = high frequency sound

Tk = Tinkle

P = P wave
T = T wave
Q = Q wave

} of E.C.G.

In addition to the clinical signs directly attributable to the cardiovascular system, six out of the nine animals examined had diarrhoeic faeces.

(ii) Traumatic Pericarditis as a long-standing condition without oedema

The two animals in this group showed different clinical signs from the previous nine cases.

There was a history of loss of condition. Appetite and thirst were normal, and there was no pyrexia. Tachycardia was present in one and both had poor pulse volumes. The respiratory rate was normal in one and increased in the other, and there was no loss of resonance on percussion of the chests.

The heart sounds were not muffled and in addition adventitious sounds occurred. In one the adventitious sound took the form of a systolic murmur, in the other a slapping sound was heard in phase with inspiration. Oedema was not present in either of the animals. The jugular veins were undistended in one and slightly distended in the second.

(iii) Atypical pericarditis manifest as an acute condition without oedema

The onset of illness was sudden. One animal was first observed recumbent, grunting and appeared to be in pain. The other was standing with elbows abducted, back arched and was very dull.

Tachycardia and poor pulse volumes were present in both. Slight

muffling of heart sounds was present in both and in addition a splashing sound obscured the second heart sound in one of the animals. Jugular veins were distended in one animal but not in the other. Subcutaneous oedema was not present in either animal. Both animals survived a short time only.

Haematological Observations

The significant haemological observations are given in Table 32, together with normal values for cattle blood. The results are grouped under the clinical classifications i, ii, and iii described.

Table 32 Haematological Data - Traumatic Pericarditis

	PCV %	R.B.C. mill/cu.mm.	Hb gm/100 ml	W.B.C. thou/cu.mm.	Neutrophils %	Lymphocytes %	Eosinophils %	Basophils %	Monocytes %
Normal	30±3	5-8	9-11	8-12	25-35	60-70	0-1	0-1	0.5
Group i									
18939	28	5.75	9.4	18	86.5	21.5	0.5		
19206	35	-	-	14.4	59	40.5			0.5
19276	27	4.06	8.3	13.75	83.5	16			0.5
19562	29	5.3	9.3	13.75	71.5	28.5			0.5
19959	28	-	9.4	6.36	41	58	1		
21333	34	5.9	10.8	20.05	91	8.5	0.5		
22619	28	4.6	8.7	27.9	88.5	11.5			
23939	24	3.84	7.2	14.00	84	16			
24386	20.5	3.82	6.9	12	68.8	31.2			
Group ii									
19337	24.5-	4.2	7.9	8.05	45	41.5	13.5		
22084	31.5-	4.86	9.6	9.8	33	55	9	3	3
Group iii									
22958	26	5.5	9.1	17.8	81.5	18			0.5
24289	28.5	5.19	9.6	13.3	70.5	29	0.5		

Group i

In this group the majority (5 cases) showed some evidence of haemodilution with lowered packed cell volumes. It has been stated that a leucocytosis occurs in traumatic pericarditis and that this is a useful diagnostic feature (Arthur, G.H. 1946). The values obtained in all the typical cases except two confirmed this statement. One of these two cases was at the upper limit of normal. The reversal of the neutrophil-leucocyte ratio also agrees with published findings (Arthur, G.H. 1947 and Holmes, J.R. 1960).

Group ii

One of this group showed low packed cell volumes and low haemoglobin concentrations, suggesting haemodilution or some degree of anaemia since in this case there was no oedema. There was in one of these animals no evidence of a leucocytosis, but in the other, with low packed cell volumes, there was a reversal of the neutrophil leucocyte ratio.

Group iii

A leucocytosis was present in both animals with a reversal of the neutrophil-leucocyte ratio.

Biochemical Examinations

In Table 33 are given the significant biochemical determinations carried out in these cases.

Biochemical Observation - Pericarditis

Table 33

Cow No.	Na m.eq/litre	K m.eq/litre	Albumin gm/100 ml.	Globulin gm/100 ml.	Alkaline Phosphatase k.a. units	SGOT s.f. units	SGPT s.f. units	urea mgm/100 ml	urea urine gm/100 ml.
Normal	142±2	4.4±0.3	3.9	4.1	10	44±6	19±13	20	1 gm.
Group i									
18938	139+	3.2	1.2	6.0	11	78	5	29	2.6
19206	133+	3.8	1.7	5.9	13	61	58	39	1.6
19276	139+	3.4	3.42	3.42	7	169	11	34	2.5
19562	128+	3.7	1.8	6.2	4	95	7	51	3.2
19959	130-	4.0	2.1	5.1	3	104	16	30	2.8
21333	148+	2.8	1.2	6.0	7	-	-	96	2.6
22619	124+	2.8	1.4	6.8	8	29	4	100	3.8
24386	144	3.6	1.35	7.65	6.7	432	22	87	3.4
23939	133	4.0	1.5	5.8	2.3	176	10	393	2.6
Group ii									
19337	151	4.0	1.9	6.5	4	58	14	6	0.3
22084	133	5.0	2.5	7.4	3.8	71	20	16.4	1.2
Group iii									
22958	139	2.8	0.95	4.75	18	220	45	124	2.6
24289	138.5	4.0	1.9	6.3	3.5	93	7	22	0.8

k.a. units = King Armstrong units
s.f. units = Sigma Frankel units

Group i

In some of the animals in this group lowered sodium and potassium concentrations suggested some dilution of electrolytes by the fluid retention of heart failure.

All animals had high plasma globulins suggesting antibody reaction to infection. The low plasma albumin may have been due to haemodilution.

The high serum glutamic oxalic transaminase (SGOT) values were taken to indicate tissue damage. The fact that the other two enzymes, alkaline phosphatase and serum glutamic pteric transaminase (SGPT) were not elevated suggested that there was little biochemical evidence of liver damage.

Group ii

In this group, the distinctive biochemical difference was that there was no evidence of uraemia and water retention.

Group iii

Of these two animals, one showed uraemia and high urine urea, while the other animal did not. Both showed elevated serum glutamic oxalic transaminase values.

Blood and Plasma Volume Determinations

The values for the blood and plasma volumes are given in Table 34.

Table 34

Blood and Plasma Volume Determinations

Cow No.	Weight Kg	Blood Volume litres	Blood Volume ml/kg	Plasma Volume litres	Plasma Volume ml/kg	Subcutaneous Oedema
Normal Mean of 30	408	25.7	63+8	20.4	50+8	Nil
Group i						
18938	473	29	60	21	44	+++
19206	308	24	78	17	55	+++
19276	380	33.5	86	27	70	+++
19562	386	43	111	38	99	++
19959	450	23.6	53	17	37	Nil
21333	445	---------- Not Determined---------				++
22619	364	32.4	89	24.8	68	+
23939	379	29.0	77	22	58	+++
24386	610	42	69	33	54	+
Group ii						
19337	383	19	50	15	39	Nil
22084	460	25	54	19.3	42	Nil
Group iii						
22958	360	18	52	13	37	Nil
24289	375	20	54	18	47	Nil

Group i In the majority of these cases even when there was oedema it was possible to demonstrate hypervolaemia and increased plasma volume.

Group ii No subcutaneous oedema was present and there was no evidence of hypervolaemia.

Group iii This group likewise showed neither oedema or hypervolaemia.

Blood Pressure and Intracardiac Pressure Determinations

The values found for arterial and right heart pressures are given in Table 35.

Group i

In the typical cases there was a marked elevation of the end diastolic pressures of the right side of the heart leading to venous engorgement of the proximate veins including the jugular. In addition, general venous engorgement as evidenced by the hypervolaemia (Table 34) aided the jugular and mammary distension. Evidence from the animals in which pressures were obtained within the pericardial sacs (Table 36) appeared to show that the fluid within them limited diastolic filling and determined diastolic pressure. Figures 71 and 72 illustrate pressure curves from two cows. In an attempt to maintain cardiac output, the systolic pressure was raised in the right ventricle. However, there was a reduction in the ventricular pulse pressure and in systemic arterial pressure.

Group ii

In the two cases there was slight elevation of the right sided pressures of the heart.

Group iii

In this group the slight elevations of right sided pressures were consistent with the slight degree of jugular distension.

In all groups the clinical quality of the pulse was generally in accordance with the magnitude of the pulse pressure measured, poor pulse volumes coinciding with small arterial pulse pressures and good pulse volumes coinciding with large arterial pulse pressures.

Table 35

BLOOD PRESSURE AND INTRA CARDIAC PRESSURE DETERMINATIONS

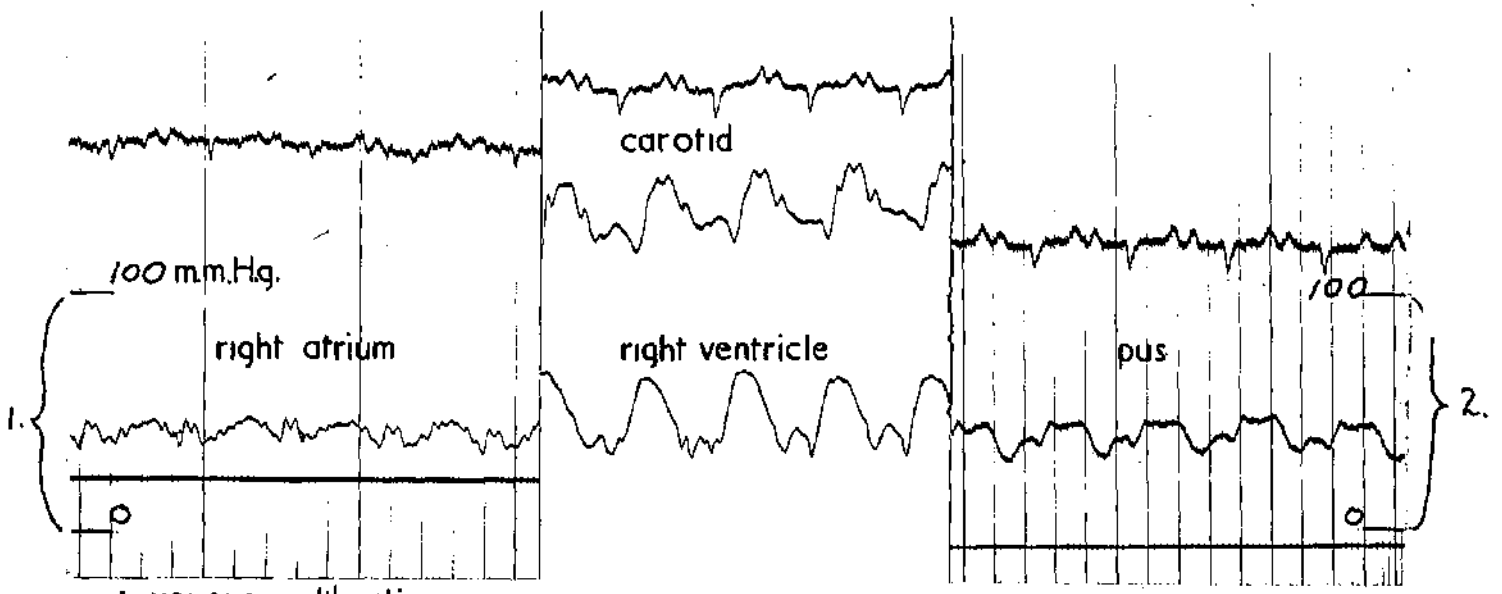
	Jugular	Right Atrium systolic	diastolic	pulse pressure	Right Ventricle systolic	diastolic	pulse pressure	Pulmonary Artery systolic	diastolic	pulse pressure	Brachial Artery systolic	diastolic	pulse pressure	Arterial pulse volume (palpation)
		mm.Hg.			mm.Hg.			mm.Hg.			mm.Hg.			
Normal	0	7	7	0	53	53	0	45	20	20	187	57	130	Good
Group i														
18938	30	50	20	30	80	50	30	75	45	30	130	35	95	Poor
19206	35	60	25	35	87	52	35	65	25	40	176	32	154	Poor
19276	42	46	16	30	76	44	32	60	28	32	136	31	105	Poor
19562	21	53	32	21	79	58	21	60	33	28	140	40	100	Poor
19959	34	44	10	34	72	40	32	70	22	48	174	52	122	Fair
22619	24	30	16	24	60	36	24	60	22	38	111	24	87	Poor
23939	50	60		50	80		40	78	18	60	---	---	---	Fair
24386	10	24	14	10	54	34	10	44	24	20	128	28	100	Poor
Group ii														
19337	0	18	11	7	46	40	5	45	30	15	145	40	105	Fair
22084	8	10	6	4	60	60	0	60	30	30	180	55	125	Good
Group iii														
22958	8	36	16	20	52	32	20	52	18	34	130	30	100	Poor
24289	10	18	8	10	45	45	0	40	20	20	140	40	100	Fair

Table 36

PUS PRESSURE-PERICARDIAL SAC COMPARED WITH END-DIASTOLIC PRESSURES IN RIGHT VENTRICLE

Animal	Pus Pressure mm.Hg.	Mean Pus Pressure mm.Hg.	End-diastolic Pressure mm.Hg.
24386	28/8	18	10
19276	46/30	37	32
22619	26/20	23	24
23939	44/30	37	40

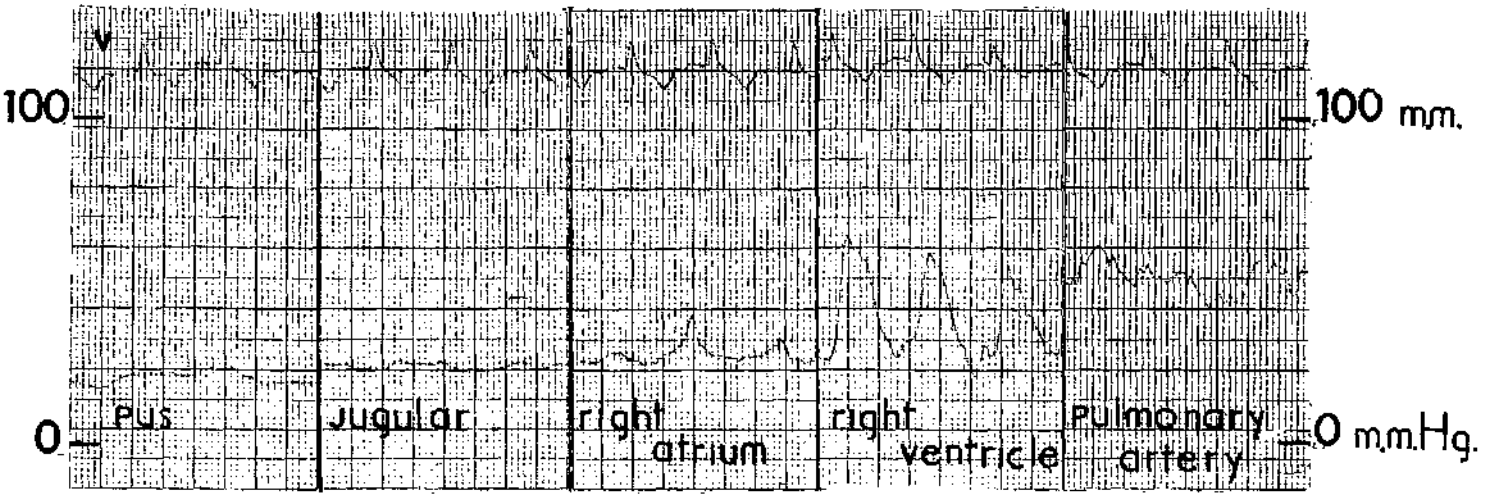
Figure 71 19276. Pressure Records



1. venous calibration

2. arterial calibration

Figure 72 22619. Pressure Curves Right Heart and Pressure in Pericardial Sac



paper speed : 25 m.m/sec.

v = v lead electrocardiogram for timing

Electrocardiographic Examinations

In Table 37 are given the parameters of the electrocardiograms of the animals in this study.

Group i

In this group the electrocardiograms showed very low complexes. With such complexes, somatic tremor often made interpretation very difficult. The low complexes obtained appeared to be due to the excess fluid present between the heart and the recording electrodes. Figures 73, 74 and 75 illustrate 3 such records.

Group ii and Group iii

Complexes in these groups tended to be of normal size.

All groups exhibited tachycardia and a shortening of the T-P interval, with the exception of one animal in Group ii.

In the majority of cases the P-R intervals were prolonged at the heart rates measured, suggesting some interference in conduction between atria and ventricles.

Cardiac Output Determinations

The values obtained from the cardiac outputs are given in Table 38.

Table 37

E.C.G. PARAMETERS - PERICARDITIS

Cow No.	Lead II Heart Rate/ Minutes	P-R Interval Seconds	T-P Interval Seconds	Wave Amplitude - centimetres P	Q	R	S	T
Normal	60 - 80	0.1-0.28	0.23-0.18	.03-0.18	.03-1.0	.03-2.6	.03-.25	0.3-1.10
Group i								
18938	108	0.2	0.04	0.05	0.1	-	-	0.1
19206	102	0.2	0.02	0.1	0.15	-	-	0.1
19276	102	0.24	0.02	0.1	0.2	-	-	0.15
19562	115	0.2	0.0	very low unanalysable				
19959	110	0.2	0.02	0.1	0.3	-	-	0.1
21333	99	0.24	0.06	0.1	-	0.2	0.2	0.15
22619	112	0.2	0.0	0.1	0.1		Analysis difficult	
24386	120	0.24	0.0	0.05	0.2	-	-	0.2
23939	125	0.16	0.04	0.1	-	0.2	0.1	0.1
Group ii								
19337	100	0.24	0.15	0.2	0.1	0.8	-	0.2
22084	70	0.16	0.28	0.2	0.0	0.6	-	0.3
Group iii								
22958	105	0.24	0.0	0.05	-	0.15	0.5	0.5
24289	96	0.16	0.12	0.1	0.6	0.1	0.0	0.5

Figure 73 E.C.G. Typical Pericarditis

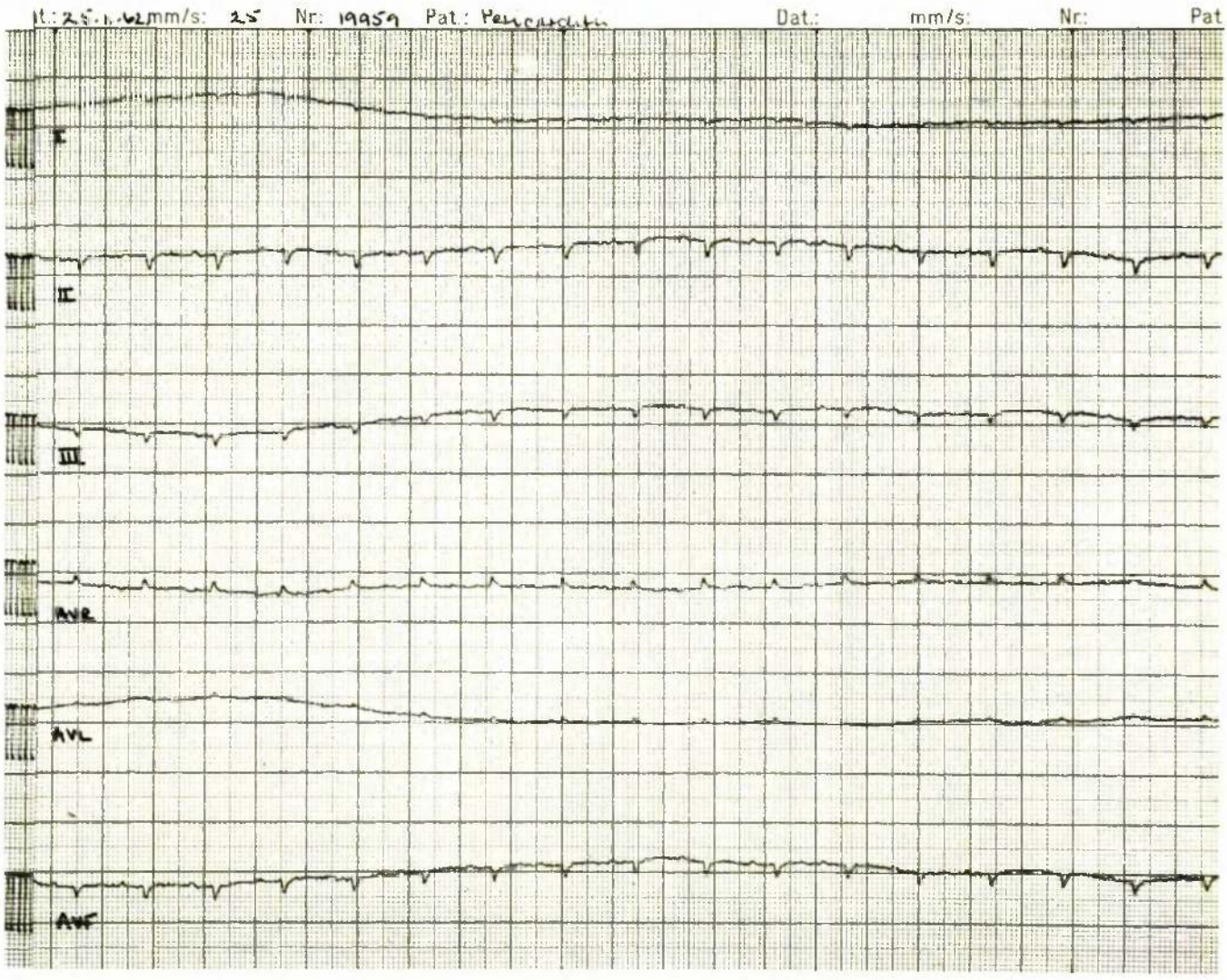


Figure 74 E.C.G. Typical Pericarditis

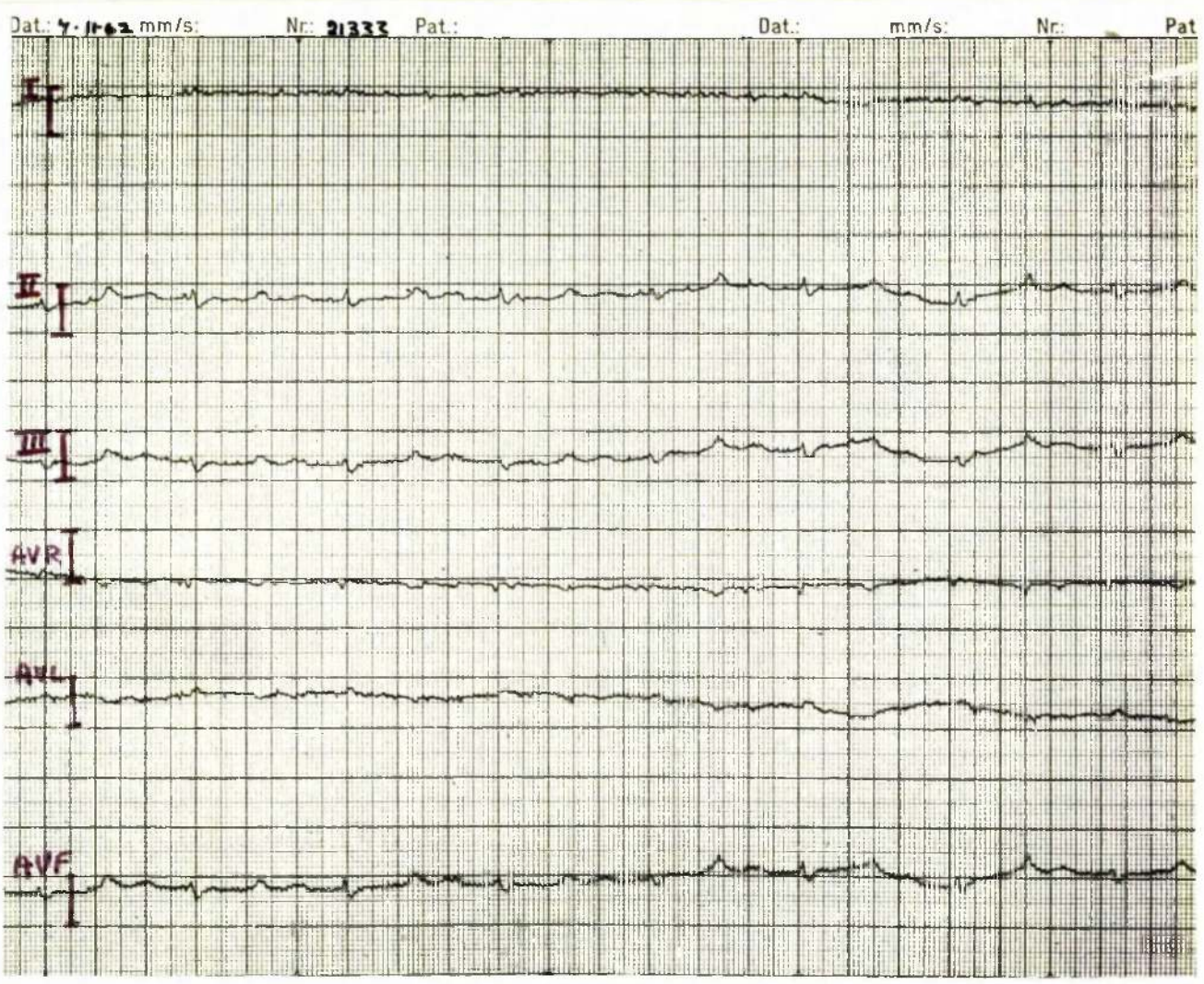


Figure 75 E.C.G. Typical Pericarditis

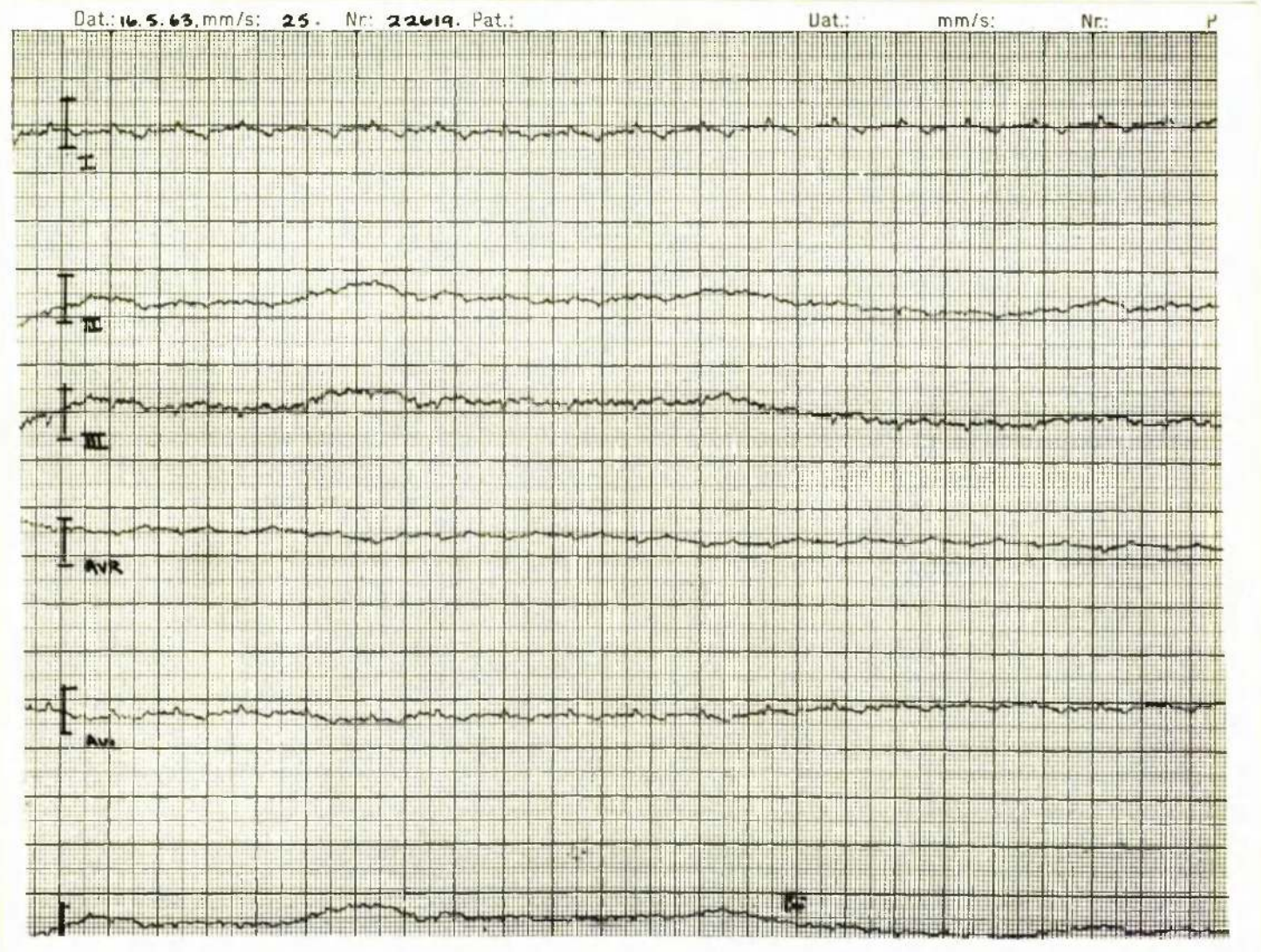


Table 38

CARDIAC OUTPUT DETERMINATIONS

Cow No.	Body Weight	Cardiac Output litres/min.	Cardiac Output ml/Kg body wt/min.
Normal	408	46	113±11
Group i			
18938	473	28	60
19206	308	27	89
19276	380	23	61
19562(a)	386	29.4	76
19562(b)	386	25	64
19959	447	30	67
21333	446	33	74
22619	364	23	63
23939	374	32	86
24386	608	51	84
Group ii			
19337	383	33	86
22084	460	57	120
Group iii			
22958	350	42	120
24289	375	47	125

Group i

All the typical cases with muffled heart sounds showed decreases in cardiac output from the normal values previously determined. The use of body weight to obtain a comparison between animals may be argued as invalid, since in oedematous animals there is an increased extracellular fluid. However, since this fluid depends upon sodium retention and sodium is freely diffusible in extracellular fluid, this fluid must play a part in the dynamics of the circulation, thus its weight could be taken into account when considering the output of the heart.

Group ii

The decrease in cardiac output in case 19337 may have been due to a decreased blood volume.

Group iii

These two animals showed no decrease in cardiac output and this suggested that the clinical signs observed were not primarily due to a decrease in cardiac activity.

Dye dilution curves from 7 typical, 1 atypical long-standing and 1 acute case are illustrated in Figures 76, 77, 78, 79, 80, 81, 82, 83 and 84.

18938 10.11.61. Pericarditis.

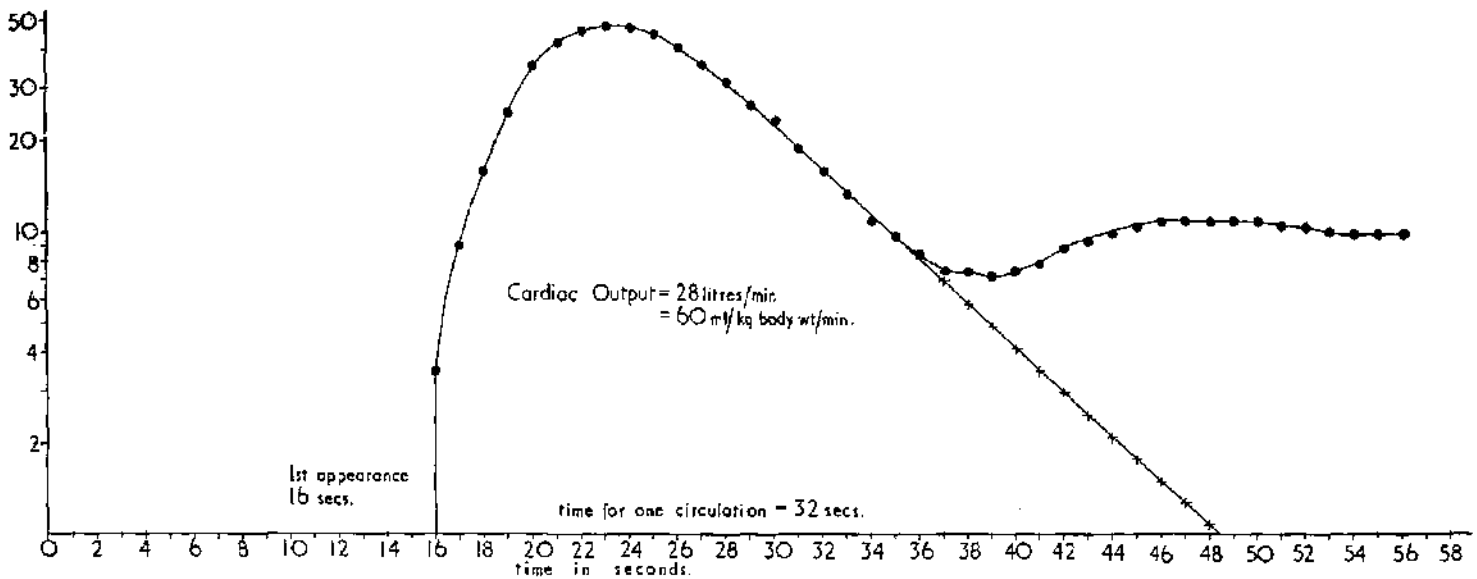


Figure 76 Typical Pericarditis

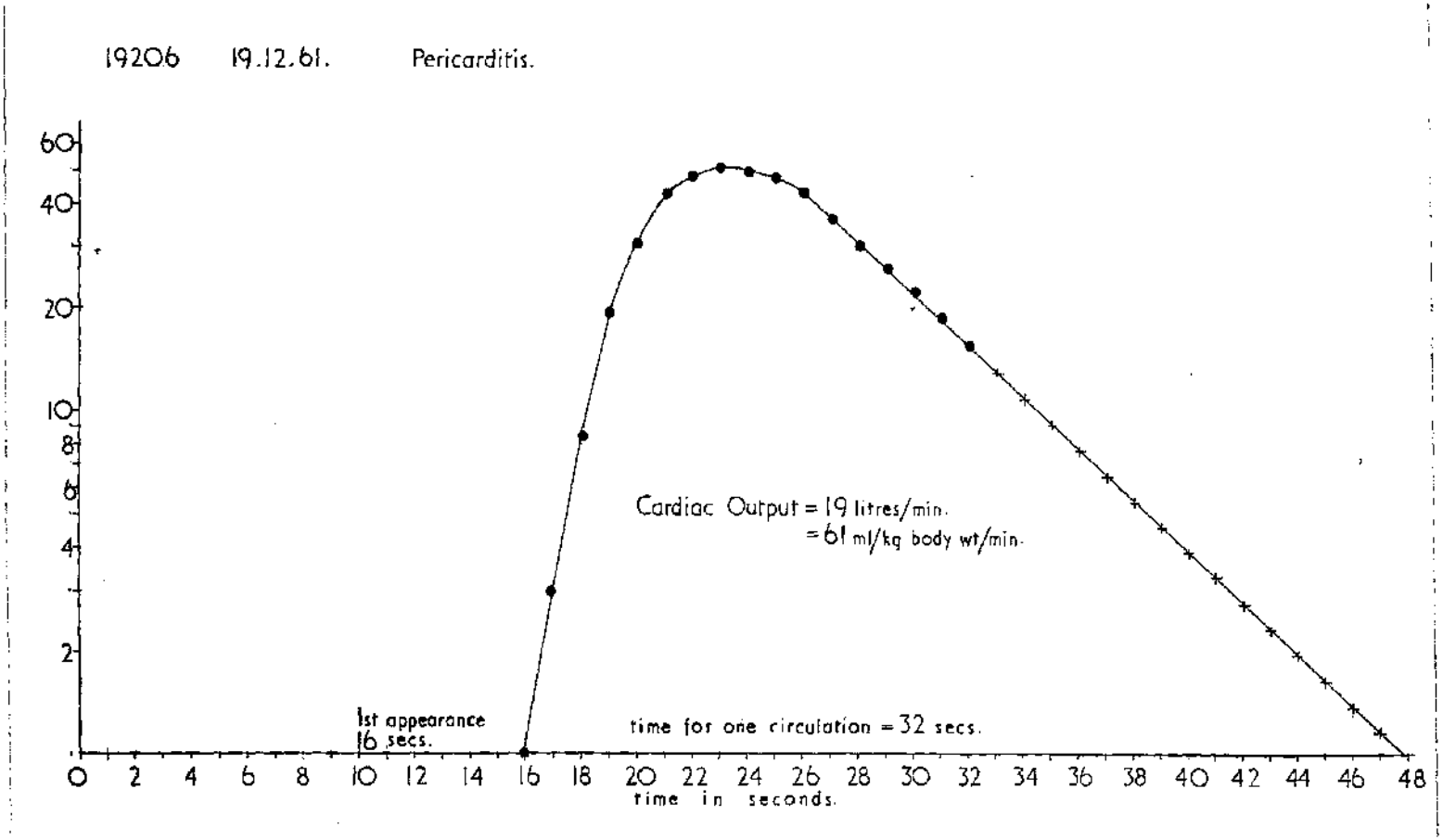


Figure 77 Typical Pericarditis

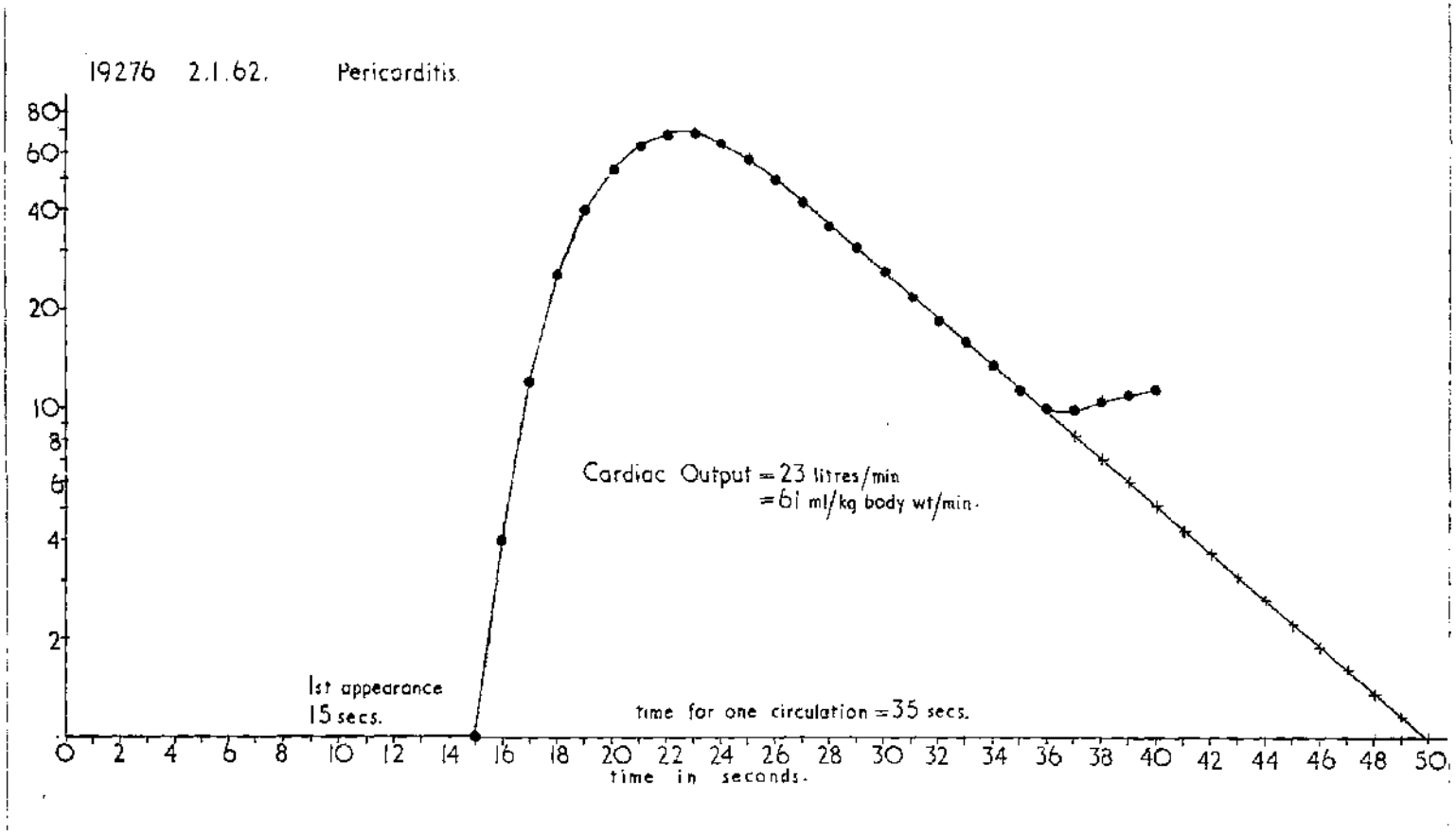


Figure 78 Pretal Pericarditis

19562 9.2.62. Pericarditis.

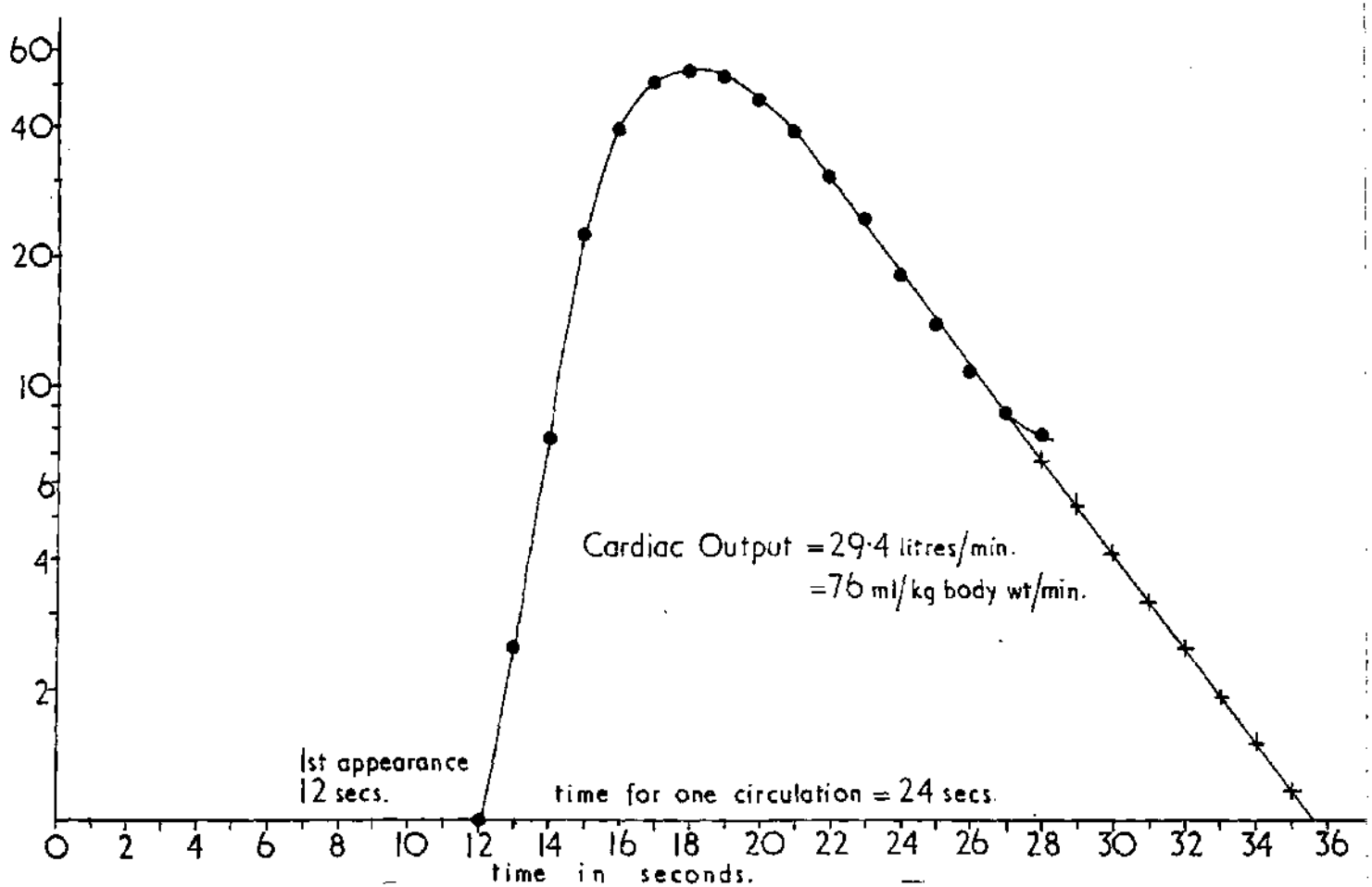


Figure 79 Typical Pericarditis

19959 17.4.62. Pericarditis.

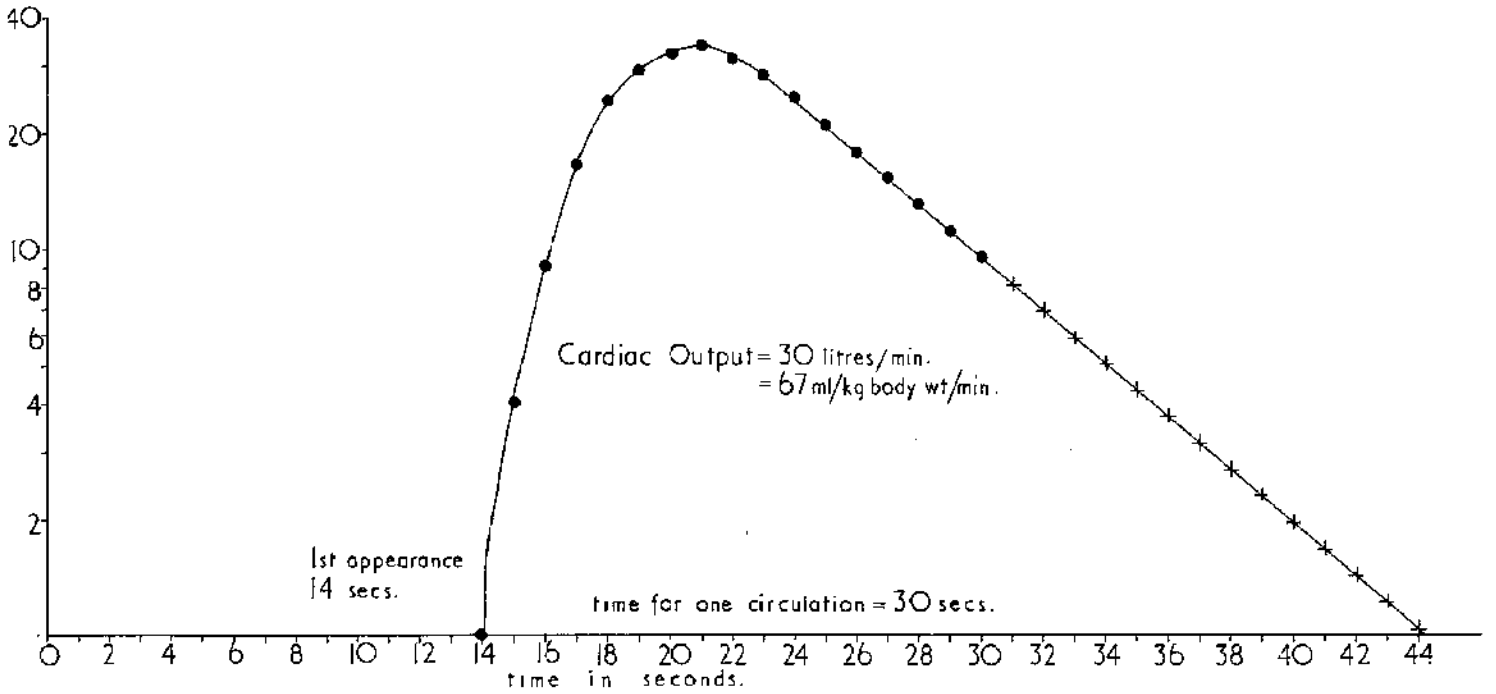


Figure 80 Typical Pericarditis

21333 7 11 62 Pericarditis.

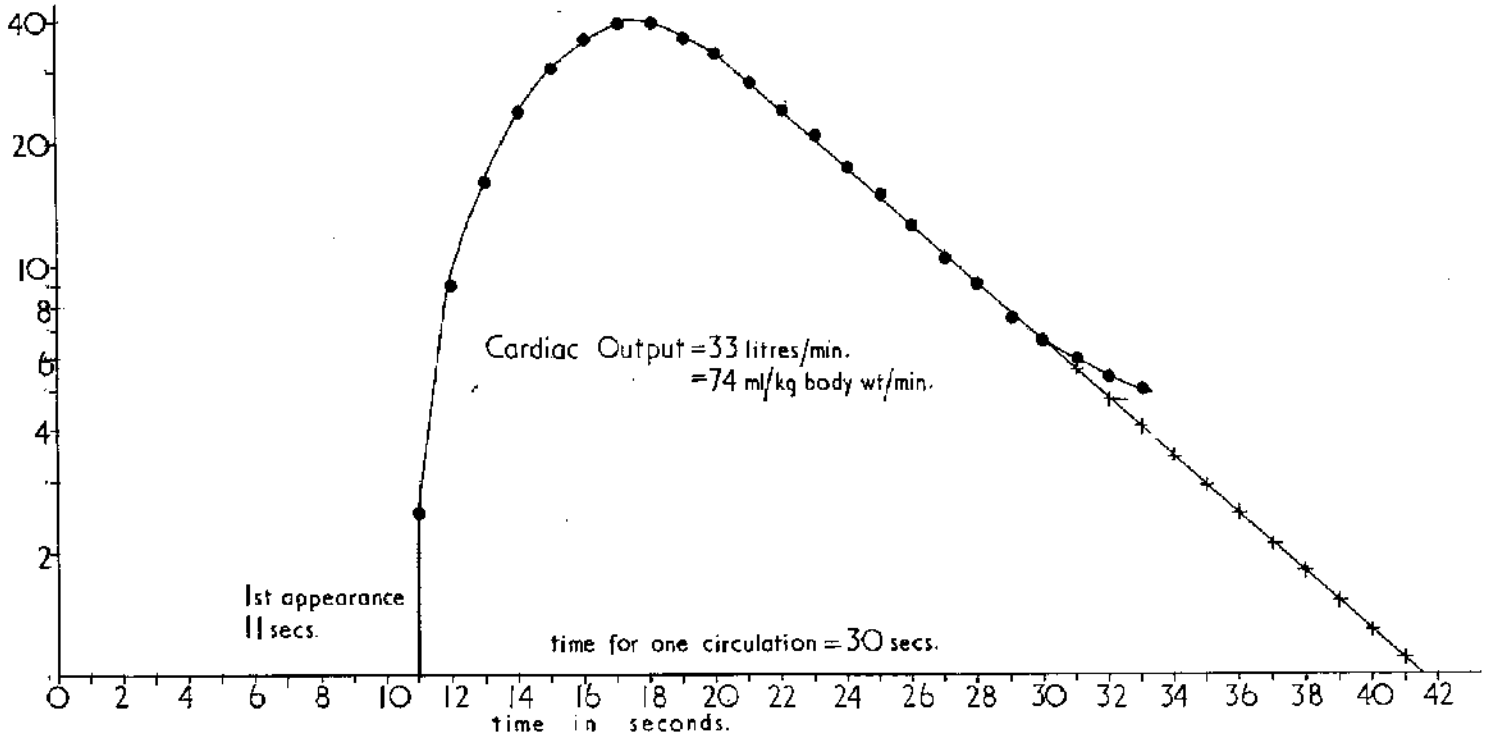


Figure 81 Typical Pericarditis

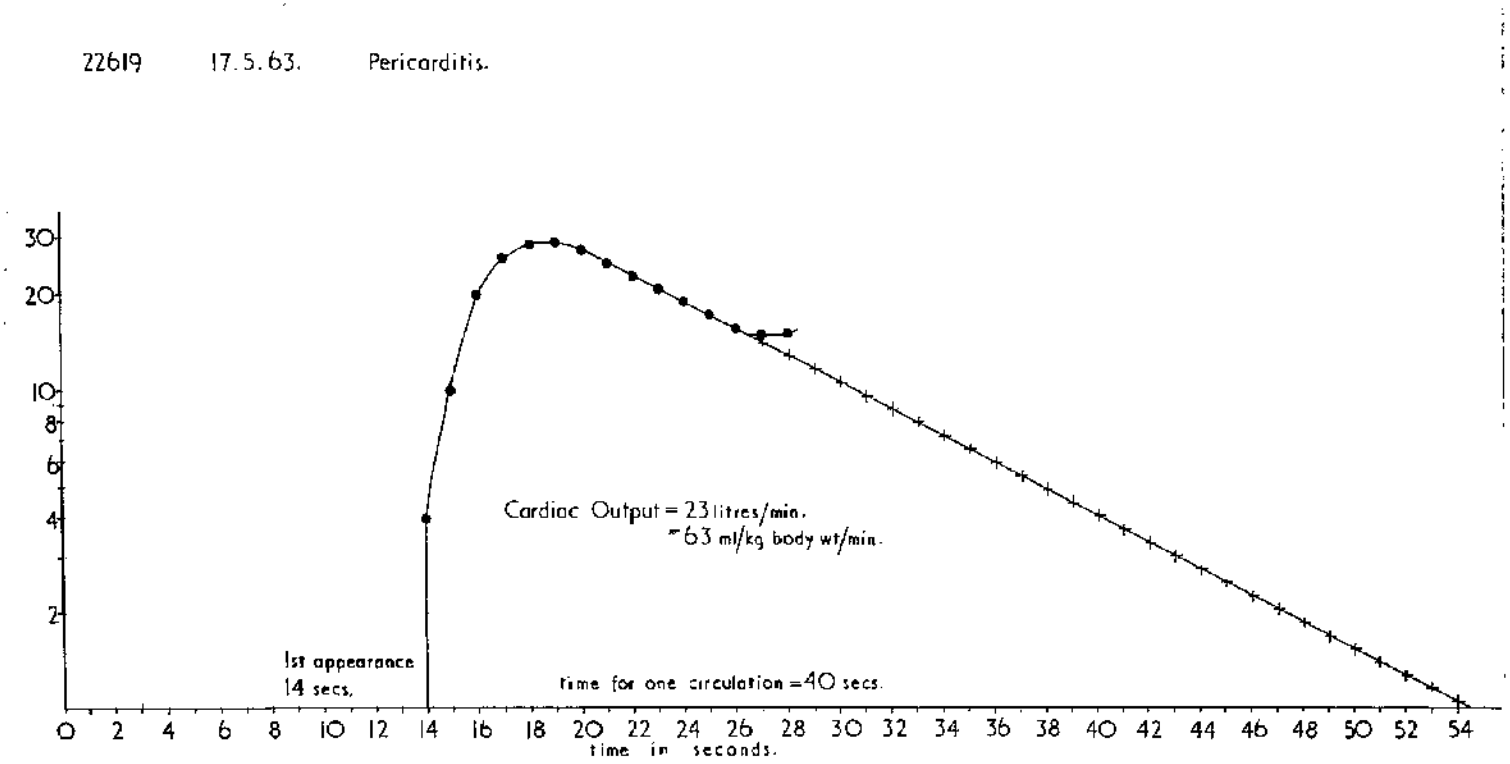


Figure 82 Typical Pericarditis

Figure 83

1933?: Atypical Chronic Pericarditis

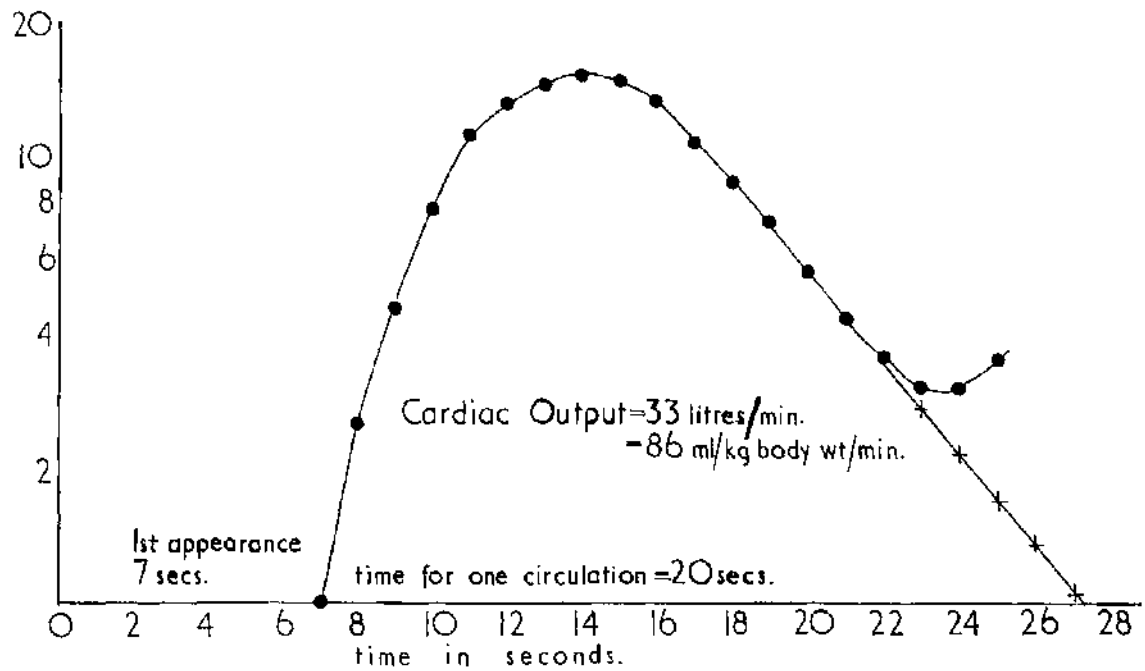
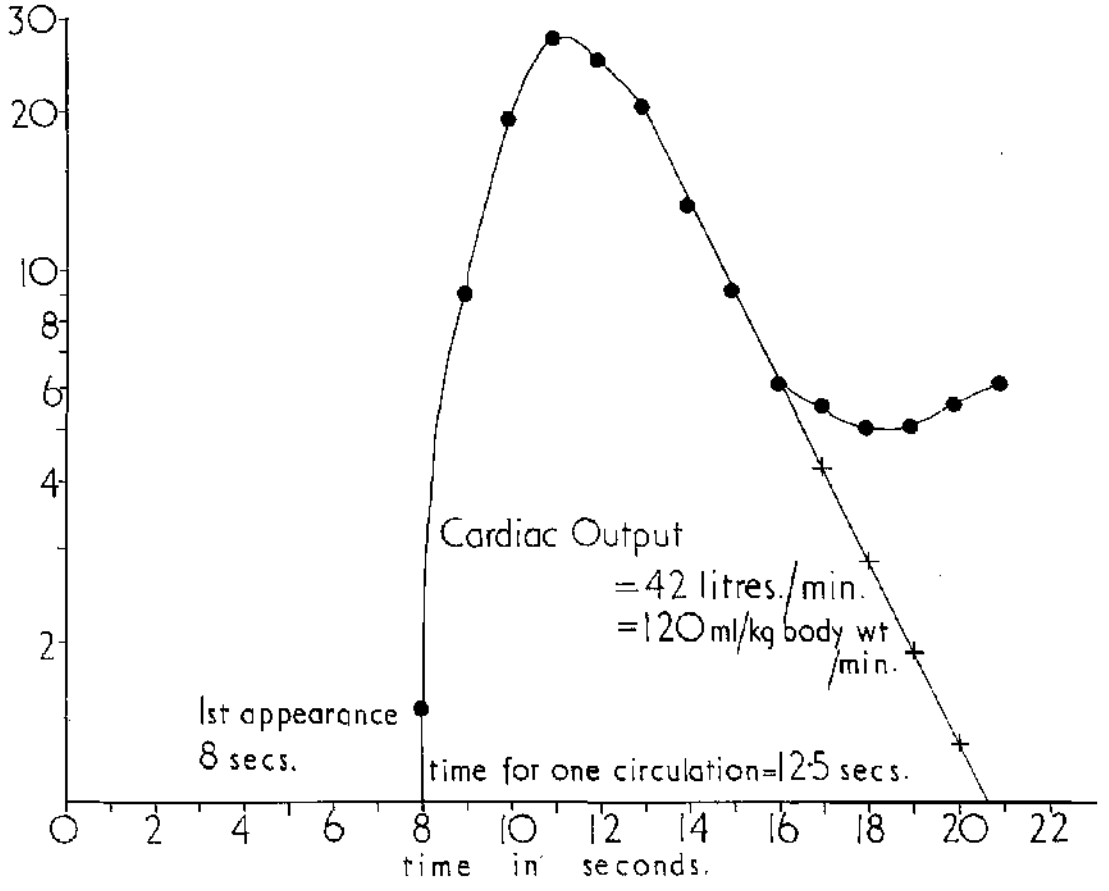


Figure 84

22958: Atypical Acute Pericarditis



Pathology - Group (i)

The abnormal amounts of interstitial fluid which were visible at postmortem are shown in Table 39 below.

Table 39

Distribution of Excessive Amounts of Interstitial Fluid in Animals in Group (i)

Number	Subcutaneous Oedema	Thoracic fluid (litres)	Pericardial fluid (litres)	Ascitic fluid (litres)	Abomasal Oedema	Mesenteric Oedema
18938	+++	6.0	2.0	27.0	+++	+++
19206	+++	10.0	6.0	10.0	++	++
19276	+++	7.0	5.0	--	---	---
19562	++	3.0	4.0	4.0	+	+
19959	---	30.0	15.0	10.0	---	---
21333	++	--	5.0	--	+	---
22619	+	7.0	6.0	--	---	---
23939	+++	4.5	7.0	0.3	---	---
24386	+	0.5	11.5	--	---	---

When subcutaneous oedema occurred the yellowish oedema fluid was present in one or all of the following sites: below the mandible, in the ventral aspect of the neck, in the brisket and along the abdomen, extending to the udder.

Animals with severe oedema also had fluid subcutaneously on the sides of the thorax as high as the costochondral junctions, in the forelegs from the shoulder joints to the carpus and in the inner aspect of the hind legs down to the hocks. The thoracic fluid was either serous or reddish brown and foul smelling, depending on the presence or absence of active pleurisy. This fluid usually contained a large amount of fibrin, and was bilateral in all cases. When ascites was present, the fluid was serous in type, and contained moderate amounts of fibrin. Oedema in the mesentery was always most prominent around the coils of the colon (Figure 85) and in the abomasum it was found either subserosally on the greater curvature, or in the folds of the body of the organ. Occasionally oedema fluid was present in small amounts along the lesser curvature of the abomasum.

Pericardium and Heart: The pericardial sac was grossly distended (Figure 86 a and b) and the wall was thickened by white fibrous tissue. The cavity contained from 2-15 litres of fluid whose appearance usually took one of two forms. It was either very thin liquid, which was reddish brown, grey or yellow, and foul smelling, or thick yellow pus which also had a foul smell and in which many bright yellow soft clots of coagulated fibrin and pus could be found. This coagulated material sometimes encased the heart completely in a layer about 1 cm. thick, which could easily be stripped off. Gas was present in all cases but was unusually abundant in case 22619, in which probably about 6 litres of gas had accumulated. Prior to opening, the pericardium had been very

Figure 85 Mesenteric oedema adjacent to the coils of the colon

Figure 86(a) Lateral view of pericardial sac

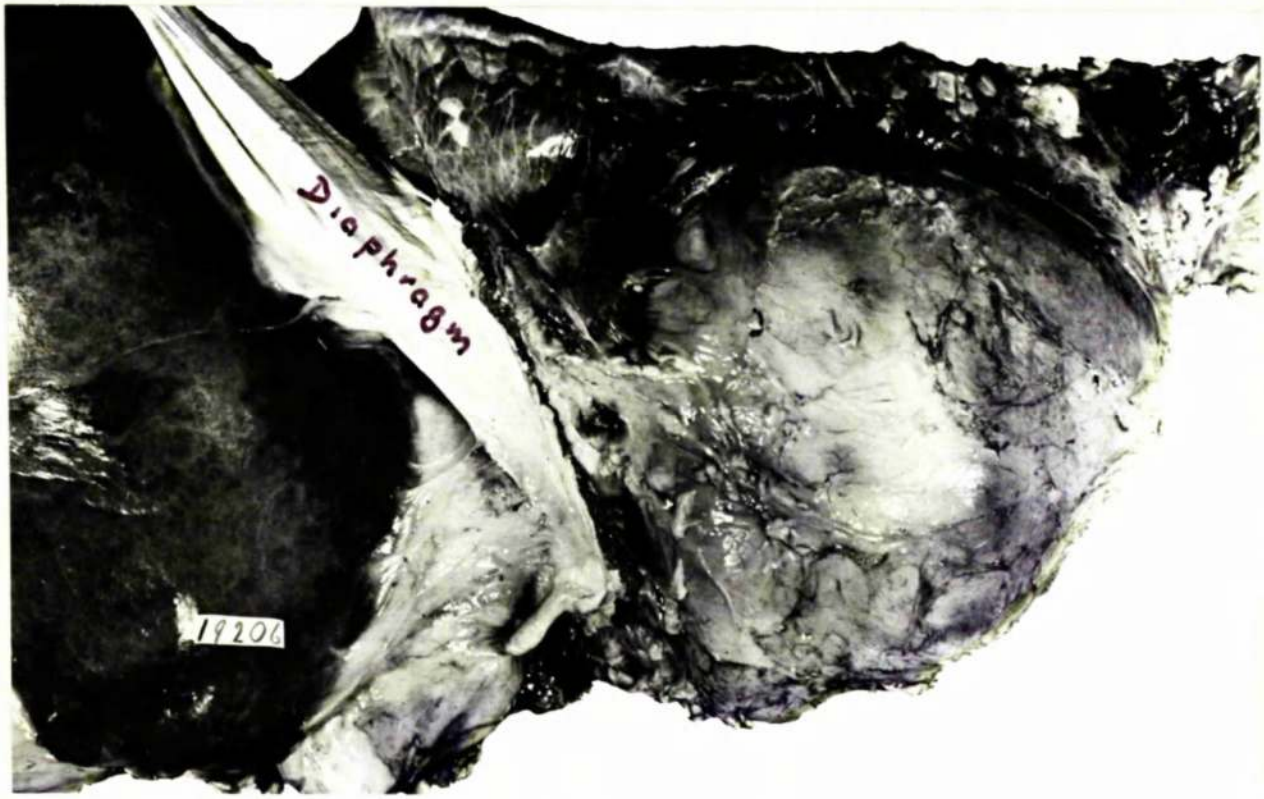
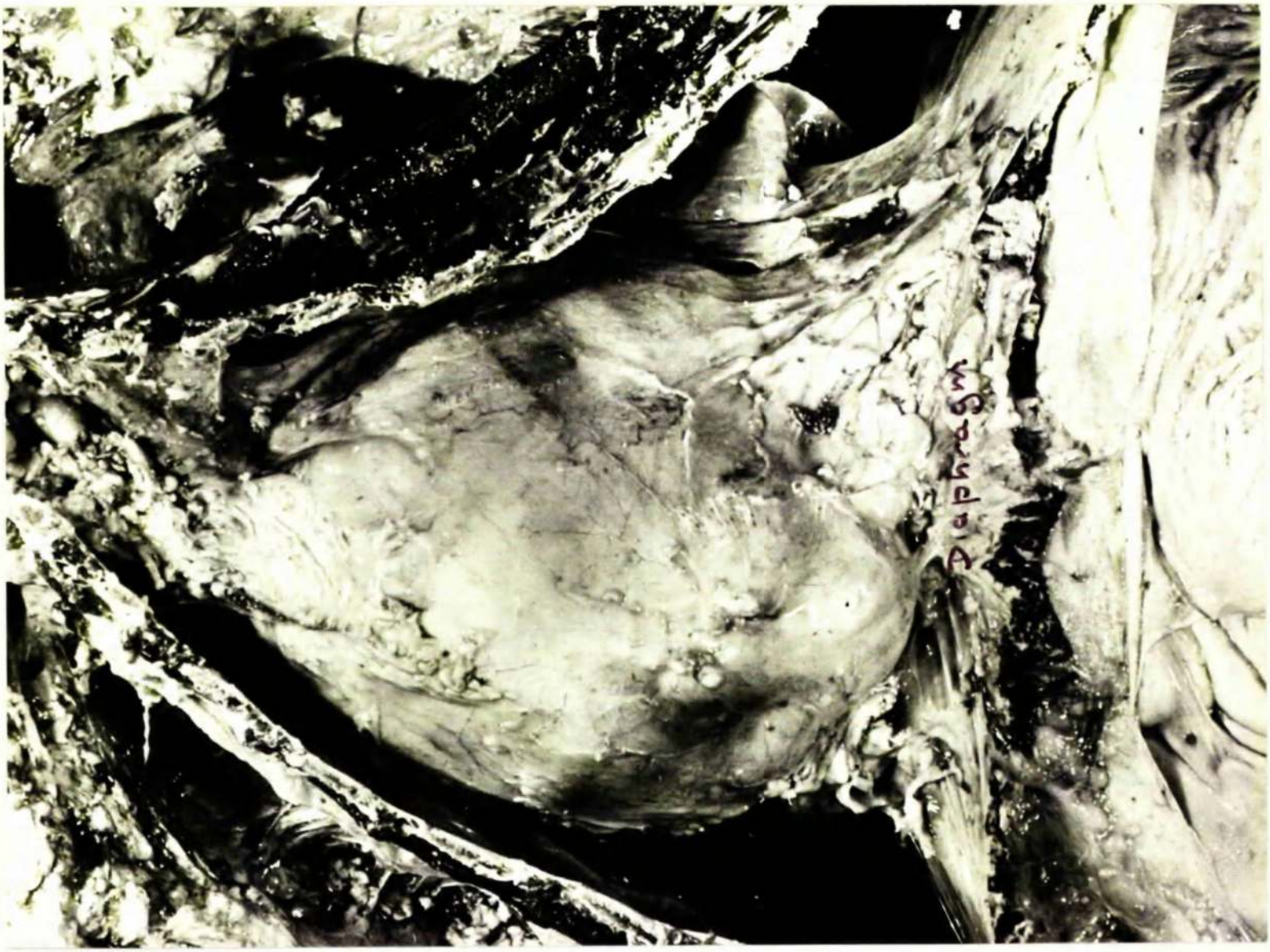


Figure 86(b)

Dorsal-ventral view of pericardial sac

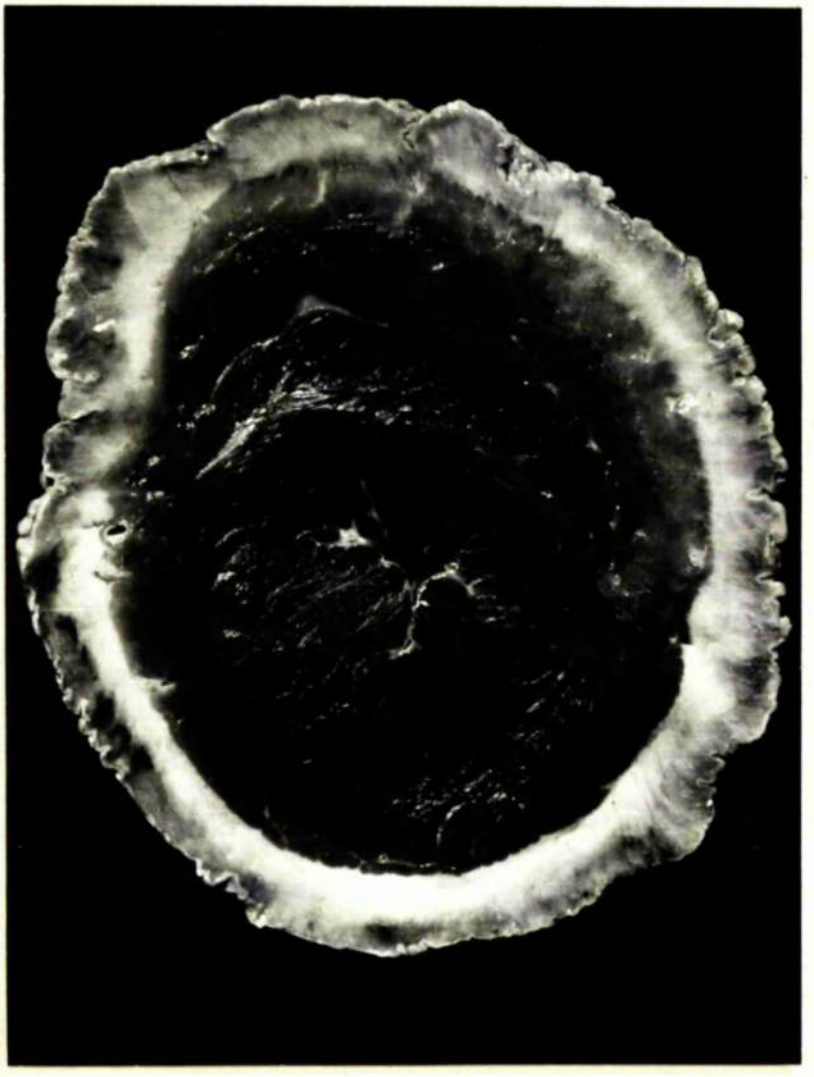


tympanitic in this animal. The cavity containing fluid and gas did not always encircle the heart completely. In four cases the heart was suspended in the cavity by the great vessels, and the atria and ventricles hung free. In one of the five other cases, the posterior border of the heart was adherent to the adjacent region of the pericardium (Figure 87) and in the remaining four, the cavity was mostly present on the anterior and right sides of the heart. The remainder of the pericardial cavity in these animals was obliterated by fusion between the visceral and parietal layers of the pericardium, although in case 18938 the apex and 7 cm. of the wall of the left ventricle were not involved in any inflammatory process and the heart at this point was covered by normal epicardium. In cases with yellow pus in the pericardial cavity, the outer layers of the epicardium also had a bright yellow colour, whereas in the other cases it was usually a brownish yellow, dirty colour and had a bosselated appearance due to variations in the thickness of a layer of spongy, brownish-yellow fibrin and pus on top of the white fibrous connective tissue. The epicardium was grossly thickened in all cases over the ventricles and the atria by the fibrous connective tissue, which varied in different cases from 0.7 cm. to 1.5 cm. thick (Figure 88). Most of the epicardial thickening was due to this glistening white fibrous tissue with only a thin layer of necrotic material on the outer surface. The parietal pericardium was usually about the same thickness as the epicardium and had a similar appearance and colour.

Figure 87

Heart adherent to the pericardium posteriorly

Figure 88 Fibrous Connective Tissue Thickening of Epicardium



Mediastinum: The mediastinal tissues were grossly thickened, white and firm. In this tissue, particularly posterior to the heart, many tracts could be found which contained thick yellow pus. In two cases pieces of wire, 4.0 cm. and 6.5 cm. long respectively were found in these tracts, while in a third a large nail 6 cm. long was found with its point sticking into the pericardial sac. The tracts were in all directions in the mediastinum and some were even found in the anterior mediastinum. The mediastinal lymph nodes were enlarged and oedematous.

Lungs: In all cases the lobes of the lungs were adherent to themselves, to the thoracic wall and the mediastinum, either diffusely or at localised areas. In three animals this was due to the formation of organised fibrous bands which were not easily broken down, but in the six others it was due to fibrinous or fibrinopurulent pleurisy. In cases 19959, 23939 and 24386 the pleurisy was confined to the right pleural cavity. The lungs were displaced dorsally to varying degrees by the enlarged pericardial sac in each case and the ventral parts of the apical cardiac and diaphragmatic lobes of each lung were sometimes collapsed as a result of the thoracic fluid. A thrombus was found in a small branch of the pulmonary artery in case 18938 and pulmonary abscesses were found in case 24386.

Reticulum: A mass of organised adhesions was present in every animal between the anterior serosal surface of the reticulum, the diaphragm and the ventral border of the liver. These adhesions were

composed of dense fibrous connective tissue and when they were dissected away, in four cases a strong fibrous cord was revealed joining the reticulum to the diaphragm (Figure 89). This cord was 8 cm. long x about 1 cm. in diameter in one animal. The centre of the anterior part of the cord contained a narrow lumen lined by yellow necrotic tissue which communicated with the tracts in the posterior mediastinum in some animals. In one instance when this cord was cut, fluid from the pericardium leaked along it. Adjacent to the reticulum, however, the cord was completely fibrosed and had no lumen. At the periphery of the diffuse adhesions, small thick-walled abscesses were found in four animals. Scarring of the mucous membrane of the reticulum was found only twice and foreign bodies were found in the reticulum lying free or sticking into the wall, or even perforating the wall in four cases. These were not the animals in which foreign bodies had been found in the mediastinum. The foreign bodies in the reticulum were sharp pieces of wire from 6 cm. to 11 cm. long, usually sharp at both ends, and in one case a nail also was found.

Liver: The liver showed obvious changes of long-standing passive venous congestion in all but one animal, case 19276. In this animal the liver was slightly enlarged, the cut surface pouted from the capsule and a large amount of blood exuded from the organ. There was slight dilatation of centrilobular veins. In the other cases, however, the livers were enlarged and had a mottled appearance through the capsule.

Figure 89 Fibrous cord joining reticulum to diaphragm

When a cut surface was examined, the centrilobular veins could be seen to be considerably dilated and were more prominent by being encircled by yellow lines of fatty change in the adjacent cells (Figure 90). The overall effect was the typical "nutmeg" liver of chronic venous congestion. In some cases the lobulation of the liver had become obscured and the cut surface was mottled red and yellow. This was most noticeable in case 18938, in which paradoxical lobulation could be seen grossly. The liver enlargement was very great in two cases and in one there were two hepatic abscesses.

Adrenals: The adrenals were very soft and friable in all animals and were larger than normal in the five whose adrenal glands were weighed.

Spleen: The spleens were not enlarged, but when cut large amounts of blood oozed from them and the red pulp had a soft, jelly-like appearance.

There were no significant lesions in the other organs.

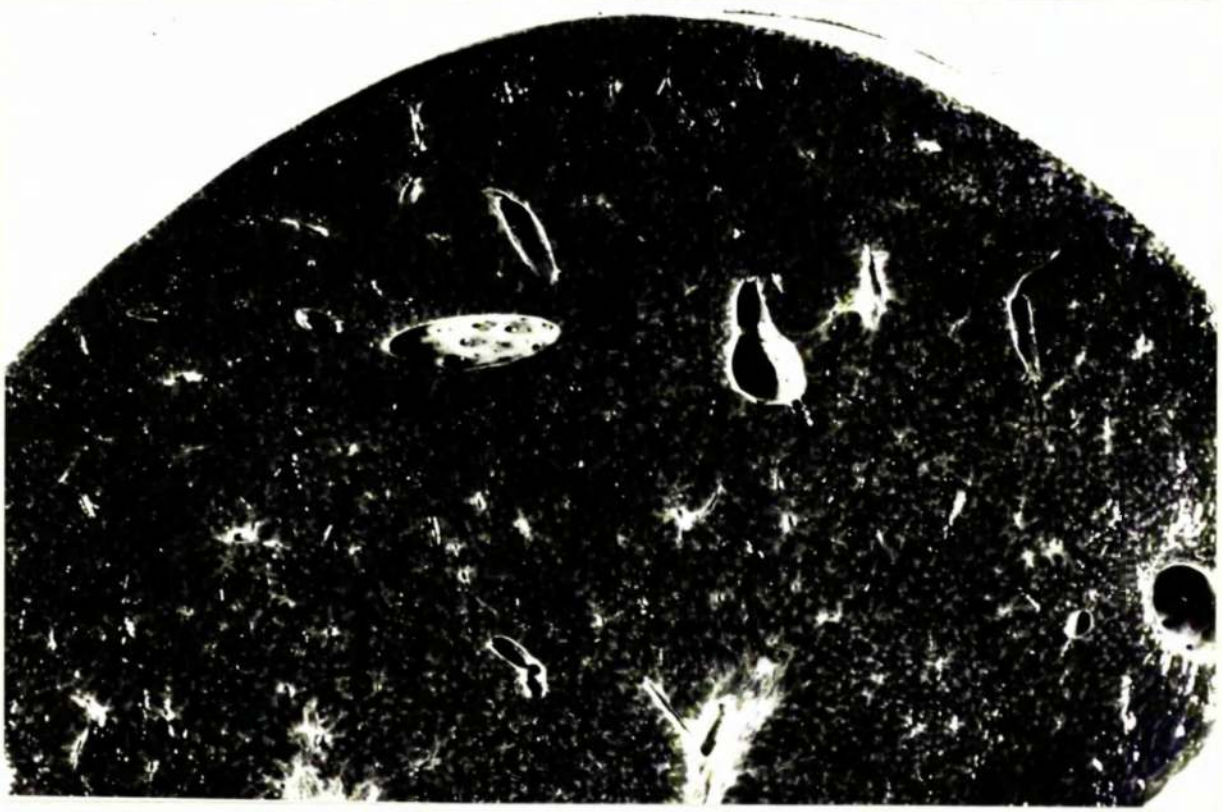
Two animals were pregnant at postmortem and a living calf was removed from a third by hysterectomy immediately after the animal had been destroyed in extremis. A fourth case aborted a 6-7 month foetus shortly before it died; this calf had subcutaneous oedema, moderate hydrothorax and ascites.

Group (ii)

Cases 19337 and 22084 were essentially similar pathologically.

There was no subcutaneous oedema or excessive amounts of fluid in the pleural, pericardial or peritoneal cavities. The pericardium was

Figure 90 C.V.C. Liver



only moderately thickened and was adherent to the epicardium by a large number of fibrous bands, so that it could be moved over the surface of the heart but could not be easily detached from it. At points where groups of these adhesions occurred together, the epicardium was thicker than in other places. The anterior surface of the reticulum was adherent to the diaphragm and in 19337 a wire was found in the reticulum. In the reticular adhesions of 22084 there were several small abscesses and a cicatrix was present in the reticular mucous membrane. Moderately extensive areas of consolidation were found in the apical, cardiac, and anteroventral parts of the lungs in 22084 and there was bronchiectasis.

Group (iii)

In case 22958 a diffuse fibrinopurulent pleurisy involved the right pleural cavity which contained 16 litres of dirty, foul-smelling fluid and the right lung was partially collapsed. The pericardium was slightly thickened and the cavity was dilated, although it only contained 0.5 litres of fluid similar to that on the right side of the thorax. A hole in the ventral part of the pericardial wall communicated with the right pleural cavity and it appeared as if much of the pericardial fluid had escaped into this site. The heart was free within the pericardial cavity and the epicardium, which was only moderately thickened, was covered by a dirty yellow exudate. On the posterior border of the wall of the left ventricle, the epicardium was ruptured and there was a depression in the wall of the left ventricle which led to a yellow

necrotic tract within the musculature of the ventricle. This tract, 2 cm. long, almost communicated with the lumen of the left ventricle, and there was a small mural thrombus where it approached the endocardium. The lesion was obviously due to a wire penetrating the ventricular wall. The posterior mediastinum was thickened in its ventral half by fibrous tissue proliferation. A small amount of fluid, 0.2 litre, was present in the peritoneal cavity and there were organised adhesions joining the anterior surface of the reticulum to the diaphragm and the ventral border of the liver. A band of adhesions was also present between the reticulum and the abomasum. Within the reticulum, a wire 5 cm. long was found sticking into the anterior wall of the organ and there was slight oedema along the greater curvature of the abomasum. The liver showed dilated vascular spaces in its dorsal part and in one lobule of the left kidney there was a red infarct. The adrenal glands were enlarged and friable.

The pericardium of case 24289 showed moderate fibrous thickening and was closely adherent to the heart over the ventricles. Over the atria the pericardium was distended and contained approximately 250 ml. of foul, yellow-grey fluid. A piece of bent wire was found in the reticulum, piercing the anterior wall and extending along a fibrous tract through the diaphragm and passing into the musculature of the posterior wall of the left ventricle. The muscle around the wire tract was necrotic and there was a region of endocarditis with mural thrombus formation within the ventricle (Figure 91).

Figure 91 Mural thrombus within ventricle

M = Mitral Valve

P_1, P_2 = Papillary Muscles

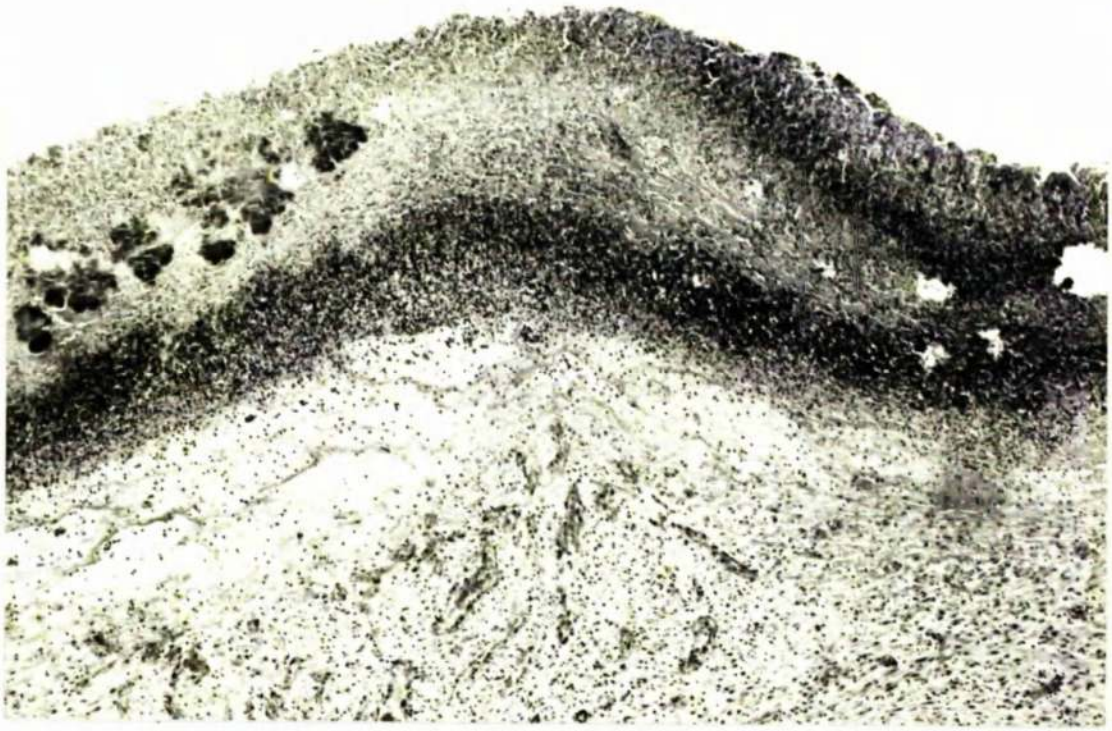
Small, yellow, purulent foci were scattered in the myocardium. Extensive fibrous adhesions between the reticulum, abomasum, rumen, diaphragm, liver and spleen were found. Several abscesses were present at the root of the mesentery and there was a severe embolic nephritis with renal infarction particularly in the left kidney. There were extensive areas of collapse in the left lung. The adrenal glands were moderately enlarged.

Blocks of tissue for histopathological examination were taken from all of the animals, from the heart, pericardium, mediastinum, mediastinal lymph nodes, lungs, liver, spleen, adrenals, kidneys, abomasum and small intestine. The tissues were fixed in corrosive formol and 10% formalin and stained by haematoxylin and eosin. Selected sections were also stained with picro-Mallory, Van Giesen, phosphotungstic acid/ haematoxylin and Sudan IV.

Histopathology - Group (i)

Heart The lesion is an organising fibrinopurulent pericarditis (Figure 92). The exudate on the heart showed an outer layer consisting of a mixture of structureless eosinophilic material, interlacing fibrin strands and colonies of bacteria, which was usually heavily infiltrated by polymorphonuclear leukocytes. Below this were many new capillaries and young fibroblasts with prominent eliptical nuclei and basophilic cytoplasm. Between the capillaries and fibroblasts were large numbers of plasma cells, macrophages and some lymphocytes. These layers were separated from the myocardium by a mass of dense fibrous connective tissue which was responsible for most of

Figure 92 Organising fibrinopurulent pericarditis



the increased thickening of the epicardium. This fibrous connective tissue was composed of many interlacing bands of mature collagen fibres and mature fibroblasts. Occasionally, foci of plasma cells, lymphocytes and polymorphonuclear leukocytes could be seen in the depth of this layer. Running through the fibrous connective tissue from the myocardium were many long, narrow blood vessels, many of which were arteries with well-developed muscular tunica media. Scattered along the course of these vessels were moderate numbers of plasma cells. The myocardial fibres at the periphery of the heart were separated from each other rather more than is normal by proliferation of the connective tissue stroma. A mild diffuse infiltration of the interstitium of the heart by small numbers of plasma cells and occasionally polymorphonuclear leukocytes, was seen in one animal. In three other animals sarcocysts were seen within Purkinje fibres in the myocardium.

Pericardium and Mediastinum. Sections from the pericardium and across fibrous tracts in the posterior mediastinum showed essentially the same changes as seen on the surface of the heart, that is adjacent to the cavity containing pus or fluid there was a layer of necrotic tissue densely infiltrated by polymorphonuclear leukocytes. This tissue was surrounded by fibroblasts, plasma cells, macrophages and endothelial cells and outside this layer there was mature, dense, fibrous connective tissue.

Mediastinal Lymph Nodes. The sinuses of the lymph nodes were distended and the reticulum cells were increased in number. The sinuses contained large numbers of different cell types, including macrophages, polymorphonuclear

leukocytes, plasma cells, lymphocytes and occasionally eosinophils. The medullary cords were packed with masses of plasma cells and their precursors, and occasionally focal aggregates of lymphocytes and lymphoblasts. The cortical tissue of the node had usually lost its follicular pattern and consisted of masses of small lymphocytes and a few lymphoblasts and occasionally eosinophils. The perinodal tissue was oedematous.

Lungs. Histological examination of the lungs confirmed the presence of the collapse seen macroscopically and in animals with fibrinous pleurisy there was a layer of fibrin on the pleura which was invaded by polymorphonuclear leukocytes, macrophages, fibroblasts and endothelial cells, forming new capillaries. Considerable numbers of plasma cells were also present. Pleural lymphatics and adjacent septal lymphatics were distended and sometimes contained plugs of fibrin. Case 19276 showed in addition to the fibrinous pleurisy, severe pulmonary oedema with congestion of alveolar walls and oedema fluid containing fibrinous bands in the alveoli, bronchioles and bronchi. There was also haemorrhage into some of the alveoli.

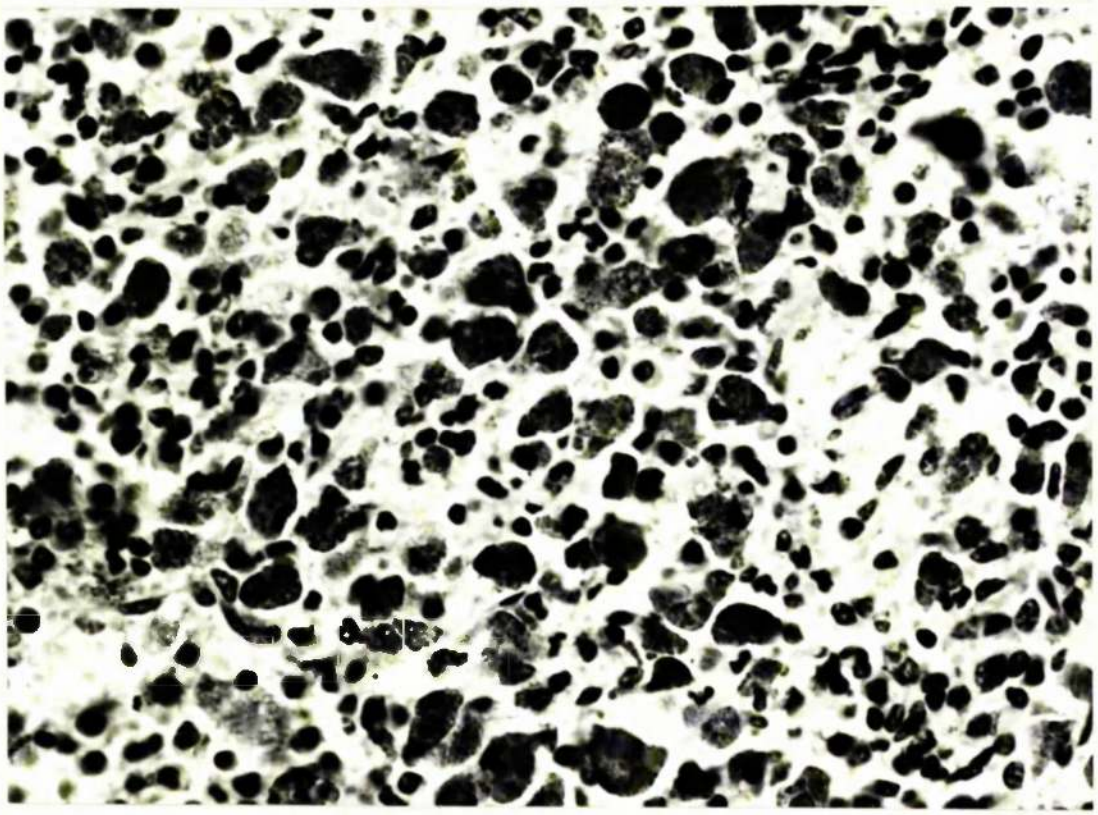
Reticular Adhesions. The cord-like adhesion between the reticulum and diaphragm showed the same features as the tracts in the posterior mediastinum.

Liver. In all cases except 19276 there was well-established chronic venous congestion. In 19276, however, the centrilobular veins and sinusoids were only slightly dilated, and there was minimal fatty change in the liver cells in the centrilobular area. The other animals showed

dilatation of the centrilobular veins and sinusoids, marked fatty change extending from the centrilobular position sometimes to involve the whole lobule. In addition there was necrosis of liver cells in the centrilobular area and accumulation of red blood corpuscles in the spaces which had become vacant after the liver cells had disintegrated completely. In case 18938 this process was very advanced, the haemorrhagic zones produced subsequent to the disappearance of liver cells and sinusoidal dilatation had linked up adjacent centrilobular areas to produce paradoxical lobulation. The portal areas were surrounded by a ring of liver cells, most of which showed fatty change and the liver cells themselves were surrounded by a zone of haemorrhage. This animal also had hepatic fibrosis with fibrous tissue proliferation near the centre of the classical liver lobule. All of the animals examined had considerable numbers of plasma cells in their portal areas.

Spleen. The Malpighian corpuscles were often reduced in size and surrounded by a halo of cells which contained a high proportion of polymorphonuclear leukocytes and red blood corpuscles. There were few germinal centres to be seen in the Malpighian corpuscles and those which could be found were sparsely populated by widely separated reticulum cells. The red pulp contained large amounts of haemosiderin in reticulo-endothelial cells and a great number of plasma cells (Figure 93).

Figure 93 Haemosiderin filled R.E. cells in spleen (H & E x 400)



Adrenals Accumulations of plasma cells were sometimes found in the adrenal cortex and there was separation of the cells of the zona glomerulosa from each other with a similar change to a lesser degree in the deeper parts of the zona fasciculata.

Kidneys Moderate fatty change was present in the collecting tubules and some of the medullary portions of the nephrons in some animals. Interstitial accumulations of plasma cells were also seen.

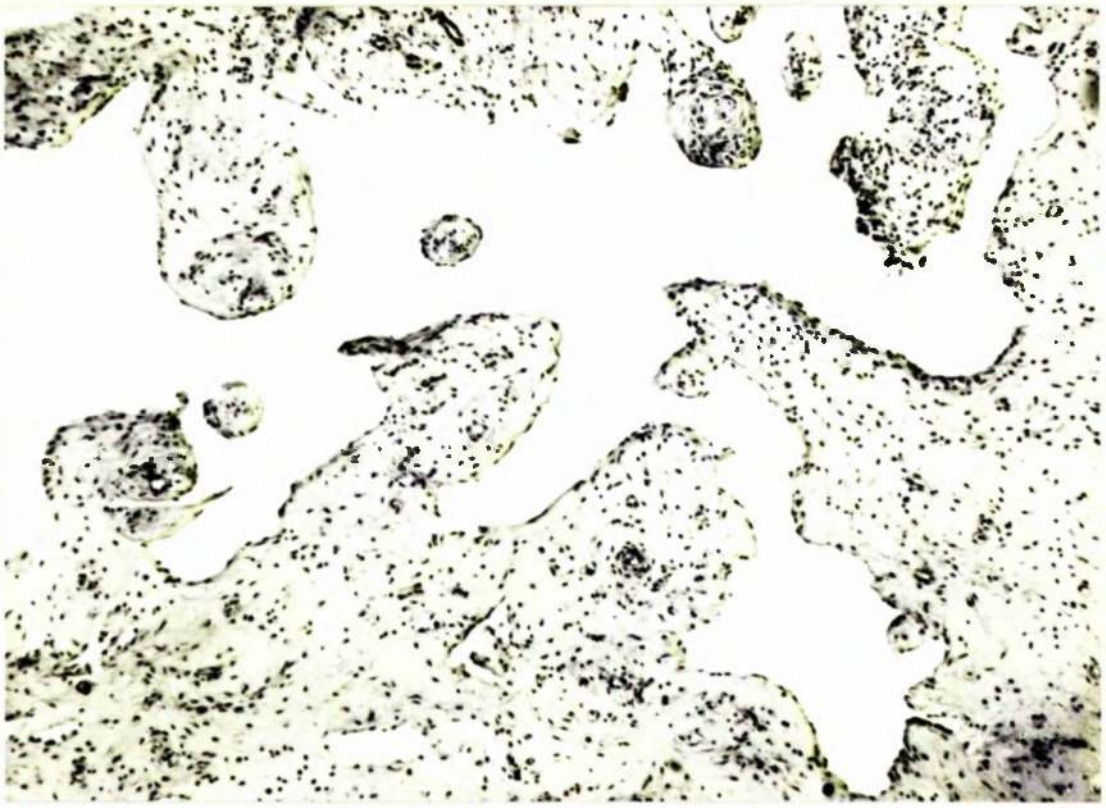
Group (ii)

In both cases histological examination of the material on the outer surface of the heart and the adhesions between the heart and the pericardium showed that it consisted of a loose type of connective tissue with a high proportion of intercellular amorphous ground substances to collagen fibres. The adhesions tended to have a villous appearance in section and on the outer surface there were accumulations of macrophages, plasma cells and lymphocytes (Figure 94). There were no significant findings in the other organs except the lungs of 22084, in which there was chronic pneumonia with bronchiectasis.

Group (iii)

Case 22958 Material from the heart showed a superficial eosinophilic mass containing fibrin strands, large numbers of polymorphonuclear leukocytes below which there were macrophages, proliferating endothelial cells, young fibroblasts, plasma cells and some lymphocytes. There was little new collagen fibre production. The necrotic tract in the wall of the left ventricle showed a central area of cellular debris with masses of polymorphonuclear leukocytes, macrophages and plasma cells around the

Figure 94 "Violin String" adhesions of adhesive pericarditis (H & E x 150)



eosinophilic remains of necrotic myocardial fibres. In between the adjacent normal fibres there was fibroblast proliferation.

On the lungs there was a severe fibrinous pleurisy. The liver showed areas in many lobules where there was loss of liver cells and pooling of blood. These areas sometimes occurred eccentrically in the liver lobule and there was little evidence of centrilobular fatty change. There was not an excessive amount of haemosiderin in the spleen but there were many plasma cells in the red pulp. Histological examination of the kidney confirmed the presence of the infarction seen at autopsy and many plasma cells were scattered along the connective tissue of the inter-lobular arteries.

The histology of the heart in 24289 was similar to the previous case except that there was more collagen formation in the epicardium and, in addition to the pericarditis, there was a focal embolic suppurative myocarditis. Focal embolic suppurative nephritis and infarction were confirmed in the kidney and pulmonary collapse with small patches of bronchopneumonia were seen in the left lung.

The adrenal glands from both animals showed moderate accumulations of plasma cells in their cortices.

c) (ii) Traumatic Pericarditis in cattle - Discussion

Traumatic pericarditis is a useful term applied to a disease which may present itself clinically in several different ways and be associated

with a variety of lesions which are related to each other in that they are all consequences of penetration of the thorax by a sharp foreign body. It is likely that in some cases the pericardium itself is not penetrated and infection spreads to it through lymphatics from a lesion in the posterior mediastinum. The thoracic lesion which usually develops around the heart is quite complex even although there is no associated pleurisy or pulmonary abscess formation. There are organising fibrinopurulent tracts in the mediastinum resulting in strong fibrous connections between the diaphragm, the sternum and the pericardium, and the heart itself if the pericardium is adherent to the epicardium at any point. This type of lesion is really a mediastinopericarditis. In man cardiac hypertrophy occurs in this condition, but the opinion is also held that the hypertrophy may result from co-existing valvular disease (Saphir 1960). Cardiac hypertrophy was not present in any of the animals in this series or in those of Holmes (1960) but has been described in some cases in cattle (Jubb and Kennedy 1963).

It is likely that the effects on the heart differ from those occurring in mediastinopericarditis in man because the adhesions do not involve so many completely rigid structures such as costal cartilages, ribs, and vertebral column, since the shape of the thorax is different and the relationship between these structures and the heart is not the same.

Constrictive pericarditis is a form of mediastinopericarditis or pericarditis in which mediastinal adhesions or thickening and rigidity of the pericardium and endocardium interfere with cardiac filling.

The lesion in advanced cases of traumatic pericarditis such as those in Group i belonged to this type in which it is conceivable that the gross epicardial thickening by fibrous tissue, particularly around the insertions of the venae cavae into the right atria, and over the right atria, and the right ventricle, may obstruct diastolic filling. By comparison of the specialised findings of pressure recordings and cardiac output determinations in groups i, ii and iii it appeared that the large amounts of fluid, pus and gas present within the rigid pericardium in Group i resulted in increased intrapericardial pressure which limited diastolic filling and this was probably the most significant factor in the development of congestive cardiac failure. In constrictive pericarditis the heart does not become hypertrophied and may even become atrophic in long-standing cases (Saphir 1960). This was not seen in any of the cases described here, nor did calcification of the pericardium or epicardium occur.

The pericardial lesion itself was essentially an organising fibrinopurulent pericarditis in all of the animals seen except those in Group ii which represent a distinct phase in the pathogenesis of traumatic pericarditis. In Group iii the lesion was seen before it had had time to become constrictive and there was a communication between the pericardium and the right pleural cavity. The short clinical course in these animals could be attributed to the early development of severe complicating lesions, namely acute fibrinopurulent pleurisy and embolic suppurative nephritis and myocarditis.

The animals in Group ii had an adhesive pericarditis. In this condition the pericardium and epicardium were not excessively thickened but were held together by many delicate "violin string" bands. There was little or no effect on cardiac function and in these cases there was no muffling of heart sounds although adventitious sounds did occur. The lesion probably resulted from organisation of an acute fibrinous pericarditis caused by foreign body penetration of the thorax which did not establish large numbers of pyogenic organisms in the pericardial sac.

When attempting to drain the pericardium it would appear to be better to do this anteriorly on the right side of the chest, since adhesions between the epicardium and pericardium occurred more frequently on the left and the anterior and right aspects of the heart are more likely to be free, as occurred in this series and in Holme(6)'s (1960). Complete evacuation of the pericardium would be very difficult even when enzymes such as streptokinase and trypsin are used because of the large quantity of thick pus and the numerous very large clots or sheets of fibrinopurulent material which are present in many cases.

The changes found in the organs other than the heart, mediastinum and reticulum in the animals in Group i were either a consequence of the onset of congestive cardiac failure or a response to the presence of a large septic focus in the animal. Into the latter category could be put the accumulation of large numbers of plasma cells in the red pulp of the spleen and the changes in the mediastinal lymph nodes. These cells

were presumably producing antibody and were responsible for the high globulin levels. The groups of plasma cells in the portal areas of the liver, the adrenal cortex and the kidneys may also have been contributing to antibody production, to antigens diffusing into the general circulation from the pericardium, since it has been shown that plasma cells develop in the spleen, lymph nodes, liver and other organs during hyperimmunisation experiments with pneumococcal antigens (Bjorneboe, Gormsen and Lundquist, 1947). Most of the adrenal gland enlargement was probably associated with the stress of a large focus of active inflammation, and these animals were in what has been described as the period of "traumatic inflammation" (Cuthbertson, 1942) during which there is a marked increase in protein catabolism mediated by the hormones of the adrenal cortex (Born, 1954). The breakdown of protein may be a contributing factor to the low plasma albumen, the loss of weight and the high blood urea in these cases, although these factors would also be affected by haemodilution, loss of appetite, and decreased renal blood flow respectively. Arthur (1946) demonstrated eosinopaenia in some cases of traumatic pericarditis in cattle and this may also have been due to increased adrenal cortical activity. No eosinophils were found in blood smears from 6 cases in Group i and from 1 in Group iii.

The adrenal cortex may also have been playing a part in the production of oedema in congestive cardiac failure by secreting aldosterone. The changes in the liver resulting from passive congestion had resulted in marked hepatic fibrosis in case 18938 and it is interesting to note

that this animal had the largest amount of ascitic fluid. The diarrhoea which occurred in 6 animals in Group i was possibly associated with inability to absorb fluid from the alimentary tract although macroscopic oedema could not be demonstrated in every case and other lesions responsible for diarrhoea in cattle were not found. This particular clinical observation has been described in the human subject with congestive cardiac failure (Wood 1958) and also in cattle with congestive cardiac failure due to high mountain disease (Alexander, Will, Grover and Reeves, 1960). Although haemosiderin may be found in the spleens of cattle with a variety of lesions the gross amounts present in the red pulp in the animals in Group i was probably a function of the congestive cardiac failure and due to slowing of the blood flow through the organs.

In man high levels of S.G.O.T. in the absence of increased S.G.P.T. levels are usually taken to indicate myocardial damage. In this series, however, only the animals in Group iii had lesions producing myocardial necrosis. It is likely that the quantitative distribution of these enzymes in the cow differs from man. In 2 cases of cor pulmonale seen in calves in congestive cardiac failure with no focus of tissue necrosis due to infection and high S.G.O.T. levels these were presumed to come from the liver (Fisher and Pirie, 1964). The presence of very large purulent foci in these animals complicates the picture and it may be

that these are also sources of S.G.O.T. In addition the renal lesions seen in a few cases cannot be overlooked as possible contributing sites. Even although in some animals there were severe changes within the liver due to congestive cardiac failure, in no case was the serum alkaline phosphatase raised, and only in a few cases was the S.G.P.T. raised. It appears that in cattle the estimation of these three enzymes is of little value in the assessment of liver dysfunction.

(d) Death in Neonatal Calf Diarrhoea

Death in diarrhoea in very young calves usually occurs in one of three stages of the disease. Death in the first stage appears to be due to septicaemia (Gay, 1962) and at this stage there may be no evidence of body fluid disturbance and no diarrhoea. At the next, so-called enterotoxaemic, stage there is no diarrhoea and death is attributed to endotoxins released within the gut (Gay, 1962). In the third stage diarrhoea is evident and a progressive dehydration takes place. At this stage there is evidence of hyponatramia, hypochloraemia (Dalton, Fisher and McIntyre, 1965), and a loss of body water (Dalton 1964). It has been suggested that hyperkalaemia may depress cardiac function and cause death (Roy, Shillam, Hawkins, Lang and Ingram, 1959).

Further experiments to those previously reported (Dalton et al. 1965) were carried out in attempts to determine in the diarrhoeic phase the parameters of body fluids, the alteration of which was associated with death, and to attempt to find out the exact cause of death.

Materials and Methods

Calves were purchased locally and managed as previously described (Dalton, Fisher and McIntyre, 1960), but no antibiotics were administered.

In the first series of experiments measurements were made of plasma sodium, potassium, chloride concentrations, and measurements were also made of plasma volumes during diarrhoea. Plasma volume was measured as the critical volume compartment since it was assumed that in dehydration this fluid compartment would be maintained longest.

In the other experiments plasma pH and plasma bicarbonate concentration were measured for evidence of metabolic acidosis.

Numerous electrocardiograms of the calves were taken during the experiments, and in the dying calves attempts were made to obtain these as near as possible to death.

The various parameters were measured in each individual on several days until death from diarrhoea took place or there was obvious recovery.

Results

1) The differences in plasma concentrations of sodium, chloride and potassium, the plasma volumes and the blood ureas of dying diarrhoeic calves and surviving diarrhoeic calves

Numerous determinations of plasma sodium, potassium chloride concentrations, of plasma volumes and blood ureas of calves with neonatal diarrhoea were made. Previous experiments (Dalton, Fisher and McIntyre, 1965) had demonstrated the plasma sodium concentration fell in diarrhoea, chloride concentration fell and blood urea concentration rose. It was also expected that plasma volume would fall. In order to compare results the diarrhoeic calves were divided into surviving and dying calves and the results tabulated. For each calf the lowest sodium and chloride concentrations and plasma volumes determined were taken, together with the highest potassium and blood urea concentrations. A mean and standard deviation was found for each parameter. Table 40 gives these results, compared with results from normal non-diarrhoeic calves. Table 40a gives the statistically significant differences.

Table 40

Mean values of lowest sodium and chloride concentrations, plasma volumes and highest potassium and blood ureas of surviving and dying diarrhoeic calves

Parameter	Normal Calves		Diarrhoeic Calves			
			Surviving		Dying	
	No.	Mean	No.	Mean	No.	Mean
Na meq/litre	65	141.8±3.5	31	129.4±4.0	25	128.9±6
K meq/litre	59	5.1±0.4	31	5.12±0.4	25	6.11±1.5
Cl meq/litre	59	100.3±3.5	31	92.3±4.0	21	94.0±5.4
Plasma volume ml/Kg. bwt.	65	66.0±8.7	28	59.1±7.5	21	56.5±10.3
Urea mg/100ml blood	60	16.0±8.0	31	41.2±9.8	23	91.03±71.3

Table 40a

Significance - Students 't' test

Parameter	Normal/Surviving	Surviving/Dying
Na^+	Surviving lower $p<.001$	No significant difference
K^+	No significant difference	Dying higher $p<.001$
Cl^-	Surviving lower $p<.01$	No significant difference
Plasma volume	Surviving lower $p<.001$	No significant difference
Urea	Surviving higher $p<.001$	Dying higher $p<.001$

Sodium

There was no significant difference between the plasma sodium concentrations of surviving diarrhoeic and dying diarrhoeic calves. Both were significantly lower than the plasma concentrations of normal non-diarrhoeic calves, confirming previous observations (Dalton et al. 1965).

Potassium

There was no significant difference between plasma potassium concentrations of surviving diarrhoeic calves and normal calves, the values for which were determined previously (Fisher 1960). The plasma potassium concentrations of dying calves were significantly higher than both normal and diarrhoeic surviving calves.

Chloride concentrations

Both the surviving diarrhoeic calves and the dying diarrhoeic calves had plasma chloride concentrations significantly lower than normal non-diarrhoeic calves but there was no significant difference between the chloride concentrations of dying and surviving calves.

Plasma volumes

The plasma volumes of both dying and surviving diarrhoeic calves were significantly lower than the plasma volumes of normal non-diarrhoeic calves. There was no significant difference between the plasma volumes of diarrhoeic surviving and diarrhoeic dying calves.

Blood urea

There was a significant difference between the blood ureas of normal non-diarrhoeic calves and diarrhoeic calves which survived. The blood ureas of dying calves were significantly higher than the blood ureas of both normal and diarrhoeic calves.

2) Electrocardiography

Serial electrocardiograms of two groups of calves during their first 14 days in the Veterinary Hospital demonstrated no significant abnormalities in the majority of calves. In these groups bradycardia was demonstrated in two diarrhoeic calves which survived and in three diarrhoeic calves which died. Of all calves examined no arrhythmias were detected in 31 diarrhoeic calves which survived, but arrhythmias were detected in 8 out of 25 calves which died. The arrhythmias varied in form, sometimes complete P.Q.R.S.T. complexes were present, but the heart rate was slow and irregular, sometimes varying degrees of A-v block were present and in one instance a complete heart block was recorded. Figures 95, 96, 97a and b, 98, 99, 100 illustrate some arrhythmias observed.

It was considered initially that the arrhythmias were related to high plasma potassium concentrations but evidence was obtained of high plasma potassium concentrations (above 6.5 m.eq/litre) with no arrhythmias and lower potassium concentrations with arrhythmias. It was considered that the 8 m.eq/litre plasma potassium concentration by infusion at which Bergman and Sellers (1953) obtained functional disturbances had no relationship to the present study. Death always occurred before their fatal concentration of 12.7 m.eq/litre. Peaked T waves described as evidence of potassium toxicity in other species (Winkler, Hoff and Smith 1938) were found in many healthy non-diarrhoeic calves and so could not be taken as evidence of such in calves (Figure 101).

Figure 95 **Electrocardiogram of a dying calf demonstrating a complete heart block**

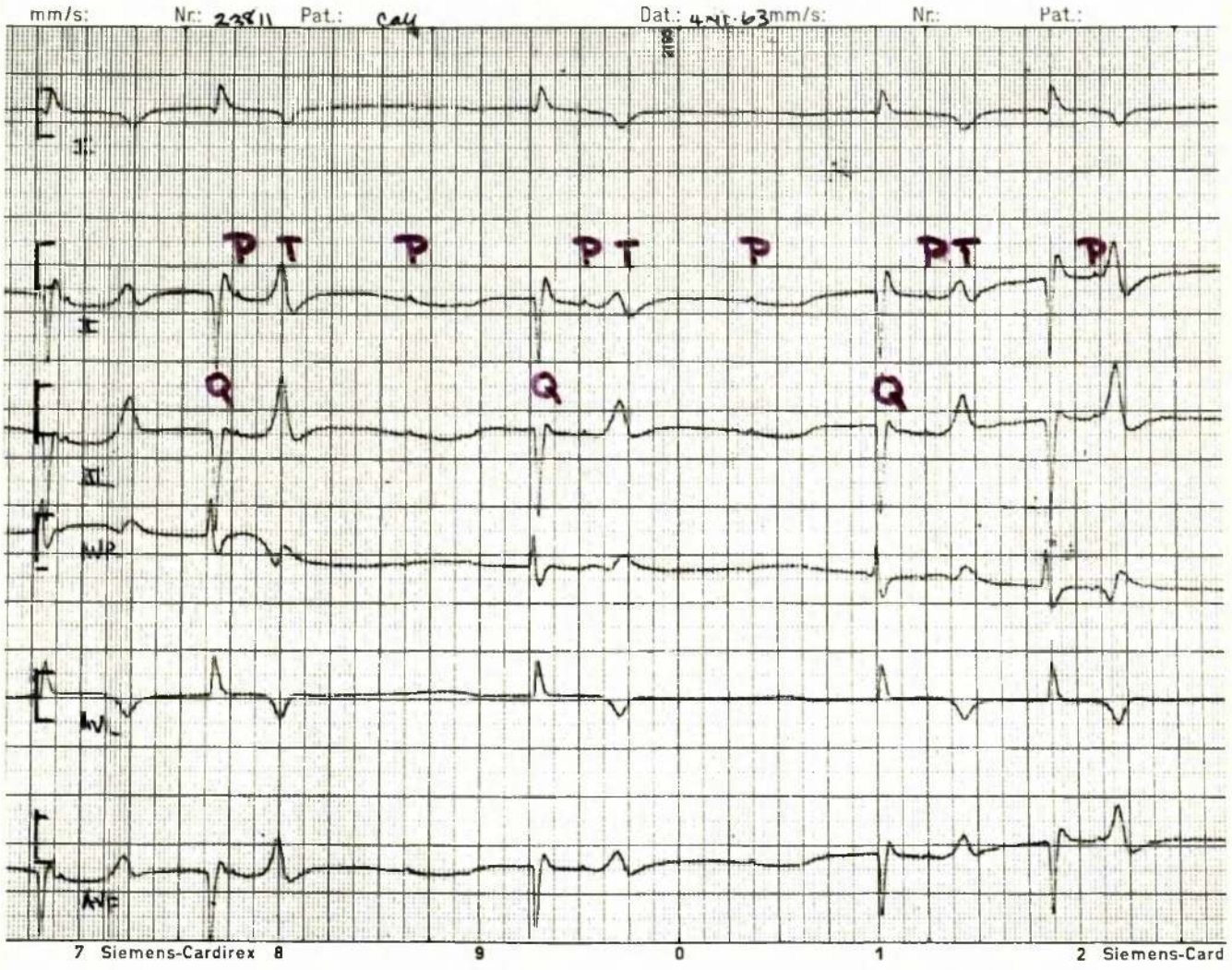
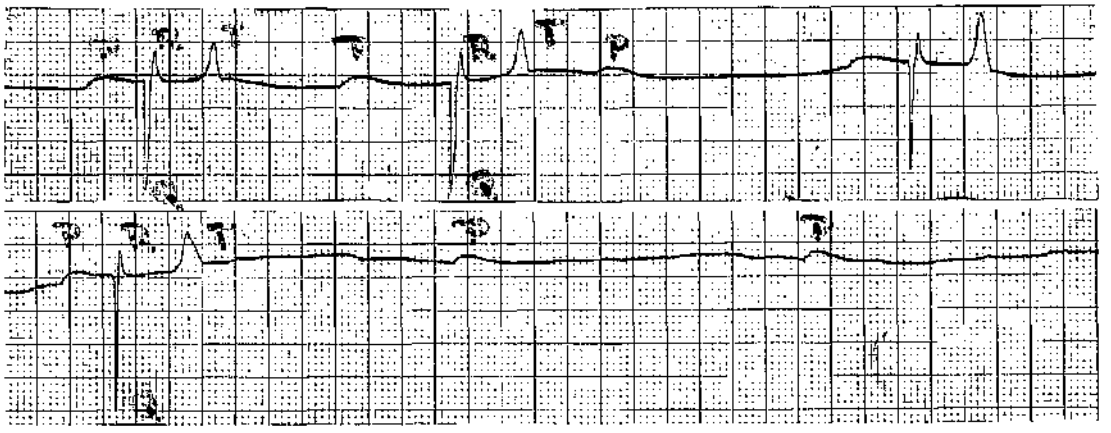


Figure 96 Calf No. 17725.

E.C.G. record at death



INCREASED P-R INTERVAL.

INCREASED DURATION OF P WAVES.

PARTIAL HEART BLOCK.

FINALLY DISAPPEARANCE OF QRS WAVES

Na 130 m.eq./l.

K 8·4 "

Ca 8·0 "

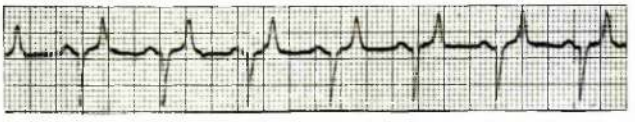
Mg 2·3 "

Figure 97(a) Calf No. 17476

Serial E.C.G. records 18-11 hours before death.

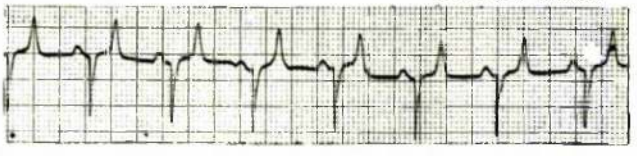
4·30 P.M.

Na 126 m.eq./l.
K 7·4 "



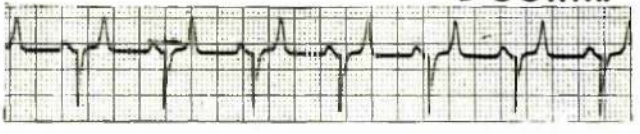
5·30 P.M.

Na 124 m.eq./l.
K 7·8 "
Ca 6·2 "
Mg 2·95 "



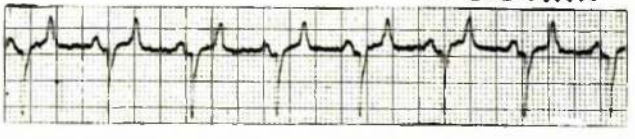
8·00 P.M.

Na 124 m.eq./l.
K 7·8 "
Ca 6·1 "
Mg 3·65 "



11·00 P.M.

Na 126 m.eq./l.
K 7·6 "
Ca 5·9 "
Mg 3·2 "



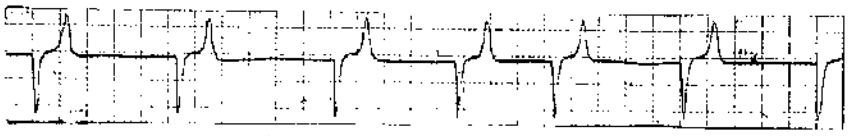
HYPERAESTHESIA AND SOMATIC TREMOR.

Figure 97(b) Calf No. 17476

E.C.G. record at death.

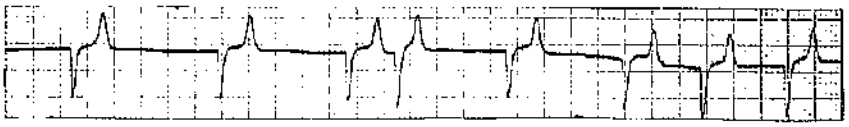
Na 126 m.eq./l
K 8·9 "
Mg 3·3 "
Ca 6·0 "

10·00 A.M.



BRADYCARDIA. ARRHYTHMIA.
DISAPPEARANCE OF P-WAVES.

10·15 A.M.



Na 125 m.eq./l
K 9·3 "
Mg 3·3 "
Ca 6·2 "

10·20 A.M.

10·25 A.M.

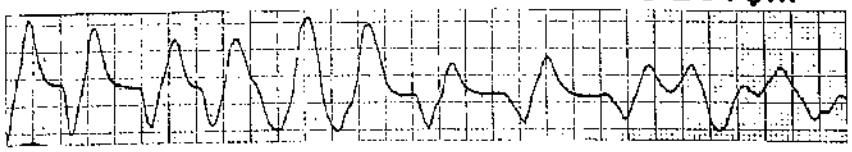


Figure 98 Calf No. 17473 - at death

Na. 118 m.eq/lt. K. 6.9 m.eq/lt.

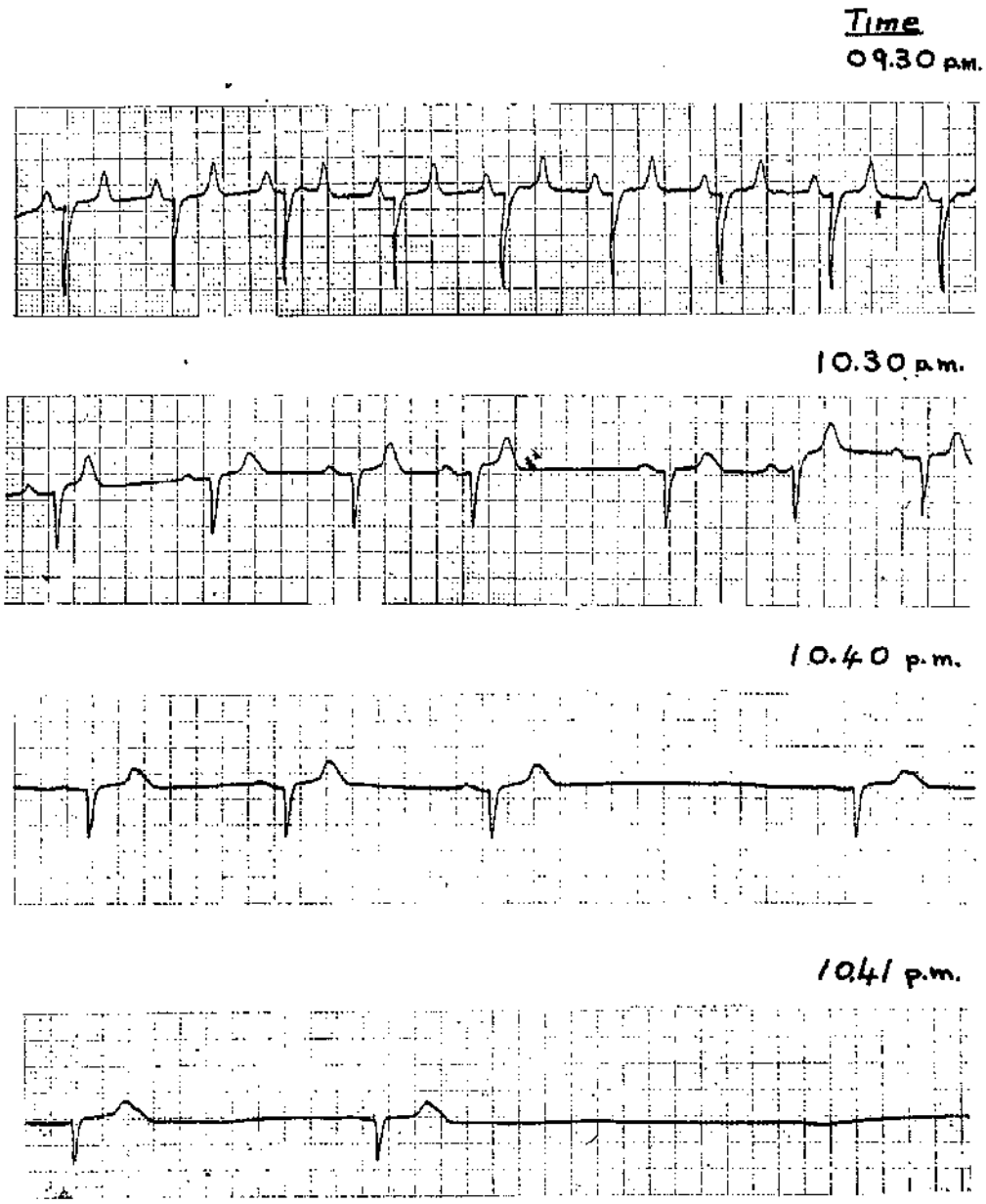


Figure 99

Calf No. 16968

Lead III one hour before death.

Na. 128 m.eq/litre

K. 8.0 m.eq/litre

Ca. 6.0 m.eq/litre

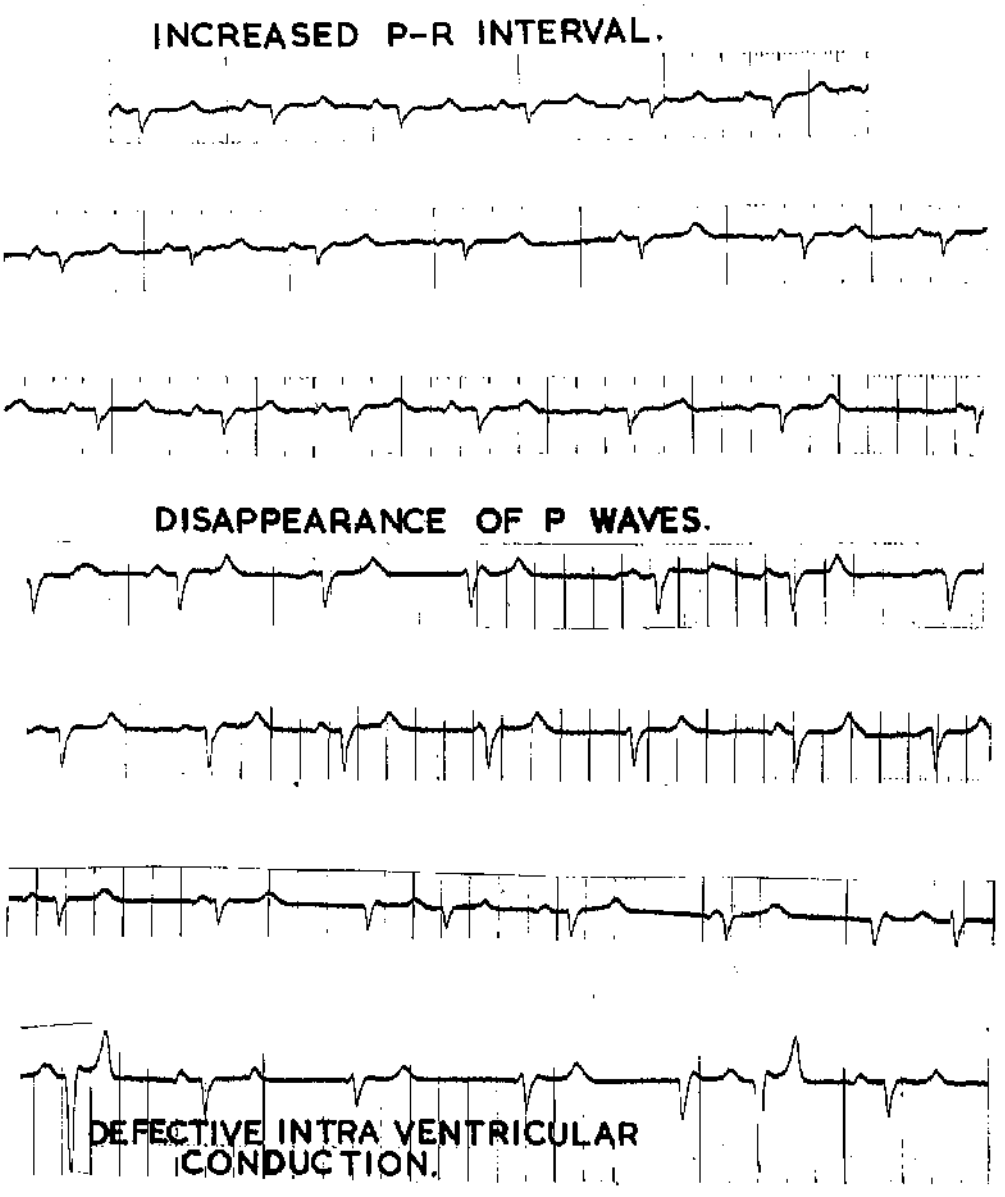


Figure 100 Calf No. 18757

Death possibly unassociated with hyperkalaemia

Na. 138 m.eq/lt. K. 5.9 m.eq/lt.

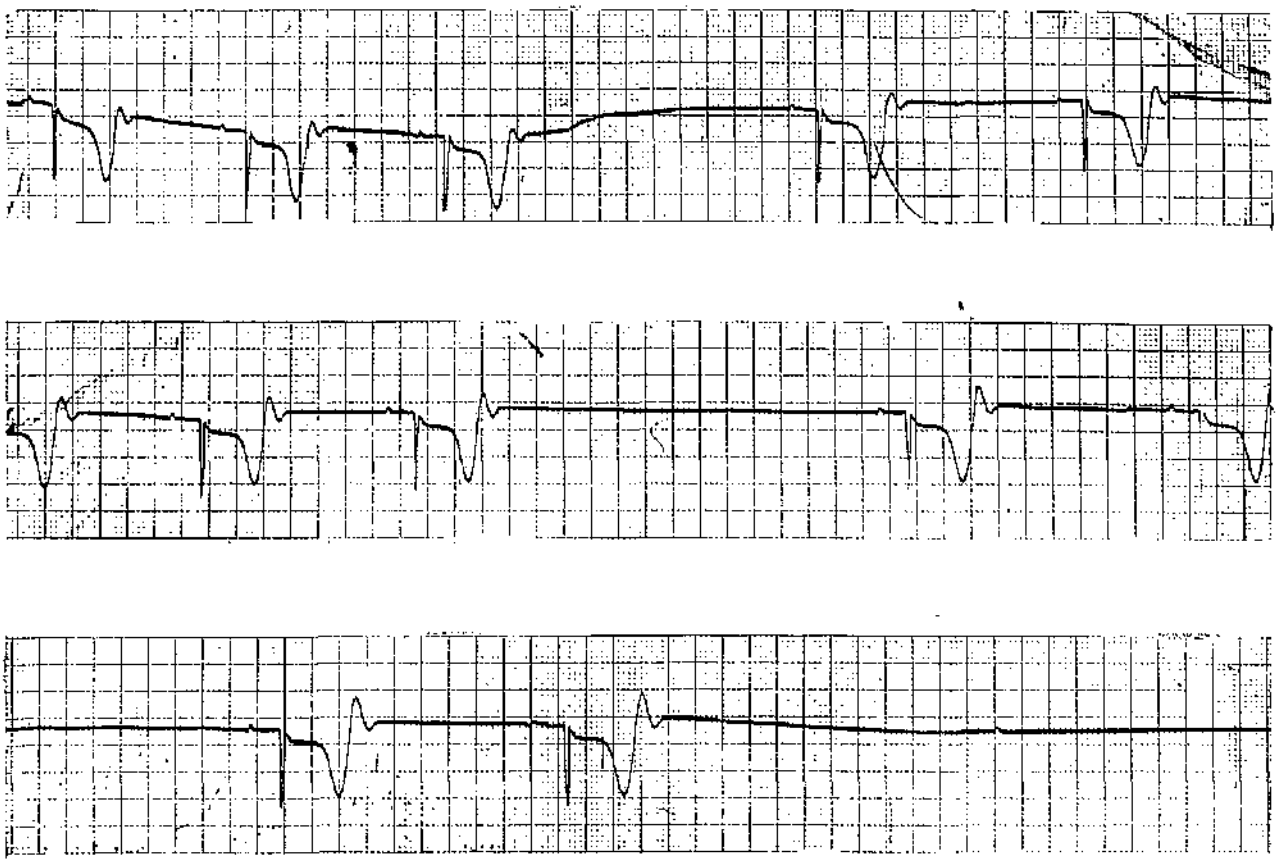
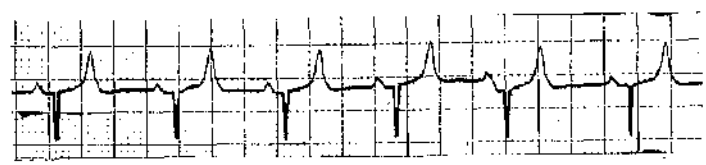
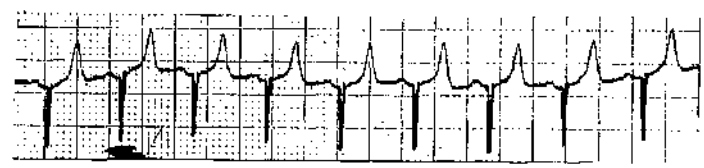


Figure 101 E.C.G. records of normal calves with high T waves

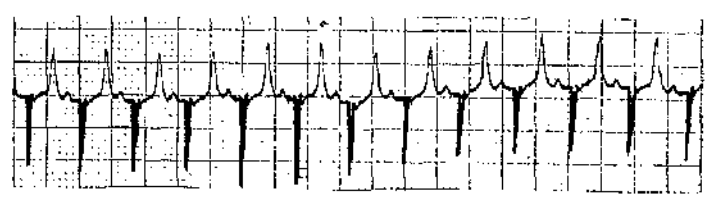
Na 139 m.eq./l.
K 4·2 " "



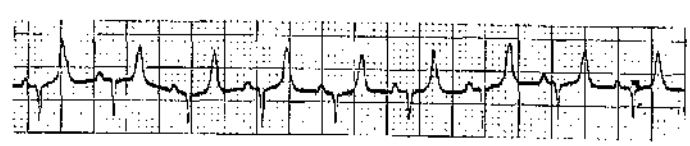
Na 136 m.eq./l.
K 4·6 " "



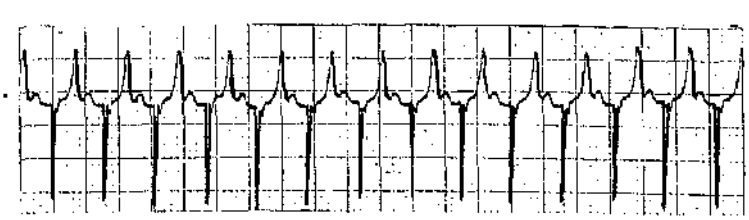
Na 136 m.eq./l.
K 4·8 " "



Na 136 m.eq./l.
K 5·2 " "



Na 139 m.eq./l.
K 4·4 " "



3) pH and Bicarbonate concentrations

Anaerobic blood samples were taken without stasis from the jugular veins of a number of normal non-diarrhoeic calves, from calves which had diarrhoea and which subsequently recovered, and from calves dying from diarrhoea, and the pH and plasma bicarbonate concentrations were determined. The mean results are given in Table 41, together with the standard deviations.

Table 41

pH and plasma bicarbonate of calves

Calves	Number	pH	HCO_3^- m.mole/litre
Normal	9	7.38±0.04	28.8±2.4
		$p<.001$	$p<.001$
Diarrhoeic recovery	9	7.29±0.07	21.6±2.5
		$p<.001$	$p<.001$
Diarrhoeic dying	5	6.85±0.14	8.9±2.7

There was a significant difference between the plasma pH of normal and diarrhoeic calves. There was a highly significant difference between the pH of diarrhoeic surviving and diarrhoeic dying calves.

The plasma bicarbonate concentrations were significantly different between non-diarrhoeic, diarrhoeic surviving and diarrhoeic dying calves. No calf with a venous blood pH below 7 was observed to survive. The value of pH of 7 for blood is given by many authors as the lowest possible consistent with life, but lower values with subsequent recovery have been recorded for short periods in anaesthetic respiratory acidosis in sheep (Fisher, 1962).

Discussion

In the calf diarrhoeas studied in this series of experiments it was confirmed that there was a lowering of plasma sodium and chloride concentrations and an elevation of blood urea concentration. In addition a lowering of plasma volume and the development of a metabolic acidosis were demonstrated.

In the comparison of the parameters in surviving and dying diarrhoeic calves, those which were significantly different were plasma potassium, plasma pH and bicarbonate and blood urea. In addition, bradycardias were observed only in the dying calves.

Death in most diseases is due to circulatory failure and death in calf diarrhoea can be considered to be no exception to this. Of the three components of the circulation, the heart, the containing vessels and the circulating fluid, it was concluded that in these experiments the primary failure was of the heart. No postmortem evidence of an increase in capacitance of blood vessels in calf diarrhoea was found, while plasma volume and plasma sodium, although below normal, were not different in dying and surviving diarrhoeic calves. Thus, neither blood vessel capacity nor circulating volume was the critical deficiency.

Evidence was obtained of a primary interference with the function of the conducting tissue of the heart which appeared to cause death. This interference was apparently brought about by the electrolyte disturbance and the severe metabolic acidosis. Hyperkalaemia was not always implicated. Histological examination of hearts of very young calves dying of diarrhoea showed no abnormality.

Some evidence supporting this conclusion was obtained previously, in that haemoconcentration and a rise of packed cell volume were not consistent features of diarrhoea in calves (Dalton et al. 1963). Furthermore, the clinical observation that heart sounds in dying diarrhoeic calves are much fainter than normal could be explained on this basis.

The more severe metabolic acidosis of dying calves may have stimulated increased reabsorption of potassium by the kidney in exchange for hydrogen ions. The higher plasma potassium and blood urea in dying calves could result from failure of the kidney to excrete. This renal failure could be due to a deficient renal blood flow as a result of a primary decrease in cardiac output and not from a deficient circulating volume.

It must be emphasised that in these experiments the milk intake was maintained and calves were observed often to drink within hours of death. The disturbance of body fluids if milk is withheld may be entirely different.

5. Discussion of the investigations into cardiac abnormalities

In the initial investigations of the additional normal parameters, utilised in addition in the fourth part of the whole study, the findings of other authors were confirmed. The only original observations made were those on heart sounds in cattle where splitting of first and second sounds was found in normal cattle and where third and fourth heart sounds were not detected. This finding on third and fourth heart sounds is in contrast to the horse (Detweiler 1958) and is probably due to the fact that the heart rate in normal cattle is nearly twice that of normal resting horses.

The study of the commonest congenital cardiac anomalies in cattle suggested that ventricular septal defect was more common in this species than in the dog or the human subject. The clinical signs varied with the size of the defect and clinically detection has been dependent on the use of the stethoscope, usually as a result of a respiratory disturbance. The differential diagnosis is considered of importance in the early recognition of an untreatable yet salvageable condition. The possibility of the early detection and utilisation of these animals for experimental surgery has been considered, but the problems involved in the provision of extracorporeal circulation and possibly hypothermia may limit their use. The possible genetic basis of these defects should be borne in mind primarily in the designing of breeding policies.

but also for the provision of animals for experimental surgery.

Survival of cases of Tetralogy of Fallot in cattle appears to be due to the persistence of a patent ductus arteriosus. However, this survival would obviously be conditioned by the exercise demands placed upon the animal. Conditions within the sheltered environment of the Veterinary Hospital where the anomaly has been detected on examination and where, as a result of such detection, exercise stress has been prohibited, are entirely different from farm conditions for the young animal. Thus our impression could be entirely false.

Discussion of the last group of congenital cardiac anomalies is difficult as a group since they differed anatomically and almost certainly in the vascular flows through the heart. The one animal in which a complete examination enabled a diagnosis to be made antemortem, when alive, was similar to the cases of Tetralogy of Fallot except that the systolic murmur was neither constant nor gross. This suggested that in the Tetralogy the systolic murmur is primarily due to the pulmonic stenosis. It was possible in this animal to arrive at an antemortem diagnosis of Eisenmenger syndrome, but it was not possible to detail the complete anatomic anomaly.

The typical cases of traumatic pericarditis in cattle with their obvious subcutaneous oedema and distended jugular veins presented the features of chronic congestive cardiac failure in cattle clinically,

physiologically and pathologically. Such large animals would be useful subjects for quantitative studies of this condition, with particular reference to quantitation of aldosterone. In those cases where the pressure of the pus in the pericardial sac was measured, it was demonstrated that this pus limited diastolic filling. The author ascribes to neither the so-called 'backward' nor 'forward' failure theories of heart failure, but in these cases the marked jugular distension, oedema and liver involvement suggest a damming back in the veins most proximate to the heart after fluid has been retained. Thus the possibility of liver dysfunction in its inability to detoxify aldosterone may be important.

The biochemical determinations, in conjunction with the pathological examinations, demonstrated that elevations of the three enzymes measured in the Veterinary Hospital as evidence of liver damage were not of value. The fact that the serum glutamic oxalic transaminase was elevated could be interpreted as due to tissue damage. Further biochemical tests such as the bromsulpthalein excretion would need to be investigated in this condition. Liver biopsy which is a practical procedure in cattle may be a more logical approach. The fact that these animals constitute a complete loss led to the consideration of the possibility of surgical intervention. Success was achieved only once out of five cases and this animal took about one year for complete healing (Jemmings and Fisher 1960). Further investigations of surgical intervention would be necessary before any conclusions were made.

The long-standing cases of pericarditis illustrated that a recovery from the acute condition could take place, giving rise to animals with clinical signs referable to the heart but not very specific of pericarditis. These animals constitute a proportion of chronically wasting cattle.

The acute cases illustrated that death could occur as a result of the penetration of the pericardium with a foreign body before the development of congestive cardiac failure. The cause of death can only be suggested as being due to toxaemia, without defining toxaemia.

The studies on neonatal diarrhoea arose from the studies in the first part, which suggested that plasma volume decrease was less significant than had been assumed. The significant number of arrhythmias in dying calves implicated some interference with cardiac function and it is possible that hyponatraemia may cause myosthenia of cardiac muscle. The severe acidosis was considered to be important in the production of arrhythmias, but how and by what constituents the acidosis is caused requires further detailed study. Studies must also be made on the possible effects of acidosis depleting intracellular potassium in the calf heart, thus interfering with polarisation and depolarisation. However, it must be emphasised that the studies presented were on very young calves, fed whilst diarrhoeic, which in all probability are physiologically different from a calf of even six weeks of age. McCance and Widdowson (1957) have shown physiological differences in the young of some species. Less detailed studies carried out by the author on calves 3-4 months of age

with the diarrhoea of Ostertagiasis have failed to demonstrate such marked biochemical abnormalities as have appeared in these very young calves.

In conclusion it may be stated that this study has demonstrated that the cardiovascular system of cattle is worthy of investigation. The many questions and problems that have arisen and have not been answered constitute a field for much further investigation, particularly if such investigation involves as many disciplines as possible.

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8. Major Publications

The major publications upon which this thesis is based are detailed below in chronological order.

1. Arterial Puncture in Cattle
   Fisher, E.W. (1956) Vet.Rec. 68: 691

2. The concentration of some of the inorganic constituents in the plasma of healthy Ayrshire cattle
   Fisher, E.W. (1960) Brit.J.Nutr. 14: 9

3. Determination of the Cardiac Output of Cattle and Horses by the Injection Method
   Fisher, E.W. and Dalton, R.G. (1961) Brit.Vet.J. 117: 143

4. An Eisenmenger Complex in an Ayrshire Heifer
   Fisher, E.W., Pirie, H.M. and Hector, A. (1962)
   Vet.Rec. 74: 447

5. Observations on the Bovine Haematocrit
   Fisher, E.W. (1962) Brit.Vet.J. 118: 513

6. Tetralogy of Fallot in a Friesian Heifer
   Fisher, E.W. and Pirie, H.M. (1964) Brit. Heart J. 26: 97

7. Malformations of the Ventricular Complex in Cattle
   Fisher, E.W. and Pirie, H.M. (1964) Brit.Vet.J. 120: 253

8. Death in Neonatal Calf Diarrhoea
   Fisher, E.W. (1965) Ibid 121: 132

9. Traumatic Pericarditis in Cattle: A Clinical, Physiological and Pathological Study
   Fisher, E.W. and Pirie, H.M. Ibid 121: 552

Reprints of these papers are given in the Appendix.

Appendix I

Collected Reprints of Major Publications

Reprinted from *The Veterinary Record*. **68.** 691. October 6th, 1956.

Arterial Puncture in Cattle

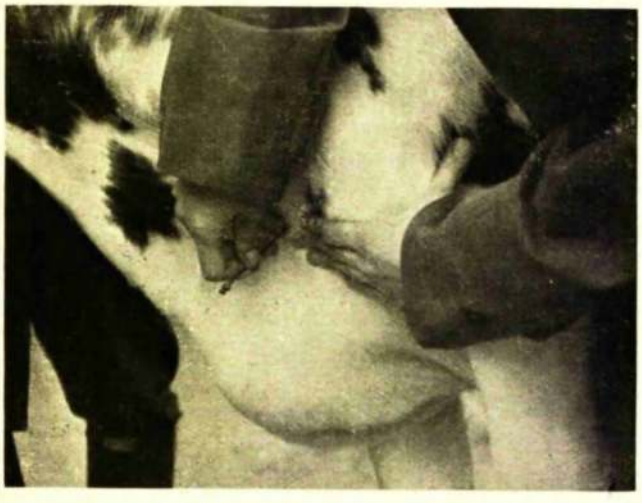
BY

E. W. FISHER

University of Glasgow Veterinary School

ARTERIAL blood samples may be required from cattle for plasma *p*H estimations for electrolyte and blood gas analyses; for estimations of cardiac output by direct Fick or dye dilution techniques; and for metabolic investigations where arterio-venous differences may give important information.

Arterial blood may be obtained in several ways. The use of exteriorised carotid arteries is limited to experimental animals (Van Leersum, 1911). Direct



puncture of the left ventricle is possible but this is not without risk to the animal. Sellers & Hemingway (1951) have carried out carotid arterial puncture in the middle third of the neck, going below the ventral border of the jugular vein, but we have found this method more difficult, unreliable, and disturbing to the cow than the method described below.

The following approach enables arterial samples to be obtained from any bovine animal including clinical cases on farms.

The cow is tethered by means of a halter so that her head is held slightly upwards and to one side. Samples are collected from the brachial artery at the root of the neck where it crosses the first rib. Five ml. of 5 per cent. Procaine + Hyaluronidase are infiltrated subcutaneously at the proposed site of the puncture. The hand is placed under the point of the shoulder as shown. In thin cows the brachial artery can be palpated and rolled between the second finger and the first rib. In fat, thick-necked animals it may not be possible to feel the pulse but arterial blood may be obtained by blind puncture at the indicated site. A 4-inch, 18-gauge, long-pointed needle is directed into the cow just medial to the second finger, parallel to the long axis of the cow and at about 15° to the horizontal. The needle has to penetrate to a depth of 1 to 3 inches. Sometimes venous blood is obtained but this is obvious both from the colour and the flow rate; slight withdrawal and redirection of the needle upward is then necessary. A sterile needle is used for each puncture. After use each needle is resharpened on a fine carborundum stone.

The technique described has been used routinely and in herd sampling to obtain about 150 arterial blood samples from cattle of all ages, including very young calves. As many as 10 cows have been bled in 45 minutes. As yet there has been no subsequent complication in any animal, and in the herd samplings no marked drop in milk yield. A few animals have been bled daily for up to seven days. There is less disturbance to the animal than in many cases of jugular puncture.

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Brit. J. Nutr. (1960), **14**, 9

The concentration of some of the inorganic constituents in the plasma of healthy Ayrshire cattle

By E. W. FISHER

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(*Received* 23 *April* 1959—*Revised* 16 *September* 1959)

The abnormal cannot be detected before the normal is known. The study of nutrition and of disease demands a yardstick which we call normal. Definitive standards have still to be achieved for the normal concentrations of some of the inorganic constituents of bovine plasma.

Since the work of Little & Wright (1925) on hypocalcaemia and of Sjollema & Seekles (1929) on hypomagnesaemia much information has been gathered about the normal concentrations of calcium, magnesium and phosphorus in the serum of dairy cattle. There is also in the literature information on the concentration of some of the other inorganic constituents of the plasma or serum of cattle. These values are summarized in Table 1. For comparison the concentrations of calcium and magnesium given in many of the papers cited have been converted from mg/100 ml into m-equiv./l.

It will be observed from the table that few authors have made determinations of the concentrations of sodium, potassium, calcium, magnesium and chloride of plasma.

This paper gives the results of the analysis of the plasma of healthy Ayrshire dairy cattle and calves for sodium, potassium, magnesium, calcium and chloride.

EXPERIMENTAL

Animals and sampling

The adult animals from which the blood samples were taken were all normal members of the University herd. They were either dry cows or cows in various stages of lactation. The lactating cows were sampled immediately after their morning milking. Dry cows present in the byre were sampled at the same time. The milking cows were out at grass during the spring and summer and received a production ration of a mixture of oats, beans and a proprietary cattle cake. During the winter, when they were housed, they received silage, roots, a small quantity of hay and the same production ration. Mineral licks were provided in the byre. At all times the cows had free access to water.

The calves were bled after their morning feed. They were normal animals separated from their mothers within the 1st week of life. Thereafter they were housed in individual pens and bucket-fed with Ostermilk (Glaxo Laboratories Ltd) (1 lb/gal water), the ration being 3–4 pints twice daily. At 3 weeks of age the calves were given hay to pick at, and at 4 weeks the Ostermilk was decreased and calf-weaner nuts were

introduced. By the time the calves were 5 weeks old they were completely weaned and on a diet of calf-weaner nuts, hay and water *ad lib.* A variety of antibiotic supplements was given prophylactically. Diarrhoea occurred in some calves but no values for plasma samples from diarrhoeic animals have been included.

Table 1. *Summary of the results of other authors for the concentrations in m-equiv./l. of some of the inorganic constituents in the plasma of cattle*

Reference	Cl^-	Na^+	K^+	Ca^{2+}	Mg^{2+}	Total cation
Anderson, Gayley & Pratt (1930)		—	—	6·3 *s* (5–8)	—	—
Brown (1946)	108 *s*	—	—	—	—	—
Craige (1947)	99 *s* (90–109)	—	—	4·5 *s* (3·6–5·1)	—	—
Craige, Johnson & Blackburn (1949)	108–89 *p*	—	—	—	—	—
	104–96 *p*	—	—	—	—	—
(three cows studied over parturition)	100–95 *p*	—	—	—	—	—
Dale, Goberdhan & Brody (1954)	—	162 *p*	5·1 *p*	7·5 *p*	3·2 *p*	177·8
Dukes (1947)	—	—	—	4·5–6 *s*	—	—
Duncan, Huffman & Tobin (1939)	97·3 *p* (93–105)	—	—	5·3 *p* (4·7–5·9)	2·4 *p* (1·6–3·1)	—
Evans & Phillipson (1957)	—	140 *p* (139–144)	4·5 *p* (4·2–4·6)	—	—	—
Godden & Allcroft (1932)	93 *s* (85–98)	—	—	5·0 *s* (4·0–5·8)	—	—
Lengemann, Aines & Smith (1952)	104·2 *p* (96·6–110)	—	—	—	—	—
McSherry & Grinyer (1954)						
Eighty-six adults	103·7 ± 3·5 *s*	142 ± 5·0 *s*	4·85 ± 0·47 *s*	5·42 ± 0·34 *s*	—	—
Twenty calves	103·0 ± 2·5 *s*	142 ± 4·0 *s*	5·25 ± 0·54 *s*	5·08 ± 0·22 *s*	—	—
Reihart (1939)	—	155 *s* (151–165)	6·3 *s* (6·1–6·4)	5·7 *s* (5·5–5·8)	1·6 *s* (1·5–1·8)	—
Sampson & Hayden (1935)	—	—	—	5·6 *s* (4·6–6·2)	—	—
Sellers & Roepke (1951 *a*, *b*)	103 *p*	144 *p* (139–146)	4·0 *p* (3·9–4·4)	4·9 *p*	1·8 *p*	154·7
Spector (1958)	104 *s* (97–111)	142 *s* (132–152)	4·8 *s* (3·9–5·8)	5·4 *s* (4·7–6·1)	2·0 *s* (0·8–2·4)	154·2
Ward, Blosser, Adams & Crilly (1953)	98 *s* (90–107)	—	—	4·7 *s* (3·8–5·3)	—	—

s, serum; *p*, plasma.

The blood samples were obtained by direct puncture of the brachial artery at the root of the neck (Fisher, 1956). This method of obtaining blood samples from cattle has been found to cause less excitement than the conventional puncture of the jugular or mammary vein. Arterial blood is more consistent in composition than venous blood, which may differ between different areas of the body. The blood samples were collected under mineral oil in heparinized centrifuge tubes, which were then sealed with soft rubber bungs. The samples were centrifuged as soon as possible at room temperature and the plasma was separated immediately and placed in clean Pyrex tubes for subsequent analysis.

Biochemical methods

Plasma sodium and plasma potassium were determined with an EEL flame photometer. Plasma calcium was determined by the method of Clark & Collip (1925), plasma magnesium by the titan yellow method as modified by Neely & Neill (1956), and plasma chloride by the method of Schales & Schales (1941).

RESULTS

The results obtained are given in Tables 2 and 3. In Table 2 the figures given for total cation were obtained by addition of the mean values of the individual cations.

Table 2. *Mean values with standard deviations and the standard error of the difference between adult and calf means of some of the inorganic constituents in the plasma of Ayrshire cattle*

	Adult animals			Calves			Difference between means
		Concentration			Concentration		
Constituent	No.	m-equiv./l.	mg/100 ml	No.	m-equiv./l.	mg/100 ml	(m-equiv./l.)
Sodium	94	142·2 ±2·0	327	65	141·8 ±3·5	326	0·4 ±0·5
Potassium	92	4·4 ±0·3	17·2	59	5·1 ±0·4	19·9	0·7 ±0·2
Calcium	94	5·0 ±0·6	10	22	4·9 ±0·2	9·8	0·1 ±0·07
Magnesium	57	1·46±0·4	1·75	29	1·14±0·3	1·37	0·32±0·07
Total cation		153			152·9		
Chloride	140	103·3 ±5·0	367	59	100·3 ±3·5	356	3·0 ±0·4

Table 3. *Mean values with standard deviations for the magnesium concentration in the plasma of pregnant, non-pregnant, lactating and dry Ayrshire cows and of calves*

Cows	No. of animals	Mean magnesium concentration (m-equiv./l.)	Standard deviation
Lactating: Non-pregnant	28	1·34	±0·33
Pregnant	25	1·57	
Dry: Non-pregnant	None		
Pregnant	4	1·59	
Calves	29	1·14	

DISCUSSION

A strict comparison of values in Tables 1 and 2 is not possible, since the results in Table 1 are for samples obtained from venous blood, whereas those in Table 2 are for samples obtained from arterial blood. Moreover, few authors state how the blood was obtained or what precautions were taken to prevent autolysis or diffusion from the red cells into plasma of anions and cations or diffusion from plasma into the cells. However, with the exception of sodium concentrations given by some authors, the results in this investigation are similar to those found by others (Table 1).

It will be observed from Table 2 that significant differences exist between the potassium and chloride concentrations of cows and calves. It will be observed from Tables 2

and 3 that a highly significant difference exists between the magnesium concentration in the plasma of cows and calves. Significant differences were not detected for any other constituent in the plasma of lactating compared with dry cows or of pregnant compared with non-pregnant cows with the exception of magnesium for which a highly significant difference was found between the concentration in the plasma of pregnant lactating cows and in that of non-pregnant lactating cows. There was, however, no significant difference between the magnesium concentration in the plasma of pregnant lactating and of pregnant dry cows.

SUMMARY

1. Plasma derived from arterial blood of Ayrshire cows and calves was analyzed for sodium, potassium, calcium, magnesium and chloride.

2. The mean concentrations in the plasma of adult cows were: sodium 142·2, potassium 4·4, calcium 5·0, magnesium 1·46 and chloride 103·3 m-equiv./l.

3. The plasma of the calves showed a significantly higher concentration of potassium, 5·1 m-equiv./l., a significantly lower concentration of chloride, 100·3 m-equiv./l., and a significantly lower concentration of magnesium, 1·14 m-equiv./l., than that of the cows.

4. Significant differences were not detected for any constituent in the plasma of lactating compared with dry cows or of pregnant compared with non-pregnant cows, with the exception of magnesium, for which a highly significant difference was found between the concentration in the plasma of pregnant lactating cows and in that of non-pregnant lactating cows.

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Printed in Great Britain

Brit. vet. J. (1961), **118**, 143

DETERMINATION OF THE CARDIAC OUTPUT OF CATTLE AND HORSES BY THE INJECTION METHOD

By E. W. Fisher and R. G. Dalton
Department of Medicine, University of Glasgow Veterinary School

The determination of the cardiac output gives a direct indication of the ability of the heart to maintain the circulation. A number of methods have been devised to make this critical determination, some, such as the thermostromuhr and the cardiometer, being applicable to experimental animals only, while others have been devised for use on the intact, unanaesthetized subject. These latter methods include the use of X-rays and measurement of heart size in systole and diastole, ballistocardiography, the Fick method, and the injection method. Of all these methods only the Fick method and the injection method have been used in the larger domestic animals.

The Fick method, by which the cardiac output is determined from the amount of oxygen absorbed or carbon dioxide excreted by the lungs per minute, requires the measurement of both ventilation rate and the concentration of oxygen or carbon dioxide in arterial and true mixed venous blood at the time that the ventilation rate is being measured. This method is unsuitable for use in adult cattle and horses if face masks are used for the measurement of ventilation rate. It has been shown in ruminants (Dougherty, 1960) that eructated rumen gases are inhaled and reabsorbed in the lung; thus ventilation measurements made with a face mask would be in error, transfers from rumen to lung via the pharynx being unrecorded. The use of face masks in horses would decrease the number of animals on which determinations could be made since few horses will tolerate face masks for the length of time (one minute at least) required for accurate measurement of ventilation rate (Fisher, 1961) without becoming excited. This would invalidate the normality of any determination of cardiac output made under these conditions. This difficulty can be overcome in both species by tracheotomizing and recording ventilation through a tracheotomy tube, but this procedure would limit the number of animals available on which determinations could be made.

The injection method on the other hand requires only the injection of a suitable non-diffusible intravascular indicator into the venous circulation and the collection of serial arterial blood samples for a short period afterwards in order to follow the passage of the indicator through the heart. The cardiac output is calculated from the equation:

$$\text{Cardiac output} = \frac{60 \times I}{ct}$$

where I = amount of dye injected;
c = mean concentration of dye;
t = time for one passage of dye through the heart.

Derivation of Equation

Consider, for example, water flowing from a pipe at a constant rate. To find the rate of flow it is necessary to collect and measure the outflow for a specific time.

$$\text{Flow per minute} = \frac{\text{Volume of outflow} \times 60}{t \text{ seconds}}$$

If there is no accurate method available of measuring this volume it is possible to determine it by adding to it a known amount (I) of a substance which will mix completely with this volume of water and, after they have mixed, finding the concentration of this substance. The volume can then be found from the equation:

$$V = \frac{I}{c}$$

Subsequently in the flow equation:

$$\text{Flow per minute} = \frac{I \times 60}{ct}$$

To consider the example of the pipe again—if a known amount of an indicator is injected into the flow and the passage of the indicator I is followed at some point distal to the injection site by the removal of serial samples, then it will be found that the mean concentration passing this point will be the same as the mean concentration of the collected volume. Furthermore, the time taken to pass this point will be the same as the time taken to fill the volume V containing the indicator at concentration c. By constructing a graph of serial indicator concentrations against time on semi-logarithmic paper as illustrated in Fig. 1 it is possible to find the mean concentration c and the time t for the passage of the indicator. Thus by serial sampling it is possible to find V from $V = \frac{I}{c}$ and also flow from $F = \frac{I \times 60}{ct}$

The volume of outflow from the heart within the circulation cannot be measured directly, but the passage of indicator can be followed by adopting a procedure analogous to that described above by taking serial arterial samples, studying the time course of the passage of indicator past the sampling point and from this finding the mean concentration c and the time t for one circulation of the indicator through the heart.

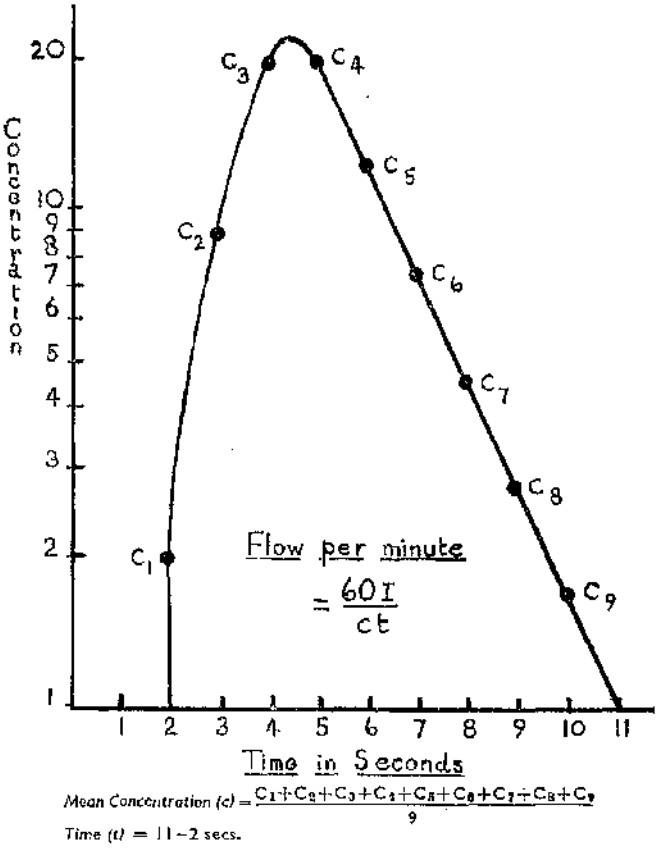

Fig. 1. Indicator time–concentration curve.

The cardiac output can then be calculated from the equation:

$$\text{Cardiac output} = \frac{60\,I}{ct}$$

Many intravascular indicators have been used for the determination of cardiac output by the injection method, including [^{131}I]albumin, sodium chloride, Fox green and Evans blue. Evans blue has been used to a greater extent than others but suffers from the disadvantage in the human of "blueing" the subject. In recent years, too, many dye-dilution recorders have been developed to facilitate the determination of cardiac output, and in the human subject ear-pierce oximeters have been used to eliminate arterial puncture. However, opinions are divided on the value of the various dye-dilution recorders and ear-pierce oximeters (Dow, 1956).

Techniques had been developed for obtaining, by percutaneous puncture, arterial blood samples from cattle (Fisher, 1956) and horses (Fisher, 1959). Both of these techniques have been used on many subjects with very little disturbance of the animal and have been shown, by means of subsequent post-mortem examinations, to cause no internal damage.

Determinations were made of the cardiac output of a number of adult cattle and horses using Evans blue as the intravascular indicator. Dye-dilution recorders and ear-pierce oximeters were not used, partly because of the controversy surrounding them and partly because it would have been necessary to carry out additional development procedures in order to use them in horses and cattle.

MATERIAL AND METHODS

All animals used in this study, so far as could be ascertained clinically and electrocardiographically, had no abnormalities of their cardiovascular systems. The cattle varied in weights from about 100 kg. to 600 kg. and in age from about nine months to adult dairy cows. The latter were in various stages of lactation and pregnancy.

The horses used were mainly heavy draught horses but determinations were also carried out on one garron, one hunter and some thoroughbreds.

It was realized that it was not possible to have either horses or cattle in the basal conditions prescribed for the determination of the cardiac output of the normal resting human subject. However, standard conditions were adopted so that the animal was as close to the resting condition as possible. All animals were allowed to settle down after their journey for a period of at least 20 hours and frequently for two or three days. Determinations were carried out in a quiet room with as few persons present as possible. Each animal was within stocks while the determination was being made, but these particular stocks merely prevented excessive backward, forward and sideways movement. The animals were haltered and the halter was held by an experienced and quiet attendant.

In order to facilitate the injection of Evans blue a nylon catheter about 15 cm. in length was inserted into the jugular vein. An area over the jugular furrow was clipped, sterilized with Cetavlon solution (Imperial Chemical Industries Ltd., Wilmslow, Cheshire) and then infiltrated with a 5 per cent solution of procaine hydrochloride. After waiting a few moments for the local anaesthetic to act, venipuncture was effected using a 2 in. No. 12 B.W.G. needle. Once the vein had been entered a 20 cm. length of 1·5 mm. diameter nylon rod was put into the vein through the needle and the needle was removed. A 15 cm. length of 4 Gauge Portex nylon rod (Portex Tubing—Portland Plastics Ltd., Hythe, Kent) was then inserted. In this manner it was possible to place in the vein a catheter of similar diameter to the venipuncture needle and to obviate the use of a very large needle. The skin then fitted tightly around the catheter. A 5 cm. length of flexible rubber tubing was connected to the nylon catheter. The rubber tubing and nylon catheter were filled with heparinized saline and then closed with a Mohrs clip. A cow with such a catheter *in situ* is shown in Fig. 2.

At the same time the area at the root of the neck through which percutaneous puncture of the brachial artery was later effected was also clipped, sterilized and infiltrated with about 10 ml. of 5 per cent procaine hydrochloride using

Fig. 2. Venous catheter *in situ*.

Fig. 3 (a). Arterial puncture *in situ* (cow).

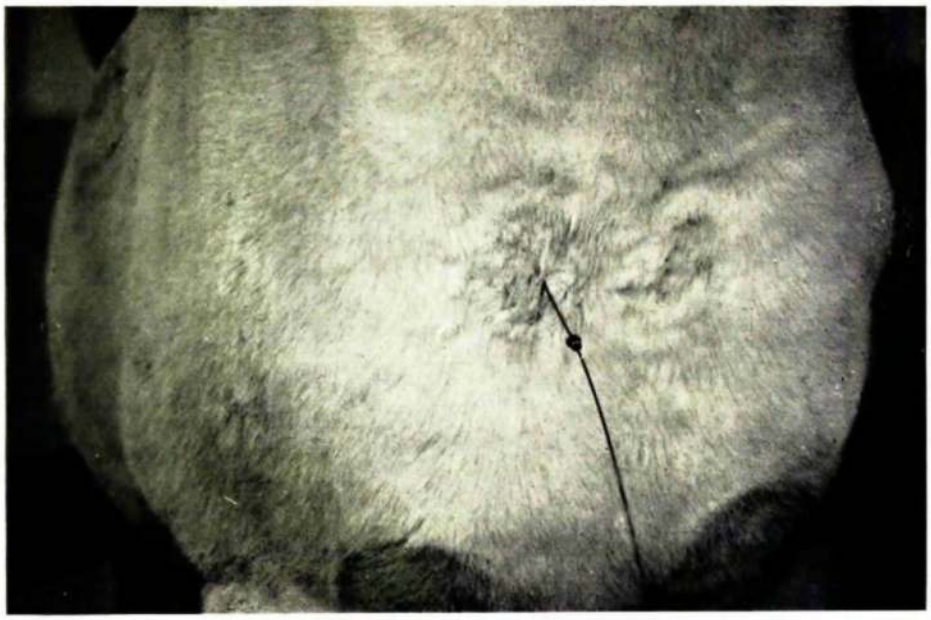

Fig. 3 (b). Arterial puncture *in situ* (horse).

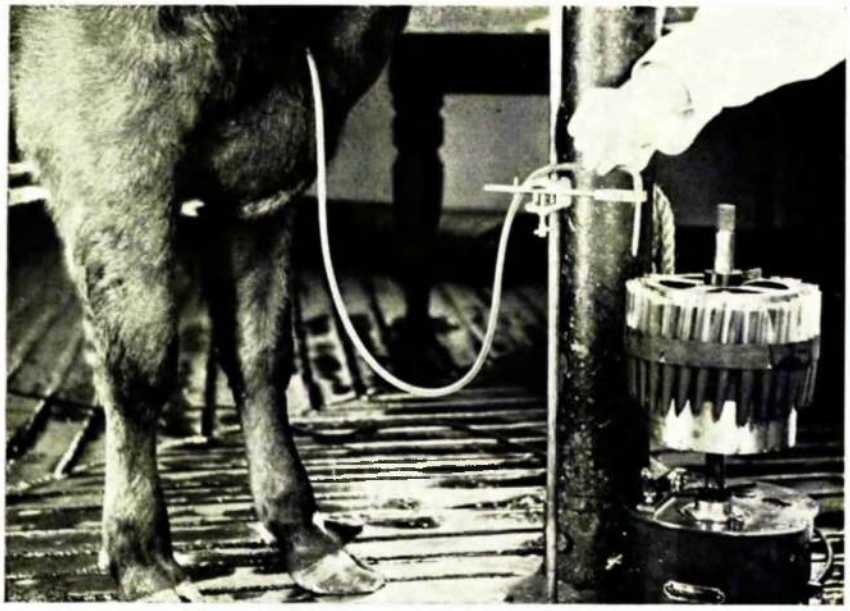

Fig. 4. Collection of serial arterial blood samples.

a No. 19 B.W.G. needle 2 in. in length in order to anaesthetize deeper tissues. The animal was then left undisturbed for about one hour.

Just prior to the actual injection of Evans blue, puncture of the brachial artery was effected at the sites shown in Fig. 3. About 40–60 ml. of blood was collected for the preparation of dye-blood and dye-plasma standards.

The Evans blue solution injected was of a concentration of 20 mg./ml. in normal physiological saline. The volume injected varied with the body weight and was of the order of 1 ml./50 kg. body weight. The amount of dye was accurately determined by weighing the syringe containing it immediately before and after injection.

The dye was injected into the jugular vein through the nylon catheter and the catheter was cleared with normal physiological saline so that all the dye entered the circulation. This double injection procedure was carried out in less than four seconds by means of a special Y piece with Leuer-lock connections and minimal dead-space. Checks on this Y piece showed that after the injection of dye and the succeeding wash with saline less than 0·1 mg. of dye remained in the Y piece.

Collection of the serial arterial blood samples was started immediately after the dye was injected. The serial arterial samples were collected in a number of heparinized centrifuge tubes which were arranged around the rim of a 6 in. diameter kymograph drum. The speed of the kymograph was regulated so that each tube collected blood for a specific time. The time per tube for cattle was one second and for horses two seconds. Such a collection is illustrated in Fig. 4. After all the tubes had collected blood the arterial collection was stopped and the needle in the artery removed.

During injection and collection, the pulse rate was counted by auscultation or more often by using a single-lead electrocardiogram. On many occasions, 10 minutes after injection of Evans blue a blood sample was taken from the brachial artery where possible, or from the opposite jugular vein to the one through which the dye was injected for the determination of plasma and blood volume. About half an hour after injection and collection the animal was taken back to its loose-box or stall.

The serial arterial blood samples were numbered, and centrifuged and the plasma was separated. From the blood collected prior to injection 20 ml. volumes were accurately measured and to each volume was added sufficient of the 20 mg./ml. Evans blue solution to make standards in which the dye concentration was either 10 mg. or 20 mg. per litre of blood. These were then mixed, thoroughly centrifuged and the plasma separated.

Comparisons were made between the readings of the plasma of the serial arterial blood samples and the plasma of the standards using an E.E.L. photo-electric colorimeter with a No. 607 Ilford Filter (Evans Electroselenium Ltd., Harlow, Essex). A graph was plotted on semi-logarithmic paper of the colorimeter readings of the serial arterial blood samples against time. The descending limb of the dye-dilution curved so obtained was extrapolated to the base line as shown in Fig. 5. It has been shown that the curve so produced is what would be expected if there were no circulation of dye such as occurred in the body

and which produced the secondary rise shown. From this curve was found the time for one complete circulation of the dye and the mean concentration of the dye.

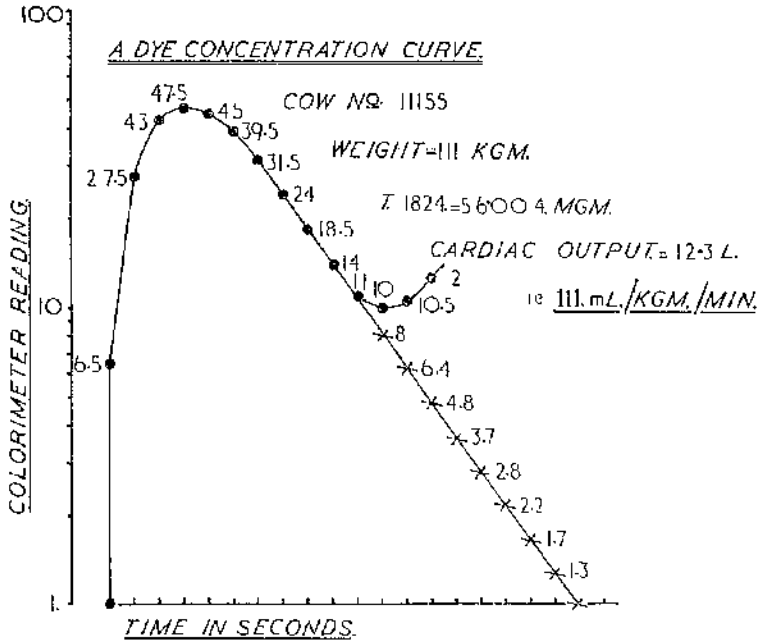

Fig. 5. Dye-dilution curve, normal cow.

The cardiac output was calculated from the equation:

$$\text{C.O.} = \frac{60 \times \text{amount of dye injected}}{\text{mean concentration} \times \text{time for one circulation}} = \frac{60I}{ct}$$

RESULTS

Thirty cardiac output determinations were made on 20 cows and heifers in Glasgow and three determinations were carried out on three adult cows in Philadelphia, U.S.A.

Twenty determinations were made on ten adult horses in Glasgow, these animals being mainly of the heavy draught type, and four determinations were made on thoroughbred horses in Philadelphia.

Calculations were made of the cardiac outputs as litres per minute and also as millilitres per kilogram body weight per minute. These results are given in Table I for cattle and Table II for horses.

TABLE I

CARDIAC OUTPUT DETERMINATIONS IN CATTLE

Expt. No.	*Cow No.*	*Body weight (kg.)*	*Cardiac Output*	
			(l./min.)	*(ml./kg.body weight/min.)*
1	11155	111	12·3	111
2	11123	201	22·0	110
3	11123	201	26·0	129
4	A	209	25·0	121
5	12234	314	32·0	102
9	12284	330	40·0	121
6	12248	342	39·0	114
7	11693	344	42·0	122
8	12284	350	37·0	106
10	10987	360	48·0	133
11	10985	361	34·0	94
12	12317	365	43·0	115
13	P.P.P.	371	40·0	108
14	12701	380	44·0	116
15	12450	387	37·0	96
16	J.C.	392	48·0	122
17	G.I.	404	48·0	119
18	T.19	420	56·0	133
19	11523	424	52·0	123
20	11523	433	48·0	111
21	B.22.	472	48·0	102
22	12282	482	53·0	110
23	12282	482	60·0	124
24	T.14.	486	62·0	128
25	S.7.	495	58·0	117
3	P.3.	500	60·0	120
26	S.1.	505	51·0	101
2	P.2.	514	54·0	105
27	E.10	515	49·0	95
28	77057	528	55·0	104
29	S.4.	534	67·0	125
30	S.8.	595	58·0	97
1	P.1.	650	65·0	100
Mean		407·7	45·8	113
S.D.				±11·33

TABLE II

CARDIAC OUTPUT DETERMINATIONS IN HORSES

Breed	*Identification no. of horse*	*Weight (kg.)*	*Cardiac output* (*l./min.*)	(*ml./kg. body weight/min.*)
			24	64
Garron	1	373	25	67
Thoroughbred	Ph.3.	384	30	78
Thoroughbred	Ph.4.	465	41	88
Thoroughbred	Ph.2.	466	35	75
Thoroughbred	Ph.1.	500	40	80
			36	71
Arab X hunter	2	509	40	79
			40	75
Clydesdale	3	534	37	69
			39	69
Clydesdale	4	562	42	73
			35	62
Clydesdale	5	568	38	67
			60	94
Clydesdale	7	636	57	90
			47	69
Clydesdale	8	683	56	82
			55	71
Clydesdale X	9	760	51	67
			70	89
Clydesdale	10	786	56	71
Mean		560	43·7	75
S.D.				±8·668

DISCUSSION

The results of the determination of the cardiac output of cattle are similar to those obtained by Doyle, Patterson, Warren & Detweiler (1960) for the cardiac output of six adult cows and are also similar to the results for the cardiac output of calves reported by Stowe & Good (1960).

The results for the resting horses were similar to those reported by Zuntz & Hagemann (1898). No significant difference was found between the cardiac outputs of draught horses and the other types of horse. When the various species of domestic animals on which determinations of cardiac output have been made are compared on a body weight basis, similar values are found in sheep (Schambye, 1952), goats (Barcroft, Boycott, Dunn & Peters, 1919) and cattle. Horses have a much lower cardiac output when at rest and so has man in the basal state (Cournand, Ranges & Riley, 1942), although non-basal values for man are somewhat higher (Wood, 1958). Values reported for the cardiac output of dogs are also much higher (Marshall, 1926). These species differences in cardiac output are given in Table III.

TABLE III

COMPARISON OF CARDIAC OUTPUT OF DIFFERENT SPECIES

Species	*Outputs (ml./kg. body weight/min.)*	*Authors*
Cattle	113	Present study
Cattle	99	Doyle *et al.*, 1960
Calves	123	Stowe & Good, 1960
Sheep	113	Schambye, 1952
Sheep	100	Cross, Dawes & Mott, 1958
Goats	120	Barcroft *et al.*, 1919
Horses	75	Present study
Horses	75	Zuntz & Hagemann, 1898
Human (basal)	85	Cournand *et al.*, 1942
Human (non-basal)	122	Wood, 1958
Dogs	138	Marshall, 1926

SUMMARY

The technique of the determination, by the injection method, of cardiac output of adult cattle and horses is described. A mean value of 113 ml./kg. body weight/min. was found for the cardiac output of 29 cattle and a mean value of 75 ml./kg. body weight/min. was found for the cardiac output of 14 horses. Comparisons are made with similar determinations carried out by other authors in the same species and with determinations carried out in other species of domestic animals and the human subject.

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An Eisenmenger Complex in an Ayrshire Heifer

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SUMMARY.—A case of congenital heart disease in an 18-month-old Ayrshire heifer is described.

The important features found during clinical and specialised examinations were: tachycardia with clear heart sounds, tachypnoea, dyspnoea on exercise, cyanosis, erythrocytosis, cardiac hypertrophy, pulmonary hypertension and gross mixing of blood from the right and left sides of the heart. Loud cardiac murmurs were not heard.

At post-mortem *examination these clinical findings were found to be due to an Eisenmenger Complex associated with atresia of the aortic arch and a pulmonic-aortic window.*

Histological examination of the lungs showed proliferative changes attributable to pulmonary hypertension in the small arteries and arterioles of all the lobes.

CONGENITAL cardiac lesions have been observed in many species but only in the human subject (Wood, 1958) and in the dog (Detweiler, 1959) has an estimate been made of their incidence. An extensive bibliography of cardiac diseases in many species has been compiled in the Comparative Cardiovascular Studies Unit of the University of Pennsylvania and this includes 51 published references to congenital cardiac anomalies in cattle (Cushmore, 1961).

The case described below is that of an 18-month-old Ayrshire heifer.

Methods of Examination

In addition to detailed clinical and pathological examinations the following specialised examinations were carried out.

Electrocardiograms

Electrocardiograms were taken using the standard limb leads of Einthoven with the right arm electrode attached to the right foreleg, the left arm electrode attached to the left foreleg, the left leg electrode attached to the left hind leg and the right leg electrode attached to the right hind leg. The electrocardiograph used was a single-channel direct writing recorder.*

Cardiac Output

Using a long polythene catheter inserted into the jugular vein it was possible to inject volumes of Evans' Blue Dye into the jugular vein, the right atrium and the right ventricle. The appearance of the dye in the brachial artery was followed by removing arterial blood samples at intervals of 1 second and measuring the concentration of dye in these samples. The application of this "Dye Dilution Method" to cattle has already been fully described (Fisher & Dalton, 1961).

Blood Pressures

Pressure recordings were made from the jugular vein and the heart in the following manner. A long polythene catheter was inserted into the jugular vein and then connected to a sensitive inductance electromanometer.† The output of this manometer was fed into a galvanometer and a photographic recorder‡ from which permanent records could be obtained. The output was also fed into a cathode ray oscilloscope so that pressure variations could be visualised without recording. The exact position of the catheter when recording was known from observation of the pressure pulse curves shown on the oscilloscope since characteristic pulse curves are obtained from different parts of the circulation of cattle (Doyle, Patterson, Warren & Detweiler, 1960).

Autopsy

The heart was examined by making incisions which followed the flow of blood (Robbin, 1957). The thickness of the right ventricle was measured at a point on the line of the second incision, in the right ventricle, half-way between the start of the incision and the pulmonary valve. The first incision into the left ventricle was made between the anterior and posterior papillary muscles and the thickness of the wall measured at a point on the line of incision half-way between the apex of the heart and the coronary groove. For histological examination blocks of tissue were taken from the heart, aorta, the brachiocephalic trunk, each lobe of the lungs, the liver and the kidneys. After fixation in corrosive formal these tissues were stained by haematoxylin and eosin, Mallory's trichrome method, Van Giesen's connective tissue stain, Weigart's elastic stain, periodic acid-Schiff and phosphotungstic and haematoxylin.

Case Report

Clinical Examination

The case was an 18-month-old Ayrshire heifer which was in good bodily condition and weighed 750 lb. It was eating 18 lb. of hay and 8 lb. of concentrates per day.

At rest its respiratory rate was 70 per minute and its heart rate 90 to 100 per minute. On auscultation a short broncho-vesicular respiratory sound was heard

* Cambridge Instrument Company Ltd., London, England.
† Elema Limited, Stockholm, Sweden.
‡ New Electronic Products Ltd., London, England.

but there were no adventitious sounds present. On percussion of the pulmonary area resonance was good. Some degree of cyanosis was observed on the mucous membranes of the tongue, conjunctivae and vulva.

The heart sounds were readily audible on auscultation of the cardiac areas on both sides of the chest and a splitting of the first sound was detectable. No murmurs were heard on initial examination but after 3 months it was possible to hear a slight diastolic murmur on some occasions when auscultating the left side of the chest just above the elbow. The pulse was almost undetectable in the median artery and in the iliac arteries it was of very poor volume. When the animal was subjected to the exercise of being run on a halter for 400 yards it became much more cyanotic and dyspnoea developed.

On haematological examination an erythrocytosis was demonstrated with an erythrocyte count of 11,000,000 cells per cu. mm. of blood, a packed cell volume of 61 per cent. and a haemoglobin concentration of 18 grammes per 100 ml. The plasma protein concentration was 6.4 grammes per 100 ml.

During 3 months in hospital the animal's appetite was maintained and its weight increased by 100 lb. It also remained bright in general demeanour.

Electrocardiogram

As illustrated in Fig. 1, the electrocardiogram showed very large QRS complexes when compared

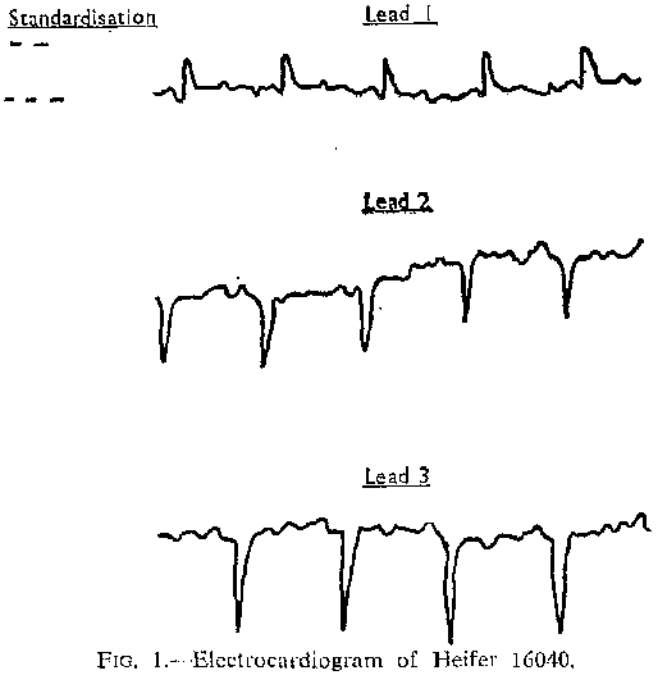

FIG. 1.—Electrocardiogram of Heifer 16040.

to those of other cattle suggesting that cardiac hypertrophy was present.

Dye Dilution Curves

The curve produced by plotting the concentration of Evans' Blue against the time of its appearance in the brachial artery is illustrated in Fig. 2A. For comparison a Dye Dilution curve obtained from a normal cow is illustrated in Fig. 2B. It is obvious that in the abnormal animal passage of all the dye

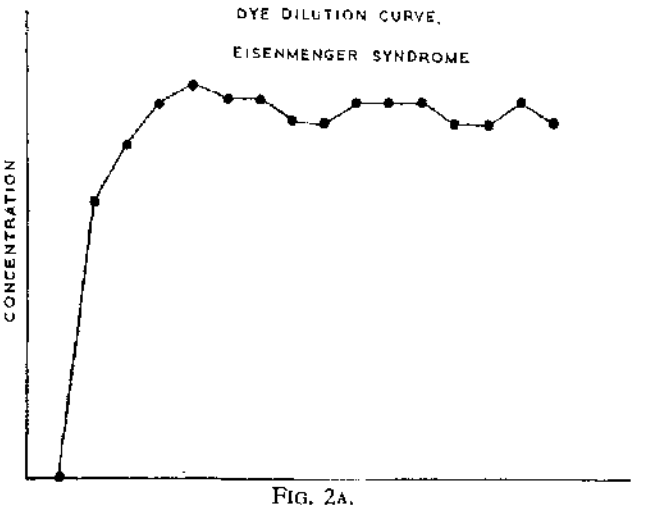

FIG. 2A.

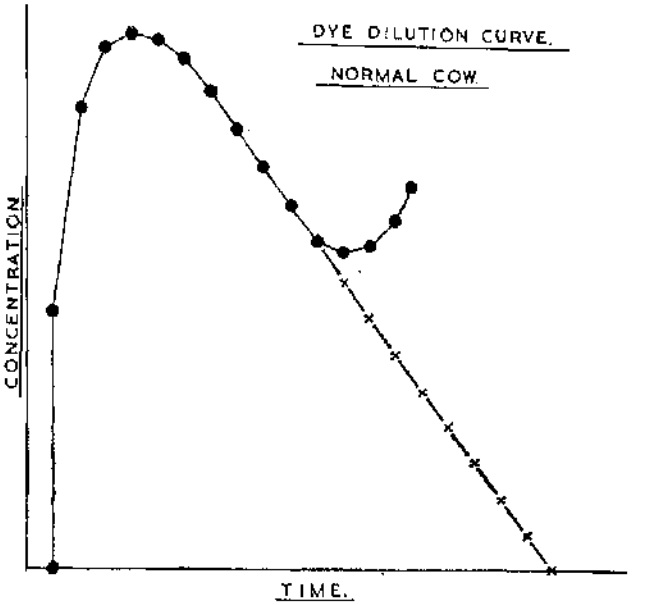

FIG. 2B.

into the systemic circulation from the heart was delayed. This type of excretion curve in man is associated with gross cardiac defects which give rise to mixing of blood from both sides of the circulation within the heart or great vessels (Wood, Swan & Helmholz, 1957). Furthermore, by selective injections of dye it is possible to localise such lesions (Swan & Wood, 1957). If dye is injected into the circulation at a point beyond such a defect, a normal type of Dye Dilution curve is obtained whereas injections before or at a defect give abnormal curves. In the animal under observation injections of Evans' Blue Dye were made into the right atrium and right ventricle, by means of a polythene catheter. The excretion curves were similar to that produced by injection of dye into the jugular vein (Fig. 2A) indicating a major ventricular septal defect or a large persistent patent ductus arteriosus or both.

Pressure Recordings

Recordings of the pressure in the right atrium, the right ventricle and the pulmonary artery were made

and these are shown in Fig. 3. It can be seen that the right atrial pressure curve was normal in shape and that the pressure was not elevated. However, the pressure curves recorded from the right ventricle and pulmonary artery were abnormal in shape with marked splitting of the systolic peaks and pressure in the right ventricle; the pulmonary artery was also elevated.

Diagnosis

In arriving at a diagnosis the following facts were considered to be significant. The cyanosis at rest which was readily exaggerated on moderate exercise and the dyspnoea produced by this exercise indicated that there was a considerable interference with oxygenation of the blood. The erythrocytosis which persisted during the time the animal was in the hospital substantiated a long-standing anoxia. The hypertrophy suggested by electrocardiographic examination was in keeping with the possibility of a major cardiac defect. The selective dye injections showed that this defect was in the ventricular septum, in the persistence of a patent ductus arteriosus or both.

The abnormal shaped pressure pulse curves which were observed each time the animal was catheterised were unlike any pulse curves observed in other cattle and, for these reasons, were not considered to be artifacts, and the elevated right ventricular pressure supported the presence of a major defect at the ventricular level while the elevated pulmonary arterial pressure suggested that this defect was probably of the type that is classified as an Eisenmenger Syndrome (Wood, 1958).

Autopsy

External examination of the heart showed that it was enlarged, the right ventricle being bulkier than normal and the apex rounded. In the atrial septum a small hole, 0.5 cm. in diameter, was present in the dorsal part of the fossa ovalis. The wall of the right ventricle was grossly hypertrophied, being 2.5 cm. thick, and the cavity of the right ventricle extended to the apex of the heart. The wall of the left ventricle was slightly hypertrophied and was 2.5 cm. thick. In the ventricular septum below the pulmonary valve, there was a large elliptical hole, 3 cm. long. The pulmonary valve and the pulmonary artery were dilated. The valve which had 3 large cusps was 5.5 cm. in diameter and the artery which was dilated above the valve was 15 cm. in circumference compared with a valve diameter of 4 cm. and a pulmonary artery circumference of 10 cm. in a normal animal of similar size.

The aorta was dextraposed and opened into the right ventricle in a recess opposite the ventricular septal defect. The aortic valve had 3 cusps and was hypoplastic, measuring only 2.5 cm. in diameter, compared with a diameter of 4 cm. in the same normal animal as above. The left coronary artery passed anterior to the pulmonary artery instead of being in its usual position posterior to it.

The ossa cordis were not developed.

Above the aortic valve the ascending aorta was hypoplastic, being only 4 cm. in circumference. It was just 7 cm. long and terminated in a dilated portion of the brachiocephalic trunk, about 3 cm. anterior to the point where this vessel had an anomalous origin from the pulmonary artery. When the dilated pulmonary artery was explored, the origin of the brachiocephalic trunk was found as a small elliptical opening 2 cm. × 0.5 cm. This opening was 7.5 cm. from the pulmonary valve. A pulmonic-aortic window, 5 cm. in circumference, was present a short distance dorsal to the opening of the brachiocephalic trunk. This opened into a dilated portion of the descending aorta, 10 cm. in circumference, and was the only communication between the descending aorta and the heart, since the aorta ended blindly proximal to this point.

The wall of this dilated region opposite the pulmonic-aortic window and also the wall of the dilated region of the brachiocephalic trunk opposite its slit-like origin in the pulmonary artery were rough in appearance. These were probably jet lesions which could be attributed to blood impinging on the wall of the vessels after being forced through the narrow apertures described (Robbins, 1957). All of

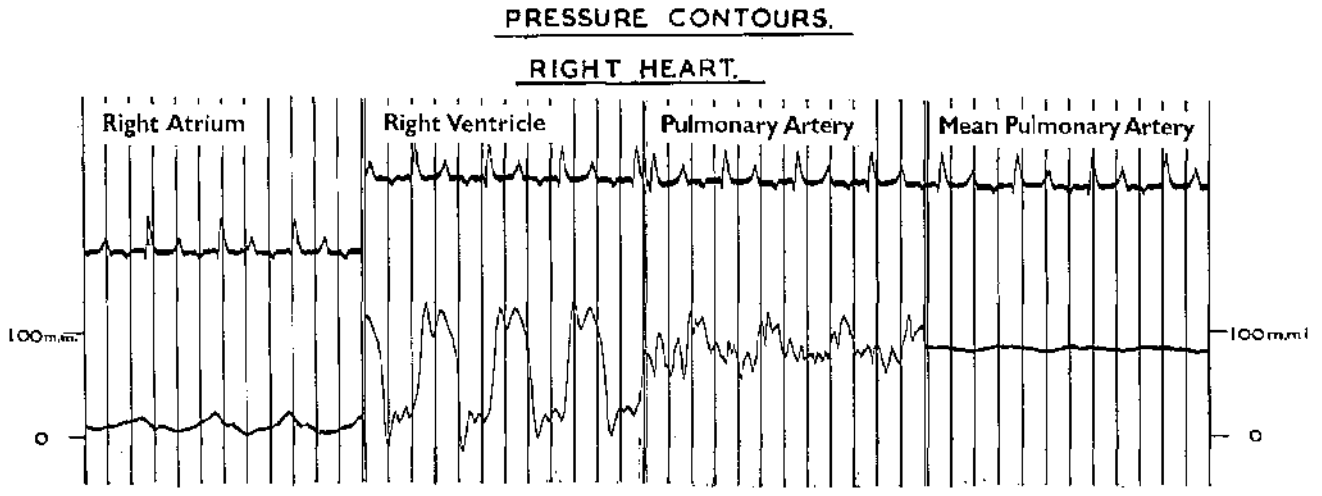

FIG. 3.

these anomalies are illustrated in Figs. 4, 5 and 6. When the large vessels were trimmed off the heart, it weighed 2,427 grammes.

Several small patches of pleurisy with adhesions were present on the dorsal borders of the posterior parts of the diaphragmatic lobes of the lungs.

On the anterior edge of the spleen, near its ventral tip, there was an abscess 2 cm. in diameter, containing thick yellow pus. Between the diaphragm and the liver in its dorsal half, there was another abscess,

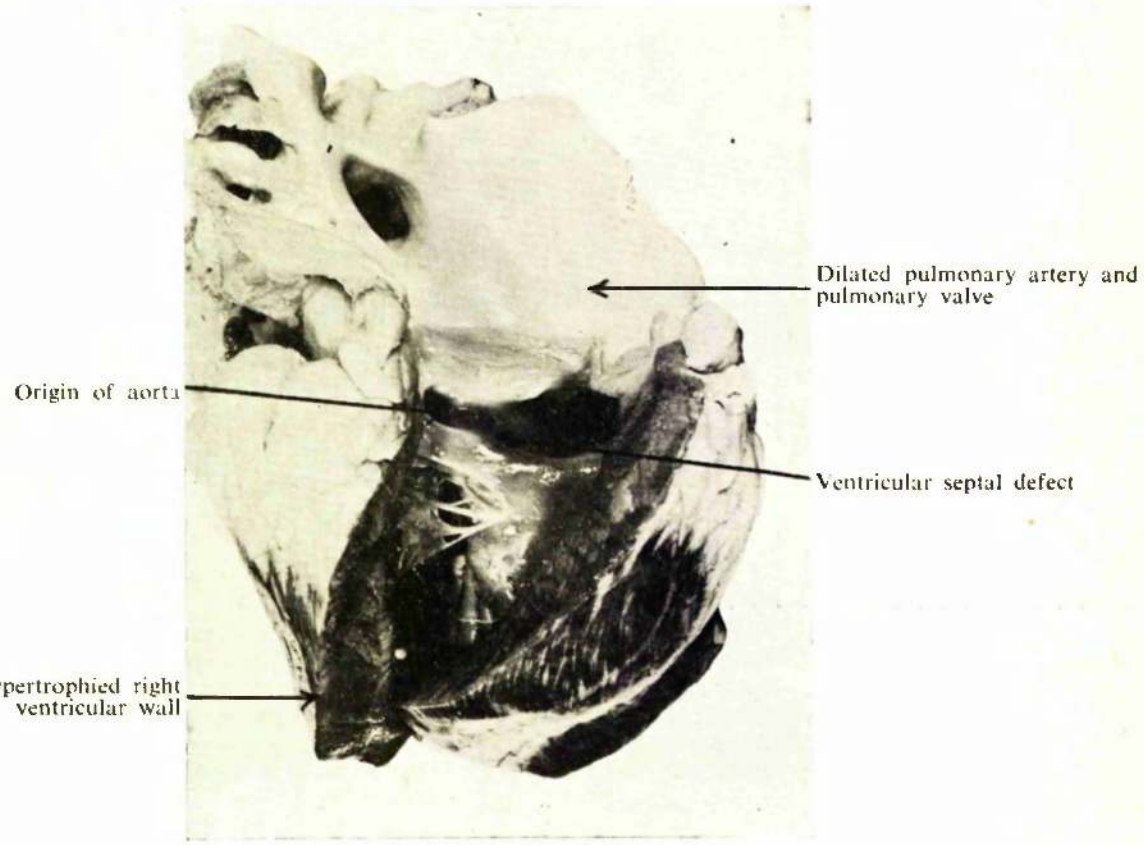

Fig. 4. Eisenmenger complex. View into right ventricle and pulmonary artery.

4 cm. in diameter, causing an adhesion between the two organs. A third abscess, 1 cm. in diameter, was present in a kidney. The bodies of all the vertebrae and the sternum were packed with dark red marrow.

Histological examination of the right ventricle showed that the muscle fibres were increased in width, and that some of them had large nuclei while others had groups of 2 to 4 overlapping nuclei. A few small accumulations of lymphocytes were present between the muscle fibres. The sections of lung tissue examined showed proliferative changes in the walls of the smaller arteries and arterioles adjacent to bronchioles, alveolar ducts, and in the septa, with narrowing of the lumina of these vessels in proportion to the thickness of the wall. These changes are illustrated in Fig. 7. There was also proliferation of the endothelium and, in a few instances, thickening of the intima. The most marked changes in these vessels were seen in the media and adventitia where the cells had proliferated resulting in an increased thickness and increased cellularity of the vessel walls. There was also proliferation and condensation of the perivascular fibrous tissue in a concentric manner around the small vessels. In a few instances, reduplication of the internal elastic lamina was detected. These changes were present in all the lobes of the lungs. Peribronchial and peribronchiolar accumulations of lymphoid cells were also seen. Sections taken from the jet lesions in the aorta and brachiocephalic trunk showed that the rough appearance was due to the thickening of the intima by proliferation of the fibroblasts and the formation of many new elastic and collagen fibres. Below these lesions the internal elastic lamina was fragmented and could be seen to be splitting longitudinally. The abscesses had fairly thick fibrous connective tissue walls infiltrated on the inner parts by plasma cells, lymphocytes and mononuclear cells.

Bacteriological examination of the abscesses yielded *C. pyogenes*.

Discussion

The Eisenmenger Syndrome was defined by Wood (1958) as pulmonary hypertension with a reversed shunt which may occur through an atrial septal defect, a ventricular septal defect or through a patent ductus arteriosus. The term "Eisenmenger Complex" is reserved for cases in which the shunt

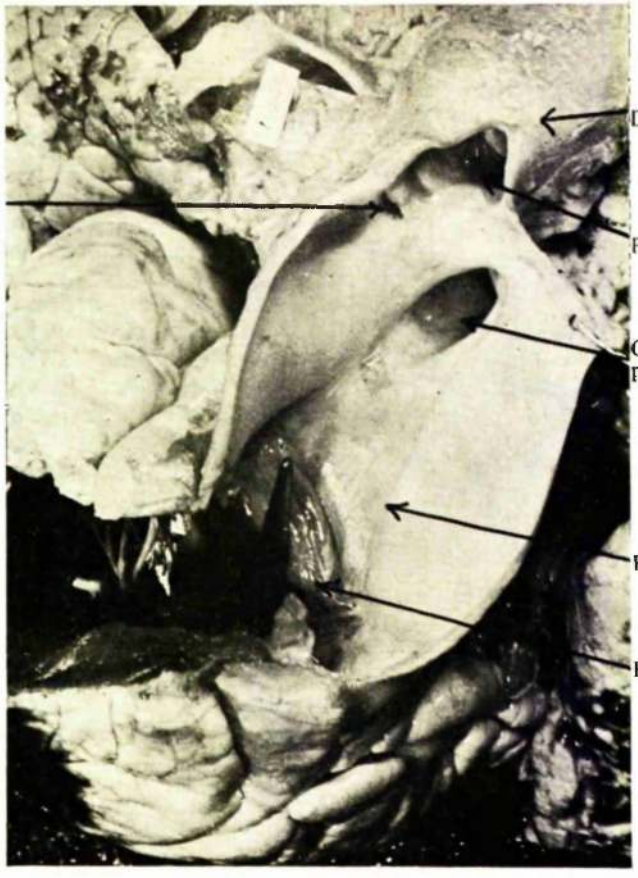

FIG. 5.—Eisenmenger complex. View into pulmonary artery.

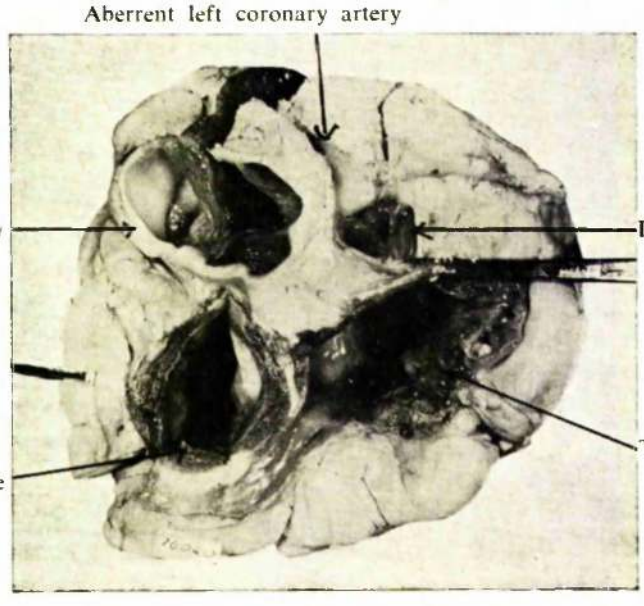

FIG. 6.—Eisenmenger complex. Base of heart.

is through a ventricular septal defect. It was not possible to determine the exact position of the shunt in this animal while it was alive and so the clinical diagnosis had to remain an Eisenmenger Syndrome. *Post-mortem* examination, however, revealed that the

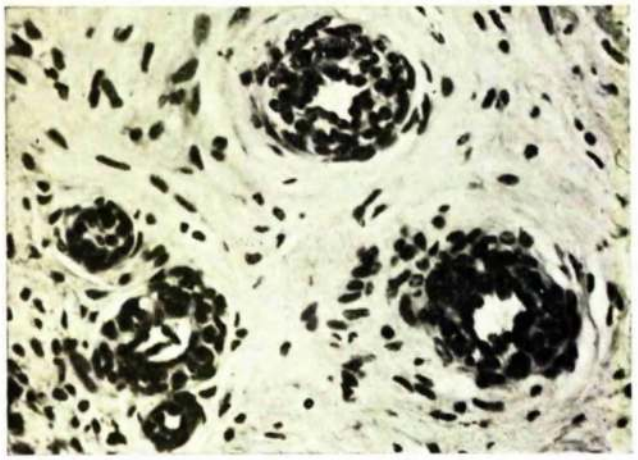

FIG. 7.—Proliferative changes in lung arterioles due to pulmonary hypertension.

animal did, in fact, have an Eisenmenger Complex.

Most cardiac ventricular septal defects are seen as a single entity or in association with anomalies in position and development of the aorta and pulmonary artery. In the latter category 2 main types of defect are recognised. These are (i) the Tetralogy of Fallot in which the aorta is dextraposed with hypoplasia and stenosis of the pulmonary artery, and (ii) Eisenmenger's Complex in which the aorta is dextraposed without any hypoplasia or stenosis of the pulmonary artery (Abbott, 1936; Eisenmenger, 1897).

The resemblance between Eisenmenger's Complex and the Tetralogy of Fallot in man has been discussed and attention drawn to the fact that stenosis of the pulmonary artery is always present in the Tetralogy but not in the Eisenmenger Syndrome (Cappell, 1958; Robbins, 1959; Anderson, 1957). These authors make no mention of stenosis or hypoplasia of the aorta occurring in cases of Eisenmenger's Syndrome. In a human case reported in 1933 by Stewart, Crawford and Baxter, the aorta, although dextraposed was otherwise normal. Abbott (1936), however, described another human case as having " a somewhat hypoplastic dextraposed aorta." The fact that the hypoplasia of aorta in this bovine case was more severe than that recorded in similar cases in man does not affect its classification as an example of an Eisenmenger Complex.

The pulmonic-aortic window present as an associated anomaly was the only route by which blood could pass from the heart to the parts of the body supplied by the descending aorta. The atrial septal defect was quite small and was regarded as a feature of no functional significance.

The hypertrophy of the right ventricle was so great that it was possible to appreciate an increase in the width of the individual myocardial fibres when compared with normal fibres without any measurements being made. The presence of large nuclei in hypertrophic cardiac muscle has been described previously (Robbins, 1957).

It is interesting to note that in this case vascular changes were present in all the lobes of the lungs. This is similar to the finding of Doyle, Goodwin, Harrison and Steiner (1957), who noticed that in man, cases of pulmonary hypertension due to congenital heart disease had changes in the vascular tree throughout the lungs whereas in pulmonary hypertension due to mitral stenosis the changes did not affect the apical regions of the lungs. Abscesses in organs are a common finding in cases of congenital heart disease in man (Wood, 1958) and it is interesting to note their presence in this case.

Taking into consideration the lesions found in this heart and the slope of the pressure contours from the right ventricle the circulation through the heart was probably as described below. Systemic venous blood entering the right ventricle was ejected into the hypoplastic dextraposed aorta and the pulmonary artery mixed with arterial blood which had passed through the ventricular septal defect from the left ventricle. The stenotic aortic valve ensured that most of the blood from the left ventricle passed into the pulmonary artery. The mixture of blood in the pulmonary artery passed to the lungs and through the pulmonic-aortic window into the descending aorta to supply the posterior part of the body. Mixed blood from the pulmonary artery would also pass into the brachiocephalic trunk through its small elliptical origin. Blood from the lungs returned to the left atrium and thence to the left ventricle. From the left ventricle some blood passed up the hypoplastic aorta but more probably passed through the ventricular septal defect into the right ventricle and then to the pulmonary artery, as previously described. The defects in this heart were such that gross mixing of blood from both ventricles took place so that both right and left ventricles contributed blood to the hypoplastic aorta and to the dilated pulmonary artery. This circulation is illustrated in Fig. 8, which is a diagrammatic

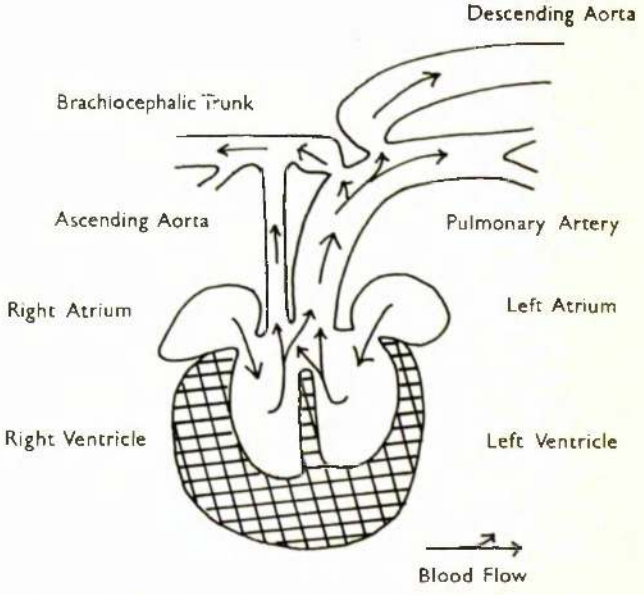

FIG. 8.—Diagrammatic representation of circulation.

version of the heart and the vessels leading from it. The pulmonic aortic window, by providing a circulation of oxygenated blood to the descending aorta, enabled life to be maintained and growth to take place within the sheltered environment of the hospital, but it is unlikely that such an animal would have survived in a commercial dairy herd.

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OBSERVATIONS ON THE BOVINE HAEMATOCRIT

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For the determination of the haematocrit of human blood it was suggested by Gregerson (1951) that centrifugation at a force of 1,600 ***g*** for a period of 30 minutes gave adequate packing of the erythrocytes. Dacie (1956) considered it advisable to centrifuge at 1,600 ***g*** for 60 minutes, whereas Wintrobe (1951) centrifuged at a force of 2,300 ***g*** for 30 minutes.

Definitive standards have not been laid down for the centrifugation of bovine blood in order to determine the haematocrit. In some investigations in which use was made of the haematocrit no statements of either time or force of centrifugation have been given (Doyle, Patterson, Warren & Detweiler, 1960; Stowe & Good, 1960). Evidence was obtained by Jennings, Mulligan & Lauder (1954) that in order to obtain packing of bovine erythrocytes it was necessary to centrifuge at a force of 1,600 ***g*** for a period of three hours when determining the haematocrit. They also found that with a force of centrifugation of 1,600 ***g*** for a period of 30 minutes the volume of trapped plasma was in the region of 12 per cent of the packed cell volume. They later found that by centrifugation at 1,500 ***g*** for three hours the trapped plasma of 28 cattle varied between 3·2 and 7·8 per cent (Jennings, Mulligan & Lauder, 1956). Reynolds (1953) by a different method found the trapped plasma to be 6 per cent in bovine blood and McLain & Ruhe (1949) found it to be 7 per cent in defibrinated blood.

In the study described below an evaluation was carried out of the accuracy of a microhaematocrit centrifuge and the time necessary for maximal packing of the erythrocytes. A comparison was made of haematocrits obtained on the same blood samples with this centrifuge and with two standard centrifuges. Using the results obtained from the microhaematocrit centrifuge and values determined with Evans' Blue, trapped plasma was calculated.

The effects on the haematocrit of some variations of blood sampling techniques were also studied. Blood samples from different blood vessels were compared. Haematocrits of blood obtained from the same vessel at different times during the day were measured, as was the effect of stasis in a blood vessel. Other variables examined were carbon dioxide loss and overnight storage.

METHODS

Heparinized blood samples were taken from healthy adult cows of the Ayrshire breed in the dairy herd of the Department of Animal Husbandry, University of Glasgow, and in the Veterinary Hospital.

For the comparison of the three centrifuges, six haematocrits were prepared from each blood sample for each centrifuge. The centrifuges used in this study were (a) a microhaematocrit centrifuge*, (b) a standard haematocrit centrifuge, the M.S.E. Minor†, and (c) another standard centrifuge with special buckets for spinning haematocrit tubes, the M.S.E. Super Medium†.

For centrifuges (b) and (c) Wintrobe haematocrit tubes were used and these were centrifuged unsealed. For the microhaematocrit centrifuge (a) capillary haematocrits were prepared.

To determine the haematocrit indirectly large volumes of blood were collected. A part of each sample was centrifuged and the plasma separated from it. From both this plasma and from the whole blood, 5×20 ml. volumes were measured. To each 20 ml. volume was added 0·2 mg. of Evans' Blue, whereupon thorough mixing was carried out by repeated inversion. The plasma of the 20 ml. volumes of whole blood was then separated by centrifugation. Thus, for each original blood sample there were 5×20 ml. volumes of plasma, each containing 0·2 mg. of Evans' Blue and 5 (20 ml.—x ml.) volumes of plasma containing the same amount of Evans' Blue where x ml. was the red cell volume. Using a photoelectric colorimeter a known concentration of Evans' Blue (0·2 mg. in 20 ml. of plasma) was compared with the unknown concentration (0·2 mg.—x ml. of plasma) and thus x was calculated. The haematocrit was five times x.

RESULTS

I. Evaluation of the microhaematocrit centrifuge and the comparison with the standard centrifuges

(a) *Analysis of the microhaematocrit centrifuge*

(i) *Error of reading the haematocrit of a single blood sample.* A total of 36 microhaematocrit tubes were prepared from the same blood sample, 12 being prepared by each of three persons. These tubes were centrifuged at an R.C.F. of 12,000 ***g*** for a period of six minutes and all the haematocrits were read by each of the three persons. The results (Table I) show that the variation obtained was ± 0·5. This compares with the best results obtained with standard centrifuges (Gregerson, 1951).

TABLE I

VARIATIONS OF READING THE HAEMATOCRIT OF A SINGLE BLOOD SAMPLE

	Mean	S.D.
Individual—A (36 haematocrits)	31·1	±0·6
Individual—B (36 haematocrits)	30·8	±0·5
Individual—C (36 haematocrits)	31·3	±0·5
Total—(108 readings)	31·1	±0·5

* Hawkesley & Sons, Limited, London, England.
† Measuring & Scientific Equipment Limited, London, England.

(ii) *Effect of time of centrifugation on the microhaematocrit.* Six microhaematocrit tubes were prepared from each of four blood samples and these were centrifuged at 12,000 ***g*** for a total time of 150 minutes. They were read at two minutes and then at 30-minute intervals. In Tables II*a* and *b* each value given represents a mean of six microhaematocrits. These indicated that complete packing of bovine erythrocytes took place in this centrifuge at this speed of centrifugation in ten minutes.

TABLE II*a*

EFFECT OF TIME OF CENTRIFUGATION ON MICROHAEMATOCRIT

Time (min.)	*Sample A*	*Sample B*	*Sample C*	*Sample D*
2	27·2	16·2	31·7	25·6
30	26·7	16·1	31·1	25·0
60	26·7	16·1	31·0	25·0
90	26·7	16·1	31·0	25·0
120	26·7	16·1	31·0	25·0
150	26·7	16·1	31·0	25·0

TABLE II*b*

THE EFFECT OF TIME OF CENTRIFUGATION ON MICROHAEMATOCRIT

Time (min.)	*Sample E*	*Sample F*	*Sample G*	*Sample H*
2	29·7	38·2	26·7	22·5
4	28·5	36·6	26·1	22·2
6	28·2	36·3	26·1	22·1
8	28·2	36·2	26·0	22·0
10	28·1	36·2	26·0	22·0
12	28·1	36·2	26·0	22·0
14	28·1	36·2	26·0	21·9
16	28·1	36·2	26·0	21·9
18	28·1	36·2	26·0	21·9
20	28·1	36·2	26·0	21·9
22	28·1	36·2	26·0	21·9
24	28·1	36·2	26·0	21·9
26	28·1	36·2	26·0	21·9
28	28·1	36·2	26·0	21·9
30	28·1	36·2	26·0	21·9

(b) *Comparison of the three centrifuges*

Six haematocrits were prepared from each blood sample for each of the centrifuges. In the standard centrifuges, centrifugation was at an R.C.F. of 1,600 ***g*** for a total time of three hours. Readings were made at 30-minute intervals and temperatures within these centrifuges were recorded. In the microhaematocrit centrifuge (a), centrifugation was at a force of 12,000 ***g*** for a total time of ten minutes, readings being made at 2, 3, 6 and 10 minutes. Each value in Table III is a mean of six haematocrit estimations made on each of 20 blood samples. These confirm the results of Jennings *et al.* (1954)

that centrifugation of cattle blood at 1,600 *g* for 30 minutes was not sufficient to ensure adequate packing of the erythrocytes. The microhaematocrit centrifuge gave better packing after ten minutes than either of the standard centrifuges gave in three hours.

TABLE III

COMPARISON OF STANDARD AND MICROHAEMATOCRIT CENTRIFUGES

	Times of Readings (min.)									
	2	3	6	10	30	60	90	120	150	180
(a) Centrifuge	31·0 ±2·82	30·5 ±2·79	30·3 ±2·87	30·1 ±2·82	— —	— —	— —	— —	— —	— —
(b) Temp. 35°C	— —	— —	— —	— —	35·6 ±3·34	33·4 ±3·05	32·4 ±3·05	32·1 ±3·05	32·1 ±3·05	32·1 ±3·05
(c) Temp. 26°C	— —	— —	— —	— —	32·8 ±3·04	32·1 ±2·85	31·7 ±2·83	31·6 ±2·76	31·5 ±2·74	31·5 ±2·74

II. The determination of trapped plasma and the centrifuged haematocrit

The trapped plasma was determined in blood samples from the mammary veins of 20 cows in the university dairy herd. For each sample the indirect haematocrit, Vc, was calculated as explained above, the centrifuged haematocrit (Vo) was determined on the microhaematocrit centrifuge and the trapped plasma calculated as a percentage of the centrifuged haematocrit. In Table IV

TABLE IV

VALUES FOR INDIRECT HAEMATOCRIT, CENTRIFUGED HAEMATOCRIT AND TRAPPED PLASMA (COWS FROM DAIRY HERD)

Cow	*Indirect haematocrit Vc*	*Centrifuged haematocrit Vo*	*Trapped plasma* $\frac{Vo-Vc}{Vo}$
Arden	26·6	30·1	11·6
Asta	30·7	34·1	9·9
Bantam	30·5	35·1	13·1
Gypsy	26·9	30·1	10·6
Matilda	24·1	28·5	15·4
Risk	25·2	30·5	17·4
Thora	27·9	31·2	10·6
Tina	28·4	30·8	7·8
Vesta	29·9	34·1	12·3
Ursula	22·9	25·6	10·5
Virtue	28·1	30·4	7·6
Meg	25·1	26·7	6·0
Wilma	23·3	26·5	12·1
Sorrel	30·5	32·8	7·0
Vera	23·2	25·9	10·4
Urdu	25·3	26·9	5·9
Harebell	27·2	29·8	8·7
Passion	27·7	30·0	7·7
Helen	27·1	31·2	13·1
Kate	28·9	32·9	12·1
Mean	26·9	30·1	10·5
S.D.	±2·49	±2·82	±3·05

each value given is a means of five values. The results show a mean for the trapped plasma of 10·5 per cent with a standard deviation of ±3·05 per cent. The mean value for the centrifuged haematocrit of these samples determined with the microhaematocrit was found to be 30·1 per cent with a standard deviation of ±2·8 per cent.

III. Effects of variations in sampling technique and the handling of blood samples

(a) Table V*a* shows the differences in the haematocrits of blood samples obtained at the same time from the jugular and mammary veins of nine non-lactating cows. Each value given in Table V*a* is a mean of five determinations.

This experiment was repeated on ten lactating cows. Each value given in Table V*b* is again a mean of five determinations. There is no significant difference between the haematocrit of blood samples from the mammary veins of lactating and non-lactating cows. The jugular samples of the non-lactating cows have a significantly higher haematocrit ($P<0·02$) than the mammary samples. The difference between the mammary and the jugular samples from lactating cows is highly significant ($P<0·001$). Moreover, the jugular samples from the lactating cows show a significantly higher ($P<0·02$) haematocrit than jugular samples from non-lactating cows.

TABLE V*a*

DIFFERENCE BETWEEN MAMMARY AND JUGULAR VEIN HAEMATOCRITS (NON-LACTATING COWS)

Cow	*Mammary*	*Jugular*	*Difference*
14948	30·9	34·9	4·0
12916	32·8	34·1	1·3
14711	36·3	37·5	1·2
Utmost	30·8	34·9	4·1
Wood	30·8	32·0	1·2
Risk	31·7	32·9	1·2
Sheppy	29·5	32·0	2·5
V.12	32·3	33·3	1·0
N.N.	30·8	32·7	1·9
Mean	31·8	33·8	2·0
S.D.	±1·95	±1·76	±1·22

TABLE V*b*

DIFFERENCE BETWEEN MAMMARY AND JUGULAR VEIN HAEMATOCRITS (LACTATING COWS)

Cow	*Mammary*	*Jugular*	*Difference*
Harebell	31·0	33·1	2·1
Fanny	32·7	36·7	4·0
Jersey	33·5	37·5	4·0
Rosabelle	28·1	30·1	2·0
Stella	33·0	33·0	0·0
Bantam	30·3	39·8	9·5
Daisy	33·2	37·8	5·6
Asta	33·6	40·7	7·1
Dora	28·5	34·3	5·8
Megan	30·7	33·9	3·2
Mean	31·5	35·7	4·2
S.D.	±2·15	±3·35	±2·80

(b) *The effect of stasis on the haematocrit*

Samples were taken from the jugular veins of five cows without stasis, from the same cows after the application of a choke rope to the jugular vein for two minutes, and after the application of a choke rope for five minutes. The results obtained (Table VI) showed that the application of the choke rope produced no significant difference in haematocrits.

TABLE VI

THE EFFECT OF STASIS ON THE HAEMATOCRIT OF JUGULAR BLOOD

Cow	*Before choke*	*2 min. choke*	*5 min. choke*
J	18·5	19·5	19·5
K	29·0	29·8	30·2
L	38·8	39·8	41·3
M	20·7	22·8	23·6
N	19·3	19·5	21·6
Mean and s.d.	25·3 ± 8·65	26·3 ± 8·65	27·2 ± 8·82

(c) *The effect of the loss of carbon dioxide from blood on the haematocrit*
From five animals blood samples were taken while exposed to the air and also under a layer of liquid paraffin to prevent loss of carbon dioxide. Each value given in Table VII is a mean of five determinations. It will be observed that there is no significant difference between aerobic and anaerobic samples.

TABLE VII

DIFFERENCE BETWEEN AEROBIC AND ANAEROBIC SAMPLES COLLECTED FROM MAMMARY VEIN

Cow	*Aerobic (heparin only)*	*Anaerobic (with liquid paraffin)*
W	35·20	33·16
X	39·50	41·33
Y	33·16	34·33
Z	32·00	32·50
V	22·90	23·60
Mean and s.d.	32·01 ± 5·93	33·0 ± 6·35

(d) *The effect on the haematocrit of blood samples being stored overnight in a refrigerator*
Haematocrits were determined on a number of blood samples in the afternoon and then again on the same samples at 10 a.m. the next morning after these samples had been stored overnight in stoppered bottles in a refrigerator at 4°C. The results, which are given in Table VIII, indicated that this type of storage produced no difference in the haematocrit.

TABLE VIII

THE EFFECT OF OVERNIGHT STORAGE ON HAEMATOCRITS

Sample	A	B	C	D	E	F	G	H
4 p.m.	35·33	37·8	32·5	32·6	15·5	28·0	34·2	29·3
10 a.m.	35·8	38·0	32·6	32·5	15·6	28·2	34·5	29·6

(e) *Hourly variations in the haematocrit*

Haematocrits were determined on blood samples taken every hour from five maiden heifers, four dry cows and five milking cows. The results (Table IX) showed that variations occurred in the individual animal from hour to hour. No consistent change was found at any particular hour in any of the groups. However, some of the individual variations were well outside the range obtained when repeated estimates were made on a single sample, as described earlier.

TABLE IX

VARIATIONS IN HAEMATOCRIT OF BLOOD SAMPLES FROM INDIVIDUAL COWS AT HOURLY INTERVALS

Time		11.00	12.00	13.00	14.00	15.00	16.00
(*a*) *Heifers*	1	26·5	26·7	27·5	26·3	28·0	27·0
	2	32·0	30·5	33·3	31·0	30·0	30·0
	3	30·0	28·5	30·0	27·3	26·5	28·0
	4	27·3	27·0	28·7	28·0	28·3	26·0
	5	26·0	26·0	27·5	27·0	27·7	27·3
(*b*) *Lactating cows*	1	31·3	34·0	35·3	33·5	34·5	34·0
	2	33·0	33·0	36·3	33·5	25·0	35·3
	3	34·0	34·0	33·7	34·7	37·5	32·3
	4	34·5	33·7	35·0	34·7	34·0	34·0
	5	34·2	36·8	33·7	32·8	33·2	32·0
(*c*) *Non-lactating cows*	1	32·0	33·0	34·7	33·5	33·0	33·0
	2	28·3	27·2	26·0	27·0	27·2	28·0
	3	29·3	26·8	26·6	27·5	27·8	27·5
	4	32·0	32·5	32·0	32·7	35·4	34·2

DISCUSSION

From the results given in Table I it is obvious that the high-speed microhaematocrit centrifuge used gives results for the bovine haematocrit comparable in repeatability with the best results obtained for the human haematocrit with standard centrifuges (Gregerson, 1951). It was obvious that variations in the different people reading the haematocrit were of little importance despite the fact that two of them had little experience of preparing and reading these microhaematocrits. The slight differences which were observed in capillary bore in the capillary tubes made no difference to the haematocrit reading.

The results given in Table III of the comparison of the three centrifuges confirmed the observations of Jennings *et al.* (1954) that centrifugation of cattle blood at 1,600 *g* for 30 minutes was not sufficient to obtain adequate packing of the red cells. The microhaematocrit centrifuge gave better packing after ten minutes than either of the standard centrifuges after three hours. The differences between each of the standard centrifuges were probably due to differences in the temperatures of the centrifugation resulting in evaporation taking place from the open-ended Wintrobe tubes in centrifuge (c) which regularly overheated due to old bearings.

There is no significant difference between the mean haematocrit of the 20

samples when read after three hours in the standard centrifuges and after ten minutes in the microhaematocrit centrifuge.

The mean value given for the trapped plasma in Table IV is higher than the values given by Jennings *et al.* (1956) and by Reynolds (1953), who used only four adult Guernsey cows to obtain this value, and by McLain & Ruhe (1949), whose values varied between 4 and 18 per cent with a mean value of 7 per cent. The high value obtained may be due to an inherent error in the method since Vasquez, Newerly, Yalow & Berson (1951) have produced theoretical reasons for errors in the method. However, Leeson & Reeve (1951) using human blood got comparable results with this method and the method used by Jennings *et al.* (1954).

The significantly higher jugular haematocrits shown in Table V*a* may indicate a loss of fluid to the saliva. The highly significant elevations of jugular haematocrits in lactating cows, as compared with non-lactating cows, may similarly indicate an even greater loss of fluid due to the increased food intake during lactation.

Turner & Hodgetts (1959) have shown that in sheep fluctuations in the jugular haematocrit as a result of soothing, isolation, visual and auditory stimuli, pentobarbitone anaesthesia, excitement, exercise and adrenaline could be attributed to changes taking place in the spleen as it retained or put out erythrocytes.

It is very doubtful if a comparison can be made between adult dairy cows used to handling and used to being tethered and sheep who react on most occasions to restraint with an obvious circulatory disturbance. Nevertheless, dynamic changes in the spleen may explain the hourly variations noted in mammary vein samples. They could not explain the differences between jugular and mammary haematocrits of dry cows and milking cows.

It is of practical importance that heparinized blood samples can be left for some hours when stoppered and kept at 4°C and suffer no change in the haematocrit.

The variations observed in sampling techniques, choice of vessel, and centrifugation clearly demonstrate the need for standardization in determining the bovine haematocrit. Once this is established some variation may still be expected from hour to hour in the individual cow.

SUMMARY

Investigations of a microhaematocrit centrifuge showed that this centrifuge gave better packing of bovine red cells in a very much shorter time than conventional centrifuges. Variations in the haematocrit were observed which were due to differences in sampling techniques, the choice of vessel, and the hour of examination.

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TETRALOGY OF FALLOT IN A FRIESIAN HEIFER

BY

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Received May 1, 1963

Only three cases of tetralogy of Fallot in cattle have been described (Hahn, 1908; Jasper, 1948; Cordy and Ribelin, 1950). None of these reports has included detailed descriptions of the clinical and physiological disturbances associated with this anomaly. The following case is reported since for the first time in cattle it was possible, using specialized techniques, to establish the diagnosis in life with reasonable certainty.

Methods of Examination

In addition to clinical and pathological examinations the following examinations were carried out.

Electrocardiograms. Electrocardiograms were taken using the standard limb leads of Einthoven and unipolar limb leads with the right arm electrode attached to the right foreleg, the left arm electrode to the left foreleg, the left leg electrode attached to the left hind leg, and the right leg electrode attached to the right hind leg. The cardiograph used was a Siemens Cardirex 6.*

Heart Sound Recordings. Using the Cardirex 6, graphic records were taken of the heart sounds at five different frequency bands, together with a lead II electrocardiogram for timing.

Dye Dilution Curves. By means of a long polythene catheter inserted into the jugular vein it was possible to inject volumes of Evans Blue dye into the right atrium, right ventricle, and pulmonary artery. The appearance of the dye in the arterial circulation was followed by removing arterial samples at one second intervals and measuring the concentration of dye in these samples.

Blood Pressures. Pressure recordings were made from the right side of the heart by inserting a polythene catheter down the jugular vein. The catheter was connected to a sensitive inductance manometer,† the output of which was fed into the Cardirex 6 for graphic recording.

Case Report

The subject, No. 19429, was admitted to the Veterinary Hospital at the age of 9 months with a history of not thriving. It was dull in demeanour, in poor condition, weighed 148 kg., and had large subcutaneous abcesses behind the left shoulder and upon the left patella. The feet were very overgrown. At rest the respiratory rate was 50 a minute and the heart rate was 100 a minute. On auscultation, bronchovesicular respiratory sounds were heard. Palpation of the chest revealed a præcordial thrill on the left-hand side and a distinct apex beat on the right-hand side. On percussion there was an increased area of cardiac dullness on both sides of the chest.

The first heart sound was obscured by a gross systolic murmur which was most intense at the pulmonic area, that is under the elbow at the third intercostal space, about 5 cm. above the level of the olecranon. The pulse volume was very poor. Cyanosis was detectable at rest on the mucous membrane of the eye, the mouth, and the vulva. When the animal was exercised by being run for a distance of 150 yards it became much more cyanotic and dyspnœa developed.

Hæmatological examination showed polycythæmia with a hæmoglobin concentration of 20·6 g. (normal 9–11 g.) and a red blood cell count of 14·3 million (normal 5–8 million). The white blood cell count and the plasma protein were normal.

* Supplied by Sierex Limited, London.

† Elema Schönander Limited, Stockholm, Sweden.

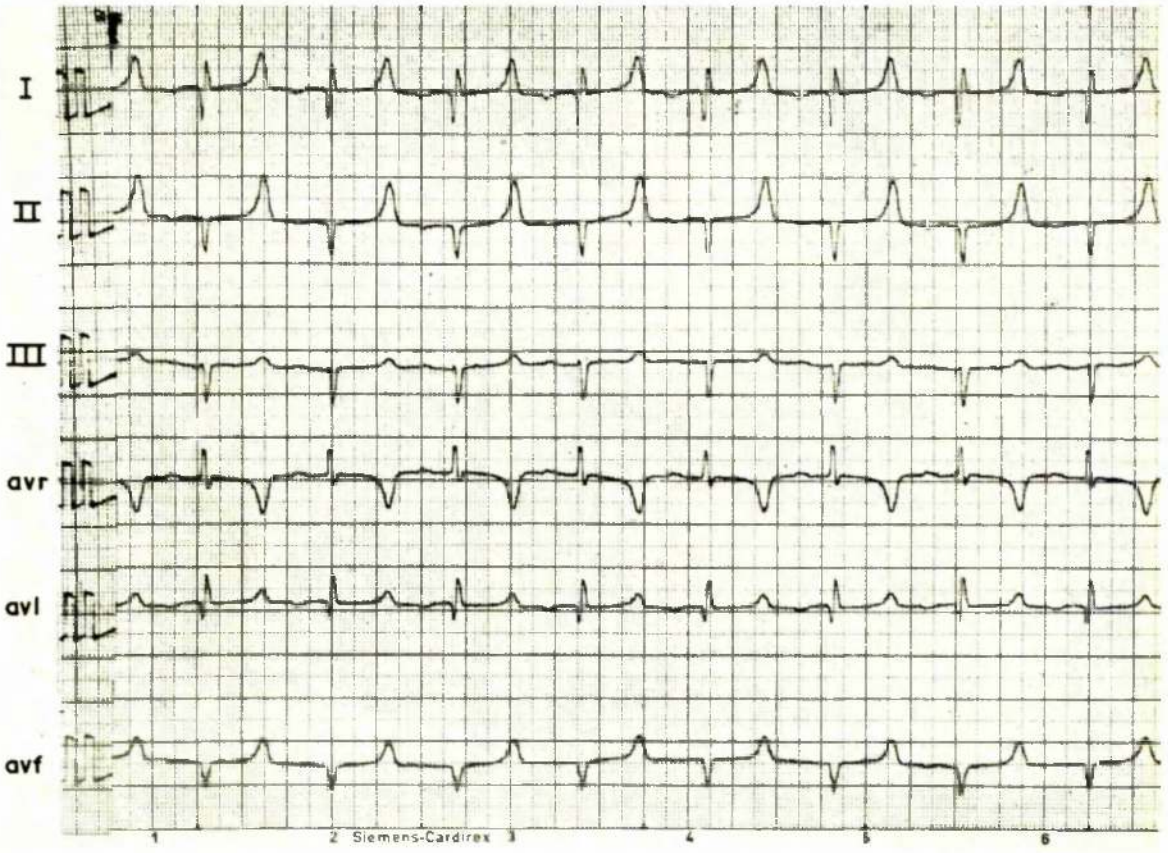

FIG. 1.—Electrocardiogram of 19429 (speed 50 mm./sec.). aVR=unipolar limb lead, right fore; aVL=unipolar limb lead, left fore; aVF=unipolar limb lead, left hind.

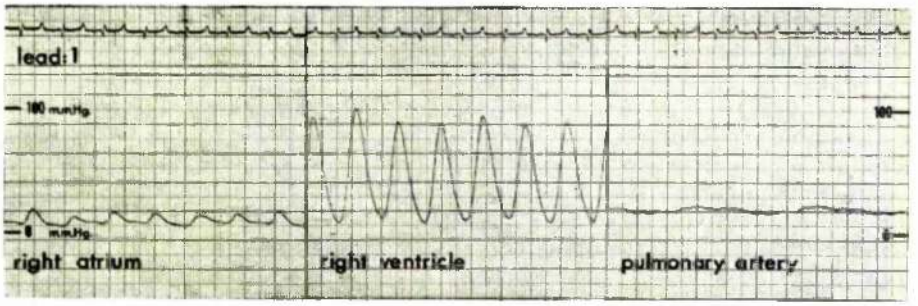

FIG. 2.—Pressure curves right heart, 19429.

The animal was kept for 10 months. During this time it showed no change in its cardiac conditon. Body weight increased from 148 to 287 kg. when it was slaughtered.

Electrocardiograms. The cardiogram (Fig. 1) showed large complexes when compared with normal cattle, suggesting cardiac hypertrophy, while the direction of the QRS complexes in limb leads and unipolar leads suggested that this hypertrophy was on the right side of the heart. Negative P waves present in leads I, II, and aVL are not usually seen in cattle, but their significance is unknown.

Pressure Recordings. The pressure recordings of the right side of the heart (Fig. 2) showed a rise in

TABLE I

CATHETERIZATION DATA (MM. HG)

	Normal heifer		Fallot's tetralogy	
	Systolic	Diastolic	Systolic	Diastolic
Right atrium	5	0	19	5
Right ventricle	53	0	93	12
Pulmonary artery	45	19	23	16
Carotid artery	180	130	105	88

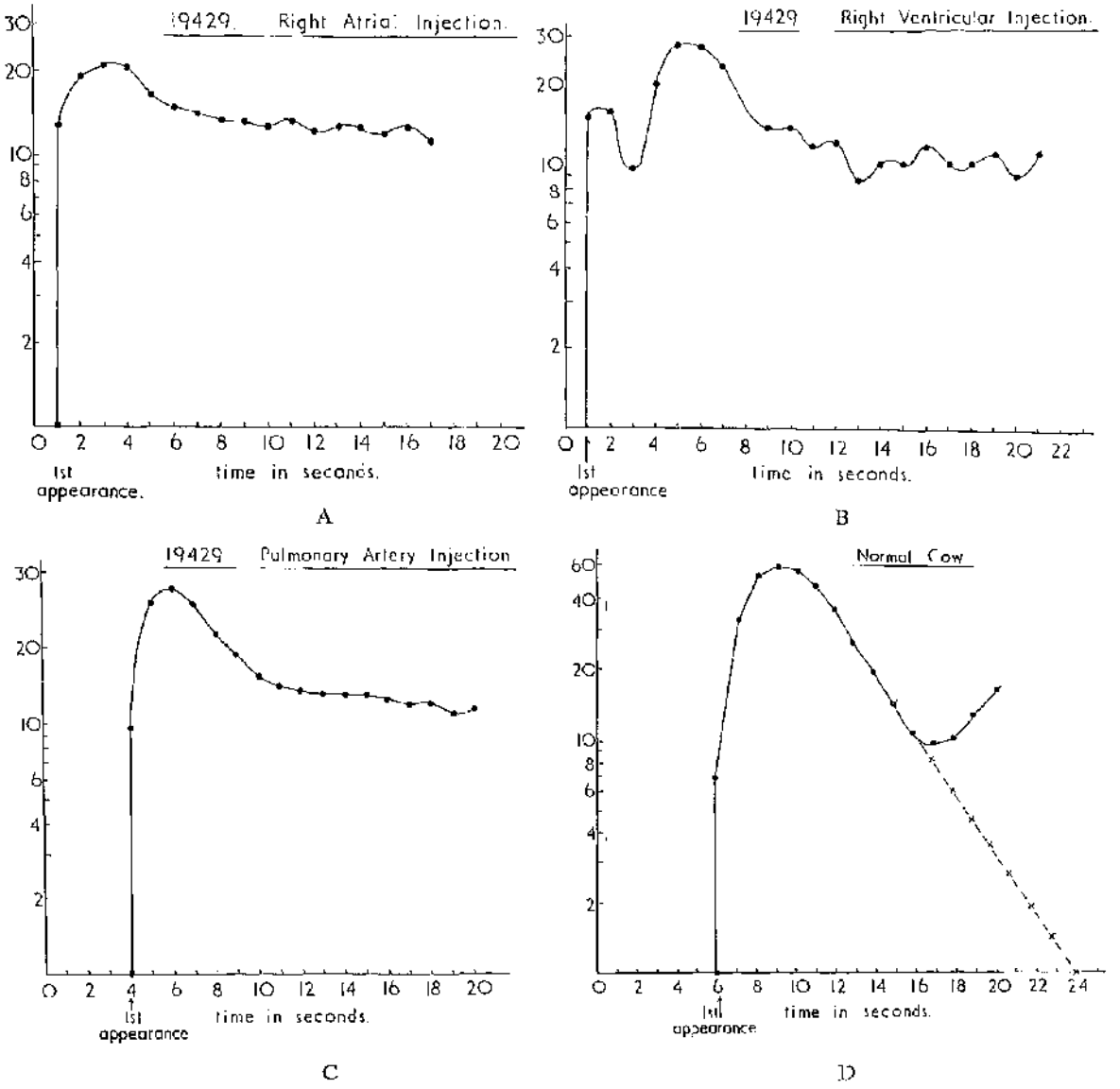

FIG. 3.—(A) Dye dilution curve, 19429. Right atrial injection. (B) Dye dilution curve, 19429. Right ventricular injection. (C) Dye dilution curve, 19429. Pulmonary artery injection. (D) Dye dilution curve, normal cow.

right atrial pressure, an increased right ventricular pressure, and a lowered pulmonary arterial pressure. The values found are given in Table I, where they are compared with a normal series of pressures found by Doyle *et al.* (1960). It will be observed that the arterial pressure was also below normal and that there was a low pulse pressure.

In cattle of this size it is not possible to localize the catheter tip by fluoroscopy. The position of catheters is known from experiments whereby catheters were fixed at sites from which particular pulse curves were obtained. These catheter positions were then determined at autopsy. On the basis of this previous experience the pressures obtained from this animal were known to be valid for the sites stated.

In addition, dye dilution curves obtained by the injection of Evans Blue at these sites and the first appearance times of the dye in the brachial artery gave further evidence of the positions of the catheter tips in this animal.

Dye Dilution Recordings. The dye dilution curves, which were obtained by plotting the varying concentrations of Evans Blue in plasma against the time of their appearances in the brachial artery, are shown in Fig. 3A, B, and C. A curve from a normal cow is also illustrated (Fig. 3D). The right atrial and right ventricular injections of dye produced curves indicating abnormal mixing of blood within the heart. Moreover, the time of first appearance of the dye was in each case more rapid than normal, suggesting a right-to-left shunt. The injection of dye into the pulmonary artery produced a dye dilution curve which was normal in shape except that the first recirculation was not so obvious as in a normal animal. The time of first appearance of dye from injection into the pulmonary artery was also normal. The delayed downstroke of the dye dilution curves 3A, B, and C suggested that in addition a left-to-right shunt existed. Therefore from these curves it was concluded that there was a gross abnormality of blood flow through the heart, which included a right-to-left shunt at the level of the ventricles and a left-to-right shunt at a higher level.

Heart Sound Recordings. These recordings, which are illustrated in Fig. 4, demonstrate the systolic murmur; and this was demonstrable at all frequencies. The pulmonary component of the second heart sound was not recorded. This abnormality is noted in Fallot's tetralogy in man (Wood, 1956).

Diagnosis. In arriving at a diagnosis, the following facts were considered significant. In this young animal there was clinical evidence of cardiac hypertrophy, a loud systolic murmur most intense at the pulmonary area, in combination with tachypnœa and cyanosis at rest. These findings, together with electrocardiographic evidence of right ventricular hypertrophy, indicated the presence of a major congenital cardiac anomaly. The dye dilution curves demonstrated a defect in the ventricular septum with a right-to-left shunt, while the pressure recordings from the right side of the heart showed the presence of pulmonary stenosis. Thus cyanosis, right ventricular hypertrophy, a right-to-left shunt in the ventricles, and pulmonary stenosis led to diagnosis of the tetralogy of Fallot.

Autopsy. The heart was enlarged, weighed 1620 g., and when viewed anteriorly the apex was rounder than normal. The gross disproportion in size between the hypoplastic pulmonary trunk and the dilated ascending aorta was obvious (Fig. 5). The wall of the pulmonary trunk was less than half the thickness of the wall of the aorta. The ductus arteriosus, which was patent, also had a thin wall and connected with the beginning of the left pulmonary artery (Fig. 5). The dilated right atrium was slightly hypertrophied, and the foramen ovale, although functionally competent, was anatomically patent.

The wall of the right ventricle, which was grossly hypertrophied (Fig. 6), was as thick as the left ventricle, and the lumen of the ventricle extended ventrally to the apex farther than normal. High in the ventricular septum was a large elliptical ventricular septal defect $3{\cdot}5 \times 1{\cdot}5$ cm. with its long axis horizontally situated (Fig. 6). Above the ventricular septal defect the aorta was dextroposed so that its anterior cusp was on the right side of the ventricular septum when viewed from above. In the left ventricle the ventricular septal defect appeared below the anterior cusp of the aorta. The aortic arch was on the left side.

The aortic valve was dilated and had three cusps which were larger than normal. The bones of the heart were well developed and the coronary arteries were normal. The aorta itself was dilated to the origin of the ductus arteriosus and the proximal part of the brachiocephalic trunk was also dilated.

The pulmonary valve was less than half the diameter of the aortic valve and had only two large cusps (Fig. 7) which were excessively large for the size of the valve and were anterior and posterior in position. Below the pulmonary valve there was an infundibular type of stenosis which had produced a narrow curving channel 5 cm. long, forming the outlet from the right ventricle to the pulmonary trunk (Fig. 6). There was no ring of fibrous tissue at the proximal opening of the channel which had thick muscular walls and was dilated immediately below the pulmonary valve, forming an infundibular chamber.

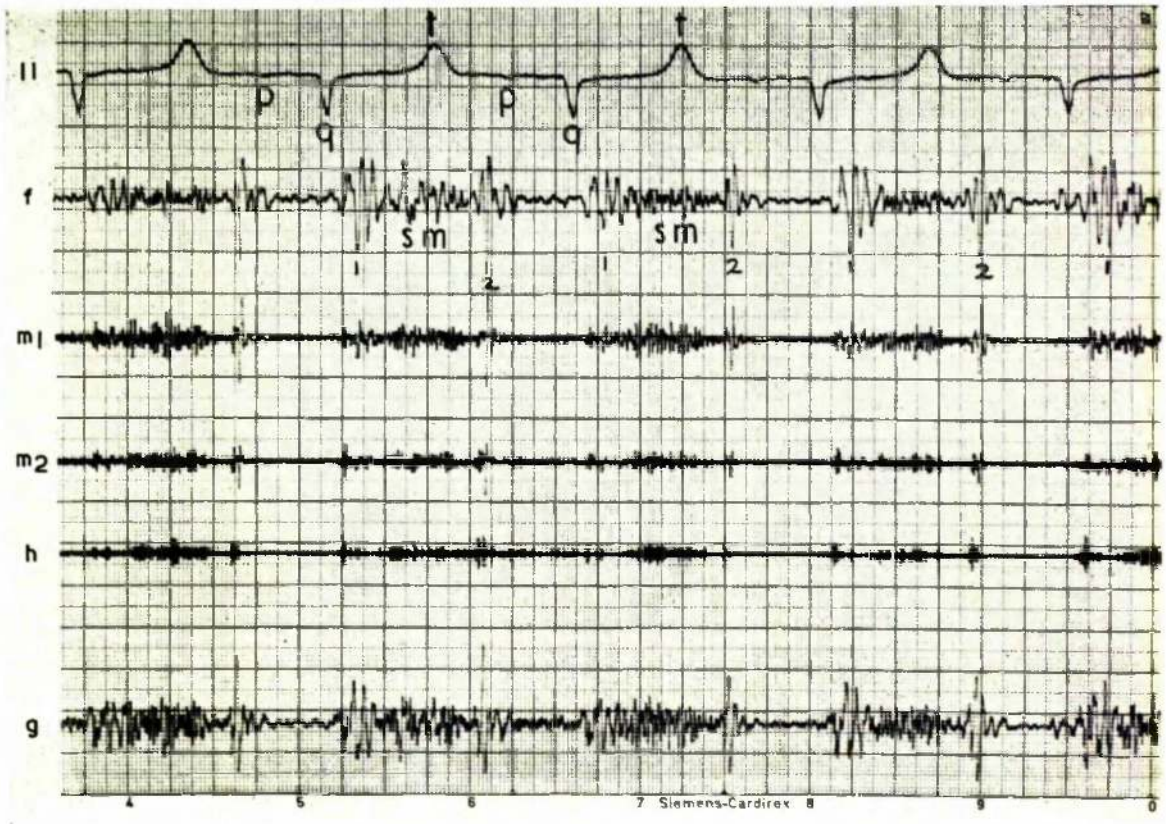

FIG. 4.—Heart sound records, 19429. Top row, electrocardiogram, lead II; second row, f, low frequency heart sound; m1, medium frequency first heart sound; m2, medium frequency second heart; h, high frequency sound; g, stethoscopic heart sound; and sm, systolic murmur.

The left atrium was normal and the wall of the left ventricle was not hypertrophied.

A large abscess 22 × 22 × 15 cm. involving the diaphragmatic surface of the liver in its dorsal half and the diaphragm itself was found. The diaphragmatic lobes of the lungs were adherent to the thoracic surface of the diaphragm over the abscess. Scattered throughout the liver were several smaller abscesses 2 cm. in diameter, either showing through the liver capsule as white circular convex areas or hidden in the liver parenchyma. No abscesses were found in the brain. The abscesses behind the left shoulder and upon the left patella had healed by the time the animal came to autopsy, and only increased amounts of fibrous connective tissue at these sites indicated where the lesions had been.

A few small pale wedge-shaped areas were seen in the cortices of the kidneys, along with some moderately large hæmorrhagic infarcts. The bone marrow in all of the vertebræ and sternebrae bodies was bright red and soft.

Histology. Histological examination of the *heart* showed that although there was considerable variation in the width of the fibres in the right ventricle, some were wider than normal. Many fibres had large nuclei, and groups of three to four nuclei close together were frequently present. In the *lungs* there were several moderately heavy peribronchial accumulations of lymphocytes. Histological examination of the *liver* and the *kidneys* showed the usual changes associated with abscess formation and infarction. No significant lesions were seen in the other organs.

DISCUSSION

Fallot's tetralogy has been described in cattle by Hahn (1908), Jasper (1948), Cordy and Ribelin (1950); in dogs by Meredith and Clarkson (1959), Glazier and Kealy (1960), Detweiler,

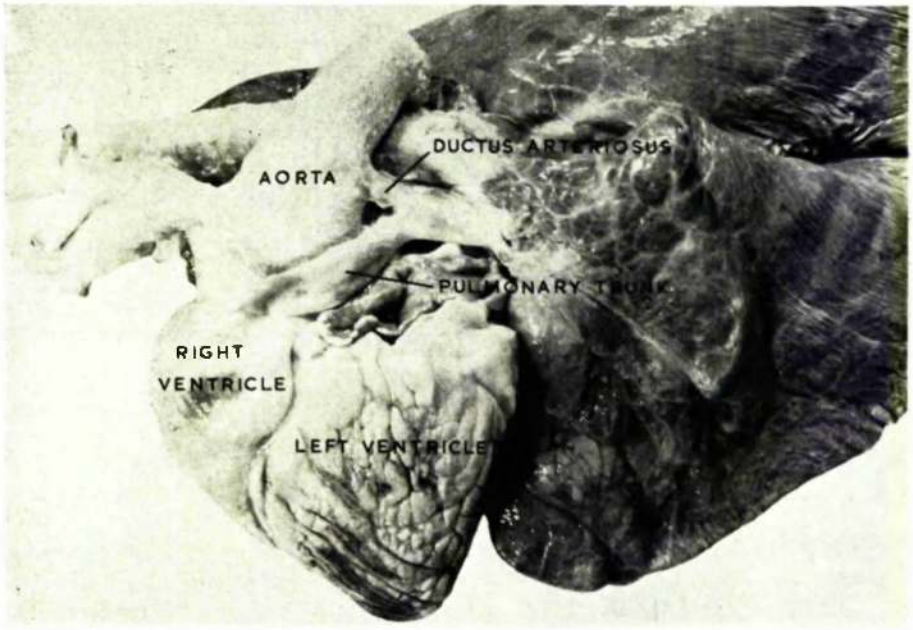

FIG. 5.—Left lateral view of heart.

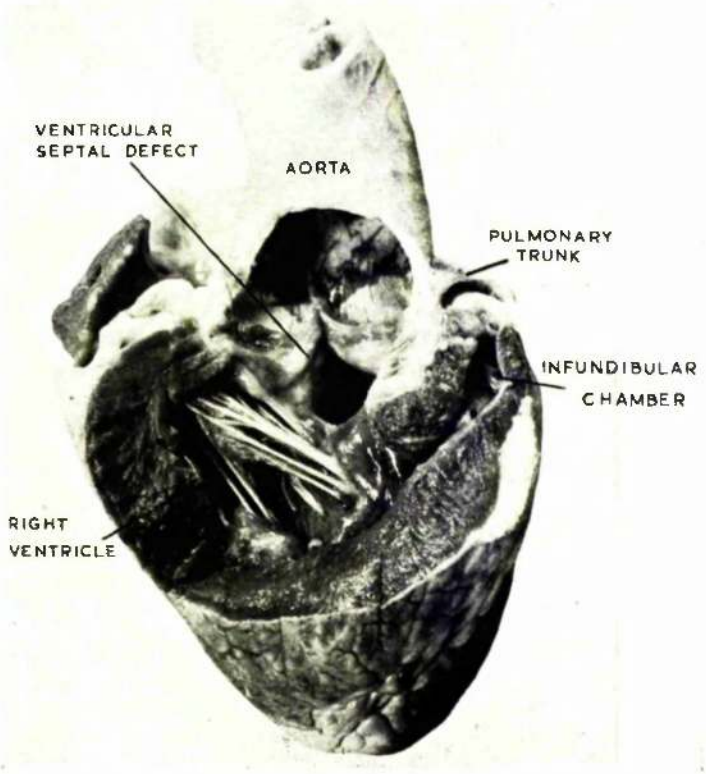

FIG. 6.—View into right ventricle.

Hubben, and Patterson (1960); in a horse by Wensvoort (1959); and in pigs by Van Nie (1961). Only in human subjects have extensive studies been made of the clinical and functional disturbances. Cardiac catheterization has been attempted in the dog (Meredith and Clarkson, 1959), but even with fluoroscopic monitoring of the catheter tip it could not be passed through the pulmonary stenosis. Three living cases of tetralogy of Fallot in cattle have been studied by us, but only in this case was it possible to catheterize the pulmonary trunk.

FIG. 7.—Bicuspid pulmonary valve.

In cattle the disease is similar to that described in the human patient, clinically, physiologically, and pathologically. Clinically there is cyanosis, tachycardia, a loud systolic murmur, tachypnœa with dyspnœa on exertion, and a poor volume pulse. Physiological examination of this case revealed right ventricular hypertrophy, right ventricular hypertension, pulmonary hypotension and the presence of a right-to-left shunt at the level of the ventricle. Pathologically the four features of the anomaly were found. In addition, in four cases observed by us and in the case described by Jasper (1948), the ductus arteriosus was patent.

It has not been possible to find evidence of tetralogy of Fallot with persistent right aortic arch in cattle, although persistent right aortic arch as a single entity has been described (Roberts, Kennedy, and Delehanty, 1953).

It is of interest to speculate whether the peculiar overgrowing of the feet observed in this animal was analogous to the clubbing of the fingers seen in cyanotic forms of congenital heart disease in man.

Although the animal survived and gained weight in the sheltered environment of the Veterinary Hospital, the weight gain was slightly less than normal, and it is doubtful if survival would have been possible under normal farm conditions.

SUMMARY

A case of Fallot's tetralogy in a Friesian heifer is described. It was possible, for the first time in a species other than man, to arrive at the diagnosis with reasonable certainty in life, by means of cardiac catheterization, and selective injections of Evans Blue dye.

We would like to acknowledge the technical assistance of Mr. J. Murphy, M.S.I.S., and of Mrs. Helen McLeod. The photographs were taken by Mr. A. Finnie, the Veterinary School photographer, to whom we also owe thanks.

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MALFORMATIONS OF THE VENTRICULAR SEPTAL COMPLEX IN CATTLE

By Edward W. Fisher and Hugh M. Pirie

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In a study of cardiovascular disease in cattle, several congenital cardiac anomalies have been observed. A high proportion of these have involved the ventricular septum. In the human subject, the term "ventricular septal complex" was used to classify congenital cardiac anomalies in which a ventricular septal defect was present either alone or associated with other cardiac anomalies (Edwards, 1960). Such anomalies have been described in many species. Figures for the incidence in man indicate that 25 per cent of cases of congenital heart disease have defects of the ventricular septum (Wood, 1958), and in the dog 15 per cent of cases of congenital heart disease have shown involvement of the ventricular septum (Detweiler, Patterson, Hubben & Botts, 1961). In a survey of 3,000 calf hearts two defects of the ventricular septum were discovered (Ruppertz, 1961). Other investigators have reported finding 15 cases out of 4,500 cattle necropsies (Olafson, 1939) and six cases out of 2,000 cattle necropsies (Cordy & Ribelin, 1950). Many individual cases have been reported (Blood & Steel, 1946; Blood, 1960; Dison, 1958; Hahn, 1908; Lilleengeen, 1934; Misdorp, Noordijk & Roek, 1959; Monti, 1954; Sheather, 1911). In the present series 16 anomalies out of a total of 19 have involved the ventricular septum. The cattle were of the common breeds found in the West of Scotland, all under three years of age and including apparently healthy animals as well as those obviously diseased.

These cases have been classified into three groups on the basis of their pathological anatomy. These are: Group I, ventricular septal defects; Group II, ventricular septal defects with pulmonary stenosis (tetralogy of Fallot); Group III, ventricular septal defects with dextroposed aorta but no pulmonary stenosis (Eisenmenger complex).

METHODS OF EXAMINATION

In addition to clinical, biochemical and haematological examinations, the following ante-mortem examinations were carried out when possible.

Electrocardiograms were taken using the standard limb leads of Einthoven and unipolar limb leads with the right arm electrode attached to the right foreleg, the left arm electrode to the left foreleg, the left leg electrode to the left hind leg and the right leg electrode to the right hind leg. The electrocardiograph used was a Siemens Cardirex 6 (supplied by Sierex Limited, London), with which graphic records were taken of the heart sounds at five different frequency bands, together with a lead II electrocardiogram for timing.

By means of a long polythene catheter inserted into the jugular vein it was possible to inject Evans Blue dye into the right atrium, the right ventricle and the pulmonary artery. When the dye appeared in the arterial circulation, arterial samples were removed at one-second intervals and the concentration of dye in these samples was measured.

Pressure recordings were made from the right side of the heart by inserting a polythene catheter down the jugular vein. The catheter was connected to a sensitive inductance manometer (Elema Schonander Limited, Stockholm, Sweden), the output of which was fed into the Cardirex 6 for graphic recording.

Autopsy

The hearts were weighed after they had been opened, emptied of blood, and the major vessels trimmed off. For the veins this was done at their junction with the atria, and for the arteries at the level of the semilunar valves. No attempt was made to remove epicardial fat.

The thickness of the right ventricle was measured at a point on the wall adjacent to the insertion of the moderator band. The thickness of the left ventricle was measured at the level of the insertion of the chordae tendineae into the papillary muscles, on the line of an incision made so that it would pass between the anterior and posterior papillary muscles, but not involve either of them.

In this series the weights of the hearts and the ventricular thicknesses were recorded for each case, but in this paper, unless it is stated otherwise, they were regarded as normal for an animal of that age, sex and breed.

Blocks of tissue for histological examination were taken from the heart, lungs, liver, spleen and kidney of each animal. The tissues were fixed in corrosive formol or 10 per cent formalin, and after dehydration and embedding they were stained with haematoxylin and eosin, picro-Mallory, van Gieson and Weigert's Elastica.

GROUP I

Eight animals which had ventricular septal defects as the primary lesion were seen in this group (Table I). The size of the defect varied and, using the circumference of the aorta as a standard, the defects were classified as large, medium and small.

Case No. 19738: *6-week-old cross-bred Aberdeen Angus, female*

This calf was admitted to the Veterinary Hospital with a gross cardiac murmur and respiratory disturbance. The animal was dull, in fair condition, and on inspection had an increased respiratory rate of 60/minute. Palpation of the chest revealed a precordial thrill at the 4th intercostal space on both sides. Percussion of the chest gave an increased area of cardiac dullness. Auscultation of the lungs revealed bronchial inspiration and bronchovesicular expiration. When the heart was auscultated at the 6th intercostal space, the heart sounds were detected, but they were partially obscured by a gross murmur. This

TABLE I

GROUP I: VENTRICULAR SEPTAL DEFECTS

Case No.	*Age at autopsy*	*Sex*	*V.S.D.†* *Aortic circumference*	*Qualitative assessment*	*Ultimate fate of animal*
19738	6 weeks	Female	1·1	Large	Died
20510	3 weeks	Male	0·9	Large	Destroyed
21342	4 weeks	Male	0·8	Large	Died
20123	6 weeks	Female	0·63	Medium	Destroyed (moribund)
18633	2 years 6 months	Female	0·59	Medium	Destroyed
19151	2 years 6 months	Female	0·36	Small	Destroyed
18961*	2 years 6 months	Female	0·31	Small	Destroyed
17736	3 months	Male	0·25	Small	Destroyed

*—Septum not perforated. †—Ventricular septal defect.

murmur was best heard at the 3rd intercostal space on the left side, at a point 5 cm. above the elbow. In character it was continuous and of the machinery type, the systolic portion ending in a distinct squeak. The heart rate was 120/minute and the pulse volume was fair. The jugular veins were distended right up to the mandible.

No cyanosis was evident at rest or on exercising. Haematological examination indicated no polycythaemia. Electrocardiographic examination showed no distinctive abnormality. X-ray of the chest showed a much enlarged cardiac shadow, particularly of the left ventricle, and the trachea was displaced upwards. There was radiographic evidence of pulmonary oedema.

In view of the machinery murmur, the cardiac enlargement—particularly of the left ventricle—and the respiratory disturbance, a diagnosis was made of a primarily left-sided heart failure, probably due to a large left to right shunt through a patent ductus arteriosus.

The animal survived only three days.

Autopsy. There was a moderately severe fibrinous pericarditis and the pericardial sac contained 100 ml. of serosanguinous fluid. The heart was grossly enlarged and weighed 660 g. The right ventricle was 1 cm. and the left 1·1 cm. thick. External examination of the heart showed that the apex was rounded. In the anteroventral part of the fossa ovalis there was a small atrial septal defect, 0·8 cm. in diameter. The right ventricle, which was grossly dilated, had a hypertrophied wall, and the pulmonary artery and valve were slightly dilated. The left atrium was dilated and the wall was hypertrophied. A large ventricular septal defect which was triangular in outline, with rounded corners, was found. The triangle measured 3 cm. × 2.5 cm. × 2.5 cm. and when viewed from the left ventricle the lesion was high in the interventricular septum with the apex of the triangle between the anterior and right cusps of the aortic valve. In the right ventricle the defect appeared posterior to the crista supraventricularis and extended slightly behind the septal cusp of the tricuspid valve, posterior to its most anteriorly situated chorda tendinea.

There was slight subcutaneous oedema along the floor of the abdomen and the thorax contained 300 ml. of serosanguinous fluid. The trachea and large bronchi were full of frothy oedema fluid, while the lungs were dark red and heavy, due to pulmonary oedema; when the lobes were sectioned, oedema fluid exuded freely from the cut surface. The liver was pale yellow, and had a nutmeg appearance. Histological examination confirmed the presence of early chronic venous congestion.

Case No. 20510: *3-week-old Ayrshire, male*

This calf was admitted as a possible case of a cardiac defect, since a gross systolic murmur had been detected on auscultation of the chest.

When examined the calf was bright and in good condition. The pulse rate was 120/minute and of good volume. On palpation of the chest a precordial thrill could be felt at the 3rd intercostal space on the left, where it was most intense, and at the 5th intercostal space on the right. Percussion of the chest revealed a loss of resonance over the lower third. Auscultation of the chest confirmed the presence of the gross systolic murmur which was most intense at the 3rd intercostal space on the left and the 6th intercostal space on the right. There was no respiratory disturbance and no cyanosis or other evidence of heart failure.

Haematological and biochemical examinations revealed no abnormalities.

The electrocardiogram suggested left ventricular hypertrophy (Fig. 1) and the phonocardiogram demonstrated the systolic murmur (Fig. 2).

The calf was then slaughtered.

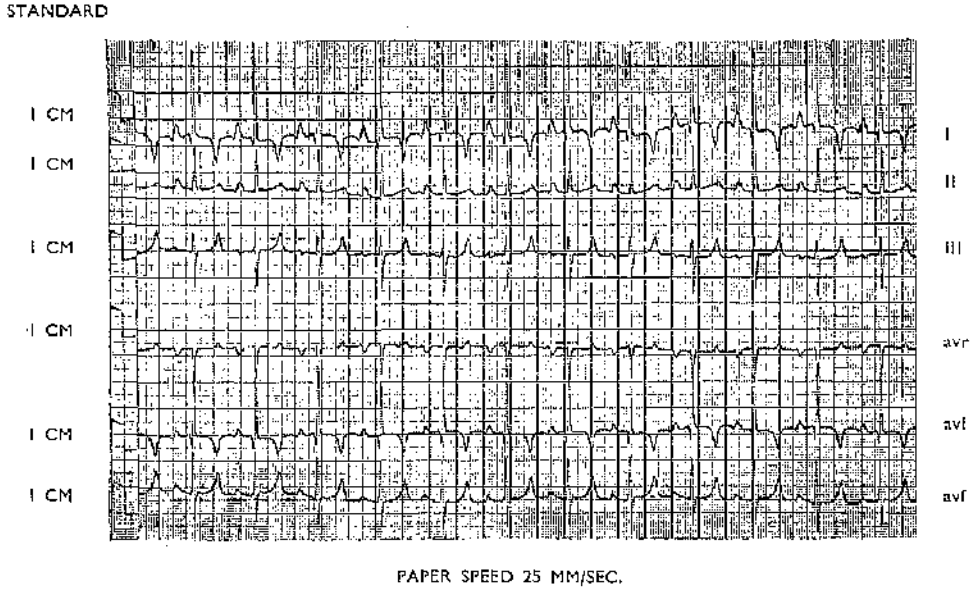


Fig. 1. Electrocardiogram. Case No. 20510

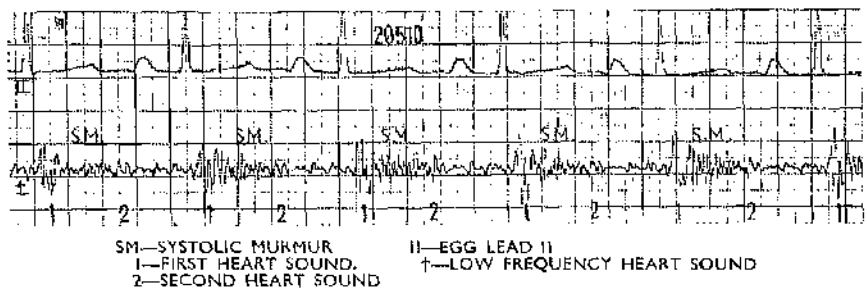


Fig. 2. Heart sounds. Case No. 20510

Autopsy. The heart was enlarged and weighed 598 g. The right ventricle was 1.3 cm. and the left 1.5 cm. thick. The pericardial cavity contained 30 ml. of serous fluid. The foramen ovale was patent but probably had been functionally competent. The right ventricle was dilated and hypertrophied. A triangular-shaped ventricular septal defect with sides 2 cm. × 2 cm. × 2 cm. was present high in the interventricular septum with the apex of the triangle dorsally. In the right ventricle it was posterior to the crista supraventricularis; in the left ventricle, whose wall was not hypertrophied, the apex of the triangle lay immediately below the anterior cusp and the right cusp of the aortic valve. The edges of the defect were rounded, thick and composed of muscle tissue. The ductus arteriosus was probe-patent. No other lesions were found.

Case No. 21342: *4-week-old Friesian, male*

This calf was admitted with a history of not thriving. When examined it was dull and in poor condition, and it was noticed that the neck was very short. The respiratory rate was 30/minute and there were no adventitious sounds. A precordial thrill could be felt on the left side of the chest but not on the right, although the apex beat was felt on the right. On auscultation an atrial 4th heart sound was heard, followed by a gross systolic murmur. This murmur was heard all over the chest but was most intense at the 5th intercostal space on the left and the 4th intercostal space on the right. The pulse rate was 100/minute and the volume was good. Cyanosis was not evident, neither was jugular distension. The condition of the calf did not change until about ten days had elapsed. The animal was then found collapsed, with a subnormal temperature, and auscultation revealed a marked cardiac arrhythmia. The calf died three hours later.

There were no biochemical or haematological abnormalities initially. The electrocardiogram suggested cardiac hypertrophy, while the phonocardiogram demonstrated the atrial sound and the systolic murmur.

When the calf was found collapsed the electrocardiogram demonstrated the presence of a complete heart block. At this time the packed cell volume was 46 per cent, which suggested some dehydration. This arrhythmia was thought to be due to hyperkalaemia and 1 litre of glucose saline was therefore administered, together with 40 ml. of 40 per cent calcium borogluconate solution. The effect of these injections was to abolish the arrhythmia, but marked

abnormalities were produced in the T waves of the electrocardiogram.

Biochemical confirmation of the hyperkalaemia was obtained when a plasma potassium concentration of 7.6 m.-equiv./l. was found. The calcium injections produced a hypercalcaemia and thus the abnormalities in the T waves.

An initial diagnosis of a ventricular septal defect was made. No explanation could be found for the hyperkalaemia since the calf was not diarrhoeic or markedly dehydrated and had refused two meals only.

Autopsy. The heart was larger than normal and weighed 378 g. The walls of the right and left ventricles measured respectively 1.5 cm. and 1.7 cm. The right atrium was dilated and although the foramen ovale was patent it appeared to have been functionally competent. As a result of dilatation, the lumen of the right ventricle extended further to the apex of the heart than normal, and in addition the wall was grossly hypertrophied. High in the ventricular septum there was an elongated triangular defect with rounded corners whose apex was situated ventrally (Fig. 3a). The width at the dorsal part was 1.5 cm., ventrally it was 0.5 cm., and it was 3 cm. long. In the right ventricle the lesions appeared posterior to the crista supraventricularis and in the left below the anterior and right cusps of the aortic valve in the outflow tract of the ventricle (Fig. 3b). The moderator band was displaced ventrally and to the left of the apex of the defect. The pulmonary valve and the pulmonary trunk were dilated. The left atrium was dilated and the left ventricle was also dilated and hypertrophied.

In the trachea and bronchi there was a large amount of pale yellow foam and fluid. The lungs, which were oedematous and congested, were heavy and dark red, and when they were cut the surface exuded copious amounts of fluid.

There were 11 thoracic vertebrae, 11 right ribs and 12 left ribs. The eighth thoracic vertebra, which was wedge-shaped, articulated with three ribs on its left side. In addition, although the vertebral arches were normal, the bodies of the sixth and seventh cervical and the first and second thoracic vertebrae were smaller than normal, distorted, and fused together, there being no proper intervertebral disc formation. The body of the 4th cervical vertebra was also shortened.

Case No. 20123: *6-week-old Ayrshire, female*

This calf was admitted to the Veterinary Hospital because a systolic murmur had been detected and the calf was not thriving.

On clinical examination, the calf was in poor condition with a markedly pendulous abdomen. The respiratory rate was 60 per minute and on auscultation bronchial inspiration and bronchovesicular expiration were heard. There was no loss of resonance on percussion of the chest, but on palpation a precordial thrill could be detected on the left at the 4th intercostal space and on the right at the 3rd intercostal space. The thrill on the right was very pronounced.

Auscultation revealed a gross systolic murmur, most intense at the 4th intercostal space on the left and at the 3rd intercostal space on the right side of the chest. Pulse volume was good and the rate was 90/minute.

Fig. 3b. View into left ventricle (21342)

Fig. 3a. View into right ventricle (21342)

PLATE II

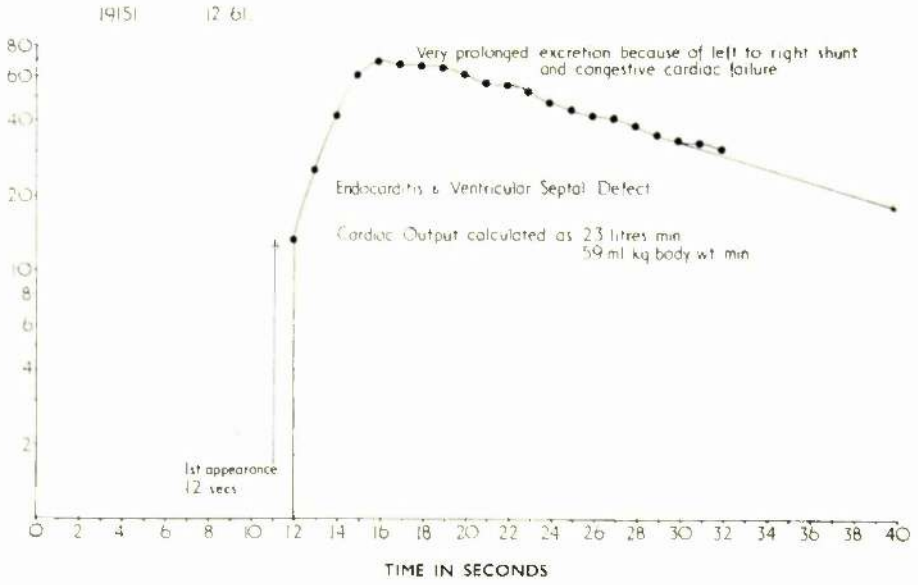
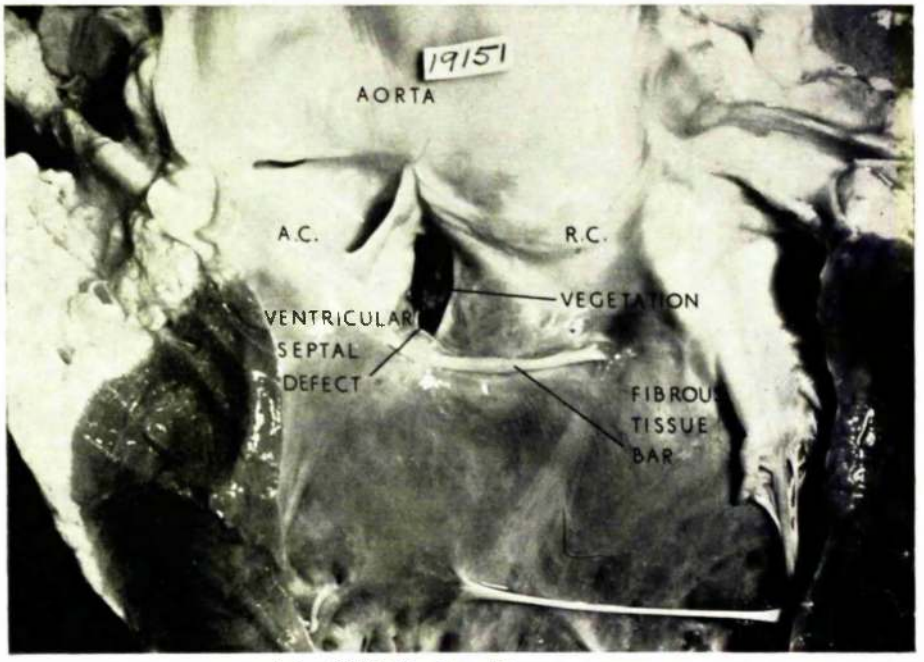


Fig. 5a.



A. C.—ANTERIOR CUSP OF AORTIC VALVE
R. C.—RIGHT CUSP OF AORTIC VALVE

Fig. 5b. View into outflow tract of left ventricle (19151)

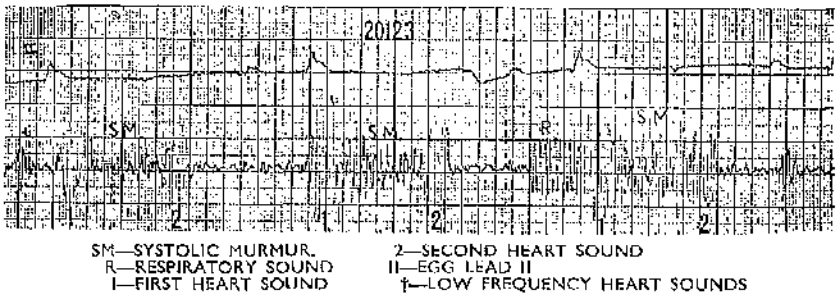


Fig. 4. Heart sounds. Case No. 20123

There was no obvious jugular distension and no oedema. The mucosae were pale pink, and showed no evidence of cyanosis.

Haematological and biochemical examinations revealed no abnormality. Electrocardiographic examination likewise revealed no abnormality. Phonocardiographic recordings taken at the 4th left intercostal space demonstrated the pan-systolic murmur (Fig. 4).

Autopsy. The heart was slightly enlarged, weighing 479 g. The right ventricle was 0.6 cm. thick and the left 1.4 cm. thick. The right ventricle was dilated and the wall was slightly hypertrophied. High in the interventricular septum a circular defect 1.2 cm. in diameter opened into the right ventricle posterior to the crista supraventricularis. This defect appeared in the left ventricle immediately below the junction of the anterior cusp and the right cusp of the aortic valve. The edges of the lesion were composed of white fibrous tissue. Instead of the usual brachiocephalic trunk arising from the aortic arch there was a brachiocephalic artery 0.9 cm. in diameter, and just dorsal to this, arising independently from the aortic arch, was the left brachial artery, 0.7 cm. in diameter.

In the apical lobe of the right lung there was a greyish-yellow patch of consolidation which proved on histological examination to be "cuffing" pneumonia.

Case No. 18633: *2½-year-old Ayrshire, female*

This cow was admitted to the hospital suffering from *hydrops amnii*. No cardiac examination was carried out and in life she suffered from no apparent cardiac dysfunction.

Autopsy: The heart weighed 1,850 g. The right ventricle was 1 cm. thick and the left ventricle was 2.1 cm. thick. After the right ventricle was opened a circular ventricular septal defect 2.2 cm. in diameter with firm white fibrous edges was seen high in the interventricular septum behind the crista supraventricularis and anterior to the anterior cusp of the tricuspid valve. When the defect was examined from the left ventricle its dorsal edge was seen to lie 0.8 cm. ventral to the right half of the anterior cusp of the aorta. The other lesions found in this animal were those associated with hydramnios.

Case No. 19151: 2½-*year-old Ayrshire, female*
This animal was bright in demeanour, in poor bodily condition and had a reduced food and water intake. Clinical examination showed that all mucosae were pale with a yellowish tinge. There was subcutaneous oedema present just in front of the udder and under the jaw. The liver could be palpated behind the last rib on the right side. A precordial thrill could be palpated on both sides of the thorax at the 5th intercostal space.

The pulse was irregular but of good volume.

On auscultation, the respiratory rate was not elevated at 30 respirations per minute, but there was slight hyperpnoea and a slight increase in normal respiratory sounds. Percussion of the thorax revealed no loss of resonance. Auscultation of the heart confirmed the irregularity of the heart rhythm, which took the form of single sounds and pauses suggestive of extra systoles. A gross systolic murmur could be detected on both sides of the thorax.

Both jugular veins were distended the whole way up the neck but no marked pulsations were detected. A pulse was palpated in the mammary vein.

Haematological examination indicated some anaemia or haemodilution, with a packed cell volume of 25 per cent and a haemoglobin of 8 g. There was no leucytosis, the white cell count being 7,400/cu. mm., but there were 74 per cent neutrophils and 25 per cent lymphocytes. The biochemical abnormalities detected were elevated serum transaminases and increased urine urea only.

Electrocardiographic examination confirmed the presence of extra systoles and suggested a right ventricular hypertrophy. Cardiac output determination gave a subnormal cardiac output with a much prolonged clearance time of dye (Fig. 5a). Cardiac catheterization showed some elevation of right atrial and right ventricular pressure but normal pulmonary and brachial arterial pressures. The final ante-mortem diagnosis was of a bacterial endocarditis with reservations in that the dye-dilution curve showed a degree of failure not manifest in the animal clinically.

Autopsy. The heart weighed 2,690 g. The right ventricle was 1.5 cm. thick and the left ventricle was 2.5 cm. thick. The valve of the foramen ovale had not been closed completely and in the anterior part of the fossa ovalis there was a small defect, 0.4 cm. in diameter. A large mass of yellow vegetation with an irregular surface blocked the anterior part of the tricuspid valve, reducing its effective orifice by about half. The vegetation was almost completely organized and when cut into it could be seen that firm white fibrous connective tissue occupied most of the mass. Several small, yellow, purulent foci were present in the fibrous connective tissue. The vegetation extended round the crista supraventricularis into the conus arteriosus of the right ventricle. This part of the vegetation was mostly composed of the thrombus material which had not organized. A small amount of vegetation was present on the pulmonary valve and a few similar lesions were found on the endocardium of the conus arteriosus. The main mass of the vegetation was dissected by several long, deep fissures which converged at a point posterior to the crista supraventricularis

where there was a ventricular septal defect. The defect was most easily seen from the left ventricle (Fig. 5b). No vegetation was present around the edges of the ventricular septal defect in the left ventricle. The defect was situated high in the interventricular septum immediately below the anterior cusp and the right cusp of the aortic valve. The diameter of the defect was 1.5 cm. and the edges were composed of white fibrous tissue. Ventral to the lesion there was a horizontal fibrous band, 4 cm. long, on the endocardium of the outflow tract of the left ventricle (Fig. 5b). In the branches of the pulmonary artery in the diaphragmatic lobe of each lung were several small emboli. Subcutaneous oedema was present to a moderate degree and in the abdominal cavity there was about 1 litre of serous fluid. The liver was grossly enlarged, weighed 10,399 g. and had the nutmeg appearance of chronic venous congestion. No other lesions were detected.

Case No. 18961 : $2\frac{1}{2}$*-year-old Ayrshire, female*

This animal was admitted with a history of recurrent bacterial pneumonia which cleared up well on antibiotics. The owner complained that it had not been thriving.

Clinical examination showed an animal bright in demeanour and in fair condition. The mucosae were pink and moist and no oedema was present. Respiratory rate was 20/minute; there was hyperpnoea with a slight increase in respiratory sounds, but no adventitious sounds were heard. The pulse was 80/minute and of poor volume. There was no obvious jugular distension.

On auscultation of the heart two clear heart sounds were heard at the 6th intercostal space on the left side but further forward under the elbow at the 4th intercostal space a harsh systolic murmur was detected. A lower-pitched

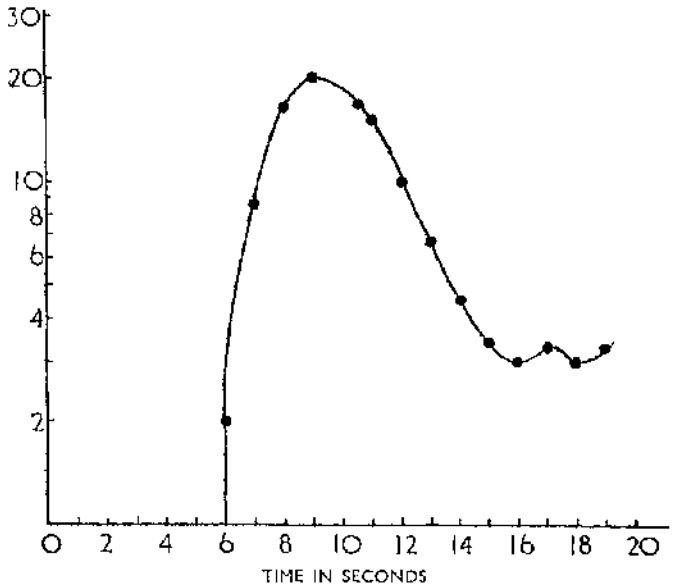


Fig. 6. Dye dilution curve. Case No. 18961

systolic murmur was heard in a similar area on the right side of the chest.

Haematological and biochemical examination revealed no abnormality. The dye-dilution curve of the cardiac output was normal (Fig. 6). Cardiac catheterization revealed no abnormality. During its stay in hospital the animal ate normally, gained weight and continued to give about a gallon of milk per day. A provisional diagnosis of a mild degree of endocarditis was made which proved to be incorrect on autopsy after slaughter two weeks later.

Autopsy. The heart weighed 2,030 g. The right ventricle was 1.4 cm. and the left 2.8 cm. thick. When the left ventricle was opened a defect was seen high in the interventricular septum in the form of a conical depression situated below the junction of the anterior and the right cusps of the aortic valve. The opening of the defect was 1.2 cm. broad and the defect narrowed as it penetrated the septum to a depth of 0.6 cm. The ventricular septum was not perforated by the defect and it was not possible to pass a probe through the ventricular septum into the right ventricle. About 1 cm. ventral to the lesion there was a transverse ridge of tissue 2 cm. long on the endocardium of the left ventricle. This ridge of tissue was white, firm, and projected about 2 mm. from the endocardium. Histological examination of the left ventricle showed focal small areas of fibrosis in the myocardium.

Scattered in all the lobes of the lungs were a moderate number of small lobular areas of consolidation, which histologically were patches of necrotizing bronchopneumonia surrounded by a zone of fibroblasts, plasma cells and macrophages.

Case No. 17736: 3-month-old Ayrshire, male

This calf was purchased as a healthy animal in a local market.

The calf was thin but bright. After a few days of diarrhoea in the first two

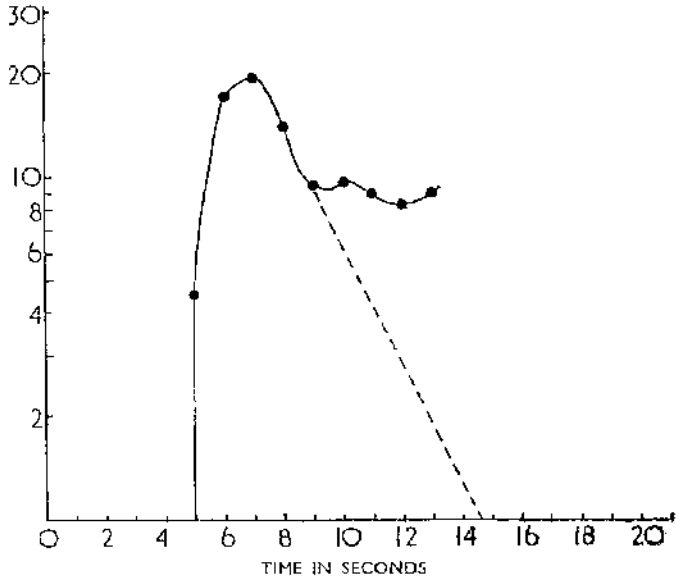


Fig. 7. Dye dilution curve. Case No. 17736

weeks, it gained weight and behaved like a normal calf. There was no cyanosis or dyspnoea at rest or on exercise. A gross systolic murmur was heard equally loudly on both sides of the thorax, but there was no palpable thrill and no evidence of cardiac enlargement on percussion. The heart rate was normal and the pulse volume was good. The electrocardiogram showed no evidence of hypertrophy or other deviation from normal. The dye-dilution curve showed an early elevation on the downward limb, suggestive of a left-right shunt (Fig. 7). Catheterization showed a slight elevation of right ventricular pressure but no other evidence of abnormality. Haematological and biochemical findings were normal.

The calf was slaughtered at three months of age.

Autopsy. The heart weighed 344 g. The right ventricle was 0.8 cm. thick, and the left ventricle was 1.5 cm. thick. When the right ventricle was opened, a defect could be seen high in the interventricular septum, posterior to the crista supraventricularis. The lesion was 0.6 cm. in diameter. In the left ventricle the defect could be seen to be immediately below the junction of the anterior and the right cusp of the aortic valve. The edges of the opening were formed of muscle tissue on all sides except dorsally, where there was a fibrous patch on its edge. No other lesions were found.

GROUP II

This group consisted of four animals (Table II) in which a ventricular septal defect was associated with pulmonary stenosis. These anomalies were of the classical tetralogy of Fallot type, since the ventricular septal defect and pulmonary stenosis were accompanied by dextroposition of the aorta and right ventricular hypertrophy.

TABLE II

GROUP II: VENTRICULAR SEPTAL DEFECTS WITH PULMONARY STENOSIS (TETRALOGY OF FALLOT)

Case No.	*Age at autopsy*	*Sex*	*Ultimate fate of animal*
18633/1	7 months (foetus)	Female	Mother destroyed
20488	3 months	Male	Destroyed
18921	8 months	Female	Destroyed
19429	1 year 7 months	Female	Destroyed

Case No. 18633/1*: 7-month-old female Ayrshire foetus*

The foetus of cow 18633, referred to earlier, was examined *post mortem* and the following was found.

Autopsy. The heart weighed 212 g. The right ventricle was 1.2 cm. and the left 1.3 cm. thick. The foramen ovale was patent but normal for a foetus at this stage of development. The right ventricular wall was slightly more hypertrophied than normal. The aorta was dextroposed. There was a moderate degree of pulmonary stenosis. High in the intraventricular septum there was a defect 1.6 cm. in diameter, which was situated below the aortic and pulmonic valves. No other lesions were found.

Case No. 20488*: 3-month-old cross-bred Hereford, male*

This calf was admitted with a history of a respiratory disturbance and a failure to thrive. On inspection the animal was dull, in poor condition and had a slight increase in respiratory rate (40/minute). The mucosae were slightly cyanosed. There was no jugular oedema. The right knee was noticed to be swollen. The pulse volume was fair and the rate was 80 per minute.

On palpation the apex beat was felt strongly on both sides of the chest and there was a precordial thrill at the 4th intercostal space on the left. Percussion showed a loss of resonance over the lower half of the chest.

On auscultation the respiratory sounds were increased with bronchial inspiration and bronchovesicular expiration. The heart sounds were clear at the 5th intercostal space on the right but a systolic murmur could be detected at the 3rd intercostal space. On the left side a systolic murmur could be detected all over the cardiac area but this was most intense at the 4th intercostal space.

When the animal was exercised it became dyspnoeic and much more cyanosed. Haematological and biochemical examinations indicated an erythrocythaemia with a packed cell volume of 46 per cent, a haemoglobin concentration of 16 g./100 ml., an erythrocyte count of 12 million/cu. mm., and a plasma protein of 6.6 g./100 ml.

Electrocardiographic examination showed electrical alternation and suggested left ventricular hypertrophy (Fig. 8). Phonocardiography confirmed the presence of the systolic murmur. Cardiac catheterization revealed an increased right ventricular pressure, but it was not possible to get the catheter into the pulmonary artery.

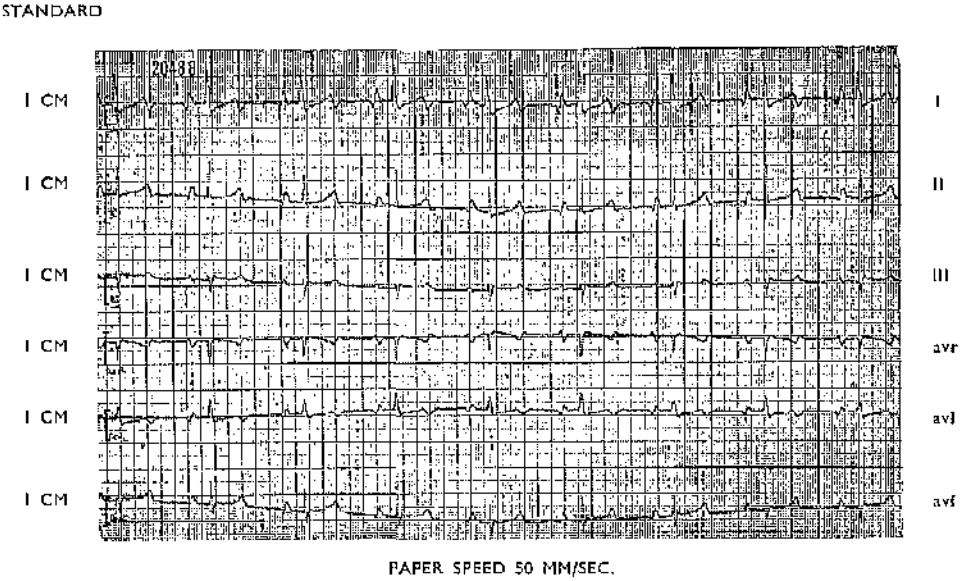


Fig. 8. Electrocardiogram. Case No. 20488

A complex cardiac defect of the Fallot type was diagnosed as a result of the clinical and specialized examinations and the animal was slaughtered.

Autopsy. The heart was enlarged, weighing 670 g. The right ventricle was 1.5 cm. thick, the left ventricle 1.7 cm. thick. When the heart was examined externally, owing to the right ventricular hypertrophy it appeared to have a double apex. It could also be seen that the pulmonary artery was very small and hypoplastic, with a thin wall, and that the ascending aorta and aortic arch were dilated. The change in the pulmonary trunk was present from the level of the pulmonary valve to the point where the vessel was joined by the ductus arteriosus, which was patent (Fig. 9). After the junction of the ductus arteriosus and the pulmonary trunk the latter vessel and the right and left pulmonary arteries were wider in diameter and had thicker walls than the first part of the pulmonary trunk. The right atrium was slightly hypertrophied and the foramen ovale was patent but functionally competent. There was marked hypertrophy of the right ventricle and the lumen of this ventricle extended further to the apex of the heart than is normal. High in the interventricular septum there was a large defect, 2 cm. in diameter, with white fibrous edges (Fig. 10). The aortic valve was immediately above the defect. The outflow tract of the right ventricle to the pulmonary trunk was stenotic. The stenosis was of the infundibular type and had resulted in a channel only 0.5 cm. in diameter leading to the pulmonary valve from the right ventricle. There was no ring of fibrous tissue at the entrance to the channel and the walls were composed of muscle. The pulmonary valve itself was small and only 1.3 cm. in diameter. It had only two cusps—a large one which appeared to consist of fused right and left anterior cusps, and a normal posterior cusp. The right coronary artery opened into the pulmonary trunk above the larger cusp. The left atrium and the left ventricle were normal. The aorta was dextroposed so that the anterior cusp was above the right ventricle. The aortic valve was dilated, being 3 cm. in diameter, and the cusps were larger than normal (Fig. 11). The bronchial arteries were slightly enlarged and an extensive plexus of small vessels could be seen in the pleura of both lungs around the hilus. In the right carpal joint there was a fibrino-purulent arthritis.

Case No. 18921: *8-month-old Friesian, female*

This heifer was admitted with a history of dyspnoea when driven out to pasture in early summer and whenever chased in the field. After being housed for five months, when driven out to pasture the dyspnoea was again noticed, and at one stage the animal collapsed and lay gasping.

The animal was in poor condition and appeared slightly stunted. When examined at rest the respiratory rate was normal but the slightest exercise caused a rapid increase in rate to 70 per minute, and an increase in the respiratory sounds. Dyspnoea appeared when the animal was driven 100 yards. Slight cyanosis, which became much more pronounced on exercise, was evident in the mucosa of the mouth and vagina. There was slight distension of the jugular veins. On palpation of the chest the apex beat was felt on both sides, but no precordial thrill was detected. Percussion of the chest revealed no abnormality.

Auscultation of the heart revealed clear heart sounds all over the chest

except at the 4th left intercostal space under the point of the shoulder, where a systolic murmur was heard. This murmur was obscured when the animal was exercised and dyspnoea produced increased respiratory sounds. The pulse volume was good and the rate was 100/minute.

Haematological and biochemical examination gave evidence of an erythrocythaemia with a packed cell volume of 50 per cent, a haemoglobin of 15 g./100 ml., an erythrocyte count of 7.2 million/cu. mm., and a plasma protein of 7 g./100 ml. Electrocardiography revealed no abnormality. A diagnosis of a complex cardiac anomaly was made but this was not followed up before slaughter.

Autopsy. The heart was enlarged and weighed 1,050 g. The right and left ventricles were each 2 cm. thick. The outline of the heart was altered because of the right ventricular hypertrophy which made this side of the heart bulkier than normal. The anterior part of the fossa ovalis contained a small circular atrial septal defect about 0.4 cm. in diameter. The right ventricle was grossly hypertrophied and so was the moderator band (Fig. 12). About 2 cm. below the pulmonary valve, which was much smaller in diameter than normal and whose circumference was only one-third of the circumference of the aortic valve, there was a ring of fibrous tissue causing an infundibular stenosis in the outflow tract of the right ventricle. A high elliptical ventricular septal defect 2·5 cm. long × 0.5 cm. dorsoventrally was present immediately below the aortic cusps. The aorta was dextroposed and the free edge of the left aortic cusp was over the ventricular septum. The valve was dilated and the cusps were larger than normal. The ostia of the left coronary artery was slightly displaced dorsally and the ostia of the right coronary artery was displaced to a similar extent dorsally, but it was also situated to the left of its normal position, so that it was above the junction of the left and anterior cusps of the aortic valve. The pulmonary trunk was hypoplastic and had a thin wall. The ductus arteriosus was patent and also had a moderately thin wall. The ascending aorta was dilated to the origin of the brachiocephalic trunk. On the pleura around the hilus of the lungs there was a plexus of small vessels, probably representing collateral circulation developing from the bronchial arteries. No abnormality was detected in the other organs.

Case No. 19429: *9-month-old Friesian heifer*

A detailed description of this case has been published (Fisher & Pirie, 1964).

Clinical examination showed poor bodily condition with large subcutaneous abscesses behind the left elbow and over the left patella. There was an increased area of cardiac dullness, a precordial thrill and a gross systolic murmur. Tachycardia and cyanosis were present at rest and the pulse volume was poor.

Electrocardiography suggested right ventricular hypertrophy. Cardiac catheterization indicated a pulmonary stenosis, while dye-dilution curves gave evidence of a ventricular septal defect. A diagnosis was made of tetralogy of Fallot.

PLATE III

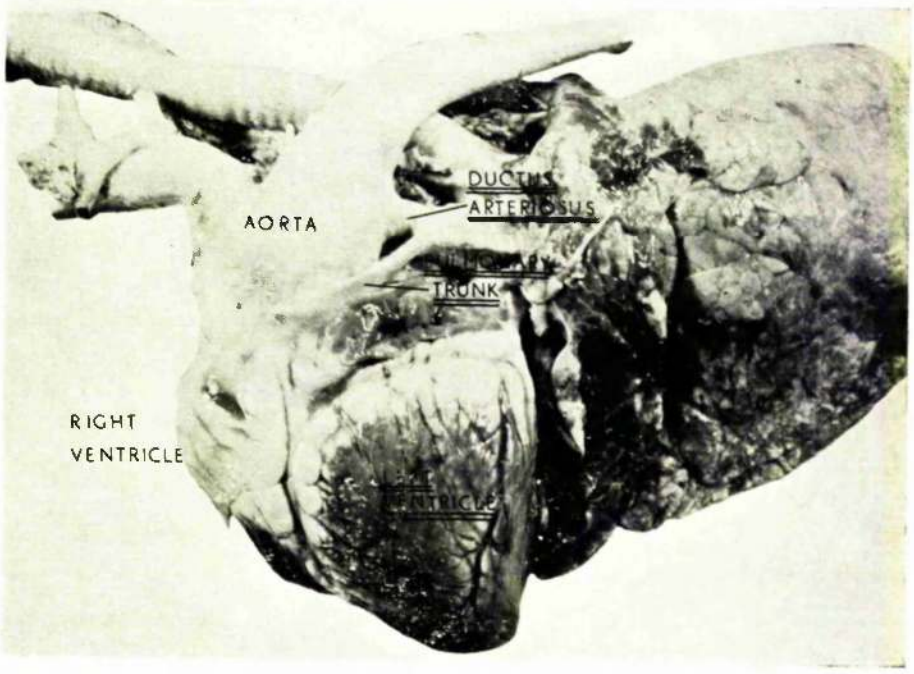


Fig. 9. Left lateral view of heart

PLATE IV

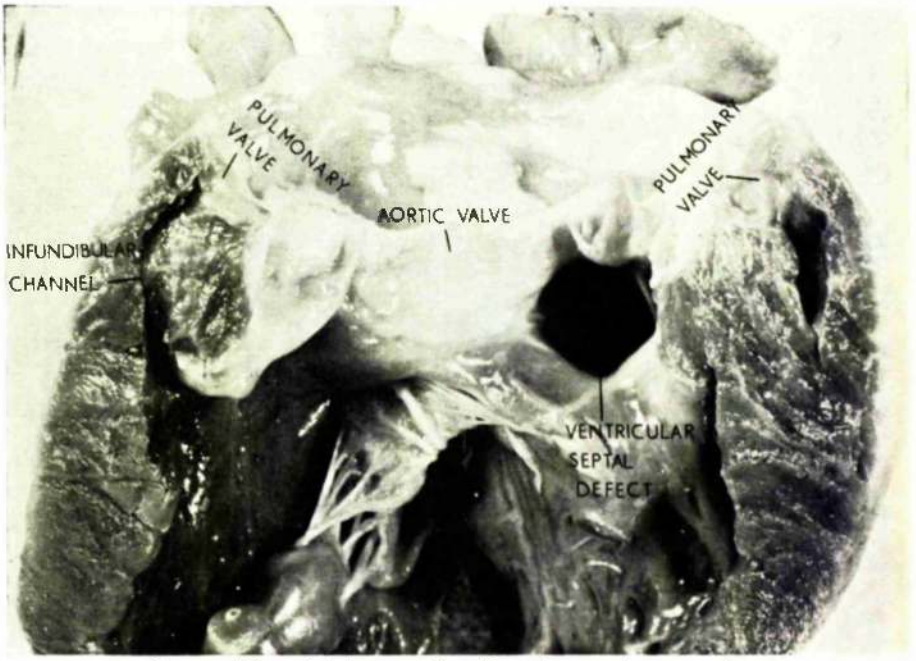


Fig. 10. View of right ventricle with major vessels removed (20488)

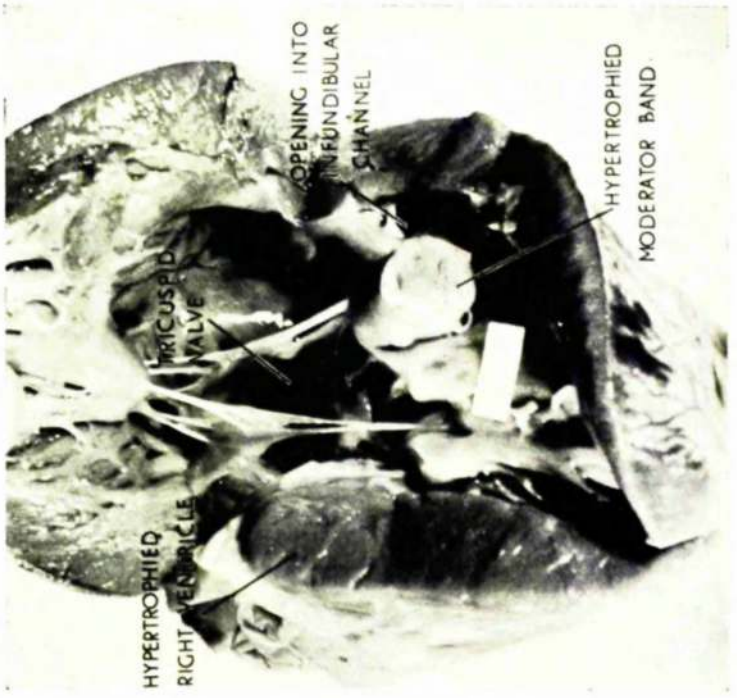


Fig. 12. View into right ventricle (18g21)

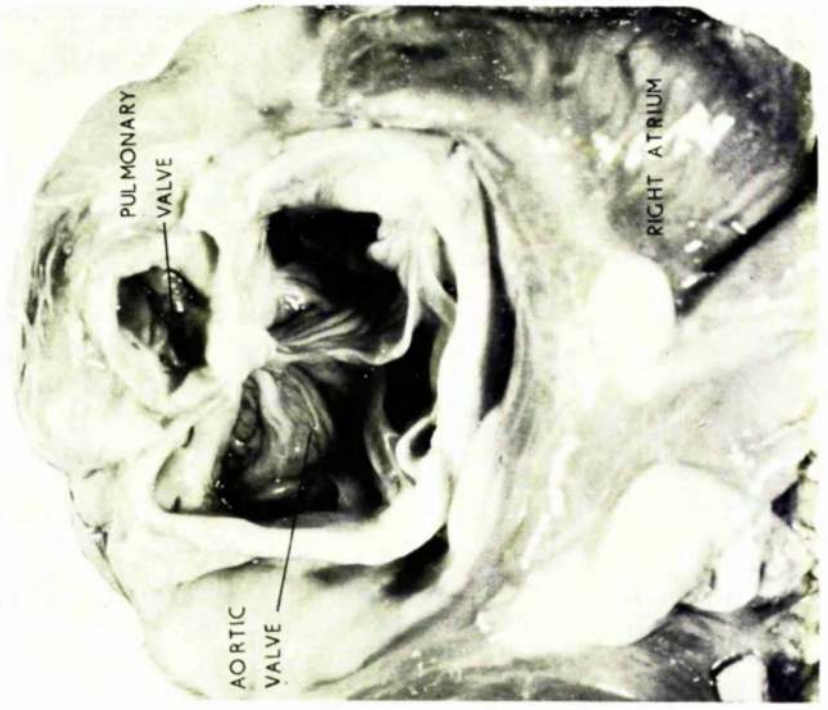


Fig. 11. Aortic and pulmonary valves (20488)

PLATE VI

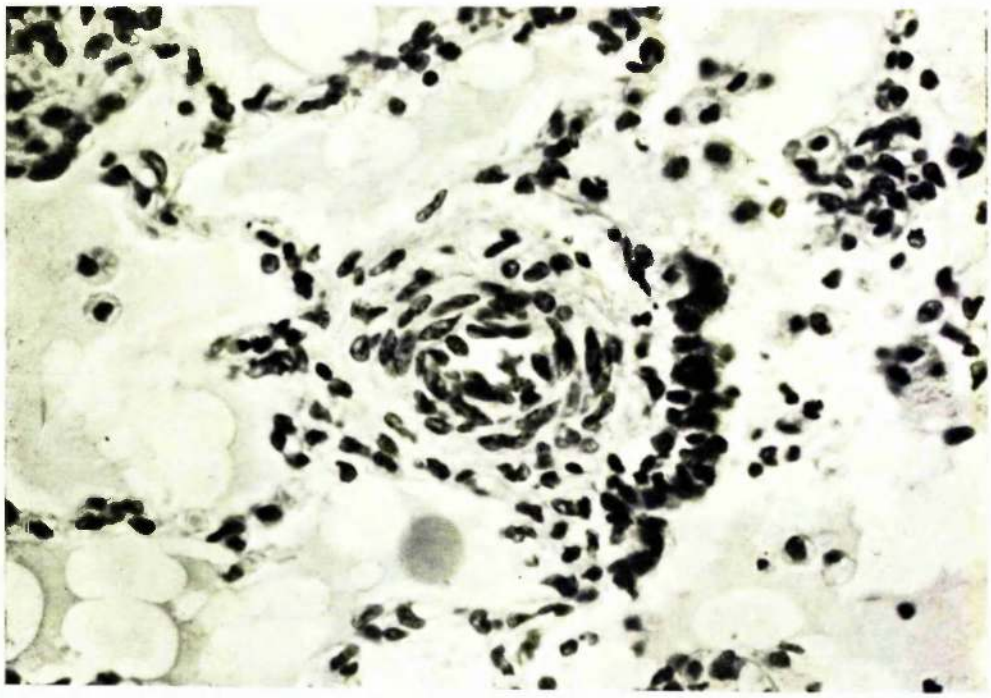


Fig. 15. Proliferative changes in lung arterioles and pulmonary oedema (20536)

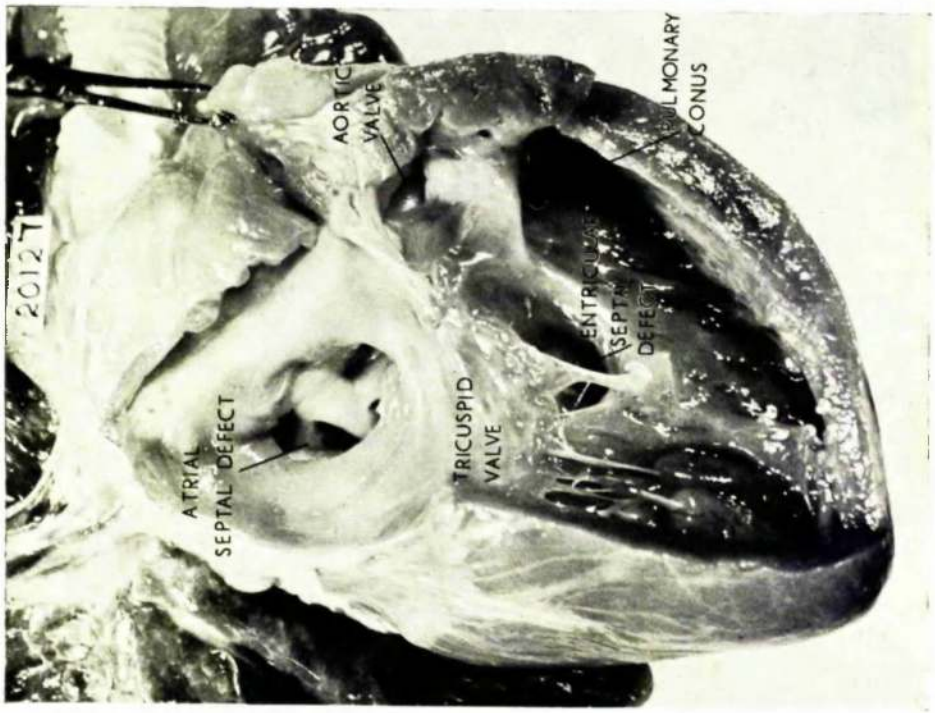


Fig. 14. View into right atrium and right ventricle (20127)

Autopsy. The heart was enlarged and weighed 1,620 g., with a right ventricle 2.5 cm. thick and a left ventricle 2·3 cm. thick.

There was gross right ventricular hypertrophy and an elliptical ventricular septal defect 3.5 cm. x 1.5 cm. high in the interventricular septum. Dextroposition of the aorta was present along with stenosis of the pulmonary tract at the infundibular level. The pulmonary valve had only two cusps and the ductus arteriosus was patent.

There were many abscesses in the liver and one large post-diaphragmatic abscess.

GROUP III

Four animals were seen in this group, which is rather heterogeneous anatomically. It is useful to classify them together, however, since all of them fit the title Eisenmenger complex, because they have a ventricular septal defect associated with a dextroposed aorta, right ventricular hypertrophy, but no pulmonary stenosis.

TABLE III

GROUP III: VENTRICULAR SEPTAL DEFECT WITH DEXTROPOSED AORTA BUT NO PULMONARY STENOSIS (EISENMENGER COMPLEX)

Case No.	*Age at autopsy*	*Sex*	*Ultimate fate of animal*
20127	3 weeks	Female	Died
21809	3 months	Female	Died
16040	1 year 9 months	Female	Destroyed
20536	2 years 6 months	Female	Died (Late pregnancy)

Case No. 20127*: 3-week-old Ayrshire, female*

This calf was admitted with a number of congenital anomalies. In addition to the cardiac defects described below, it was small, blind because of non-development of the eyes, had a very short tail and had prognathus.

On inspection the animal was in fair condition with a slight increase in the respiratory rate to 50/minute. The pulse rate was rapid (120/min.) but the volume was good. When the chest was palpated a precordial thrill could be detected on both sides at the 4th intercostal space. Percussion revealed no abnormality. Auscultation revealed normal respiratory sounds but on both sides of the chest a continuous murmur of the machinery type could be heard all over the chest. There was no cyanosis evident in the mucosae. Exercise

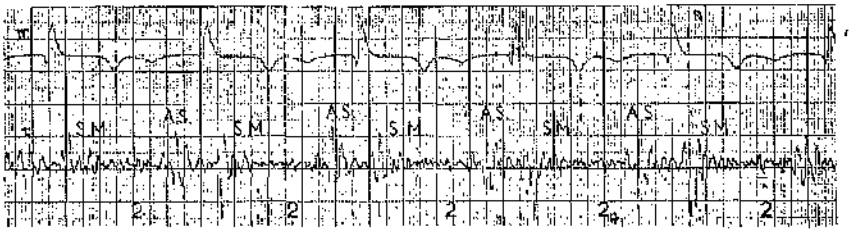


Fig. 13. II Lead II Electrocardiogram. A.S. Atrial sound. I Low frequency heart sound record. S.M. Systolic murmur. 1 1st heart sound. 2 2nd heart sound.

produced dyspnoea, but no cyanosis. Electrocardiography revealed no abnormality. Phonocardiography distinguished the murmur as occupying the latter part of the diastole and the whole of the systole (Fig. 13).

On the basis of the clinical signs and the character of the murmur a diagnosis of a widely patent ductus arteriosus was made, such signs in other species (dog and man) being pathognomic of this condition (Detweiler, 1959; Wood, 1958).

The calf died after ten days.

Autopsy. The heart was larger than normal and weighed 260 g. The right ventricle was 1.2 cm. thick and the left ventricle was also 1.2 cm. thick. In the pericardial sac there was 15 ml. of serous fluid. The right atrium was dilated and in the region of the fossa ovalis there was a large atrial septal defect 2 cm. in diameter (Fig. 14). The posterior edge of the defect was thin and membranous. The right ventricle was dilated and the wall hypertrophied. Close behind the septal cusp of the tricuspid valve there was a circular ventricular septal defect 2 cm. in diameter whose edges were formed by muscle tissue (Fig. 14). In the position where one would normally expect to find the crista supraventricularis, the aortic valve opened into the right ventricle (Fig. 14). The aorta was completely dextroposed and arose solely from the right ventricle. The left ventricular wall was not hypertrophied and the only outlet for blood from the left ventricle was through the ventricular septal defect. The ductus arteriosus was probe-patent.

The lungs were heavy and dark red in colour. When the trachea and bronchi were opened they were seen to contain a large amount of frothy fluid. Owing to the severe pulmonary oedema, cutting the lungs allowed a large amount of fluid to exude from the surface.

Histological examination of the lungs confirmed the presence of pulmonary congestion and severe oedema with oedema fluid in the bronchi, bronchioles, alveolar ducts and alveoli.

There was anophthalmos. The palpebral fissures were small and no eyeball could be seen until the orbit was dissected, when a small vestigial structure was found on each side. The third eyelids were normal.

Case No. 21809: *3-month-old Ayrshire, female*

This calf was submitted dead, thus no ante-mortem examination was carried out.

Autopsy. The heart was enlarged and weighed 740 g. The walls of the right and left ventricles measured 0·9 cm. and 1·3 cm. respectively. The pericardium contained 10 ml. of yellowish fluid. The right atrium was dilated. The right ventricle was grossly dilated and hypertrophied, and the moderator band was thicker than normal. High in the ventricular septum and posterior to the crista supraventricularis there was a large circular defect 2 cm. in diameter with muscular edges. Above the defect the aorta was dextroposed. The pulmonary valve and the pulmonary trunk were dilated. The left ventricle was dilated and hypertrophied. The coronary ostia were dilated and the isthmus of the aortic arch was coarcted.

Congestion and oedema were present in the lungs in addition to severe pneumonic consolidation which affected the apical cardiac and anterior third of the diaphragmatic lobe.

Subcutaneous oedema was found, and the thorax and abdominal cavities each contained 1 litre of straw-coloured fluid. The liver was moderately enlarged and showed changes of chronic venous congestion.

Case No. 16040*: 1 year 9 month-old Ayrshire heifer*

This Ayrshire heifer has already been fully described (Fisher, Pirie & Hector, 1962). To summarize the clinical findings, there was cyanosis at rest, marked exercise intolerance, but no gross cardiac murmurs. The cardiac anomaly was detected *ante mortem* and confirmed *post mortem*.

Autopsy. The heart was larger than normal and weighed 2,427 g. Both the right and left ventricular walls were 2.5 cm. thick.

A large ventricular septal defect was found and the aorta was both dextroposed and hypoplastic, while the pulmonary valve and pulmonary trunk were dilated. The right ventricle was grossly hypertrophied. Associated with these anomalies was a pulmonic aortic window, atresia of part of the aortic arch, a small atrial septal defect, and the course of the left coronary artery was abnormal. Abscesses were found posterior to the diaphragm, in the spleen and in one kidney.

Histological examination of the lungs showed proliferative changes in the arterioles due to pulmonary hypertension.

Case No. 20536*: 2 years six month-old Ayrshire, female*

This heifer was approximately five months pregnant when admitted to the Veterinary Hospital as a suspected case of traumatic pericarditis. She was dead on arrival and the following was found on autopsy.

Autopsy. The heart was enlarged and weighed 3,028 g. The apex of the heart was rounded. The right ventricle was dilated and the wall grossly hypertrophied. The pulmonary valve was normal. High in the ventricular septum there was a large elliptical ventricular septal defect. The left ventricle was dilated and the wall was markedly hypertrophied. The ventricular septal defect was present immediately below the aortic valve, which was dextroposed, dilated, and had three large cusps. In the left ventricle at the ventral edge of the ventricular septal defect, a band of fibrous tissue extended out onto the ventricular surface of the anterior cusp of the mitral valve and formed a ring of fibrous tissue below the aortic valve giving rise to subaortic stenosis. The animal had died in congestive cardiac failure and there was subcutaneous oedema in the brisket region. In addition, a considerable amount of straw-coloured fluid was found in the thoracic and abdominal cavities, and there was oedema in the mesentery adjacent to the coils of the colon. The liver was enlarged and showed changes of chronic venous congestion.

Histological examination of the lungs showed proliferative changes in the arterioles attributable to pulmonary hypertension (Fig. 15).

No abnormalities were found in the foetus.

DISCUSSION

It is impossible to get the true incidence of congenital cardiac lesions in cattle from this series. In our experience, however, congenital lesions involving the ventricular septum in cattle are more frequently found than lesions of the atrial septum, or of the pulmonary or aortic valves. The three cases referred to earlier which could not be classified in this series were two cases of ectopia cordis and one case of complete transposition of the great vessels.

The initial detection of all cases seen alive has depended upon the use of the stethoscope. The stimulus for its use has been a respiratory disturbance. Random stethoscopic examinations of the chest of apparently normal calves also led to the detection of two cases. The primary cardiac finding was a loud systolic murmur; occasionally a diastolic murmur was also detected.

Cyanosis and polycythaemia were not observed in animals in group I but were seen in cases in groups II and III, being a constant feature in the animals whose lesions were classified as tetralogy of Fallot. From the limited number of cases observed in group III it appeared that when there was a dextroposed aorta but no pulmonary stenosis, cyanosis was not present early in life. Cyanosis is not a common clinical sign in cattle and, apart from congenital heart cases, has only been observed by us in moribund dyspnoeic animals in the terminal stages of pneumonia.

Specialized techniques have aided the diagnosis of these anomalies.

Electrocardiography was often able to predict cardiac hypertrophy but was unable to predict which ventricle was involved to the greatest extent. Where pericarditis or pericardial effusions were present the QRS complexes were of normal size or smaller.

Pressure recordings from the right side of the heart detected right atrial and right ventricular hypertension in several cases, and proved the existence of pulmonary hypertension in one case and pulmonary hypotension due to pulmonary stenosis in another. Because of the size of the animals fluoroscopy was not employed, but the pressure records were identified from the shape of the pressure curves. As a result of previous experience and experiments, the shape of the curves was known to indicate that the catheter was in a particular site. In some cases, however, bizarre curves were obtained which could not be identified accurately. In the one case of a successful catheterization of a pulmonary stenosis, the serial dye-dilution curves proved that the pressures were from the sites stated.

Dye-dilution curves were used in a qualitative manner only to detect abnormal pathways of blood flow. They have demonstrated left to right shunts through ventricular septal defects and also right to left shunts in animals with complex anomalies. Analysis of the abnormal curves obtained from some cases was not always possible before death but correlation of the blood flow and the lesion found at autopsy could be made in retrospect.

Retardation of growth was apparent in all animals with a ventricular septal defect associated with other complex anomalies.

Skeletal abnormalities were seen in one animal in group I, and one animal

in group III. In addition, in the latter animal there was anophthalmos and although it has been shown that vitamin A deficiency can cause eye defects and cardiac deformities in experimental animals, there was no evidence that the dam of this animal had suffered from a deficiency of vitamin A.

Abscesses, which have been described as a frequent complication of some congenital cardiac anomalies of man, were present in two cases at several sites, but not in the brains.

Group I

All of the ventricular septal defects occurred in the outflow tracts of the ventricle and involved that part of the heart which is the pars membranacea. In the right ventricle they were posterior to the crista supraventricularis and in the left ventricle were found just below the junction of the anterior and right cusp of the aortic valve or extending from this site ventrally. In case 18961, however, although the ventricular septum was not completely perforated, the deficiency of tissue was in exactly the same situation as in the other animals with complete defects.

The severity of the functional disturbance varied directly with the size of the defect, and duration of survival varied inversely.

Associated congenital lesions which were probably not functionally significant were found in four cases. There were small atrial septal defects in two animals, horizontal ridges of fibrous tissue on the endocardium of the left ventricle below the defect in two animals, and in one animal anomalous origin of the left brachial artery from the aortic arch.

Bacterial endocarditis of the tricuspid valve and the right ventricular side of the defect was a major complication in one case, since clinically the functional disturbance was of the type usually seen as bacterial endocarditis rather than that produced by a ventricular septal defect.

In our series, in one instance congenital cardiac lesions were found in a heifer and her foetus. It was not possible to demonstrate any other familial tendency but a genetic factor has been suggested in one herd of Hereford cattle (Belling, 1962).

Group II

The ventricular septal defects were again large and high in the interventricular septum. The pulmonary valve was abnormal in all cases and, as well as being hypoplastic, in two instances only two cusps were present. In cases with tetralogy of Fallot pulmonary stenosis may be at the level of the pulmonary trunk, the pulmonary valve, or infundibulum. Three of the cases recorded here had infundibular stenosis and in one case stenosis was valvular. The ductus arteriosus was patent in all cases but could only be definitely considered abnormal in the three seen alive. This is not a common feature of tetralogy of Fallot in man (Edwards, 1960), and undoubtedly provides a useful collateral channel by which the pulmonary flow can be augmented. In addition to patency of the ductus arteriosus a small atrial septal defect was found in one animal, and abnormalities of the origin of the coronary arteries, in particular of the right coronary artery, were found in two cases.

Group III

All of the animals in this group had complicating lesions which were probably functionally significant. These were in case 20127, a large atrial septal defect; in case 21809, coarctation of the isthmus of the aorta; in case 16040, atresia of part of the aortic arch and the pulmonic aortic window; and in case 20536, subaortic stenosis.

Cyanosis was not present in the calves, but they had marked exercise intolerance. If they had survived, cyanosis probably would have developed due to changes in lung vessels and subsequent pulmonary hypertension.

Although a functionally significant atrial septal defect was seen only once, small atrial septal defects in the fossa ovalis due to over-resorption of the septum primum were seen in four cases. Foramina ovales which are anatomically patent but functionally competent can be considered normal in cattle. We have observed this condition in six out of 31 animals over one year of age with no cardiac disease, and in four out of 30 animals with cardiac disease, which is comparable with the findings in the human subject (Edwards, 1960).

In the two animals which had survived for over 18 months, histological examination of the lungs showed proliferative changes in the pulmonary vasculature which were due to pulmonary hypertension.

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DEATH IN NEONATAL CALF DIARRHOEA

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SUMMARY

In experiments comparing dying and surviving diarrhoeic calves it was found that when the milk intake was maintained during diarrhoea death was associated with significant rises in plasma potassium and blood urea and significant falls in plasma pH and bicarbonate.

In the dying calves brachycardia was observed to a greater extent than in surviving calves and in addition cardiac arrhythmias were recorded in 30 per cent of the dying calves. It is postulated that under the conditions of the experiments, diarrhoea produced a primary cardiac failure.

INTRODUCTION

Death during diarrhoea in very young calves occurs in one of three phases of the disease. Death in the first phase appears to be due to septicaemia and at this stage there may be no evidence of marked body fluid disturbance and no diarrhoea. At the next, so-called enterotoxaemic, phase there is no diarrhoea and death is attributed to endotoxins released within the gut (Gay, 1962). In the third phase diarrhoea is evident and a progressive dehydration takes place. At this stage there is evidence of hyponatraemia, hypochloraemia (Dalton, Fisher & McIntyre, 1964), and a loss of body water (Dalton, 1964). It has been suggested that hyperkalaemia may depress cardiac function and cause death (Roy, Shillam, Hawkins, Lang & Ingram, 1959).

Further experiments to those previously reported (Dalton *et al.*, 1964) were carried out to determine in the diarrhoeic phase the exact parameter of body fluids the alteration of which was associated with death, and to attempt to find out the exact cause of death.

MATERIALS AND METHODS

Calves were purchased locally and managed as previously described (Dalton, Fisher & McIntyre, 1960) but no antibiotics were administered.

In the first series of experiments measurements were made of plasma sodium, potassium and chloride concentrations and also of plasma volumes during diarrhoea. Plasma volume was measured as the critical volume compartment since it was assumed that in dehydration this fluid compartment would be maintained longest.

In the other experiments plasma pH and plasma bicarbonate concentration were measured for evidence of metabolic acidosis.

Numerous electrocardiograms of the calves were taken during the experiments, and in the dying calves attempts were made to obtain these as near as possible to death.

The various parameters were measured in each individual on several days until death from diarrhoea took place or until there was obvious recovery.

RESULTS

(1) *Differences in plasma concentrations of sodium, chloride, and potassium, and in plasma volumes and blood ureas of dying and surviving diarrhoeic calves*

Numerous determinations of plasma sodium and potassium chloride concentrations, and of plasma volumes and blood ureas of calves with diarrhoea were made. Previous experiments (Dalton, Fisher & McIntyre, 1964) had demonstrated that the plasma sodium concentrations fell in diarrhoea, chloride concentration fell and blood urea concentration rose. It was also expected that plasma volume would fall. In order to compare results the diarrhoeic calves were divided into surviving and dying calves and the results tabulated. For each calf the lowest sodium and chloride concentrations and plasma volumes determined were taken, together with the highest potassium and blood urea concentrations. A mean and standard deviation was found for each parameter. Table I gives these results, compared with results from normal non-diarrhoeic calves. Table I(a) gives the statistically significant differences.

TABLE I

MEAN VALUES OF LOWEST SODIUM AND CHLORIDE CONCENTRATIONS, PLASMA VOLUMES AND HIGHEST POTASSIUM AND BLOOD UREAS OF SURVIVING AND DYING DIARRHOEIC CALVES

Parameter	*Diarrhoeic calves*				*Normal calves*	
	Surviving		*Dying*			
	No.	*Mean*	*No.*	*Mean*	*No.*	*Mean*
Na, m-equiv./litre	31	129·4 ±4·0	25	128·9 ±6	65	141·8±3·5*
K, m-equiv./litre	31	5·12±0·4	25	6·11± 1·5	59	5·1±0·4*
Cl, m-equiv./litre	31	92·3 ±4·0	21	94·0 ± 5·4	59	100·3±3·5*
Plasma volume, ml./kg. body wt.	28	59·1 ±7·5	21	56·5 ±10·3	65	66·+8·7**
Urea, mg./100 ml. blood	31	41·2 ±9·8	23	91·03±71·3	60	16±8·0***

*—Fisher, 1961.
**—Dalton & Fisher, 1961.
***—Dalton, Fisher & McIntyre, 1964.

TABLE I(A)

SIGNIFICANCE—STUDENTS 't' TEST

Parameter	*Normal/surviving*	*Surviving/dying*
Na+	Surviving lower $p<0.001$	No significant difference
K+	No significant difference	Dying higher $p<0.001$
Cl−	Surviving lower $p<0.01$	No significant difference
Plasma volume	Surviving lower $p<0.001$	No significant difference
Urea	Surviving higher $p<0.001$	Dying higher $p<0.001$

Sodium. There was no significant difference between the plasma sodium concentrations of surviving and dying diarrhoeic calves. Values in both were significantly lower than the plasma concentrations of normal non-diarrhoeic calves, confirming previous observations (Dalton *et al.*, 1964).

Potassium. There was no significant difference between plasma potassium concentrations of surviving diarrhoeic calves and normal non-diarrhoeic calves, the values for which were determined previously (Fisher, 1960). The plasma potassium concentrations of dying calves were significantly higher than those of both normal and diarrhoeic surviving calves.

Chloride concentrations. Both the surviving and the dying diarrhoeic calves had plasma chloride concentrations significantly lower than normal non-diarrhoeic calves but there was no significant difference between the chloride concentrations of dying and surviving calves.

Plasma volumes. The plasma volumes of both dying and diarrhoeic calves were significantly lower than the plasma volumes of normal non-diarrhoeic calves. There was no significant difference between the plasma volumes of diarrhoeic surviving and diarrhoeic dying calves.

Blood urea. There was a significant difference between the blood ureas of normal non-diarrhoeic calves and diarrhoeic calves which survived. The blood ureas of dying calves were significantly higher than the blood ureas of both normal and diarrhoeic calves.

(2) *Electrocardiography*

Serial electrocardiograms of two groups of calves during their first 14 days in

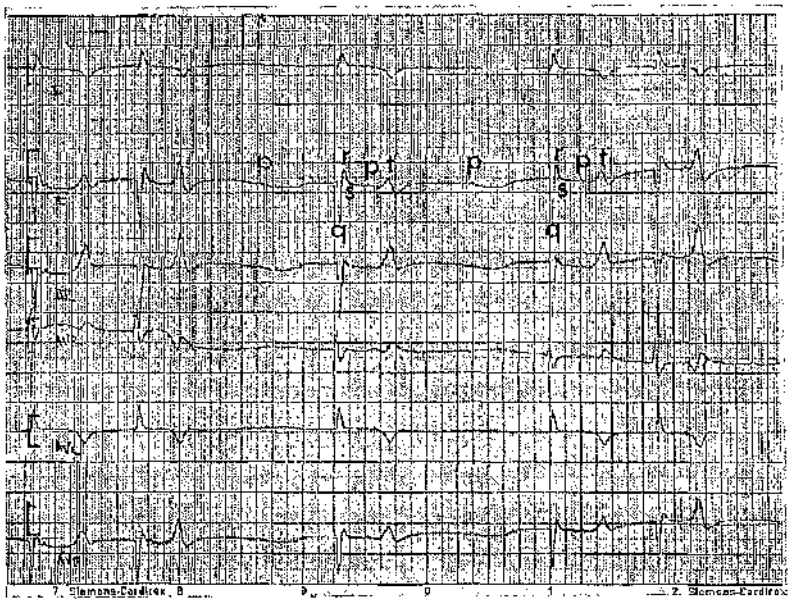

Fig. 1. Record showing complete heart block.
Na = 130 m-equiv./l. K = 7·2 m-equiv./l.
pH = 6·80 HCO_3 = 7 m-mole/l.

the Veterinary Hospital demonstrated no significant abnormalities in the majority of calves. In these groups bradycardia was demonstrated in two diarrhoeic calves which survived and in three diarrhoeic calves which died. Of all calves examined no arrhythmias were detected in 31 diarrhoeic calves which survived, but arrhythmias were detected in 8 out of 25 calves which died. The arrhythmias varied in form, sometimes complete P.Q.R.S.T. complexes were present, but the heart rate was slow and irregular; sometimes varying degrees of A-V block were present and in one instance a complete heart block was recorded (Fig. 1).

It was considered initially that the arrhythmias were related to high plasma potassium concentrations but evidence was obtained of high plasma potassium concentrations (above 6·5 m-equiv./litre) with no arrhythmias (Fig. 2) and lower potassium concentrations with arrhythmia (Fig. 3). It was considered that the 8 m-equiv./litre plasma potassium concentration by infusion at which Bergman & Sellers (1953) obtained functional disturbances bore no relationship to the present study since death always occurred before their fatal concen-

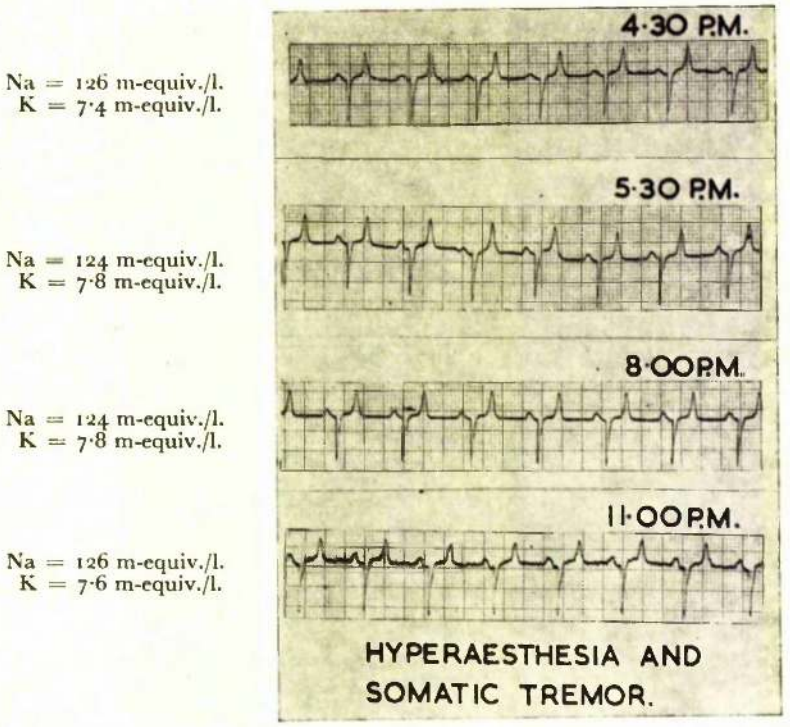

Fig. 2. Hyperkalaemia without arrhythmia.

tration of 12·7 m-equiv./litre. Peaked T waves described as evidence of potassium toxicity in human subjects (Winkler, Hoff & Smith, 1938) were found in many healthy non-diarrhoeic calves and so could not be taken as evidence of such in calves (Fig. 4).

(3) *pH and bicarbonate concentrations*

Anaerobic blood samples were taken without stasis from the jugular veins of a number of normal non-diarrhoeic calves, from calves which had diarrhoea and subsequently recovered and from calves dying from diarrhoea, and the pH and

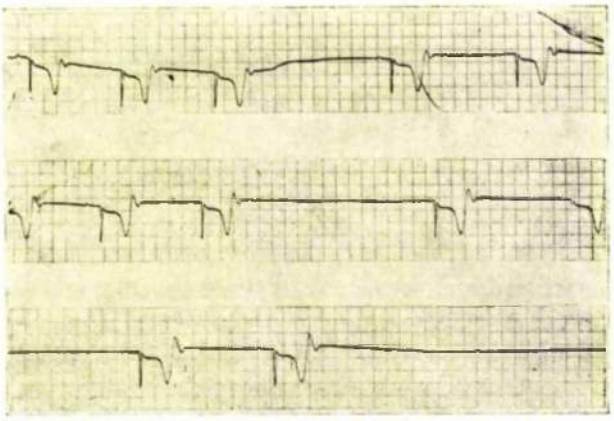

Fig. 3. Arrhythmia without hyperkalaemia.
Na = 138 m-equiv./l. K = 5·9 m-equiv./l.

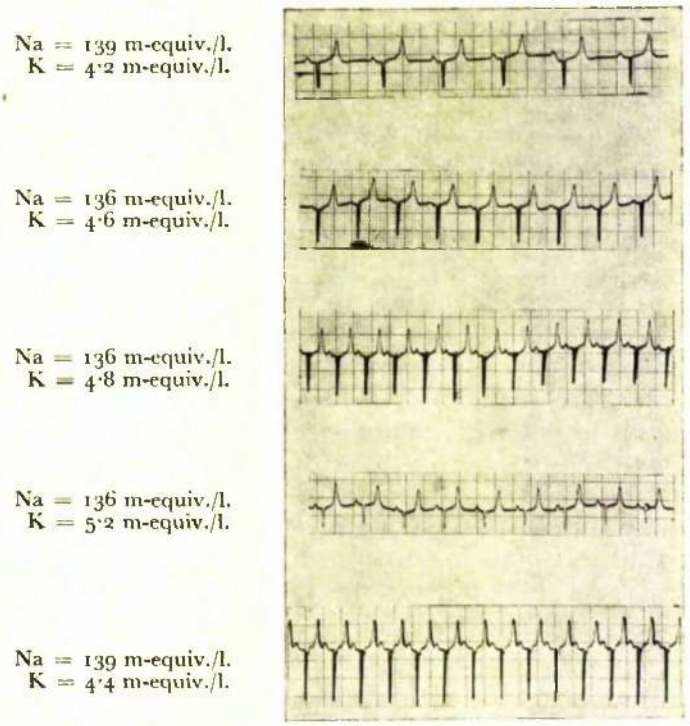

Fig. 4. Ecg records of normal calves with high T waves.

plasma bicarbonate concentrations were determined. The mean results are given in Table II, together with the standard deviations.

There was a significant difference between the plasma pH of normal and diarrhoeic calves and between the pH of diarrhoeic surviving and diarrhoeic dying calves.

TABLE II

pH AND PLASMA BICARBONATE OF CALVES

Calves	*Number*	*pH*	HCO_3^- *m-mole/litre*
Normal	9	7·38±0·04	28·8±2·4
		$p<0·001$	$p<0·001$
Diarrhoeic recovery	9	7·29±0·07	21·6±2·5
		$p<0·001$	$p<0·001$
Diarrhoeic dying	5	6·85±0·14	8·9±2·7

The plasma bicarbonate concentrations were significantly different between non-diarrhoeic, diarrhoeic surviving and diarrhoeic dying calves. No calf with a venous blood pH below 7 was observed to survive. The value of pH 7 for blood is given by many authors as the lowest possible consistent with life, but lower values with subsequent recovery have been recorded for short periods in anaesthetic respiratory acidosis in sheep (Fisher, 1961).

DISCUSSION

In the calf diarrhoeas studied in this series of experiments it was confirmed that there was a lowering of plasma sodium and chloride and an elevation of blood urea. In addition a lowering of plasma volume and the development of a metabolic acidosis were demonstrated.

In the comparison of the parameters in surviving and dying diarrhoeic calves, those which were significantly different were plasma potassium, plasma pH and bicarbonate and blood urea. In addition, bradycardias were observed to a greater extent in the dying calves and arrhythmias were observed only in the dying calves.

Death in most diseases is due to circulatory failure and death in calf diarrhoea can be considered to be no exception to this. Of the three components of the circulation, the heart, the containing vessels and the circulating fluid, it was concluded that in these experiments the primary failure was of the heart. No post-mortem evidence of an increase in capacitance of blood vessels in calf diarrhoea was found, while plasma volume and plasma sodium, although below normal, were not different in dying and surviving diarrhoeic calves. Thus neither blood vessel capacity nor circulating volume was the critical deficiency.

Evidence was obtained of a primary interference with the function of the conducting tissue of the heart which appeared to cause death. This interference was apparently brought about by the electrolyte disturbance and the severe metabolic acidosis. Hyperkalaemia was not always implicated.

Some evidence supporting this conclusion was obtained previously in that haemoconcentration and a rise of packed cell volume were not consistent features of diarrhoea in calves (Dalton *et al.*, 1964). Furthermore the clinical

observation that heart sounds in dying diarrhoeic calves are much fainter than normal could be explained on this basis.

The more severe metabolic acidosis of dying calves may have stimulated increased reabsorption of potassium by the kidney in exchange for hydrogen ions.

The higher plasma potassium and blood urea in dying calves could result from failure of the kidney to excrete. This renal failure could be due to a deficient renal blood flow as a result of a primary decrease in cardiac output and not from a deficient circulating volume.

It must be emphasized that in these experiments the milk intake was maintained and calves were observed often to drink within hours of death. The disturbance of body fluids if milk is withheld may be entirely different.

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TRAUMATIC PERICARDITIS IN CATTLE: A CLINICAL, PHYSIOLOGICAL AND PATHOLOGICAL STUDY

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SUMMARY

Detailed investigations of 13 cows with traumatic pericarditis showed that the nine cases recognized as clinically typical had all the physiological, biochemical and pathological features of chronic congestive cardiac failure. Of the other four, two were long-standing chronic cases with none of these features, while two were acute. The two acute deaths could be attributed to factors other than the traumatic pericarditis producing heart failure.

INTRODUCTION

Metallic foreign bodies ingested by cattle collect in the most anterior of the four stomachs, the reticulum. Thin, sharp objects such as nails or pieces of wire may be forced through the wall by contractions of the organ and thereafter a localized infective focus established which may be in the peritoneal cavity, the liver, the lung, or the pericardial sac, and, rarely, may lead to a subcutaneous abscess perforating to the exterior. Because of the proximity of the pericardial sac to the reticulum, traumatic pericarditis occurs frequently.

Traumatic pericarditis is a well-recognized condition of cattle, and has been a topic of many clinical and pathological reports (Arthur, 1947; Blair, 1905; Holmes, 1960; Schleiter, 1958; Stephens, 1944). Stowe & Good (1961) reported on some physiological changes of one case in a cow. Studies were made by us on 13 cases, reported below.

CLINICAL OBSERVATIONS

There were three distinct syndromes:

(A) The classical type of traumatic pericarditis with subcutaneous oedema as a usual clinical feature (nine cases).
(B) Traumatic pericarditis as a long-standing condition without oedema (two cases).
(C) Traumatic pericarditis manifest as an acute condition without oedema (two cases).

A. *Typical Traumatic Pericarditis*

In most cases the onset of clinical signs had been 12–14 days previously. The first sign was either the loss or the development of a capricious appetite.

Following this the animals became dull, lost condition, stood with elbows abducted and were unwilling to move. The jugular veins were visibly distended as far as the mandible and there was variable oedema in the submandibular space and the brisket, but rarely in the limbs. Slight pyrexia was usually present. The respiratory rates were slightly increased with hyperpnoeic inspirations and often a double expiratory effort. The pulse rate was increased from the normal (72 + 10 per minute) and the volume was fair or poor. On percussion of the chest, there was loss of resonance over the lower one-third to a half. Auscultation of the thorax, in addition to indicating the abnormal respiratory movements, revealed tachycardia, a muffling of heart sounds and occasionally the adventitious sounds described as "tinkles" or splashing. Fig. 1 is the phonocardiographic record of a tinkling sound. Six of the nine animals had diarrhoea.

B. *Traumatic Pericarditis as a Long-standing Condition Without Oedema*
There was loss of condition. Appetite and thirst were normal. There was no pyrexia. Tachycardia was present in one animal and both had poor pulse volumes. The respiratory rate was normal in one and increased in the other, and there was no loss of resonance on percussion. The heart sounds were not muffled but adventitious sounds occurred. In one case the adventitious sound was a systolic murmur, in the other a slapping sound was heard in phase with inspiration. Oedema was not present in either animal. The jugular veins were undistended in one and slightly distended in the other cow.

C. *Atypical Pericarditis Manifested as an Acute Condition Without Oedema*
The onset of illness was sudden. One animal was first observed recumbent and grunting, and appeared to be in pain. The other was standing with elbows abducted and back arched, and was very dull. Tachycardia and poor pulse volumes, and slight muffling of heart sounds were present in both. A splashing sound obscured the second heart sound in one of the animals. Jugular veins were distended in one animal but not the other. Subcutaneous oedema was not apparent. Both animals survived a short time.

HAEMATOLOGICAL OBSERVATIONS (TABLE I)

Group A
Five cases showed evidence of haemodilution with lowered packed-cell volumes (PCV). Leucocytosis occurs in traumatic pericarditis and according to Arthur (1946) is a useful diagnostic feature. The values obtained in all except two cases confirmed his observation and one of these had a figure at the upper limit of normal. The reversal of the neutrophil-leucocyte ratio agrees with the observations of Arthur (1947) and Holmes (1960).

Group B
One case showed low packed-cell volumes and haemoglobin concentrations, suggesting haemodilution, or some anaemia, since there was no oedema. In one animal no leucocytosis was found, but in the other, with low packed-cell volumes, there was a reversal of the neutrophil-leucocyte ratio.

TABLE I

HAEMATOLOGICAL DATA—TRAUMATIC PERICARDITIS

Cow No.	*PCV (%)*	*R.B.C.* (10^6/*cu. mm.*)	*Hb* (*g*/100 *ml.*)	*W.B.C.* (10^3/*cu. mm.*)	*Neutrophils* (%)	*Lymphocytes* (%)	*Eosinophils* (%)	*Basophils* (%)	*Monocytes* (%)
Normal	30 ± 3	5–8	9–11	8–12	25–35	60–70	0–1	0–1	0·5
Group A									
18939	28	5·75	9·4	18	86·5	12·5	0·5		
19206	35	—	—	14·4	59	40·5			0·5
19276	27	4·06	8·3	13·75	83·5	16			0·5
19562	29	5·3	9·3	13·75	71·5	28·5			
19959	28	—	9·4	6·36	41	58	1		
21333	34	5·9	10·8	20·05	91	8·5	0·5		
22619	28	4·6	8·7	27·9	88·5	11·5			
23939	24	3·84	7·2	14·00	84	16			
24386	20·5	3·82	6·9	12	68·8	31·2			
Group B									
19337	24·5	4·2	7·9	8·05	45	41·5	13·5		
22084	31·5	4·86	9·6	9·8	33	55	9		3
Group C									
22958	26	5·5	9·1	17·8	81·5	18			0·5
24289	28·5	5·19	9·6	13·3	70·5	29	0·5		

TABLE II

BIOCHEMICAL OBSERVATION—PERICARDITIS

Cow No.	Na (m-equiv./l.)	K (m-equiv./l.)	Albumin (g./100 ml.)	Globulin (g./100 ml.)	Alkaline phosphatase (k.a. units)*	SGOT (s.f.)	SGPT (s.f.)†	Urea (mg./100 ml.)	Urea urine (g./100 ml.)
Normal	142±2	4·4±0·3	3·9	4·1	10	44±6	19±13	20	1·0
Group A									
18938	139+	5·2	1·2	6·0	11	78	5	29	2·6
19206	133+	3·8	1·7	5·9	13	61	58	39	1·6
19276	139+	3·4	3·42	3·42	7	169	11	34	2·5
19562	128+	3·7	1·8	6·2	4	95	7	51	3·2
19959	130−	4·0	2·1	5·1	3	104	16	30	2·8
21333	148+	2·8	1·2	6·0	7	—	—	96	2·6
22619	124+	2·8	1·4	6·8	8	29	4	100	3·8
24386	144	3·6	1·35	7·65	6·7	432	22	87	3·4
23939	133	4·0	1·5	5·8	2·3	176	10	393	2·6
Group B									
19337	151	4·0	1·9	6·5	4	58	14	6	0·3
22084	133	5·0	2·5	7·4	3·8	71	20	16·4	1·2
Group C									
22958	139	2·8	0·95	4·75	18	220	45	124	2·6
24289	138·5	4·0	1·9	6·3	3·5	93	7	22	0·8

* King-Armstrong units.
† Sigma Frankel units.

Group C
Leucocytosis occurred in both animals with a reversal of the neutrophil ratio.

BIOCHEMICAL OBSERVATIONS (TABLE II)

Group A
In some animals lowered sodium and potassium concentrations suggested dilution of electrolytes by the fluid retention of heart failure. All animals had high plasma globulins, perhaps due to antibody reaction to infection, and the low plasma albumin may have been due to haemodilution. The high serum glutamic oxalic transaminase (SGOT) values might indicate tissue damage. The other two enzymes, alkaline phosphatase and serum glutamic pyruvate transaminase (SGPT), were not elevated, suggesting little biochemical evidence of liver damage.

Group B
The distinctive sign was absence of uraemia or occurrence of water retention.

Group C
One cow had uraemia and high urine urea, and the other did not, but both had elevated serum glutamic oxalic transaminase values.

TABLE III

BLOOD AND PLASMA VOLUME DETERMINATIONS

Cow No.	*Weight (kg.)*	*Blood volume* (*l.*)	(*ml./kg.*)	*Plasma volume* (*l.*)	(*ml./kg.*)	*Subcutaneous oedema*
Normal (mean of 30)	408	25·7	63±8	20·4	50±8	Nil
Group A						
18938	473	29	60	21	44	+++
19206	308	24	78	17	55	+++
19276	380	33·5	86	27	70	+++
19562	386	43	111	38	99	++
19959	450	23·6	53	17	37	Nil
21333	445	Not Determined		Not Determined		++
22619	364	32·4	89	24·8	68	+
23939	379	29·0	77	22	58	+++
24386	610	42	69	33	54	+
Group B						
19337	383	19	50	15	39	Nil
22084	460	25	54	19·3	42	Nil
Group C						
22958	360	18	52	13	37	Nil
24289	375	20	54	18	47	Nil

BLOOD AND PLASMA VOLUME DETERMINATIONS (TABLE III)

Group A
In most cases, even with oedema, there was hypervolaemia and increased plasma volume.

TABLE IVa

BLOOD PRESSURE AND INTRACARDIAC PRESSURE DETERMINATIONS

Cow No.	Jugular	Right atrium systolic diastolic pulse pressure (mm. Hg.)			Right ventricle systolic diastolic pulse pressure (mm. Hg)			Pulmonary artery systolic diastolic pulse pressure (mm. Hg)			Brachial artery systolic diastolic pulse pressure (mm. Hg)			Arterial pulse volume (palpation)
Normal	0	7	7	0	53	53	0	45	25	20	187	57	130	Good
Group A														
18938	30	50	20	30	80	50	30	75	45	30	130	35	95	Poor
19206	35	60	25	35	87	52	35	65	25	40	176	32	154	Poor
19276	42	46	16	30	76	44	32	60	28	32	136	31	105	Poor
19562	21	53	32	21	79	58	21	60	33	20	140	40	100	Poor
19959	34	44	10	34	72	40	32	70	22	48	174	52	122	Fair
22619	24	30	16	24	60	36	24	60	22	38	111	24	87	Poor
23939	50	60	10	50	80	40	40	78	18	60				Fair
24386	10	24	14	10	54	54	10	44	24	20	128	28	100	Poor
Group B														
19337	0	18	11	7	46	40	5	45	30	15	145	40	105	Fair
22084	8	10	6	4	60	60	0	60	30	30	180	55	125	Good
Group C														
22958	8	36	16	20	52	32	20	52	18	34	130	30	100	Poor
24289	10	18	8	10	45	45	0	40	20	20	140	40	100	Fair

Group B
No subcutaneous oedema or hypervolaemia was present.

Group C
No animal showed oedema or hypervolaemia.

BLOOD PRESSURE AND INTRACARDIAC PRESSURE DETERMINATIONS (TABLE IVa)

Group A
In typical cases there was marked elevation of the end-diastolic pressures of the right side of the heart leading to venous engorgement of the proximate veins including the jugular. General venous engorgement was demonstrated by the hypervolaemia (Table III) which complemented the jugular and mammary distension. In animals in which pressures were obtained within the pericardial sacs (Table IVb), the fluid within had limited diastolic filling and determined diastolic pressure. In an attempt to maintain cardiac output the systolic pressure was raised in the right ventricle, but there was a reduction in the ventricular pulse pressure and in systemic arterial pressure.

TABLE IVb

PRESSURE OF PUS IN PERICARDIAL SAC COMPARED WITH END-DIASTOLIC PRESSURES IN RIGHT VENTRICLE

Animal	*Pus pressure (mm. Hg)*	*Mean pus pressure (mm. Hg)*	*End-diastolic pressure (mm. Hg)*
24386	28/8	18	10
19276	46/30	37	32
22619	26/20	23	24
23939	44/30	37	40

Group B
There was a slight elevation of right-sided pressures of the heart.

Group C
The slight elevations of right-sided pressures were consistent with the slight degree of jugular distension.

In all groups, the clinical quality of the pulse was, generally, in accordance with the magnitude of the pulse pressure measured; poor pulse volumes coincided with small arterial pulse pressures and good pulse volumes with large arterial pulse pressures.

ELECTROCARDIOGRAPHIC EXAMINATIONS (TABLE V)

Group A
The records showed very low complexes; somatic tremor often made interpretation very difficult. The low complexes appeared to be due to the excess fluid present between the heart and the recording electrodes (see Fig. 2).

Group B and Group C
Complexes in these groups tended to be of normal size.

All groups exhibited tachycardia and a shortening of the T–P interval,

TABLE V

E.C.G. PARAMETERS—PERICARDITIS

Cow No.	Lead II			Wave amplitude (centimetres)				
	Heart rate/min.	P–R interval (sec.)	T–P interval (sec.)	P	Q	R	S	T
Normal	60–80	0·1–0·28	0·23–0·39	0·03–0·18	0·03–1·0	0·03–2·6	0·03–0·25	0·3–1·10
Group A								
18938	108	0·2	0·04	0·05	0·1	—	—	0·1
19206	102	0·2	0·02	0·1	0·15	—	—	0·4
19276	102	0·24	0·02	0·1	0·2	—	—	0·15
19562	115	0·2	0·0	Very low, unanalysable				
19959	110	0·2	0·02	0·1	0·3	—	—	0·1
21333	99	0·24	0·06	0·1	—	0·2	0·2	0·15
22619	112	0·2	0·0	0·1	0·1	Analysis difficult		
24386	120	0·24	0·0	0·05	0·2	—	—	0·2
23939	125	0·16	0·04	0·1	—	0·2	0·1	0·1
Group B								
19337	100	0·24	0·15	0·2	0·1	0·8	—	0·2
22084	70	0·16	0·28	0·2	0·0	0·5	—	0·3
Group C								
22938	105	0·24	0·0	0·05	—	0·15	0·5	0·5
24289	96	0·16	0·12	0·1	0·6	0·1	0·0	0·5

with the exception of one animal in Group B. In most cases the P–R intervals were prolonged at the heart rates measured, which suggested some interference in conduction between atria and ventricles.

CARDIAC OUTPUT DETERMINATIONS (TABLE VI)

Group A

All typical cases, with muffled heart sounds, showed decreases in cardiac output from normal values. The body weight, for a comparison between animals, may be argued to be invalid, since in oedematous animals there is increased extracellular fluid. Since this fluid is dependent on sodium retention, and sodium is freely diffusible in extracellular fluid, this must play a part in the circulatory dynamics and its weight could be considered when cardiac output is reviewed.

TABLE VI

CARDIAC OUTPUT DETERMINATIONS

Cow No.	*Body wt. (kg.)*	*Cardiac output*	
		l./min.	*ml./kg. body wt./min.*
Normal	408	46	113±11
Group A			
18938	473	28	60
19206	308	27	89
19276	380	23	61
19562 (i)	386	29·4	76
19562 (ii)	386	25	64
19959	447	30	67
21333	446	33	74
22619	364	23	63
23939	374	32	86
24386	608	51	84
Group B			
19337	383	33	86
22084	460	57	120
Group C			
22958	350	42	120
24289	375	47	125

Group B

The decrease in cardiac output (case 19337) may have been due to a decreased blood volume.

Group C

The two animals showed no decrease in cardiac output, which indicated that the clinical signs were not due to a primary decrease in cardiac activity.

PATHOLOGY

Technique

Blocks of tissue for pathological examination were taken from all the animals, from the heart, pericardium, mediastinum, mediastinal lymph nodes, lungs,

liver, spleen, adrenal glands, kidneys, abomasum and small intestine. The tissues were fixed in corrosive formol and 10 per cent formalin and stained by haematoxylin and eosin, picro-Mallory, Van Gieson, phosphotungstic acid haematoxylin, and Sudan IV.

Group A

Macroscopic

The abnormal amounts of interstitial fluid which were visible at post-mortem are shown in Table VII. Subcutaneous oedema occurred below the mandible, in the ventral aspect of the neck, in the brisket, along the abdomen, and extended to the udder. Animals with severe oedema had fluid on the sides of the thorax as high as the costochondral junctions, in the forelegs from the shoulder joints to the carpus and in the inner aspect of the hind legs down to the hocks. The fluid in the pleural cavity was bilateral. Oedema in the mesentery was most prominent around the coils of the colon and in the abomasum it was subserosal on the greater curvature or submucosal in the folds of the body of the organ.

TABLE VII

DISTRIBUTION OF EXCESSIVE AMOUNTS OF INTERSTITIAL FLUID IN ANIMALS IN GROUP A

No.	*Subcutaneous oedema*	*Thoracic fluid (l.)*	*Pericardial fluid (l.)*	*Ascitic fluid (l.)*	*Abomasal oedema*	*Mesenteric oedema*
18938	+++	6·0	2·0	27·0	++	+++
19206	++	10·0	6·0	10·0	++	++
19276	++	7·0	5·0	—	—	—
19562	++	3·0	4·0	4·0	+	+
19959	—	30·0	15·0	10·0	—	—
21333	++	—	5·0	—	+	—
22619	+	7·0	6·0	—	—	—
23039	++	4·5	7·0	0·3	—	—
24386	+	0·5	11·5	—	—	—

Pericardium and Heart. The pericardial sac was grossly distended (Fig. 3), and contained 2–15 litres of fluid, whose appearance took one of two forms: it was a very thin liquid, reddish-brown, grey or yellow, and foul-smelling, or a thick yellow foul pus, in which there were many bright yellow soft clots of coagulated fibrin and pus. The coagulated material sometimes completely encased the heart in a layer about 1 cm. thick, which could be stripped off easily. Gas was present in all cases, but was unusually abundant in case 22619, in which about 6 l. had accumulated. The cavity containing fluid and gas did not always encircle the heart completely. In four cases, the heart was suspended in the cavity by the great vessels, and the atria and ventricles hung free. In one case, the caudal border of the heart was adherent to the adjacent pericardium (Fig. 4), and in four cases the cavity was mostly evident on the anterior and right sides of the heart. The remainder of the pericardial cavity was obliterated by fusion between the visceral and parietal layers of the pericardium. The epicardium was in all cases grossly thickened over the ventricles and the atria by fibrous connective tissue, 0·7 cm. to 1·5 cm. thick

(Fig. 5). Most of the epicardial thickening consisted of glistening white fibrous tissue, with only a thin layer of necrotic material on the outer surface. The parietal pericardium was about the same thickness as the epicardium and had a similar appearance and colour.

Mediastinum. The mediastinal tissues were grossly thickened by fibrosis, and many tracks containing thick yellow pus were found, particularly posterior to the heart. In two cases, pieces of wire, 4·0 cm. and 6·5 cm. long, were found in these tracks, and in a third case, a large nail (6 cm.) was found penetrating the pericardial sac. The tracks travelled in all directions in the mediastinum and some were even found in the anterior mediastinum. The mediastinal lymph nodes were enlarged and oedematous.

Lungs. In all cases, the lobes of the lungs were adherent to each other, to the thoracic wall and to the mediastinum, either diffusely or at many localized areas. In three animals this was an adhesive pleurisy, but in the six others it was a fibrinous or fibrinopurulent pleurisy, confined to the right side in three animals. The lungs were displaced dorsally to varying degrees by the enlarged pericardial sac, and the ventral parts of the apical, cardiac and diaphragmatic lobes of each lung were collapsed as a result of the fluid in the pleural cavities.

Reticulum. A mass of organized adhesions was present in every animal between the anterior serosal surface of the reticulum, the diaphragm and the ventral border of the liver. Within the diffuse adhesions in four cases a strong fibrous cord held the reticulum to the diaphragm (Fig. 6). In one case, when the cord was cut, fluid from the pericardium leaked out; but usually, adjacent to the reticulum, the cord was fibrosed and had no lumen. In four animals, at the periphery of the diffuse adhesions there were small thick-walled abscesses. Scarring of the mucous membrane of the reticulum occurred twice. The foreign bodies which were found in four cases in the reticulum were pieces of wire, 6 cm. to 11 cm. long, and in one case a nail also was found.

Liver. The organ showed obvious changes of chronic passive venous congestion in all but one animal (case 19276). In the latter the liver was slightly enlarged, due to venous congestion, but it did not have the "nutmeg" appearance of the others. Paradoxical lobulation could be seen grossly in case 18938. The liver enlargement was very great in two cases and in one there were two hepatic abscesses.

Adrenal glands. The adrenal glands were soft and friable in all animals, and were larger than normal in the five whose adrenal glands were weighed.

Spleen. The spleens were not enlarged in any case.

There were no significant lesions in the other organs.

Two animals were pregnant at death. A living calf was removed from a third cow by hysterectomy immediately after it had been killed *in extremis*. A fourth case aborted a six-seven month foetus shortly before it died; the

foetus had subcutaneous oedema, moderate hydrothorax and ascites.

Microscopic

Heart. The lesion was an organizing fibrinopurulent pericarditis (Fig. 7). The outer layers of exudate on the heart were separated from the myocardium by dense fibrous tissue which was responsible for most of the epicardial thickening.

Running through the fibrous tissue from the myocardium were long, narrow arteries with well-developed muscular *tunica media*, and scattered along the vessels were moderate numbers of plasma cells. In three animals sarcocysts were present in Purkinje fibres.

Pericardium, mediastinum and reticular adhesions. These showed changes essentially similar to those on the epicardium. Adjacent to the cavity with pus or fluid there was a layer of necrotic tissue densely infiltrated by polymorphonuclear leucocytes. This tissue was surrounded by fibroblasts, plasma cells, macrophages, capillaries and endothelial cells, and at the periphery there was dense fibrous connective tissue.

Mediastinal lymph nodes. The sinuses contained large numbers of macrophages, polymorphonuclear leucocytes, plasma cells (Fig. 8), lymphocytes and occasionally eosinophils. The medullary cords were packed with plasma cells and focal aggregates of lymphocytes and lymphoblasts. The cortical tissue of the node had lost its follicular pattern. The perinodal tissue was oedematous.

Lungs. Histological examination confirmed the presence of the collapse and pleurisy seen macroscopically. Case 19276 also had severe pulmonary oedema.

Liver. All cases (except 19276) showed changes of well-established chronic venous congestion. In 19276, the centrilobular veins and sinusoids were only slightly dilated, and there was minimal fatty change in the hepatic cells in the centrilobular area. In case 18938 the changes resulting from passive venous congestion were very advanced, paradoxical lobulation had occurred and there was hepatic fibrosis with proliferation of fibrous tissue near the centre of the liver lobule. Many plasma cells were seen in the portal areas of every liver.

Spleen. Two significant changes were seen in the red pulp of the spleen. There were (i) numerous plasma cells and (ii) many reticuloendothelial cells full of haemosiderin (Fig. 9).

Adrenals. Accumulations of plasma cells were sometimes found in the adrenal cortex and there was separation of the cells of the zona glomerulosa.

Kidneys. Interstitial groups of plasma cells and moderate hydropic degeneration in the collecting tubules were seen.

Group B

Macroscopic

Cases 19337 and 22084 were essentially similar pathologically. There was no subcutaneous oedema or excess fluid in the pleural, pericardial or peritoneal cavities. The pericardium was only moderately thickened and it adhered to the epicardium by a large number of thin fibrous bands, "violin string" adhesions, so that it could be moved over the surface of the heart but could not be easily detached from it. The cranial surface of the reticulum adhered to the diaphragm and in case 19337 a wire was found in the reticulum. In the reticular adhesions of 22084 there were small abscesses and a cicatrix was present in the reticular mucous membrane. Moderately extensive areas of consolidation and bronchiectasis were found in the apical, cardiac, and anteroventral parts of the lungs in 22084.

Microscopic

In both cases the pericardial thickening and adhesions consisted of loose connective tissue. The adhesions had a villous appearance in sections and on the outer surface there were accumulations of macrophages, plasma cells and lymphocytes (Fig. 10). There were no significant findings in the other organs except chronic pneumonia and bronchiectasis in case 22084.

Group C

Macroscopic

Case 22958. A diffuse fibrinopurulent pleurisy affected the right pleural cavity, which contained 16 l. of foul-smelling fluid, and the right lung was partially collapsed. The pericardium was slightly thickened and contained 0·5 l. of fluid similar in appearance to that in the right thorax. A hole in the ventral part of the pericardial wall communicated with the right pleural cavity and much of the pericardial fluid had obviously escaped. The heart was free within the pericardial cavity and the moderately thickened epicardium was covered by a yellow exudate. On the posterior border of the left ventricular wall the epicardium was ruptured over a necrotic track within the cardiac musculature, which almost communicated with the lumen of the left ventricle. A small thrombus was present on the endocardium above the lesion. The posterior mediastinum was thickened ventrally by fibrous tissue, and a little fluid was present in the peritoneal cavity. Fibrous adhesions joined the anterior surface of the reticulum to the diaphragm and the ventral border of the liver, and there was a band of adhesions between the reticulum and the abomasum. A wire (5 cm. long) was found in the anterior wall of the reticulum and slight oedema was seen along the greater curvature of the abomasum. The liver had dilated vascular spaces in its dorsal part and the left kidney had a recent infarct. The adrenals were enlarged and friable.

Case 24289. The pericardium had moderate fibrous thickening and adhered closely to the heart over the ventricles. Over the atria, the pericardium was distended and contained 250 ml. of foul, yellow-grey fluid. A bent wire ex-

tended from the reticulum, along a fibrous track through the diaphragm, and into the posterior wall of the left ventricle. The muscle around the wire was necrotic and there was a thrombus within the ventricle (Fig. 11). Small, purulent foci were scattered in the myocardium. Extensive fibrous adhesions had developed between the reticulum, abomasum, rumen, diaphragm, liver and spleen. Several abscesses were found at the root of the mesentery and there was severe embolic nephritis, with renal infarction, particularly in the left kidney. There were extensive areas of collapse in the left lung and the adrenal glands were moderately enlarged.

Microscopic

Case 22958. Sections from the heart showed fibrinopurulent pericarditis with only early organization. The liver had areas with loss of hepatic cells and pooling of blood eccentrically within lobules, but there was little evidence of centrilobular fatty change.

In case 24289 the epicardial fibrosis was more extensive and there was a focal embolic suppurative myocarditis. Focal embolic suppurative nephritis and infarction were found in the kidneys, and pulmonary collapse, with small areas of bronchopneumonia, was seen in the left lung.

DISCUSSION

Traumatic pericarditis is a useful term to apply to a disease which is present as a clinical complex and can be associated with a variety of lesions, related one to the other in that they are all a consequence of penetration of the thorax by a foreign body. In some cases the pericardium itself may not be penetrated and infection spreads to the pericardium via lymphatics from a lesion in the posterior mediastinum.

The lesion is usually a mediastinopericarditis. An aetiologically different form of mediastinopericarditis occurs in man and may be associated with cardiac hypertrophy (Saphir, 1960). Cardiac hypertrophy was not present in any of the animals in this series or in those of Holmes (1960), but has been described in some cattle (Jubb and Kennedy, 1963).

The functional effects on the bovine heart probably differ from those of mediastinopericarditis of man, because the adhesions in man often affect completely rigid structures such as costal cartilages, ribs and vertebral column, whereas the shape of the thorax is different in the cow and the relationship between these structures and the heart is not the same.

Constrictive pericarditis is one form of mediastinopericarditis, or pericarditis, in which mediastinal adhesions or thickening and rigidity of the pericardium and epicardium interfere with cardiac filling. This type of lesion occurs in advanced cases of traumatic pericarditis, as in Group A. When pressure recordings and cardiac output determinations in Groups A, B and C were compared, the large amounts of fluid, pus and gas present in the rigid pericardium in Group A were seen to result in increased intrapericardial pressure which limited diastolic filling. This was probably the most significant factor in the development of congestive cardiac failure.

The pericardial lesion in Groups A and C was essentially an organizing fibrinopurulent pericarditis. In Group C the lesion was seen presumably before sufficient time had elapsed for it to become constrictive, and there could be no significant build-up of intrapericardial pressure, in one case because the amount of fluid was small and in the other because there was a communication between the pericardium and the right pleural cavity. The short clinical course in these animals could be attributed to the early development of severe complicating lesions.

The animals in Group B had adhesive pericarditis. There was little or no effect on cardiac function, and there was no muffling of heart sounds although adventitious sounds did occur. The lesion resulted, probably, from the organization of an early acute fibrinous pericarditis caused by a foreign body which did not establish large numbers of pyogenic organisms in the pericardial sac.

In attempts to drain the pericardium, it might be better for the surgeon to approach it anteriorly on the right side of the thorax, since adhesions between the epicardium and pericardium occur more frequently on the left, and the anterior and right aspects of the heart are more likely to be more free (this series; and Holmes, 1960). Complete evacuation of the pericardium in those cases where the contents are not liquid would be very difficult, even when enzymes (streptokinase and trypsin) are used, because of the quantity of thick pus and the numerous large clots of fibrinopurulent material.

The changes found in organs other than the heart, mediastinum and reticulum in the animals in Group A were a consequence of the onset of congestive cardiac failure, or a reaction to the presence of a large septic focus in the animal. In the latter category and associated with the high level of serum globulin are the accumulations of large numbers of plasma cells in the red pulp of the spleen and the mediastinal lymph nodes. The plasma cells in the liver, adrenals and kidneys may also have been contributing to this reaction and it is interesting to compare these changes with those occurring during hyperimmunization experiments with pneumococcal antigens in which plasma cells develop in the spleen, lymph nodes, liver and other organs (Bjorneboe, Gormsen & Lundquist, 1947).

The diarrhoea which occurred in six cases in Group A was probably due to circulatory deficiency or alimentary fluid imbalance since other lesions responsible for diarrhoea in cattle were not found.

This particular clinical observation has been described in the human subject with congestive cardiac failure (Wood, 1958) and also in cattle with congestive cardiac failure due to high mountain disease (Alexander, Will, Grover & Reeves, 1960).

In man, high levels of SGOT in the absence of increased SGPT levels are usually taken to indicate myocardial damage. In this series, however, only the animals in Group C had lesions producing myocardial necrosis. It is likely that the quantitative distribution of these enzymes in the cow differs from that in man, and in two cases of cor pulmonale, seen in calves in congestive cardiac failure with no focus of tissue necrosis due to infection, the high SGOT levels were presumed to come from the liver (Fisher & Pirie, 1965). The

presence of very large purulent foci in these animals complicates the picture and it may be that these are also sources of SGOT. In addition, the renal lesions seen in a few cases cannot be overlooked as possible contributing sites. Even though some animals showed severe changes within the liver which were due to congestive cardiac failure, in no case was the serum alkaline phosphatase raised, and only in a few cases was the SGPT raised.

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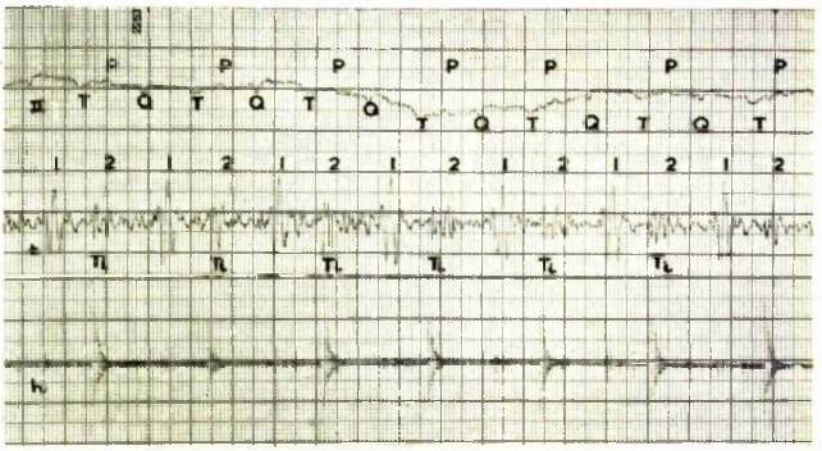
PLATE I



1 = 1st heart sound
2 = 2nd heart sound
II = lead II electrocardiogram
t = low frequency sound
h = high frequency sound
P = P wave of ECG
T = T wave of ECG
a = a wave of ECG
Ti = tinkle

Fig. 1. Heart sounds (case 22619), showing "tinkle".

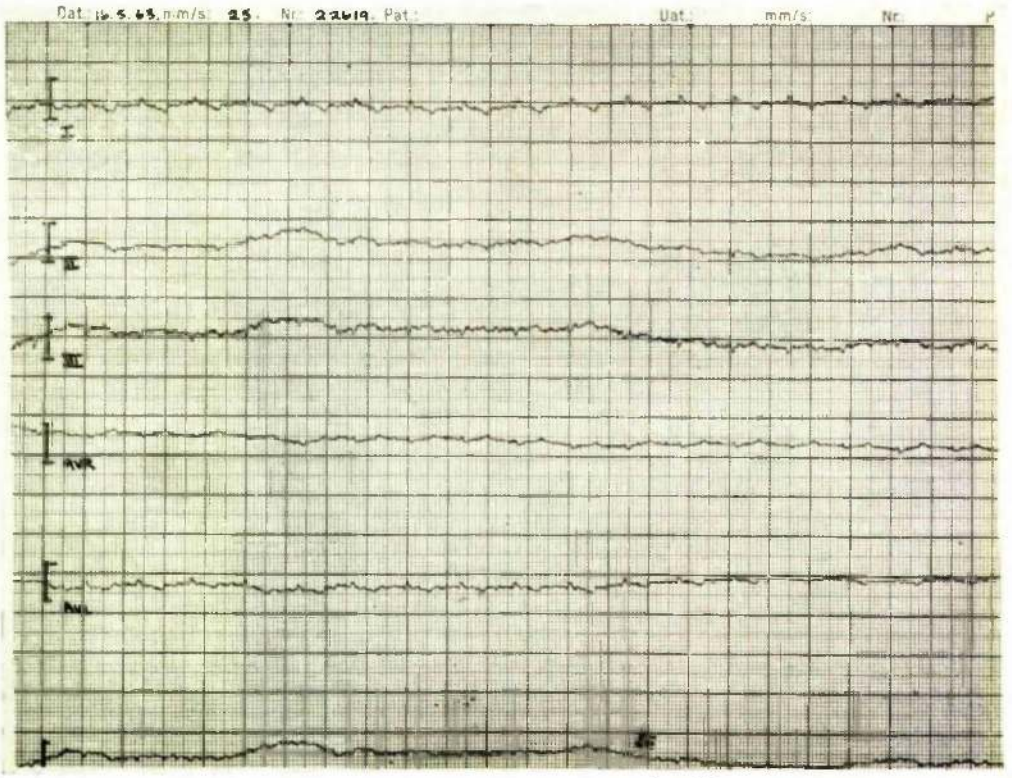


Fig. 2. Electrocardiogram of a typical pericarditis.

PLATE II

Fig. 3. Distended pericardial sac viewed ventrally.

Fig. 4. Interior of pericardial sac.

PLATE III

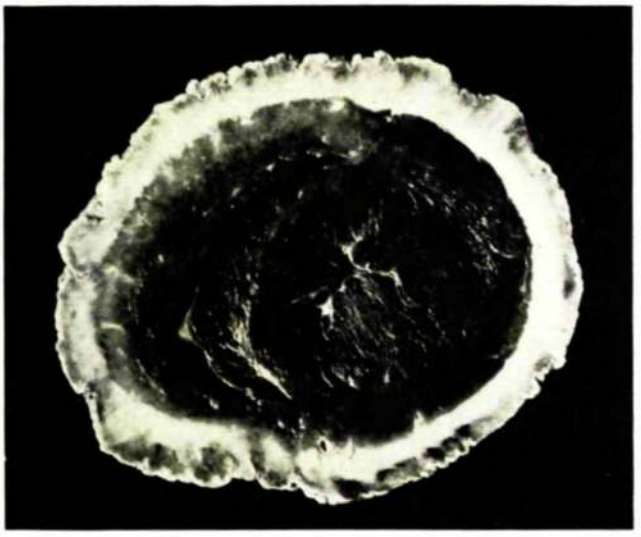


Fig. 5. Gross epicardial thickening due to fibrous connective tissue.

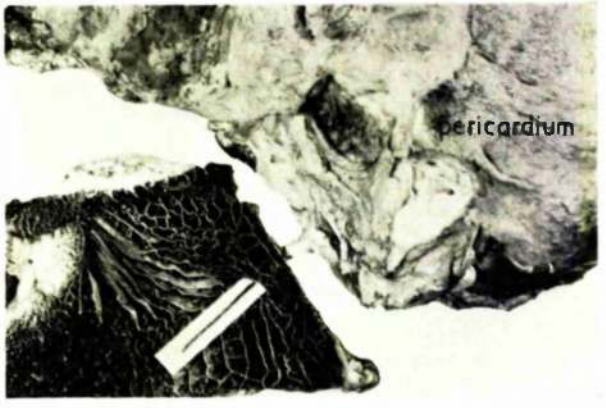


Fig. 6. Cord-like adhesion between reticulum and diaphragm with foreign body *in situ*.

PLATE IV

Fig. 7. Organizing fibrinopurulent pericarditis with bacterial colonies in outermost layer (H & E x 50).

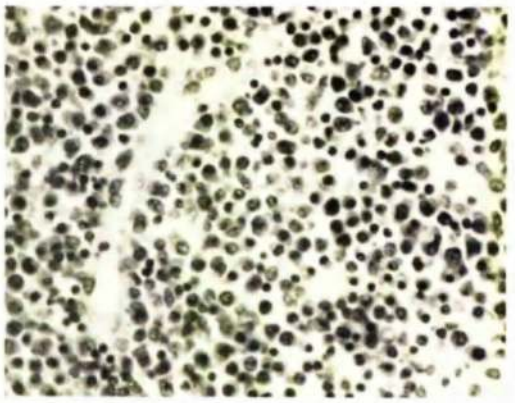


Fig. 8. Plasma cells in medullary cord of mediastinal lymph node (H & E x 300).

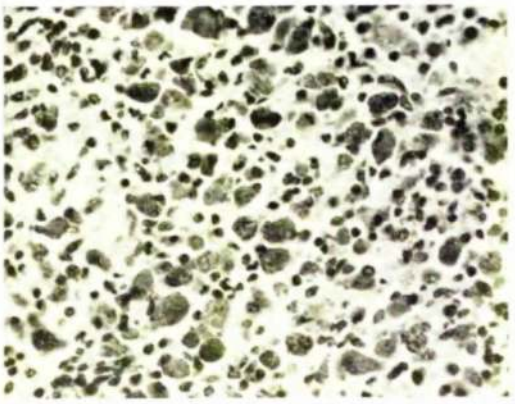


Fig. 9. Haemosiderin-filled reticuloendothelial cells in spleen (H & E x 200).

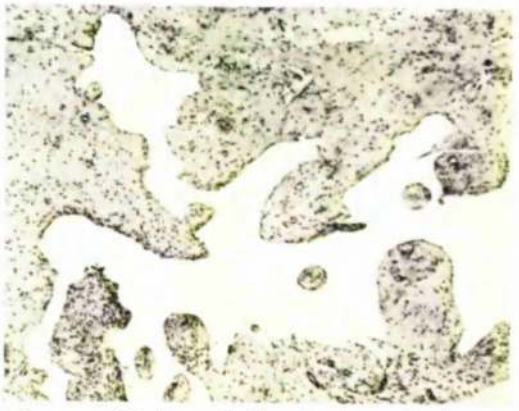


Fig. 10. "Violin string" adhesions of adhesive pericarditis (H & E x 75).

Fig. 11. Necrotic lesions due to foreign-body penetration of myocardium.

Appendix II

Arterial Puncture in Large African Game Animals

The method of arterial puncture described was attempted in intact, unanaesthetised yet immobilised game animals in East Africa. Success was achieved in four out of the five species in which it was attempted. Arterial pressure records were taken in Zebra (Equus burchelli), Wildebeeste (Gorgon taurinus), Giraffe (Giraffa camelo pardalis) and Eland (Taurotragus oryx).

Figure 102 illustrates arterial pressure recording in a female Eland.

Figure 103 illustrates the pressure records obtained from Zebra, Wildebeeste and Eland. These records were taken in the bush at a distance from a laboratory. The transducer and manometer were those used previously+, the recorder was a pen recorder++ especially adapted. Electric power was supplied by an alternator fitted to a Land Rover.

Too few records were taken to draw any conclusions, but the success of the method demonstrated the possibilities of functional cardio-vascular studies on these game animals.

The one species in which the method was not successful was the Rhinoceros (Diceros bicornis). In this species it was considered that the thickness of the neck would require a much longer needle than the 8" length available in Africa at that time.

\+ Elema-Schonander Ltd., Sweden

++ Cambridge Instrument Co., England

Figure 102 A pressure recording in a young female Eland

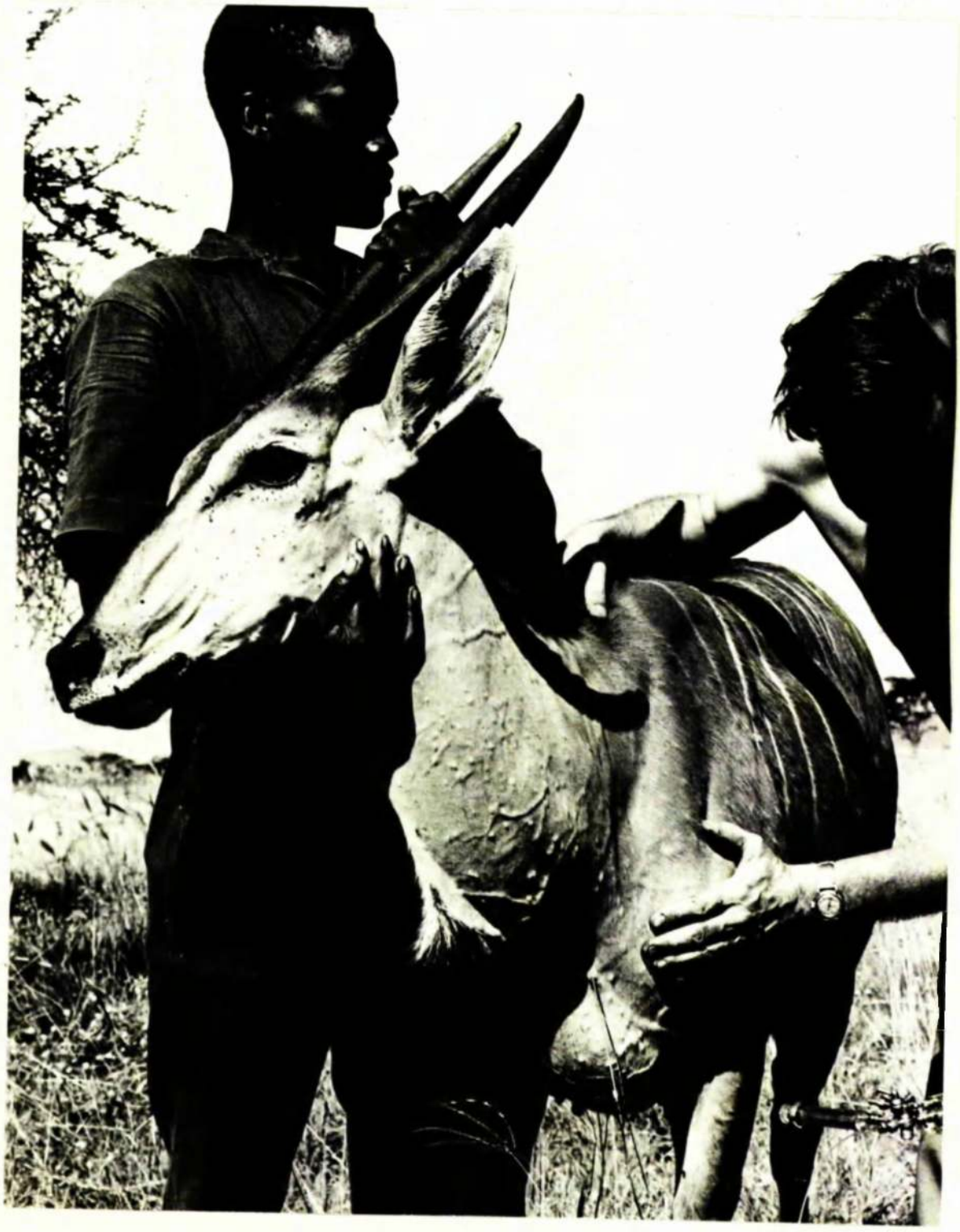
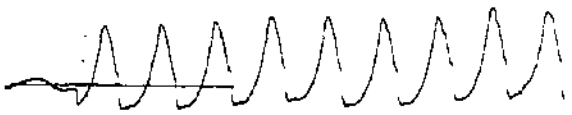


Figure 103

Arterial Pressure Records of
Large East African Game Animals

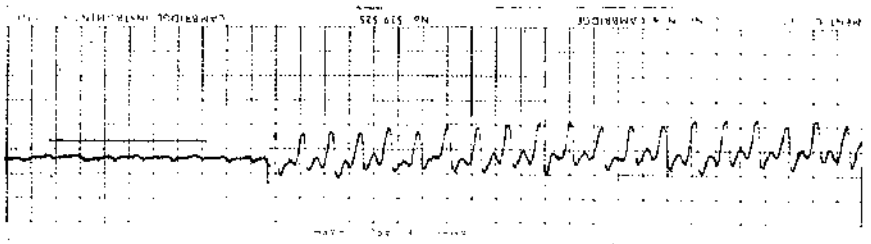
Zebra



Systolic 160 mmHg

Diastolic 120 mmHg

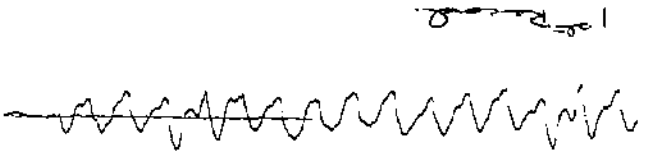
Wildebeeste



Systolic 120 mmHg

Diastolic 65 mmHg

Eland



Systolic 170 mmHg

Diastolic 130 mmHg