AN APPLICATION OF PHYSIOLOGICAL ANTHROPOMETRY.

THE DETERMINATION OF LEG SUBCUTANEOUS FAT, MUSCLE AND BONE WIDTHS AND VOLUMES IN YOUNG MALE AND FEMALE ADULTS

by

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PREFACE

In conjunction with the present study, it is appropriate that the following acknowledgements be made.

I am indebted to Professor W.F. Floyd, Head of the Department of Ergonomics and Cybernetics in the University of Technology, Loughborough, for his help and encouragement and placing the facilities in the department at my disposal; to Professor Stuart Kirk, my supervisor, and Dr. Ernest Hamley, Reader in Human Biology, both of the Department of Ergonomics and Cybernetics, who have given me every possible assistance from the inception of the study to the reading of the manuscript; also, of the same department - Dr. Elwyn Edwards, Reader in Ergonomics, for his guidance on statistical matters over the past few years, and to Professor Eric Stroud, Professor of Pediatrics, King's College Hospital, University of London, whose advice and encouragement spurred me to postgraduate research.

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ABSTRACT

AN APPLICATION OF PHYSIOLOGICAL ANTHROPOMETRY.

THE DETERMINATION OF LEG SUBCUTANEOUS FAT, MUSCLE AND BONE WIDTHS AND VOLUMES IN YOUNG MALE AND FEMALE ADULTS

A part of the United Kingdom's contribution to the preparatory stages of the International Biological Programme - Human Adaptability section, concerned the structure of the body and its relationship to function during submaximal and maximal exercise. An extension of this work, with particular reference to the limb composition, is reported.

This thesis sets out to answer the following problems, the questions are posed and the conclusions follow.

1. What techniques can best describe the leg musculature made use of in carrying out the work?

Three methods are compared: soft-tissue roentgenogrammetry, anthropometry and water displacement. Some methods exhibit advantages over others but, in general all are interchangeable, therefore, the choice can be made on the grounds of suitability and convenience.

2. Are there any inherent dangers during the soft-tissue roentgenogrammetric procedure?

Inherent faults in the male and female "Armadillo" gonad protector are demonstrated and a new alternative design is reported. Measurements made under the conditions of soft-tissue roentgenogrammetry of the arm, calf and thigh for investigative purposes revealed skin and gonadal dosages of 12 to 23 mrad and less than 0.01 to 0.13 mrad

respectively, using the new protector. Emphasis is placed on adequate filtration (not less than 3 mm al.), the use of fast films and intensifying screens, and light beam delineator diaphragms to keep the area radiographed to the minimum.

3. Which of the two muscle indices of width and volume give the best relationship to aerobic capacity and total body potassium (^{40}K)?

The measurement of aerobic capacity was made on groups of male and female College of Education and University students, during sessions on a Müller cycle ergometer, which emphasises the use made of the musculature of the thigh and calf in carrying out the work. The results show that the width of the muscle mass in the thigh and calf estimated from soft-tissue radiographs give a better linear relationship to the consumption of oxygen during exercise and to total body potassium than do total leg muscle volumes. Although the relationship of the total leg muscle volume is positively correlated for young men ($r = 0.67$, $p < 0.001$), the correlation is considerably less for young women ($r = 0.21$, $p > 0.1$). This may be due to a sex-linked difference in muscle composition, on the basis that men have more muscle cells per unit of lean body mass than do women. Further it is shown that variation in describing maximal oxygen uptake is diminished by allowing for composition and distribution of body muscle. The results also show that body muscle can be obtained from anthropometric or roentgenogrammetric techniques or by monitoring total body potassium.

4. Can the two limb muscle indices by predicted indirectly from simple anthropometric techniques?

Use has been made of the leg muscle width, at specific locations, as an index of limb muscle mass. From the results it is suggested that limb muscle mass may be predicted indirectly, in terms of limb circumference and by means of skinfold thickness. It is also shown that when using similiar techniques leg muscle volume may be predicted indirectly for men but not for women.

5. What are the relationships between skinfold caliper and X-Ray measurements of subcutaneous fat made at the same site?

It is shown that there are high significant correlations between X-Ray and caliper for the majority of sites, however, there does not exist a simple conversion factor which is applicable to numerous sites on both of the sexes. By accepting that soft-tissue radiographs record accurately the depth of the subcutaneous fat layer at any given part of the body, the values can be treated as absolute measures of fat thickness. Because roentgenogrammetry is not always possible in field studies and some of the chosen body sites are limited and not easily reproduceable, it is felt that simple linear regression equations based on previous radiographic studies can predict from skinfold caliper measurements an acceptable single value. The lateral calf site is recommended as being the most reproduceable of the four leg fat sites in young men and young women.

6. Can leg subcutaneous fat widths and volumes be related to total body fat?

Subcutaneous fat estimates in the form of widths, volumes and skinfold values are used to predict total body fat. The data show that for the sample population total body fat can be estimated with a reliability of $\pm$ 1.84% for men and $\pm$ 2.91% for women when using simple and convenient methods of skinfold caliper measurements.

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CHAPTER I

CHAPTER I

STATEMENT OF THE PROBLEM WITH AN HISTORICAL INTRODUCTION TO HUMAN BODY COMPOSITION

1. Theoretical Introduction and aims of this study.

Primarily, this is a methodological study aimed at developing improved techniques for measuring the leg widths and volumes of subcutaneous fat, muscle and bone in the legs of young men and women, together with some of the problems encountered. Its secondary aim is to relate the correlation of indices of limb muscle width and volume to maximal oxygen uptake and whole body potassium and to show what differences might exist due to sexual differentiation.

This study was undertaken in order to assess the feasibility of methods of measurement which, under field conditions, concentrated on factors underlying the capacity for exercise - in particular dimensions and functions of the lungs, heart, blood and skeletal muscle.

If the structure of the body could be related to function during submaximal and maximal exercise, then it was hoped to provide a base line for the assessment of aerobic capacity by methods that would be acceptable to the majority of subjects available in a population. This is the general field of physiological anthropometry and in this study the specific interest is to correlate certain aspects of body composition (especially in the legs of young men and women) with functional activity.

Maximal oxygen uptake (VO_2 Max) reflects the capacity of the oxygen transport system of the body plus the amount of skeletal muscle which can be brought into effective use. The measurement of VO_2 Max was made during sessions on a cycle ergometer modified by Müller and Olech (1964). In pedalling, the effective amount of musculature which can be brought into use during the exercise is mainly that of the thigh and calf. Astrand and Saltin (1961) have shown that the consumption of oxygen is dependent upon the load on the muscles and on the muscle mass at work. Accordingly, it is not surprising that attention should be focused on describing estimates of limb muscle based on Anthropometry - by direct measurements, soft-tissue Roentgenogrammetry and water displacement.

Human physique can be regarded as having several aspects - size, represented by the skeletal dimensions, external form or shape and internal form represented by the tissue composition. External form is dependent, in part, on the internal body composition since there are complex relations between both. The skeletal muscle can be determined by numerous methods, in fact, the calf mass has long been used in radiographic studies of body composition:- Stuart (1940), Reynolds (1950), Garn (1953), Tanner (1955) and their associates. What is truly representative of actual muscle is arguable, since widths, cross-sectional area, circumferences and masses appear to be highly inter-correlated when not related to the length of the limb. It remains to be seen what contribution the limb segments make to the total body muscle mass. However, Garn (1963) points out that it would be premature to dismiss either the upper arm or lower leg from consideration in the Roentgenogrammetric approach to total muscle mass within a homogeneous population. If the arm and calf muscles are eliminated from the limb contribution to total muscle, does this make a serious material difference to the prediction? In order to test these hypotheses use was made of the fact that mineral potassium is present in the active metabolising cells of the body but not to any influential extent in the fat or fluid compartments. The bulk of the cells are muscle cells and, therefore, by monitoring this fixed proportion of potassium which is in the form ^{40}K and emits gamma radiation, an estimate can be made of the whole body potassium, thus providing a measure of total body muscle from which direct comparison with the estimate of limb muscle can be made.

2. Historical Introduction

The study and analysis of human body composition is by no means complete in spite of some eighty years having elapsed since the first attempts were recorded. Early forms of measuring instruments and methods focused attention on identifying individual differences between muscular and 'soft-tissues'. Richer (1890), a Frenchman, was the first to write about the role of adipose tissue, He distinguished between the various areas of 'soft-tissues', by measuring the subcutaneous fat folds with a simple caliper, and assumed the skin to be of uniform thickness whilst demonstrating wide variations in the fat thicknesses taken from the back of the hand, the eyelid and different regions of the trunk.

One of the first approximations of the amount of 'soft-tissue' in relation to skeletal size was the index of body weight to height. Later the ratios of weight/height and height divided by the cube root of weight (Sheldon, 1940) were used to measure the body mass in relation to its length, but this unfortunately had limitations as it made no differentiation between fat and muscle and gave little information about limb size. In the United States of America, Welham and Behnke (1942) proved the inaccuracies of these criteria in the first studies using underwater weighing. They showed in a group of football players that they were 'overweight' not because of excess fat but because of extra muscle bulk, yet these young healthy men had been rejected from military service and were also declared a poor risk by the Life Insurance Companies due to excess weight. Their actual body weight was 24.6% above the military standard for men of the same age and stature. Because height and age are only taken into account in ordinary height and weight standards, the Committee on Nutritional Anthropometry (1956) recommended that two diameters, bi-iliac and biacromial, should be measured as indicators of the width of the skeletal frame to strengthen the variations in body types.

Various researchers have used the body and limb circumferences as indicators of subcutaneous fat. These parameters although extremely helpful in describing body size, do not distinguish between the portion of the circumference due to the skin plus underlying fat and that due to the deeper muscle and bone components. It appears then, that it is important to take into account gross body weight and early attempts were made by the German anatomists Bischoff (1863) and Volkman (1874), to obtain body composition data from direct analysis of the human body. The intention is not to give a detailed description of the relevant work on direct analysis of body composition, but simply to show that this type of approach provides a final calibration and validation for the indirect methods.

Matiegka (1921) was responsible for introducing the modern anthropometric approach to body composition. He was interested in functionally oriented anthropometry with an aim to devising a system for analytical and quantitative description of human physique. In particular he was anxious to visualize the somatometric evaluation of physique by body measurements, as components related to the physiological assessment of man's health and capacity for work.

In subsequent years studies of human body composition received great stimulus from workers like Scammon (1930) who provided the weight of anatomically separated subcutaneous adipose tissue compared with chemically extracted fat. From a methodological consideration came the works of Moulton (1923) with his concept of 'chemical maturity' based on work with farm animals, and Hammond (1932) with his complete dissection of the pig. By this technique he separated the total body mass of a number of pigs into component organs and tissues. Another major contribution came from Behnke (1941) in his studies of deep sea diving by the United States Navy. He developed formulae for the analysis of weight of the living human body into its 'fat' and 'lean' fractions on the basis of the ratio of body weight to body volume and of total body water (Behnke, et al., 1942).

During the past twenty years, many new developments for quantitative assessment of the major tissue components have been made, based mainly on anthropometry, body densitometry and chemical analyses including the use of dilution studies with radioactive isotopes. The majority of these methods have been reviewed in an excellent article by Keys and Brozek (1953).

Anthropometry, the measurement of Man, not only includes measurements by anthropometer, flexible tape and skinfold caliper but would also include soft-tissue roentgenogrammetry, densitometry and whole body monitoring etc. With these procedures, recent research has fortified much of Matiegka's original 'dynamic' approach to anthropometry and given substance to his concept of partitioning the human 'body' into gross morphological components of adipose tissue, muscle and bone in relation to man's capacity for work. At the time of Matiegka's publication in 1921, he had little indication that his work was so far ahead of his contemporaries, that it would lie completely dormant for decades. It is with this thought in mind that I trust this thesis may not be considered out of date!

In studies concerned with factors relating to man's working ability, his physical competence can be evaluated by measuring his oxygen consumption during maximal exertion at the limits of his aerobic capacity. Because the aerobic capacity reflects the ability of the cardio-respiratory system to fulfil the metabolic demands, and upon the quantity of skeletal muscle involved in energy production, it is not surprising that one of the most important features of body composition is its close relationship to functional aerobic capacity, as measured by the maximal oxygen uptake. Buskirk and Taylor (1958) demonstrated that in adults there is a very close relationship between lean body mass and the maximal oxygen consumption and an appropriate measure of muscle mass might provide the best possible index for the VO_2 Max as a test of maximal respiratory-cardiovascular function.

Cotes and Davies (1969) have shown that within a specific environment the aerobic capacity is mainly determined by the physical and functional dimensions of the relevant organs. Environmental changes are influenced by factors such as diet, altitude, atmospheric pollution, temperature and the amount of physical activity (Bannister & Cotes, 1959; Malhotra et al, 1966; Pugh, 1967; Edholm, 1969; Cotes et al., 1970), whereas functional dimensions are influenced by sex, age, cardiac output, ventilatory and oxygen transfer efficiencies, the effectiveness of the skeletal muscle and by disease. The qualitative functions in the environment and related organs are the prime interest of physiologists, whilst the quantitative functional dimensions are more the concern of anthropometrists. Studies which are not strictly anatomical or physiological have been described by Wallace Fenn (1968) as Physiological Anthropometry.

The proportion of muscle in lean body mass has been demonstrated by Luft et al (1963) who found that regression equations could be established for the calculation of oxygen consumption from the proportion of L.B.M. and potassium content. The practicability of this calculation is based on potassium being found almost exclusively within metabolising cells, and only minimally in fat, bone and collagen; so that reliable estimates of active muscle mass would be expected from determinations of total body potassium (^{40}K).

Such techniques extend the methods of roentgenogrammetry by permitting a correlation between visual two dimensional measurements with what are effectively internal volume and mass measurements.

CHAPTER II

CHAPTER II

THE DETERMINATION OF GROSS LEG VOLUME BY WATER DISPLACEMENT

Purpose and aims of the water displacement method.

The experimental design of a comprehensive investigation into the gross leg volume in male and female young adults called for a method which would reveal with a high degree of accuracy the actual overall volume of the leg together with the separate volumes of the thigh, calf and foot segments.

By marking the limb segments at reproducible anatomical sites and using the 'Archemedian' principle of water displacement it was felt that these requirements could be met.

Material and Methods

For the upper boundary of the leg volume an anatomical site close to the ileo-femoral joint was desirable, also one which was easily distinguished and had a high degree of reproducibility. To meet these requirements the gluteal furrow fold was chosen. The thigh-calf segment was 'separated' at the tibial-femoral joint space, a location which is readily palpable. So as to determine the actual volume of the calf region it was necessary to 'separate' the foot, therefore, a point at the minimum ankle circumference was chosen. The three anatomical points were then marked using a dermographic pencil. (Fig. 1)

A cylindrical steel tank (16 gauge thickness) measuring 57 cm by 107 cm having a total volume of 273 litres, was used

Fig. 1. Method for taking limb circumference measurements using flexible steel metric tape. Other sites are shown.

for the total leg water-displacement estimations. To the base of the tank was connected the end of a one metre length of polyvinyl tubing (3.65 cm I.D.). The other end was attached to a variable height outlet (Fig. 2) which could be raised or lowered on a metric height gauge (Figs. 2 and 3). "BARTOL"* hard P.V.C. pipe was used for the construction of the outlet system.

For the water displacement determination of the lower leg region, a smaller tank, 36.5 cm by 60 cm having a total volume of 63 litres, was used (Fig. 4); it was modified in a manner identical to that of the larger tank.

Two perspex tanks (Fig. 5), shaped in the form of a boot measuring 36 cm by 12.5 cm by 22 cm with a graduated sight-glass attached to the side, were used to determine the volume of the feet.

With the subject standing erect and the feet together, the heights of the three skin marks above the measuring surface top were measured with a 'Harpenden' digital reading anthropometer (Tanner & Whitehouse, 1957). The measuring surface, in this case, was a specially constructed stool normally used for sitting heights. This design ensures that the anthropometer is kept in the true vertical position (Fig. 6). The variable height gauge on the tank was then set (to the nearest mm) to the recorded height of the gluteal furrow fold. Water was piped

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*The word "BARTOL" is a registered trade name.

FIG. 2. THE "BARTOL" P.V.C. VARIABLE HEIGHT OUTLET SYSTEM FOR THE LEG VOLUMETER.

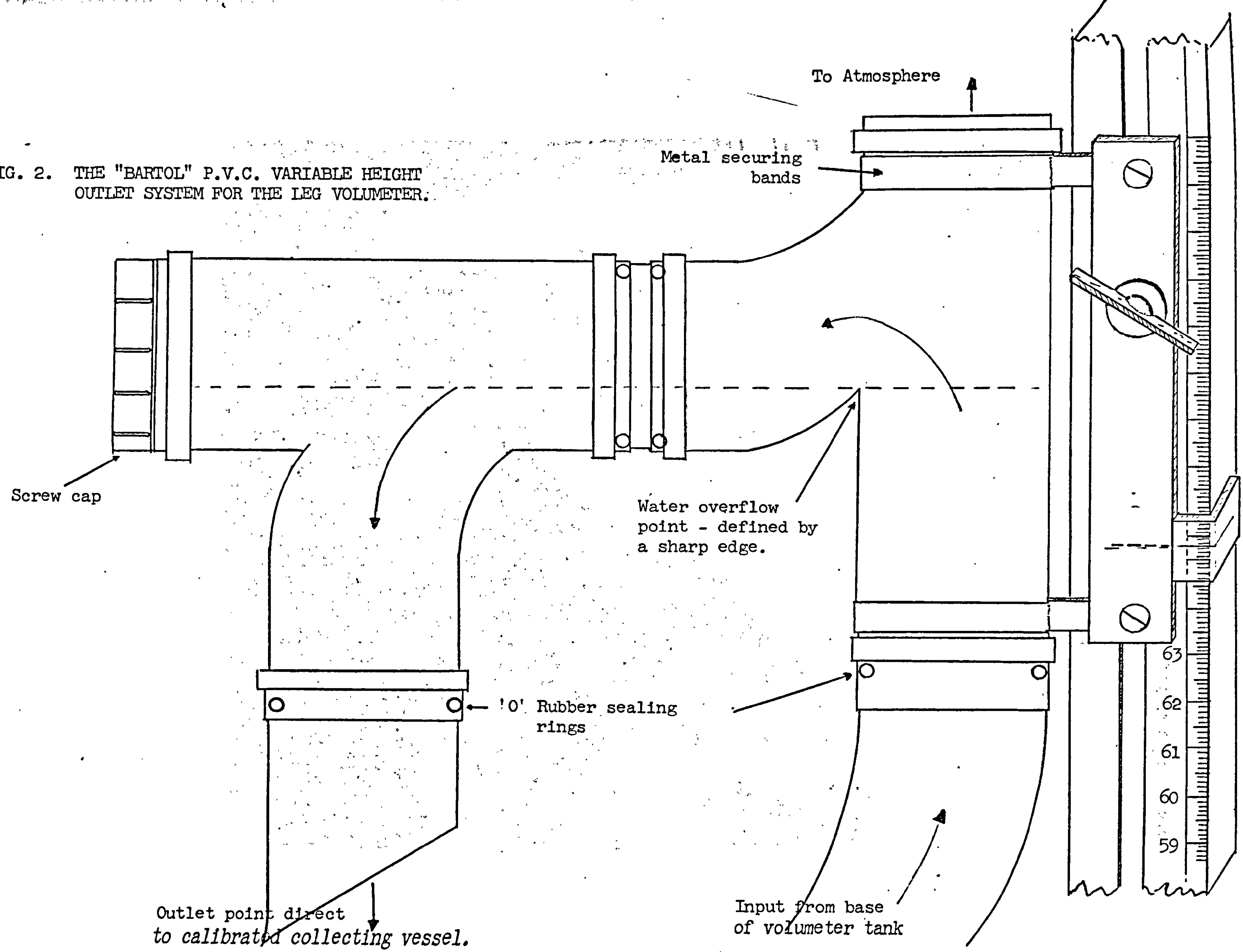


Fig. 3. Constant level volumetric tank with adjustable level, for the determination of total leg volume. Calibrated collecting drum is shown in situ.

Fig. 4. Constant level volumetric tank with adjustable level, for the determination of lower leg volume.

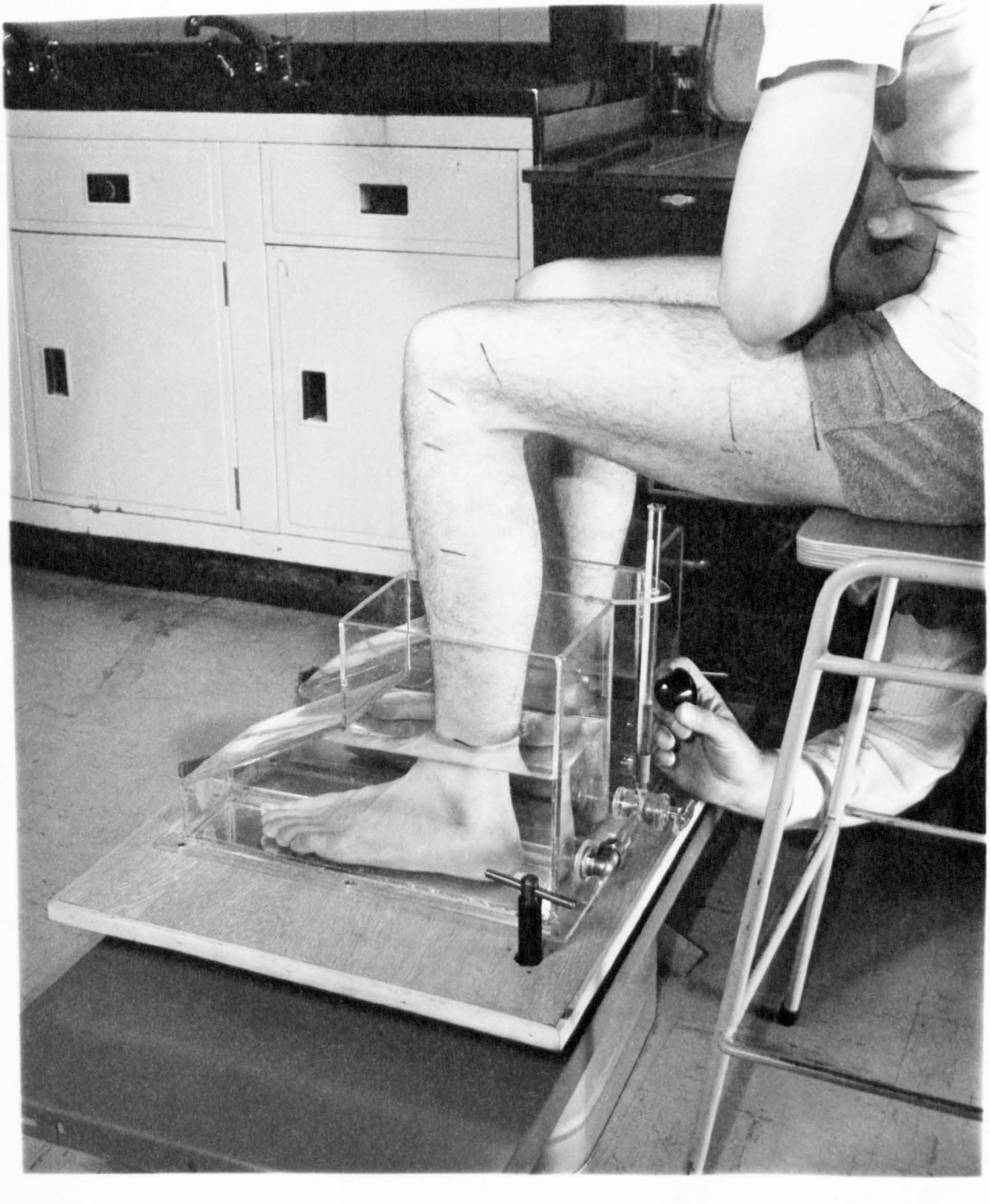


Fig. 5. Volumeter tanks, for the determination of individual or combined volumes of the foot. Reliability of repeated determinations $\pm$ 10 cc.

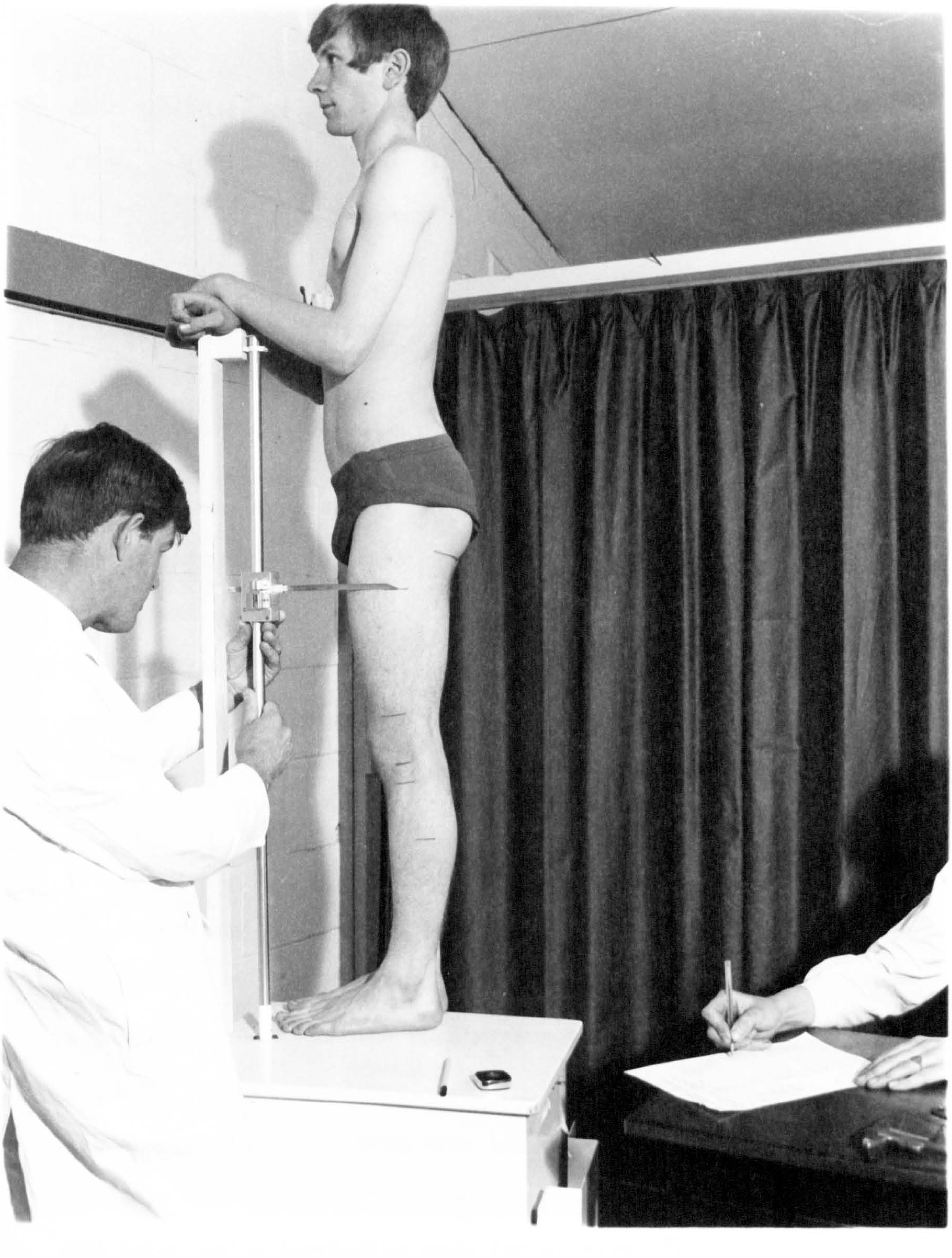


Fig. 6. Method for measuring heights of skin-marks above table-top level, using a "Harpenden" digital reading anthropometer.

into the drum and allowed to fill until it ran out of the overflow. An immersion heater brought the temperature of the water to 37°C, ± 1°C; it was maintained at this temperature by a suitable thermostat. When the water had stopped dripping from the overflow, a 50 litre calibrated drum was placed underneath the outlet pipe whilst the subject slowly climbed down into the tank by means of a small ladder.

It was important that the subject stood in the same position in which the measurements were made, also to keep still to prevent oscillations on the water surface from being set up. Care was taken with the male subjects to see that they held their genitals out of the water. Trunks were not worn as it was found that up to 150 cc of water could be soaked up - depending upon the type of material in the garment. At the end of the water displacement period (approx. 7 min.) the height gauge was raised, to prevent any further water overflowing, whilst the subject climbed out of the tank. The collecting drum was placed on to a levelling board and the reading was taken through the sight glass to the nearest 10 cc. As an additional check the water was also weighed on a beam type scale accurate to 10 grams. At the time of weighing, the temperature of the water in the drum was taken and a correction made for density.

The procedure for the lower leg followed the same pattern as for the total leg except that the height gauge was set at the corresponding height for the tibial-femoral joint space.

To determine the foot volume the subject sat on a table top so that the lower legs were in a perpendicular position with the feet at right angles to them in the tanks (Fig. 5). The plastic tanks were secured on a board which could be levelled by adjusting two levelling screws. Water at 37°C was gently poured into the tank up to the level of the minimum ankle skin mark. The optimum level was determined when the skin marker dye from the black dermographic pen permeated into the water. When the surface oscillations had stopped, a reading was taken through the sight glass. Having taken the feet out of the tank the level was brought up to the first recording by adding a measured amount of water; this represented the volume of the feet. Where there were marked differences in the lengths of the right and left foot, volume determinations were made individually by isolating one tank from the other by means of a 3-way stop-cock. In the majority of cases there was little variation between them, therefore the volume of the two feet were taken together.

To reduce the surface tension a wetting agent was added to each tank, thus increasing the accuracy of reading in the foot and collecting tanks and by lowering the resistance in the site glass and on top of the levelling bridges inside the outlet pipes.

The subjects were 32 male students from a Physical Education College plus 11 University students and 15 female students from a College of Education. All were healthy. They volunteered to take part in the study after being given a complete description of what the experiments entailed.

Statistical treatment of data

The data were punched on I.C.L. 80 column punch cards and a simple programme was written in FORTRAN IV language to calculate the mean, range, standard deviation and standard error of each parameter. The computations were made on a 1905 I.C.L. computer.

Results

The reliability of repeated displacements for the gross volume of the legs, calves and feet were respectively ± 50 cc, ± 30 cc and ± 10 cc.

The mean value, standard deviation and range for the male and female total leg, thigh, calf and foot volume are presented in Table 1. The gross leg compartment volumes, by water displacement, show only slight differences between the sexes, the male being the larger by + 0.08 litres for the thigh, + 0.23 litres for the calf, and + 0.52 litres for the foot.

Discussion

It was considered of great importance that the anthropometer should be held in the true vertical position by a suitable device and not held in the hands of the observer. In the latter case it was found that when a gluteal height of approximately 80.0 cm from the ground was measured, a deviation

TABLE 1. MEANS, STANDARD DEVIATION AND RANGES OF THE GROSS LEG COMPARTMENTS VOLUMES IN YOUNG MALES AND FEMALES, DETERMINED BY WATER DISPLACEMENT.

	MALES				FEMALES			
	N.	Mean	S.D.	Range	N.	Mean	S.D.	Range
Age, Yrs.	43	25.80	5.32	18.60 to 38.19	15	19.18	1.38	18.01 to 22.74
Total Leg Vol. - H_2O (Litres)	43	16.28	2.40	13.32 to 25.00	15	15.84	2.13	13.74 to 21.71
Thigh Vol. - H_2O	11	10.75	1.60	8.96 to 13.89	15	10.67	1.68	8.96 to 15.08
Calf Vol. - H_2O	11	5.37	0.82	4.36 to 6.70	15	5.14	0.61	4.31 to 6.63
Foot Vol. - H_2O	43	2.27	0.33	1.51 to 3.05	15	1.75	0.17	1.45 to 1.97

of $\pm 5^{o}$ with the anthropometer from the vertical would produce an error at the tip of the anthropometer arm (radius 10.0 cm) of 10 mm. Likewise it was important that the subject did not sway from the vertical. This was overcome by the subject holding on to the top of the apparatus (Fig. 6).

The time spent in the tank was dependent upon two factors:

1) the amount of co-operation from the subject, and

2) on the diameter of the outlet pipe.

From the initial experiments it was determined that 3.81 cm diameter was the minimal acceptable - this gave an 'exposure' time of about seven minutes. With a smaller diameter it was found that the subjects became restless, thereby setting up oscillations on the surface of the water which not only prolonged the operation but gave inaccurate determinations.

Apart from this technique having numerous scientific and clinical applications, e.g. segmental changes during growth (Skerlj, 1955), during dieting and exercising (Carns and Glasgow, 1957; Carns et al., 1960); muscle volumes in limbs which have sustained injuries to nerves (Jackson, Jackson and Seddan, 1946), limb volume changes associated with normal and toxaemic pregnancy (White, 1949; Lunborg and Theobald, 1963), nutritional studies (Garn, 1957), and in research on the swelling of the upper limb following post-mastectomy lymphoedema (Kettle, Rundle and Oddie, 1958), its application in this study was to serve as a standard of reference for the next phase of the study.

C H A P T E R III

CHAPTER III

ANTHROPOMETRIC DETERMINATION OF LEG FAT AND MUSCLE PLUS BONE VOLUMES

Purpose and aims of the anthropometric technique

Having established a standard basic water displacement method for deriving the gross limb volume, it was considered necessary to develop an anthropometric technique which was reasonably simple, yet which compared favourably with the results of the water displacement method. It was considered that for population studies, especially in the field, water for filling the tanks may not be readily available; also, the bulk and weight of the tanks would add considerably to the transportation costs.

An anthropometric method for partitioning the volume of the leg into six segments which are similar to truncated cones is described (Jones and Pearson, 1969).

Methods and Materials

With the subject standing erect and the feet slightly apart the height above the floor and the circumference are taken at 7 sites on the left leg. The sites are illustrated in Figure 7; they are the gluteal furrow, one-third of the subischial height up from the tibial-femoral joint space, the minimum circumference above the knee, the maximum circumference around the knee joint space, the

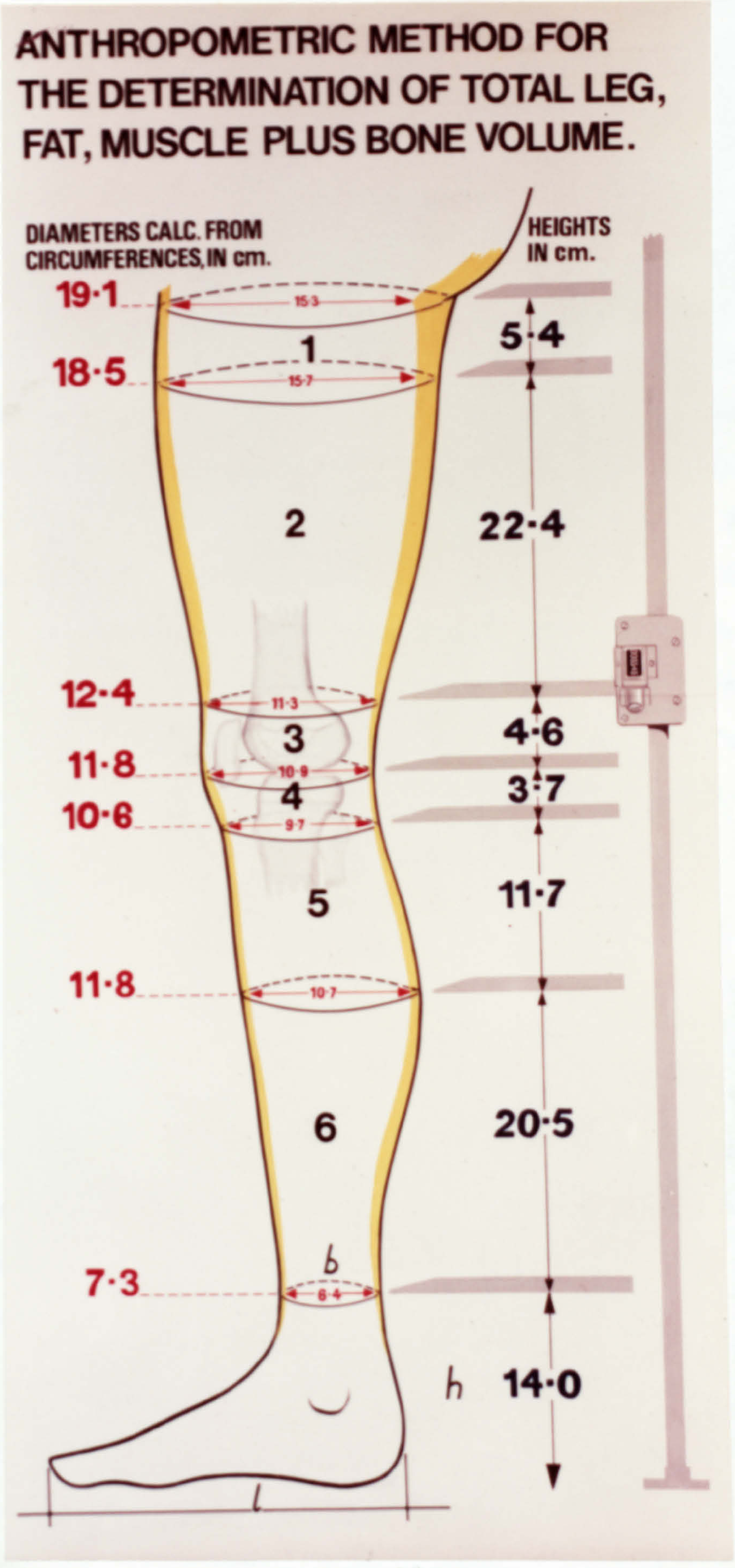

ANTHROPOMETRIC METHOD FOR THE DETERMINATION OF TOTAL LEG, FAT, MUSCLE PLUS BONE VOLUME.
DIAMETERS CALC. FROM CIRCUMFERENCES, IN cm.
HEIGHTS IN cm.
19·1
15·3
1
5·4
18·5
15·7
2
22·4
12·4
11·3
3
4·6
11·8
10·9
4
3·7
10·6
9·7
5
11·7
11·8
10·7
6
20·5
7·3
b
6·4
h
14·0
l

Fig. 7.

minimum circumference below the knee, the maximum calf circumference and the minimum ankle circumference. The levels were marked with a dermographic pencil; the circumferences measured with a flexible steel metric tape and the heights above the floor level measured with a digital reading anthropometer (Tanner and Whitehouse, 1957). Skin-fold thicknesses were measured with a Harpenden fat caliper (Edwards et al., 1955) at four sites, viz. the anterior and posterior thigh in the midline at the one-third subischial height level and the medial and lateral calf at the maximum circumference level. Because the calipers pick up a double layer of skin-fold tissue under pressure of $10g/mm^2$ the reading is converted to a true single measurement using a regression equation applicable to each sex and fat site. This is based on a comparison between X-Ray fat and skin-fold caliper fat using the linear relationship which we have found exists between the two.

The formula to calculate the volume of a truncated cone ($\frac{h}{3}(a + \sqrt{ab} + b)$, where a and b are the areas of two parallel surfaces derived from circumference measurements), was applied to the six truncated cones (Fig. 7). Validation of the calculated thigh and calf volumes was carried out by comparing the values with those obtained by the water displacement method with apparatus especially designed for the purpose (reliability of repeated displacements $\pm$ 50 cc.).

Because of the difficulty in measuring the subcutaneous fat and muscle in the foot, the computed or water volume values were subtracted from the total leg volume. The computed values for the foot were obtained by assuming the foot to be wedge shaped ($\frac{1}{2}$ l x b x h, where b is the diameter calculated from the minimum ankle circumference). This method has been shown to give the best overall results when compared with two other techniques (Appendix I).

To estimate the muscle plus bone volume, the two corrected fat caliper readings for the thigh and calf were summed, the results subtracted from their respective diameters and the inner cone volumes calculated as previously mentioned. An estimate of the subcutaneous fat volume was obtained by subtracting the muscle plus bone value from the total leg volume.

Validation of the fat volume results was made by comparing them with the results obtained by soft-tissue roentgenogrammetry (Table 2 and Fig. 8).

The subjects were the same 32 male and 15 female young adults as used previously.

Statistical treatment of the data.

A multiple regression analysis computer programme written in Fortran IV language was used to calculate means, standard deviations, correlation coefficients and standard errors of the estimates. The programme was used in a simple linear regression form to calculate $y = a + bx$.

TABLE 2. COMPARISON OF RESULTS OBTAINED BY: (1) WATER DISPLACEMENT AND ANTHROPOMETRY FOR TOTAL LEG, THIGH, CALF AND FOOT VOLUMES. (2) X-RAY AND ANTHROPOMETRY FOR TOTAL LEG, THIGH AND CALF SUBCUTANEOUS FAT VOLUMES.

		MALES				FEMALES			
Body Component volume	Method	Mean (1.)	S.D. (1.)	Corr. coeff.	Matched pairs	Mean (1.)	S.D. (1.)	Corr. coeff.	Matched pairs
Total leg	W.D. A	16.28 16.35	2.40 2.45	0.98	-0.07	15.84 15.60	2.13 1.92	0.99	+0.24
Thigh	W.D. A	10.75 10.74	1.60 1.78	0.98	+0.01	10.67 10.64	1.68 1.47	0.98	+0.03
Calf	W.D. A	5.37 5.27	0.82 0.88	0.99	+0.10	5.14 4.95	0.61 0.54	0.93	+0.19*
Foot	W.D. A	2.27 2.33	0.33 0.37	0.91	-0.06	1.75 1.78	0.17 0.16	0.83	-0.03
Total leg fat	X-R. A	2.88 2.80	1.02 0.91	0.94	+0.08	6.52 6.29	1.79 1.27	0.86	+0.23
Thigh fat	X-R. A	2.15 2.03	0.81 0.75	0.94	+0.12	4.93 4.67	1.50 1.05	0.84	+0.26
Calf fat	X-R. A	0.74 0.78	0.24 0.19	0.84	-0.04	1.59 1.62	0.37 0.31	0.86	-0.03

In all cases the correlation coefficient is highly significant $P < 0.001$.

*Significant difference of the mean values (by matched pairs t-test) $P < 0.05$.

W.D. = water displacement; A = anthropometry; X-R. = X-Ray.

TOTAL LEG, FAT VOLUME

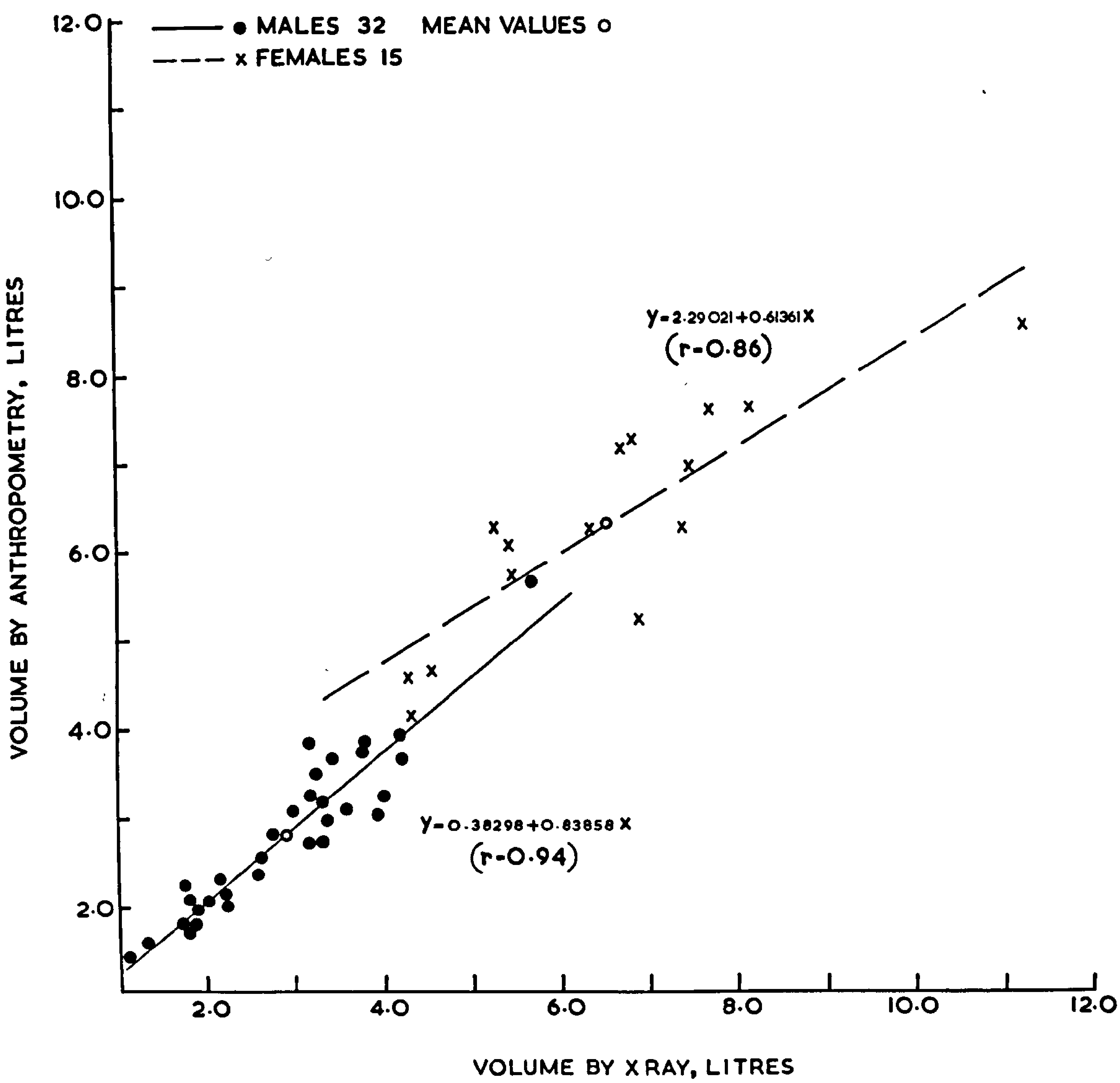


Fig. 8. The relationship between two methods for calculating the total leg (thigh plus calf) subcutaneous fat volume. X-Ray v.s. Anthropometry. Coefficient of Variation about the regression line is males ± 11.28%, females ± 10.61%.

Student's 't'-test (two-tailed) was used to test the significance of the difference between the mean values.

Results

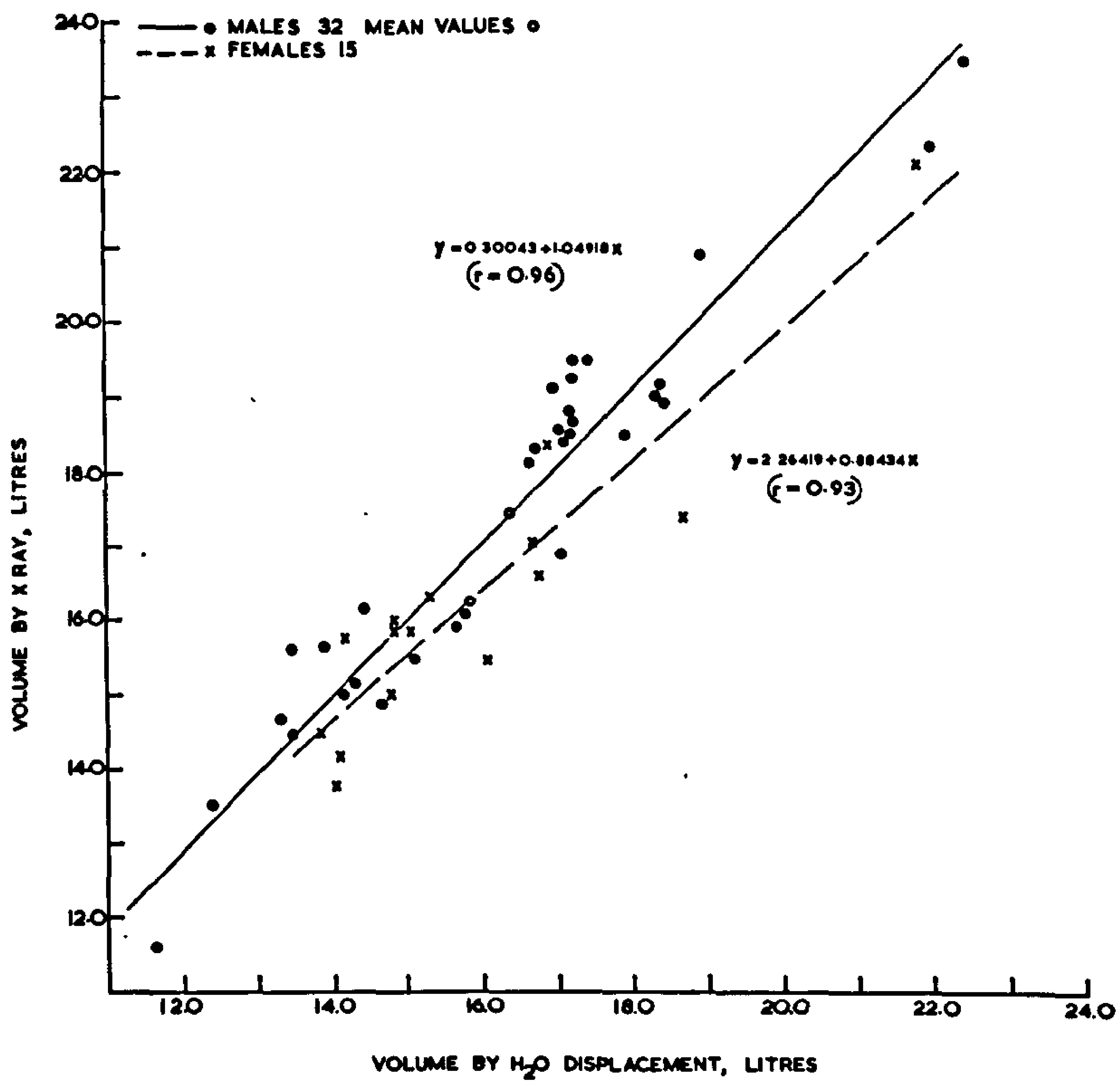
Table 2 and Figs. 9 (a) and (b) and 10 (a) and (b) show the comparison of results between water displacement and anthropometry for the total leg and foot, thigh and calf, also between X-Ray and anthropometry for total leg, thigh and calf subcutaneous fat volumes.

In all cases the correlation coefficient is highly significant and the differences between the means (apart from those with asterisks) are non-significant. In the regression equations involving the two measurement techniques, the regression coefficients do not differ significantly from 1.

The mean gross Anthropometric values for the thigh, calf and the foot show that there are differences between the sexes, the male showing the higher values.

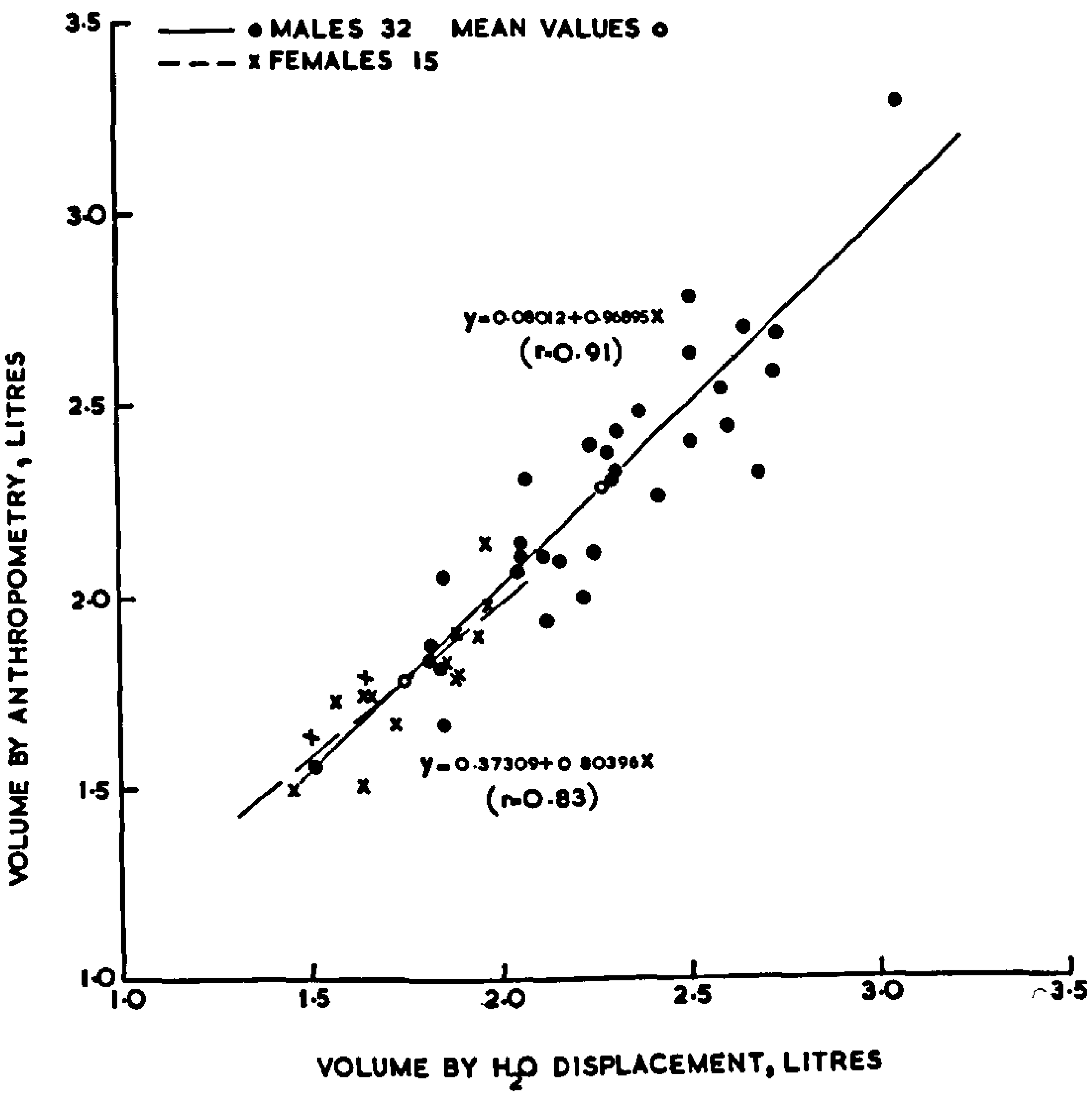
Presented in Figure 11 are histograms of the muscle plus bone and subcutaneous fat components of the leg in young males and females. There are striking differences between the sexes; whilst the gross volume compartments have similar values for each sex, the amount of fat in the female thigh and calf is more than twice that of the male. The highest proportion of fat as a percentage of each gross compartment (thigh and calf) is found in the thigh,

TOTAL LEG VOLUME



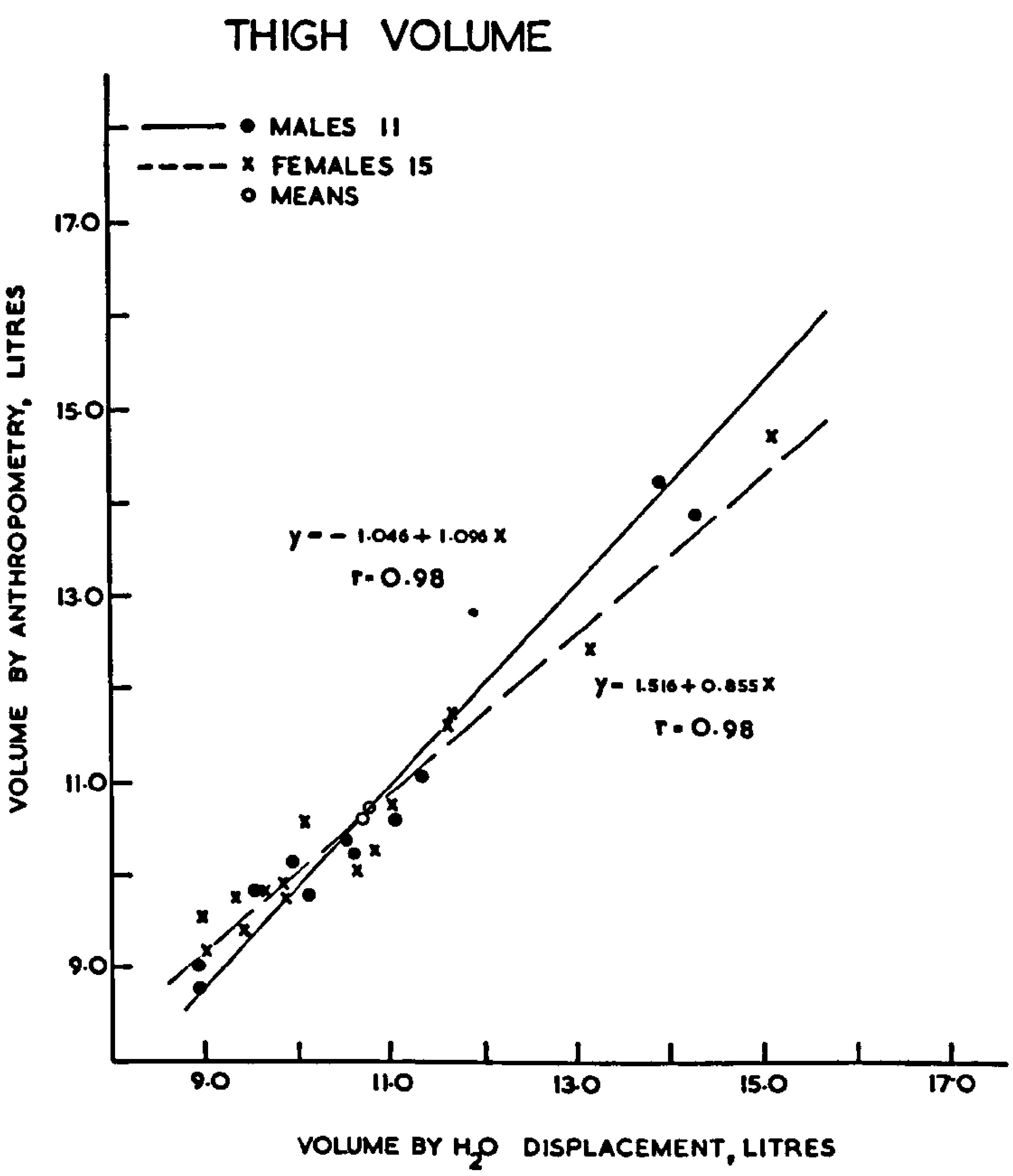
a).

FOOT VOLUME

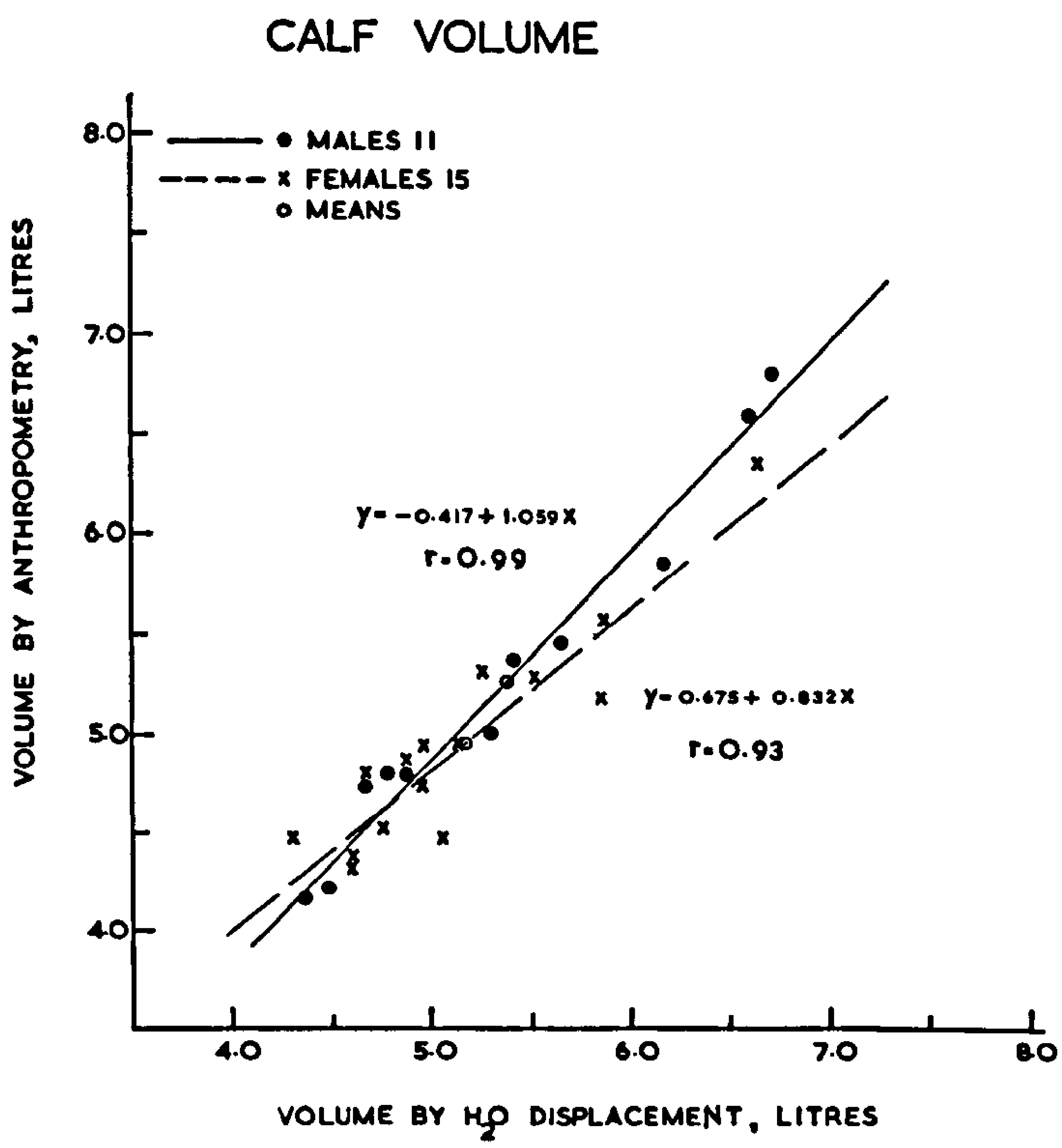


b).

Fig. 9. The relationship between two methods, water displacement and anthropometry for calculating the gross volume of a) the leg and b) the foot.



a).



b).

Fig. 10. The relationship between two methods, water displacement and anthropometry for calculating the gross volume of a) the thigh and b) the calf.

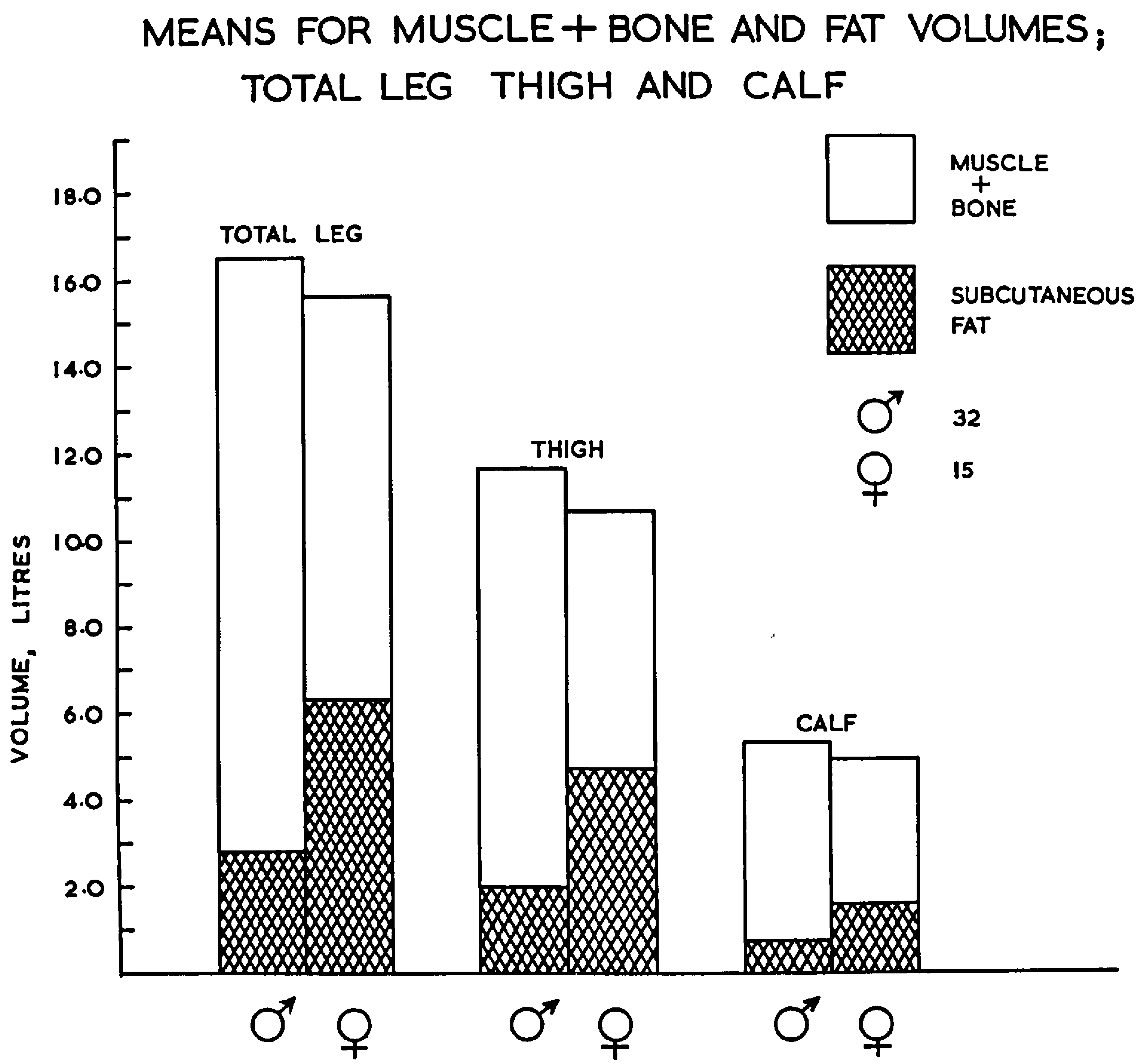


Fig. 11. Gross and tissue component volumes in the legs of male and female young adults.

17.2% and 43.7%, and in the calf, 14.8% and 31.8%, for men and women respectively. For the "lean mass" there is a reversal of the compartments, with the highest percentage appearing in the calf, 85.2% for men and 68.2% for women.

Discussion

From the results it appears that it is possible to use a mathematical model using anthropometric measurements in place of either the water displacement or, in the case of the subcutaneous fat, soft-tissue roentgenogrammetric techniques. However, when using the anthropometric technique certain reservations must be exercised:

1) It is recommended that subjects stand perfectly erect and hold on to a support when vertical measurements are being made with the anthropometer.

2) The anthropometer should be placed in a vertical holding device (Fig. 6) to prevent large discrepancies in the measurements, which would occur at the tip of the arm of the anthropometer should it move out of vertical alignment.

3) That appropriate regression equations are computed for age, site and sex to convert the "double" caliper skin-fold to a single measurement. Considerable significance is attached to this conversion factor. It is dealt with in considerable detail in the following chapter.

C H A P T E R IV

CHAPTER IV

COMPARISONS OF SKINFOLD CALIPER AND ROENTGENOGRAMMETRIC MEASUREMENTS OF SUBCUTANEOUS FAT.

Introduction

A number of research workers have compared the relationship between skinfold calipers and X-Ray measurements of subcutaneous fat made at the same site (Best and Kuhl, 1953; Hammond, 1955; Baker, 1955; Garn, 1956; Garn and Gorman, 1956; Clarke, Geser and Hunsdon, 1956; Brozek and Mori, 1958; Baker, Hunt and Sen, 1958; Tanner, Hughes and Jones, 1967; Jones and Pearson, 1969). It can be said in general that most of these authors have found coefficients of correlation of +0.8 - +0.9 between the two measurements.

Garn (1961) points out that the evidence of Baker, Hunt and Sen (1958, p. 47) showing that the elastic properties of the skinfold depend somewhat on the site chosen, age, and sex, is disturbing and rather upsets the idea that a simple conversion factor exists between skinfold and X-Ray measurements.

Prior to this statement by Baker and his colleagues, Garn and Gorman (1956) had published a paper comparing pinch caliper and X-Ray measurements of skin plus subcutaneous fat at the level of the lowest rib at the midaxillary line in young men aged 20-21 years. They showed that the differences between the caliper and X-Ray readings are large, the former being 65% of the double X-Ray value.

Because the caliper measurements are so called representative of a compressed "Double' fold, it is necessary to compare them with twice the value of the uncompressed mean radiographic value.

Garn also mentions that at present there are no adequate data to separate the effects of the factors of age, site and sex; it was with this remark in mind that we decided to analyse our own data and compare the differences between the sexes and the selected sites.

His results suggest that a simple conversion factor does exist and when the X-Ray values are multiplied by 1.3 they are in close agreement with the pinch caliper values. Also that it is likely that reduction of the true values by compression (300 g over 30 mm^2 area) is a constant 35%. Best and Kuhl (1953) reported two skinfold thicknesses (lateral and medial brachial skinfold) and compared them with the corresponding radiographic sites. The average lateral radiographic fat site was exactly 75% of the double skinfold thickness whilst the thinner medial site was the same as the caliper. These skinfold thicknesses were taken using the Medical Nutrition Laboratory Caliper, which has flat round measuring surfaces, 3.0 mm in diameter under a pressure of 200 g. The subjects in their experiment were men aged 22-39 years and the difference between the two observations was stated to be due to the compressibility of the skinfold.

Baker (1955) in a study on the relationship of desert heat stress to gross morphological change, took the mean of six sites, viz.: arm, forearm, leg, back, chest and waist, using a caliper described by Newman (1952), and calculated a regression equation between the caliper sites and X-Ray fat thickness equivalents. The coefficient of correlation between the two was 0.85 and the actual depth of fat was predicted from the skinfold reading:-

$$\text{Fat thickness} = 0.614 \times \text{skinfold} + 1.710 \pm 1.340.$$

Baker criticized some of his own earlier work which had shown that variable compression of the tissues had constituted the greatest source of error in his radiographic results. Therefore, in his later studies he overcame this by using a special limb support mounted on a cassette tunnel, which allows for changing the cassettes without disturbing the limb. However, with this apparatus he used an adjustable cassette height which in effect would give varying magnification (Tanner, 1962)(Fig. 32(a) and (b)). It should also be remembered that in the X-Ray technique the tube head (anode) was centred only 36 inches above the cassette holder, which means that the angle of divergence of the X-Ray beam is considerable, and this would produce an enlargement distortion error of approximately 12.5% (Fig. 38). In the paper there is no mention of any correction being made to the radiographic subcutaneous measurements.

Hammond (1955) gave mean caliper (Harpenden and Franzen) measurements for boys aged 2-18 years, a group of adult male factory workers, and girls aged 2-15 years, taken at six sites, which he stated were representative of the results obtained from many sites. He transformed his caliper results into terms of actual fat thickness as indicated by uncompressed fold thickness measured from X-Ray plates. Hammond showed that a similar relationship existed between the Franzen type caliper and X-Ray results as calculated from an accuracy trial in 1952, when a double transformation from Franzen to Harpenden and from Harpenden to X-Ray results was used. Therefore, his correlations between caliper and X-Ray of 0.82 for males and 0.89 for females for the anterior thigh site can be compared with the figures as quoted in this thesis (Table 4). His paper in 1955 (p. 207) shows a Figure (4) with the data from the biceps, triceps and anterior thigh all put together in the form of a scatter diagram from which he computed the regression equation:-

$$\text{Fat} = 0.95x - 0.0074x^2,$$

where x = caliper reading in 1/10th of a mm. He points out however, that the same relationship is produced irrespective of the site since the scatter is too great to distinguish any constant differences in the relationship according to site. Although not stated in the paper it has been established (Hammond, personal communication) that the large range of measurements is due to both males and females being included and, of course, the biceps measurement which is the smallest of the three contributes largely to the low values in the scatter. From his regression equation it appears that the conversion factor is 0.9 times the caliper value which means that his X-Ray value was 45.1% of the double skinfold thickness.

Harrison Clarke (1956) and two of his colleagues reported a low relationship of r = 0.79 between caliper measurements (make and pressure unspecified) and roentgenograms for the biceps site. He states that because of this low relationship between the two variables they should not be interchangeable. It may be that because the object film distance was not standardised and that an anode film distance of only 30" was used, this may account for the obviously large discrepancies between each of the paired values.

Brozek and Mori (1958) showed mean relative values of skinfolds equal to 84% of the radiographic values measured on the dorsal surface of the upper arm in men aged 52-62 years. It would appear useful for comparative purposes, only to look at data where calipers of standard pressure, i.e. 10 gm/mm^2, have been used in conjunction with radiographic measures of uncompressed subcutaneous tissue.

In this study the relationship of the skinfold caliper (Harpenden 10 gm/mm^2) values with the radiographic equivalent taken on the anterior and posterior thigh, medial and lateral calf in young men and women of varying age groups are compared and discussed.

Methods

The skinfolds were measured using a Harpenden Caliper (Edwards et al., 1955). These calipers have oblong shaped jaws with a surface area of 90 mm under constant pressure of 10 gm/mm^2.

Skinfolds were picked up between the thumb and first finger of the left hand, making certain that all underlying muscle was excluded from the double fold. The caliper jaws were applied approximately 1 cm. behind the tip of the finger and thumb and held in position for about 5 seconds before the reading was taken. Four sites were chosen in the leg; they were: the anterior and posterior thigh taken over the belly of the respective muscles in the mid-line at the one-third subischial level (Figs. 12 and 13), and the medial and lateral calf site in a vertical line from the medial malleolus to the medial tibial condyle and the lateral malleolus to the head of the fibula respectively. The level was at the maximum circumference of the calf (Figs. 14 and 15). All caliper measurements were made with the limb non-weight bearing and with the muscles completely relaxed. So as to avoid inter-observer errors, all the anthropometric measurements were taken by one experienced observer.

The roentgenogrammetric techniques and sites used are as outlined in Chapter V ("Methods", p. 93). Direct measurements were taken from the radiographs using a needle point dial reading caliper (Tanner & Whitehouse, 1955) which was calibrated before use, and could be read to the nearest 0.1 mm (Fig. 16). All values were reduced by a factor of 3.8% or 4.4% (according to the type of X-Ray used) because of magnification and distortion.

Results

1. <u>The relationship between X-Ray and caliper fat findings</u>

The mean values, standard deviations, percentage differences (expressed as a percentage of the true double X-Ray value), percentage

Fig. 12. Technique for taking skinfold measurements of the Anterior Thigh Site.

Fig. 13. Technique for taking skinfold measurements of the Posterior Thigh Site.

Fig. 14. Technique for taking skinfold measurements of the Medial Calf Site.

Fig. 15. Technique for taking skinfold measurements of the Lateral Calf Site.

Fig. 16. Technique for taking measurements from a radiograph using a special dial-reading needle point caliper, accurate to 0.1 mm.

due to compression and the ratio of the caliper to X-Ray for skinfold measurements at four leg sites for young men and women are presented in Table 3. The largest mean X-Ray fat value for men and women is seen in the posterior thigh site with values of 7.90 mm and 22.39 mm. For men and women the lateral calf site is the least affected by caliper compression and the ratio of caliper to X-Ray equivalent is very nearly 2:1. The sites most affected by compression are the anterior thigh for males - 24.7% - and the posterior thigh for women - 28.5%. On average the male sites show a higher percentage due to compression than do the females.

It can be seen from Figures 25 to 28 that the mean values on the regression lines for the females are considerably higher than those for the males, confirming that both the X-Ray and caliper fat thicknesses are highest in the female. When all male and female fat sites are combined and the mean values, on the best fit lines, are projected downwards to the abscissa and sideways to the ordinate, it can be demonstrated that for an identical caliper fat value for men and women, the equivalent X-Ray fat value would be lowest in the female group.

2. Comparison with data from other studies

Presented in Table 4 are the comparisons of data from this study with those from other studies showing the correlation, mean values and ratio between skinfold caliper and equivalent sites studied radiographically. It also gives information regarding the skinfold caliper pressure per mm of jaw surface area. Large dis-

TABLE 3.

MEANS AND STANDARD DEVIATIONS OF THE 4 SKINFOLD CALIPER AND ROENTGENOGRAMMETRIC MEASUREMENTS. THE PERCENTAGE OF THE RADIOGRAPHIC EQUIVALENT, % DUE TO COMPRESSION AND THE CONVERSION FACTOR CALIPER TO SINGLE X-RAY VALUE

Site	MALES					% of Radio. Double Width	% due to Compres-sion.	Ratio Caliper : X-Ray	FEMALES					% of Radio. Double Width	% due to Compres-sion.	Ratio Caliper : X-Ray
	N	CALIPER		X-RAY					N	CALIPER		X-RAY				
		x mm.	S.D.	x mm.	S.D.					x mm.	S.D.	x mm.	S.D.			
Anterior Thigh	46	9.52	3.81	6.32	2.29	75.3	24.7	1.51:1	16	29.61	7.29	16.14	3.59	91.7	8.3	1.84:1
Posterior Thigh	46	12.27	5.90	7.90	3.47	77.7	22.3	1.55:1	16	32.04	7.03	22.39	9.09	71.5	28.5	1.43:1
Medial Calf	46	5.71	2.12	4.04	1.34	70.7	29.3	1.41:1	16	17.17	5.74	9.29	2.61	92.4	7.6	1.85:1
Lateral Calf	46	6.39	2.22	3.42	1.06	93.4	6.6	1.87:1	16	15.68	4.20	7.56	1.88	103.7	-3.7	2.07:1
All 4 sites combined	184	8.48	4.62	5.42	2.87	78.2	21.8	1.56:1	64	23.63	9.50	13.85	7.77	85.3	14.7	1.71:1

TABLE 4. A COMPARISON OF DATA FROM VARIOUS STUDIES AND AUTHORS SHOWING THE RELATIONSHIP BETWEEN SKINFOLD CALIPERS AND X-RAY MEASUREMENTS TAKEN AT THE SAME SITE, FROM DIFFERENT ASPECTS OF THE BODY.

Author	Site	n	Sex	Caliper pressure	Caliper x mm.	X-Ray x mm.	r	% of X-Ray Double fold	% due to Compression	Ratio
Garn & Gorman (1956)	Midaxillary	65	M	$10 gm/mm^2$	12.0	9.3	0.88	64.5	35.5	1.3 : 1
Brozek & Mori (1958)	Dorsum Upper Arm	126	M	$10 gm/mm^2$	13.0	7.9	0.82	82.3	17.7	1.6 : 1
Baker (1955)	Dorsum Upper Arm	83	M	$6.7 gm/mm^2$	13.7	9.2*	0.85	74.5	25.5	1.5 : 1
Hammond (1955)	Biceps				3.2	2.9	0.83	55.2	44.8	1.1 : 1
	Triceps	228	M	$10 gm/mm^2$	6.1	5.5	0.89	55.5	44.5	1.1 : 1
	Ant. Thigh				-	-	0.82	-	-	-
Hughes, Tanner and Jones (1966) (Unpublished data)	Biceps	29	M		4.6	3.9	0.88	59.5	40.5	1.2 : 1
	Biceps	23	F	$10 gm/mm^2$	8.1	8.4	0.93	48.1	51.9	0.96: 1
	Triceps	29	M		9.6	7.0	0.83	68.7	31.3	1.4 : 1
	Triceps	23	F		17.5	14.2	0.92	62.3	37.7	1.3 : 1
Jones (1970).(For other sites see Table 3)	Ant. Thigh	46	M	$10 gm/mm^2$	9.5	6.3	0.93	75.3	24.7	1.5 : 1
Best & Kuhl (1953)**	Lateral Upper Arm	22	M	$28 gm/mm^2$	9.2	6.7	0.81	68.5	31.5	1.5 : 1
	Medial Upper Arm				3.6	3.7	0.54	47.9	52.1	0.97: 1
Clarke, Geser and Hunsdon (1956)	Upper Arm (Σ Biceps, triceps Medial & Lateral)	30	M	Not stated	-	-	0.79	-	-	-

*Predicted from regression equation.

**Calculated from the raw data.

crepancies can be seen between the values in the studies, when calipers of different pressures are used on the same sites (see data from Table 4, Brozek and Mori, compared with Baker and with Best and Kuhl). There are also discrepancies in the studies between the percentages due to compression using the same caliper pressure.

Coefficients of correlation show how close two variables relate throughout a range of observations. The nearer r is to 1.0, the more significant is the correlation. The probability, p value, indicates the frequency at which correlations of this magnitude will occur, in relation to the sample size n, on the basis of chance alone. Thus, $p < 0.001$ indicates that a particular correlation of a given magnitude or greater would occur less than once in a thousand times by chance, under the hypothesis that the population correlation coefficient is zero. It is generally accepted that p values of < 0.01 are highly significant. However, the correlation coefficient can be a misleading statistic. Unless the correlation coefficient is 1.00 some variation will exist about the best fit straight line relating the two variables. This variability can be specified conveniently in two ways: (a) the coefficient of variation $(\frac{\text{S.E. of estimate}}{\text{Mean y variable}} \times 100)$ gives the proportion of the variation of the y estimate about the regression line, and (b) the standard error of the estimate (s.d. about the line) measures the scatter of the observed points about the line of best fit. Both of these statistics are shown in Table 5.

TABLE 5. LINEAR REGRESSION EQUATIONS ($\hat{y} = a + bx$) RELATING FOUR UNCOMPRESSED ROENTGENOGRAMMETRIC VALUES ($\hat{y}$) TO EQUIVALENT SKINFOLD CALIPER MEASUREMENTS (x)

Subcutaneous Fat Site	Sex	N	r	p	Regression Equations $y = a + bx$			
					(a) intercept	S.E. of estimate mm.	(b) Regn. Coeff.	Coeff. of Var. %
Anterior Thigh	M	46	0.93	<0.001	1.01419	0.86	0.55696	± 13.63
	F	16	0.83	<0.001	4.08859	2.08	0.40689	± 12.91
Posterior Thigh	M	46	0.90	<0.001	1.36874	1.50	0.53231	± 19.00
	F	16	0.77	<0.001	-9.40519	6.04	0.99236	± 26.95
Medial Calf	M	97	0.87	<0.001	0.98517	0.76	0.49945	± 17.40
	F	61	0.89	<0.001	1.27296	1.30	0.47684	± 13.60
	M & F	158	0.95	<0.001	1.07448	0.99	0.48750	± 15.47
Lateral Calf	M	70	0.82	<0.001	0.87011	0.62	0.39259	± 17.82
	F	38	0.80	<0.001	2.09455	0.91	0.33943	± 12.96
All 4 sites combined	M	259	0.91	<0.001	0.40936	1.06	0.57202	± 20.76
	F	131	0.88	<0.001	-2.13699	2.98	0.67215	± 26.64

3. <u>The correlation and linear regression, X-Ray vs. Caliper.</u>

It can be observed in Table 5 that the coefficients of correlation between the radiographic fat widths and the equivalent caliper sites for the four areas in the leg are all highly significant, $p < 0.001$. The r values range from 0.82 to 0.93 for the males and from 0.77 to 0.89 for the females. The male lateral calf and female posterior thigh sites are responsible for the lowest r values. The male anterior thigh and female medial calf sites give the highest r values. The mean r values when all four sites are combined are $r = 0.91$ and 0.88, for males and females respectively. Table 5 also gives the linear regression equations for the four leg sites for men and women. It can be seen that considerable differences exist between the intercepts (elevation of the line) and the regression coefficients (slope of the lines) when inter-site and sex comparisons are made. Therefore, it was felt appropriate to examine statistically, by covariance analysis, (a) the differences between each fat site within the male and female samples, and (b) the differences between the sexes for each site. Furthermore, the subjects of a given sex who made up the total number for each site were drawn from different geographical locations and occupations. Therefore, the first covariance analysis was to test the regression lines for each sub-sample within a sex to see if there was a homogeneous sample.

4. <u>Variations within the sub-group samples.</u>

Linear regressions equations relating X-Ray to caliper measurements of fat at four sites for male and female sub-groups are shown in Table 6 .

a) Anterior thigh site

The best fit straight lines (regression lines) for measurements on the anterior thigh for two male sub-groups are graphically illustrated in Fig. 17. Similar data for the single female group are shown in Figure 18. The appropriate analysis of covariance and variance appears as Table 7 (a) and (b) respectively. The former shows that there is a non-significant difference ($F = 0.10$, $p > 0.05$) between the slopes for the two male sub-groups, i.e. there is no difference between the two regression coefficients. Also the slope of the regression line through the sub-group means is the same as the average slope of the lines for the two sub-groups ($F = 3.68$, $p > 0.05$). This implies that the intercepts for the two sub-group lines are not significantly different from one another. Therefore, it is justifiable to combine the two groups and fit an overall regression line (Table 5). Its slope is significantly ($F = 272.90$, $p < 0.001$) different from zero.

Only one group - 16 female students from a College of Education - is represented for the anterior thigh site. They appear in Figure 18. In the analysis of variance, Table 7 (b), which relates to these data, the overall line is significantly ($F = 30.41$, $p < 0.001$) different from zero.

b) Posterior thigh site

For the two male posterior thigh sub-groups (Figure 19), the regression coefficients are not significantly different ($F = 1.62$, $p > 0.05$) from each other (Table 8a), but the slope of the line through the two sub-group means is not the same as the mean slope of the two regression lines ($F = 6.83$, $0.01 < p < 0.05$). However, it can be seen from Table 6 that the two intercepts are not too dissimilar. Furthermore, since the proportion of the variation of the y estimate about the regression is about $\pm$ 19% for both groups with S.E.'s of $\pm$ 1.39 and $\pm$ 1.42 mm, we may be justified in combining the data into a single regression line (Table 5) which has a significant slope ($F = 196.90$, $p < 0.001$) different from zero.

The posterior thigh data for a single female group appear in Figure 20. The analysis of variance is given in Table 8 (b), from which it will be seen that the overall slope is highly significant ($F = 20.04$, $p < 0.001$) and is not different from zero.

c) Medial calf site

Figures 21 and 22 show regression lines of best fit for four and three sub-groups for men and women respectively for the medial calf fat site. For both sexes, there are no significant differences ($F = 0.43$ and 0.34, $p > 0.05$) between the regression coefficients for sub-groups. Table 9 (a) shows that the male sub-group means vary significantly ($F = 15.90$, $p < 0.001$) about their own regression line, therefore a best fit straight line through all the data is not justifiable.

In the female data (Table 9b) there are no significant differences ($F = 0.02$, $p > 0.05$) between the deviations of the sub-group means about their regression lines. There are also no significant differences ($F = 0.02$, $p > 0.05$) between the deviations of the group mean about their own regression line. However, the slope of the line through the three sub-group means is not the same as the slopes of the three regression lines ($F = 17.64$, $p < 0.001$), indicating that the intercepts differ; therefore, an overall line should not be fitted.

From Table 6 and Figure 21, it can be seen that because the regression coefficients for the male group are similar ($F = 0.43$) the four best fit lines are more or less parallel to one another but they are considerably spread apart by differing intercepts. The S.E. of the estimates for this group range from 0.42 mm to 0.76 mm, which in terms of measuring is very small; therefore, there may be justification in fitting an overall regression line. When this is done the line is significantly different ($F = 307.30$, $p < 0.001$) from zero, S.E. about the line $\pm$ 0.76 mm.

The situation is similar for the female medial calf sub-groups where the slopes appear parallel to one another. Their means fall on a straight line, yet their regression through the means do not follow these lines very well. Table 5 shows that if an overall regression line is fitted the S.E. of the estimate is 1.30 mm. The S.E. of the estimate for the sub-groups range from 0.71 to 1.44, which shows the upper range outside of the overall estimate of 0.14 mm. On this evidence there may be justification for combining the groups.

TABLE 6. LINEAR REGRESSION EQUATIONS OF X-RAY FAT WIDTHS (y) ON HARPENDEN CALIPER READINGS (x) FROM 4 DIFFERENT LEG SITES IN YOUNG MALE AND FEMALE ADULTS.

	MALES		FEMALES	
<u>Anterior Thigh</u>				
Group 2: Jan. 1968	$y = 1.217 + 0.552x$	S.E. = 0.79	$y = 4.088 + 0.407x$	S.E. = 2.08
Group 3: Nov. 1968	$y = 0.928 + 0.526x$	S.E. = 0.97	---	
<u>Posterior Thigh</u>				
Group 2: Jan. 1968	$y = 0.948 + 0.598x$	S.E. = 1.39	$y = -9.405 + 0.992x$	S.E. = 6.04
Group 3: Nov. 1968	$y = 0.918 + 0.505x$	S.E. = 1.42	---	
<u>Medial Calf</u>				
Group 1: May 1966	$y = 0.767 + 0.561x$	S.E. = 0.65	$y = 1.593 + 0.499x$	S.E. = 1.44
Group 2: Jan. 1968	$y = 1.245 + 0.518x$	S.E. = 0.76	$y = 2.318 + 0.406x$	S.E. = 1.21
Group 3: Nov. 1968	$y = 0.320 + 0.584x$	S.E. = 0.42	---	
Group 4: Jan. 1970	$y = 0.249 + 0.503x$	S.E. = 0.48	$y = 1.179 + 0.444x$	S.E. = 0.71
<u>Lateral Calf</u>				
Group 2: Jan. 1968	$y = 1.231 + 0.350x$	S.E. = 0.76	$y = 1.965 + 0.357x$	S.E. = 1.17
Group 3: Nov. 1968	$y = 0.510 + 0.437x$	S.E. = 0.45	---	
Group 4: Jan. 1970	$y = 0.268 + 0.466x$	S.E. = 0.46	$y = 2.704 + 0.287x$	S.E. = 0.69

S.E. = $\pm$ Standard error of the estimate about the regression line (mm)

Fig. 17. REGRESSION LINES FOR AN INDIVIDUAL LEG SITE IN YOUNG MALES FROM DIFFERENT POPULATION SAMPLES

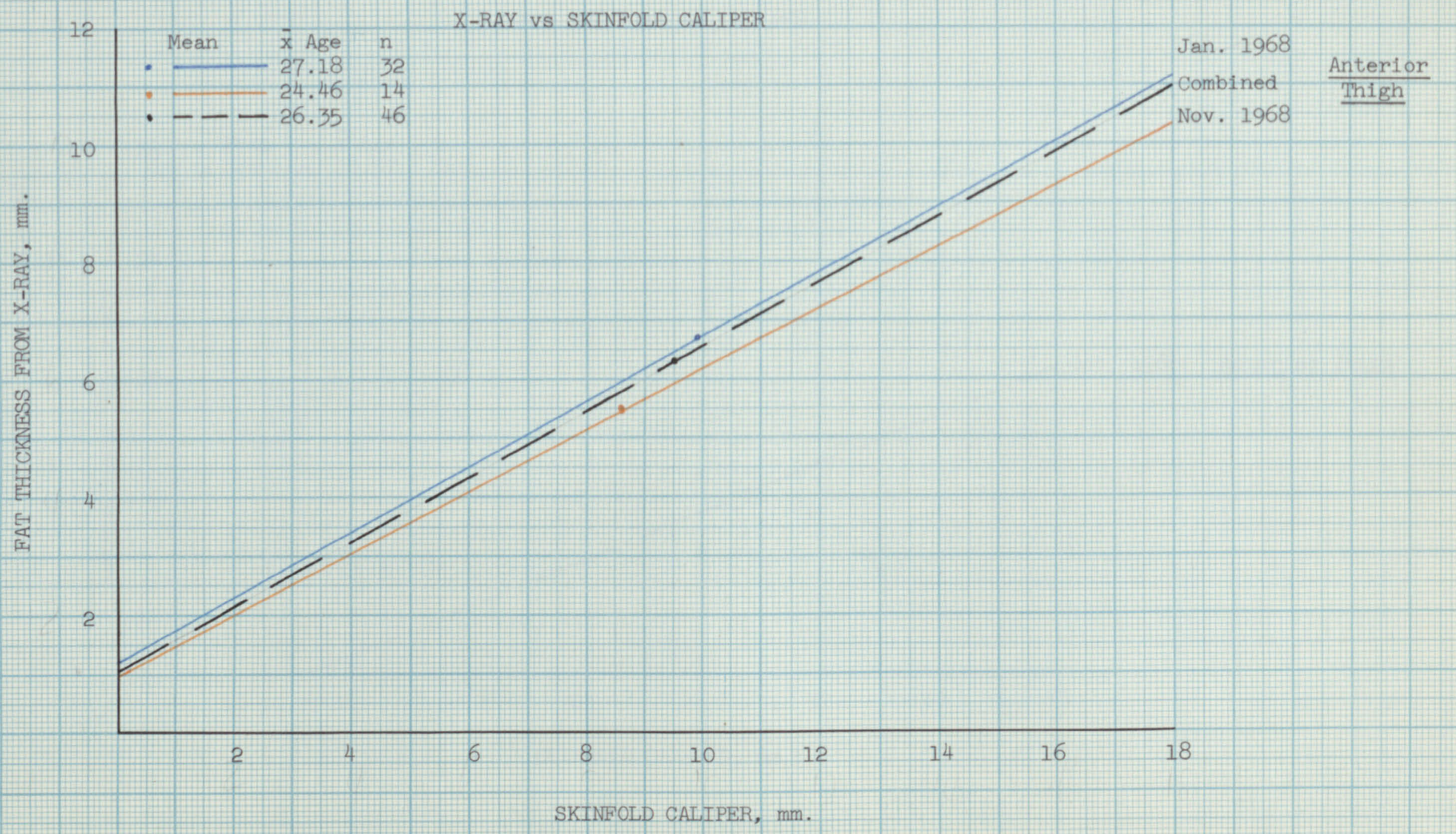


Fig. 18. REGRESSION LINE FOR AN INDIVIDUAL LEG SITE IN YOUNG FEMALES FROM DIFFERENT POPULATION SAMPLES

X-RAY vs SKINFOLD CALIPER

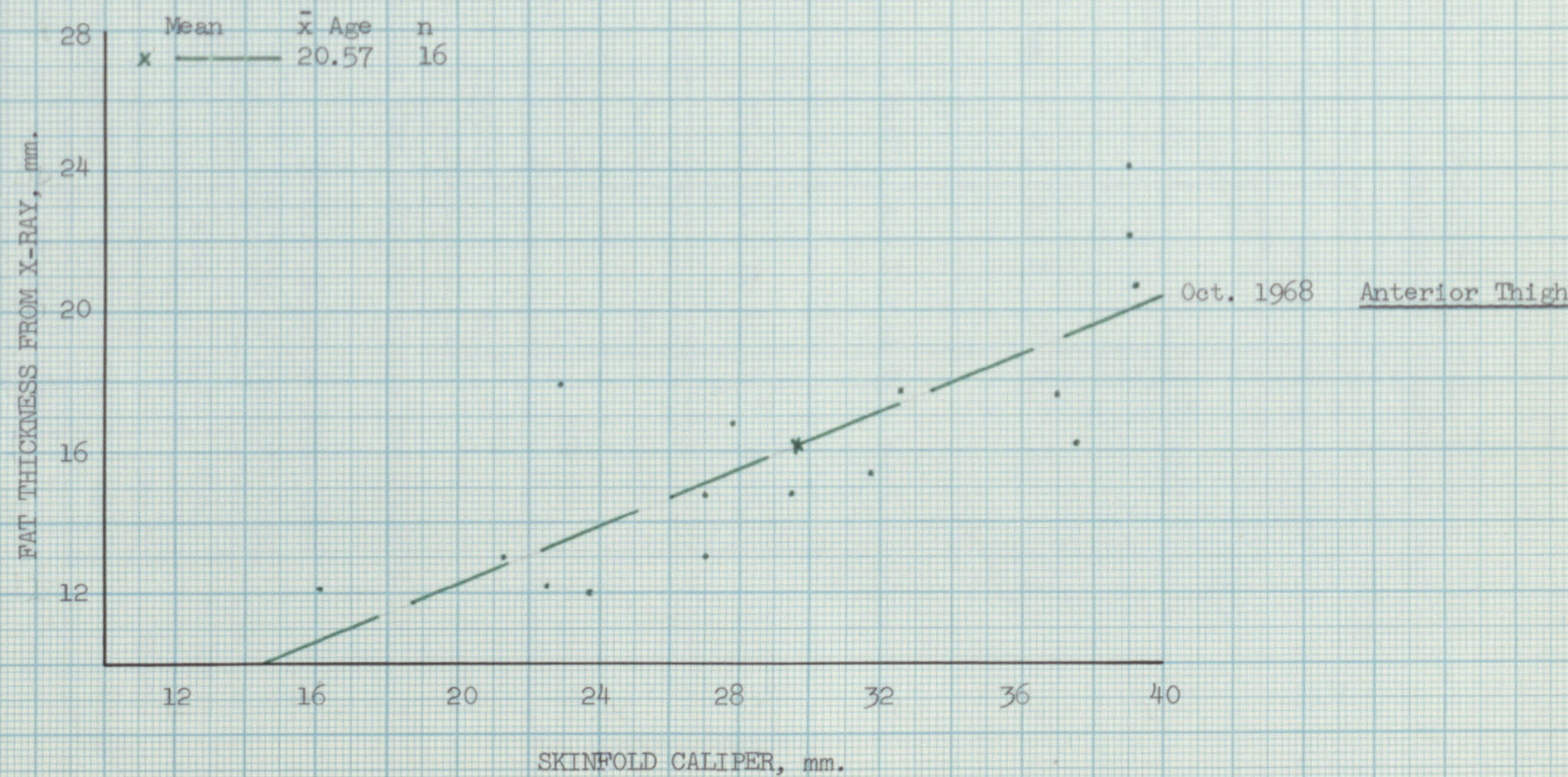


TABLE 7(a). SUB-GROUPS FOR MALE ANTERIOR THIGH

ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.		M.sq. = $\frac{s.sq.}{d.f.}$		F. Ratio		Significance
(c) Average within slope vs. slope of means ($\bar{b} - \hat{b}$).	2.61		1	S_4^2	2.61	$\frac{S_4^2}{S_1^2}$	3.68	N.S.
(d) *Dev. of gp means about own reg. line	-	k - 2	0	S_3^2	-	$\frac{S_3^2}{S_1^2}$	-	
(b) Between individual slopes	0.07	k - 1	1	S_2^2	0.07	$\frac{S_2^2}{S_1^2}$	0.10	N.S.
(e) About individual lines	29.93	n - 2k	42	S_1^2	0.71	-		
Dev. about overall line	32.62		44		0.74			
(a) Due to overall line	202.40		1		202.40		272.90	$p < 0.001$
Total Variation y	235.02		45					

*(d) vanishes when only two groups are present.

TABLE 7(b). FEMALE ANTERIOR THIGH GROUP

ANALYSIS OF VARIANCE TABLE

Source of Variation	s.sq.	d.f.	M.sq.	F. Ratio	Significance
Attributable to regression	132.02	1	132.02	30.41	$p < 0.001$
Deviation from regression	60.79	14	4.34		
Total	192.82	15			

Fig. 19. REGRESSION LINES FOR AN INDIVIDUAL LEG SITE IN YOUNG MALES FROM DIFFERENT POPULATION SAMPLES

X-RAY vs SKINFOLD CALIPER

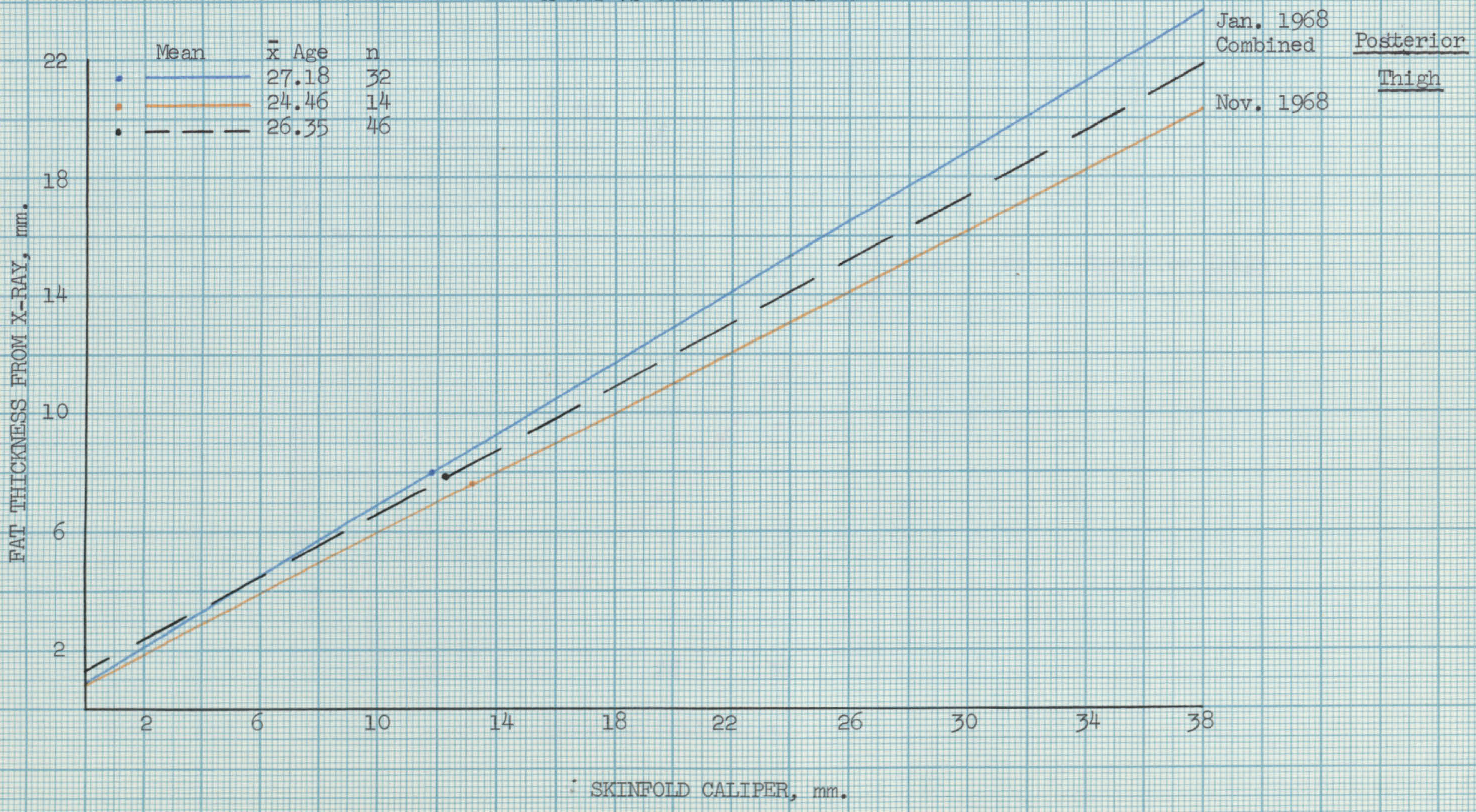


Fig. 20. REGRESSION LINE FOR AN INDIVIDUAL LEG SITE IN YOUNG FEMALES FROM DIFFERENT POPULATION SAMPLES

X-RAY vs SKINFOLD CALIPER

TABLE 8(a). SUB-GROUPS FOR MALE POSTERIOR THIGH
ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.	M.sq.	F. Ratio	Significance
(c)	13.41	1	13.41	6.83	$0.01 < p < 0.05$
(d)	-	0	-	-	
(b)	3.19	1	3.19	1.62	N.S.
(e)	82.49	42	1.96	-	
Deviation about overall line	99.09	44	2.25		
(a)	443.36	1	443.36	196.90	$p < 0.001$
Total variation y	542.35	45			

TABLE 8(b). FEMALE POSTERIOR THIGH GROUP
ANALYSIS OF VARIANCE TABLE

Source of Variation	s.sq.	d.f.	M.sq.	F. Ratio	Significance
Attributable to regression	730.21	1	730.21	20.04	$p < 0.001$
Deviation from regression	510.06	14	36.43		
Total	1240.27	15			

Fig. 21. REGRESSION LINES FOR AN INDIVIDUAL LEG SITE IN YOUNG MALES FROM DIFFERENT POPULATION SAMPLES

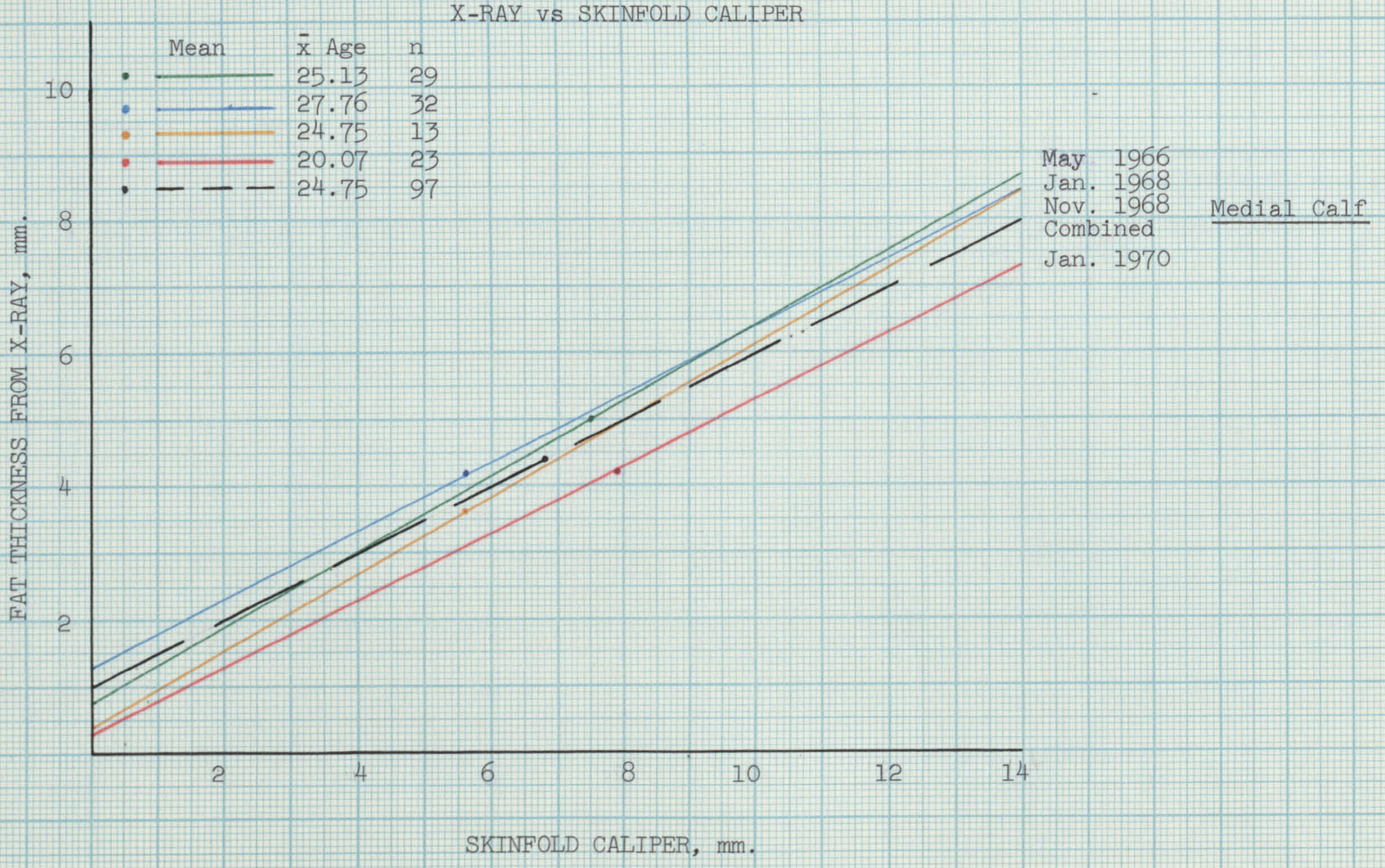


Fig. 22. REGRESSION LINES FOR AN INDIVIDUAL LEG SITE IN YOUNG FEMALES FROM DIFFERENT POPULATION SAMPLES

X-RAY vs SKINFOLD CALIPER

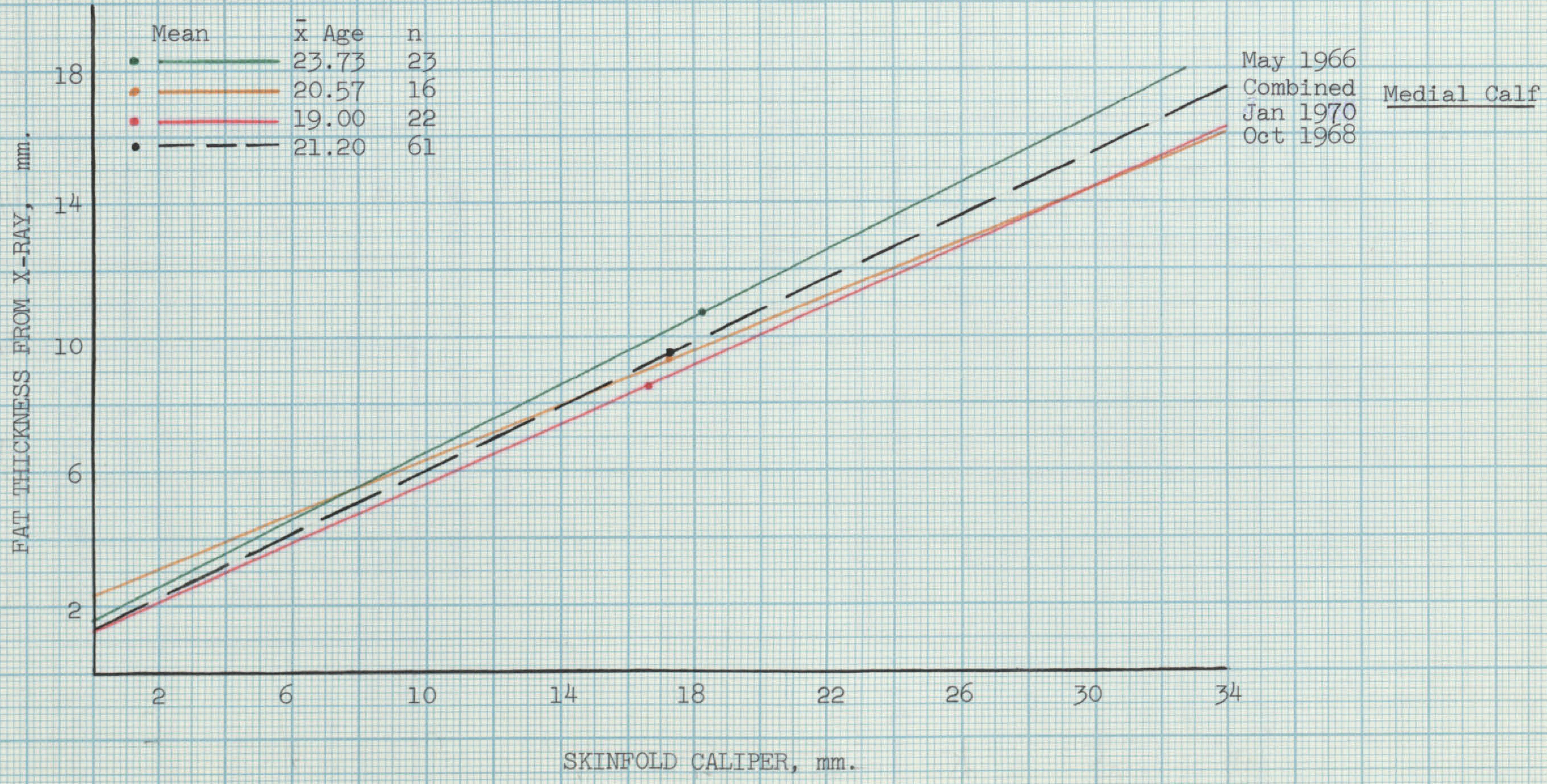


TABLE 9(a). SUB-GROUPS FOR MALE MEDIAL CALF ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.	M.sq.	F. Ratio	Significance
(a)	6.03	1	6.03	15.12	p <0.001
(d)	12.67	2	6.34	15.90	p <0.001
(b)	0.52	3	0.17	0.43	N.S.
(e)	35.48	89	0.40	-	
Deviation about overall line	54.70	95	0.58		
(a)	176.93	1	176.93	307.30	p<0.001
Total variation y	231.63	96			

TABLE 9 (b). SUB-GROUP FOR FEMALE MEDIAL CALF ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.	M.sq.	F. Ratio	Significance
(c)	23.90	1	23.90	17.64	p <0.001
(d)	0.03	1	0.03	0.02	N.S.
(b)	0.93	2	0.47	0.34	N.S.
(e)	74.54	55	1.36	-	
Deviation about overall line	99.41	59	1.68		
(a)	367.73	1	367.73	218.24	p< 0.001
Total variation y	467.14	60			

Fig. 23. REGRESSION LINES FOR AN INDIVIDUAL LEG SITE IN YOUNG MALES FROM DIFFERENT POPULATION SAMPLES

X-RAY vs SKINFOLD CALIPER

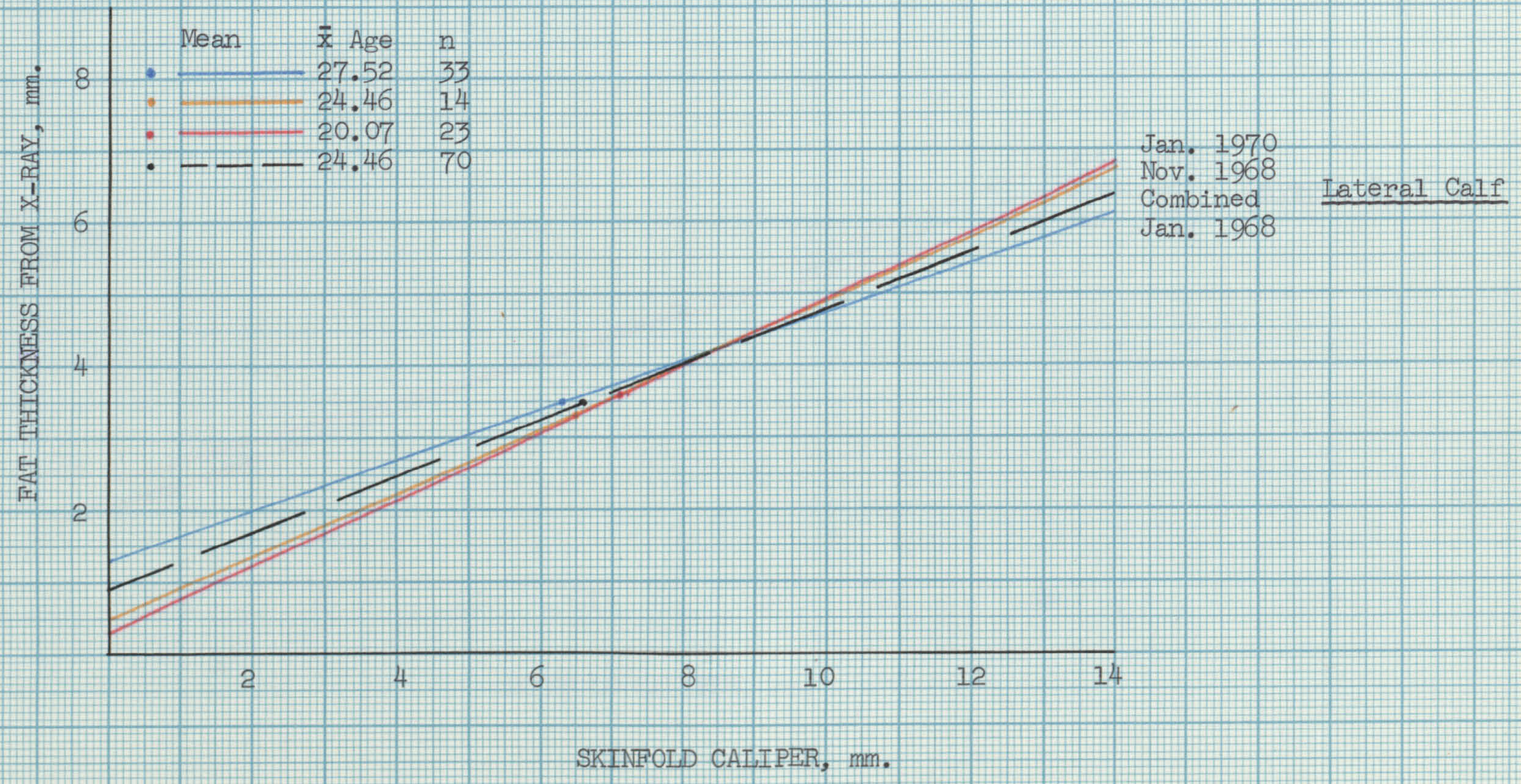


Fig. 24. REGRESSION LINES FOR AN INDIVIDUAL LEG SITE IN YOUNG FEMALES FROM DIFFERENT POPULATION SAMPLES

X-RAY vs SKINFOLD CALIPER

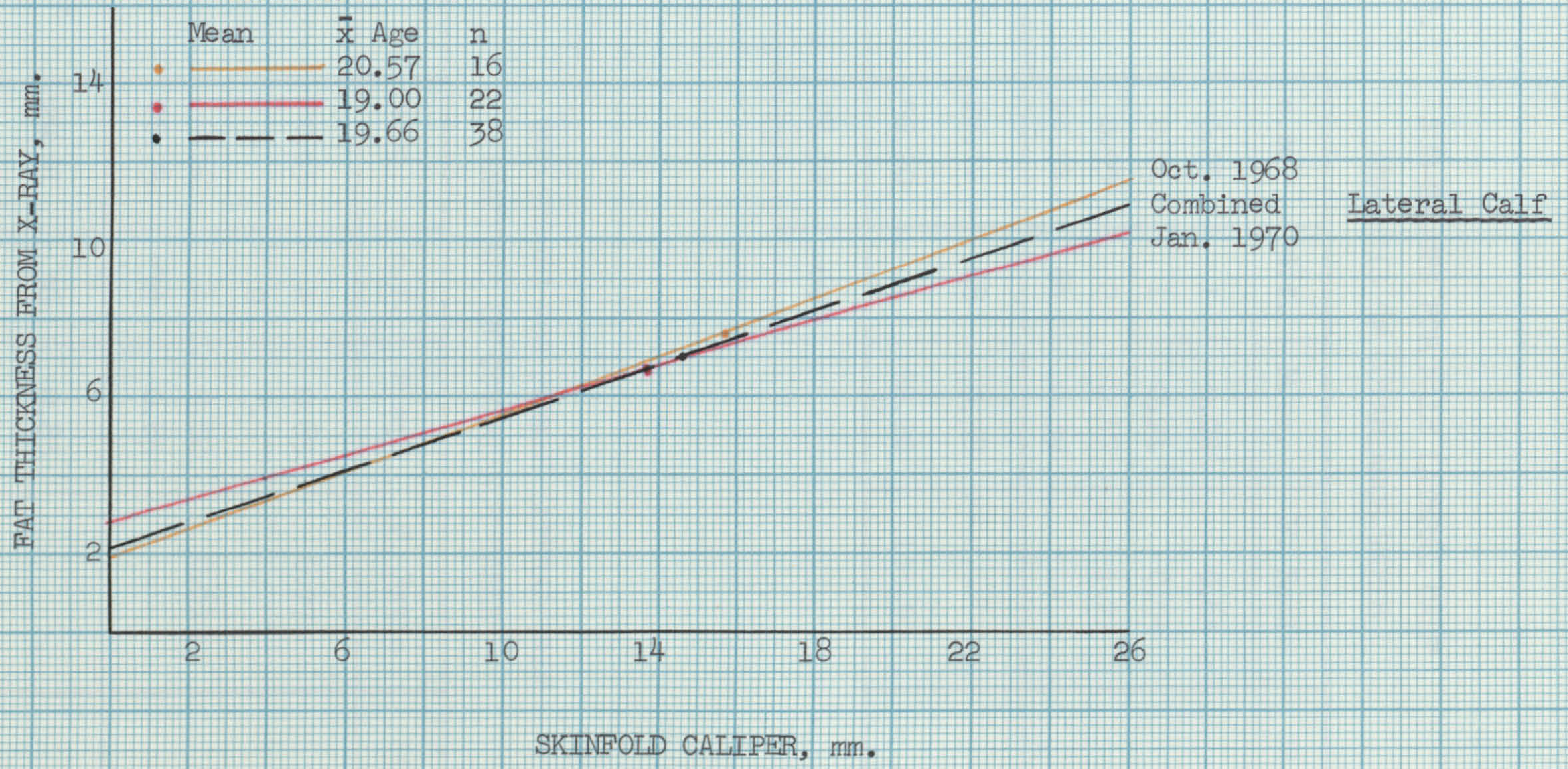


TABLE 10 (a). SUB-GROUPS FOR MALE LATERAL CALF ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.	M.sq.	F. Ratio	Significance
(c)	0.25	1	0.25	0.64	N.S.
(d)	0.21	1	0.21	0.54	N.S.
(b)	0.93	2	0.47	1.21	N.S.
(e)	24.74	64	0.39	-	
Deviation about overall line	26.12	68	0.38		
(a)	52.20	1	52.20	135.90	p <0.001
Total variation y	78.32	69			

TABLE 10 (b). SUB-GROUPS FOR FEMALE LATERAL CALF ANALYSIS OF COVARIANCE TABLE.

Source	s.sq.	d.f.	M.sq.	F. Ratio	Significance
(c)	0.65	1	0.65	0.77	N.S.
(d)	-	0	-	-	
(b)	0.52	1	0.52	0.61	N.S.
(e)	28.75	34	0.85	-	
Deviation about overall line	29.91	36	0.83		
(a)	54.95	1	54.95	66.14	p < 0.001
Total variation y	84.86	37			

d) Lateral calf site

The best fit straight lines for the male and female sub-groups lateral calf fat data appear in Figures 23 and 24. Table 10(a) and (b) show that there are no sources of variance which are significant ($p > 0.05$) except those associated with overall lines. Therefore, an overall regression line can be fitted to each male and female group. The slopes of both these regression lines are significantly different ($F = 135.90$, $p < 0.001$ and $F = 66.14$, $p < 0.001$) from zero.

5. <u>The comparison between males and females for the individual fat sites.</u>

a) Anterior thigh site

Figure 25 shows the best fit lines through the male and female data for the anterior thigh fat site. Table 11 shows that there is a significant difference ($F = 5.02$, $0.01 < p < 0.05$) between the individual slopes, indicating that there is justification for fitting separate regression lines for each of the male and female groups.

b) Posterior thigh site

For the best fit lines in this region (Figure 26), it can be seen that there is a marked divergence between the male and female regression lines, and, as expected, there is a significant difference ($F = 10.14$, $0.001 < p < 0.01$, Table 12). Accordingly, separate regression equations must be applied for the male and female posterior thigh fat site.

c) Medial calf site

Figure 27 shows the best fit regression lines for the male and female groups for the medial calf fat site. Table 13 shows that there is no source of variance which is significant ($p > 0.05$), except that due to the overall line. Therefore, it is justifiable to combine the sexes for this site and use a single regression line $y = 0.488 + 1.074x$ S.E. = 0.99 which is significantly different ($F = 1565.37$, $p < 0.001$) from zero.

d) Lateral calf site

In this region the male and female best fit lines (Figure 28) have slopes which do not differ significantly ($p > 0.05$) from one another. However, the slope of the line through the male and female groups means is not the same as the slopes of their regression lines ($F = 7.48$, $0.001 < p < 0.01$, Table 14). This indicates (as can be seen in Table 5) that although the regression coefficients are not different from one another there are large discrepancies between the intercept values. Therefore, regression equations must be used which discriminate between the sexes for this site.

6. <u>The four leg sites of the total sample, considered separately and as one group</u>.

Presented in Figures 29 and 30 are 4 regression best fit lines for each of the male and female groups, representing the total population sample for the anterior and posterior thigh, medial and lateral calf fat sites. In the male group the 4 lines do not have the same slopes ($F = 2.68$, $0.01 < p < 0.05$) and there are highly

Fig. 25. REGRESSION LINES FOR AN INDIVIDUAL LEG SITE IN YOUNG MALES AND FEMALES X-RAY vs SKINFOLD CALIPER

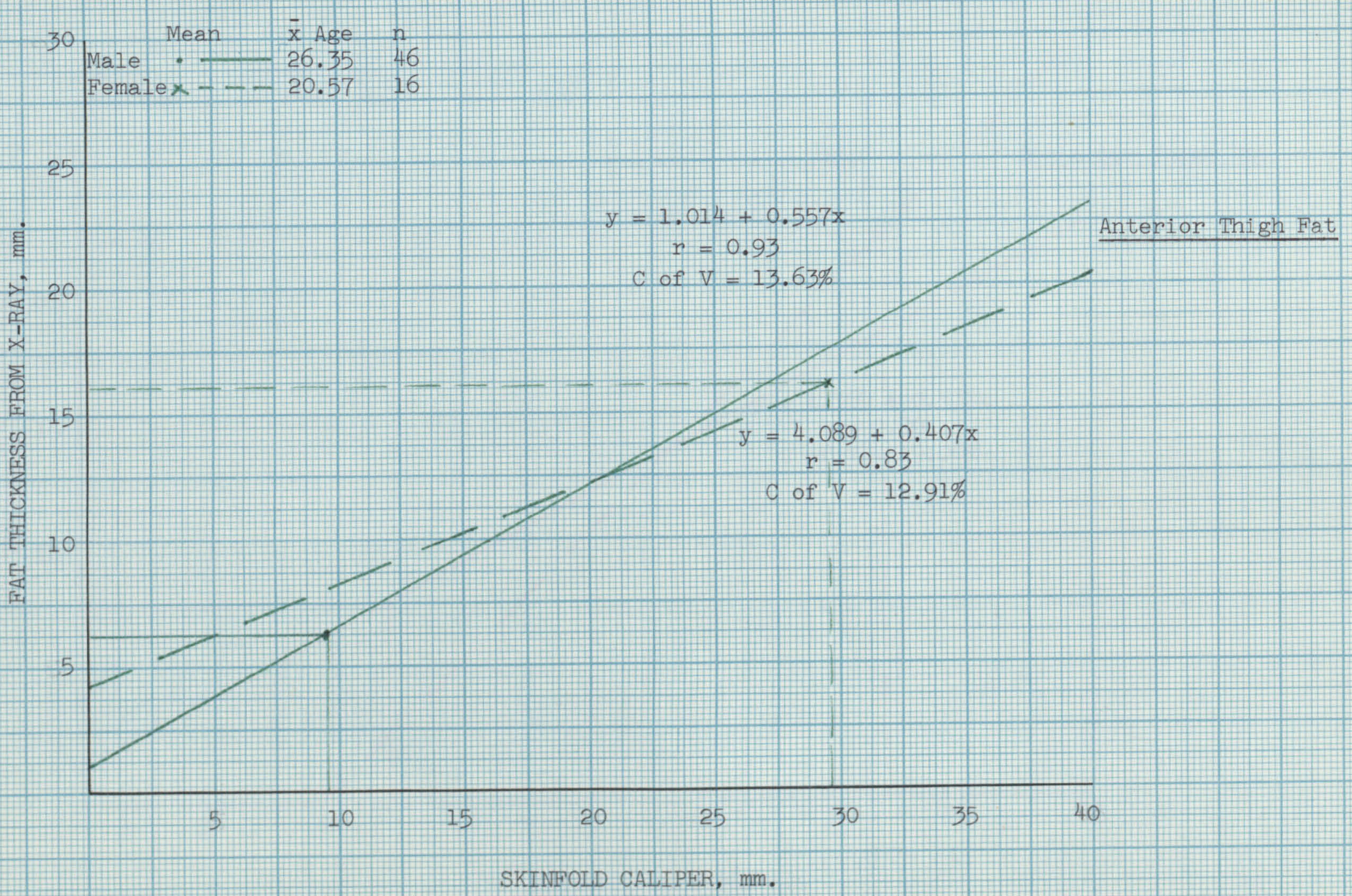


Fig. 26. REGRESSION LINES FOR AN INDIVIDUAL LEG SITE IN YOUNG MALES & FEMALES

X-RAY vs SKINFOLD CALIPER

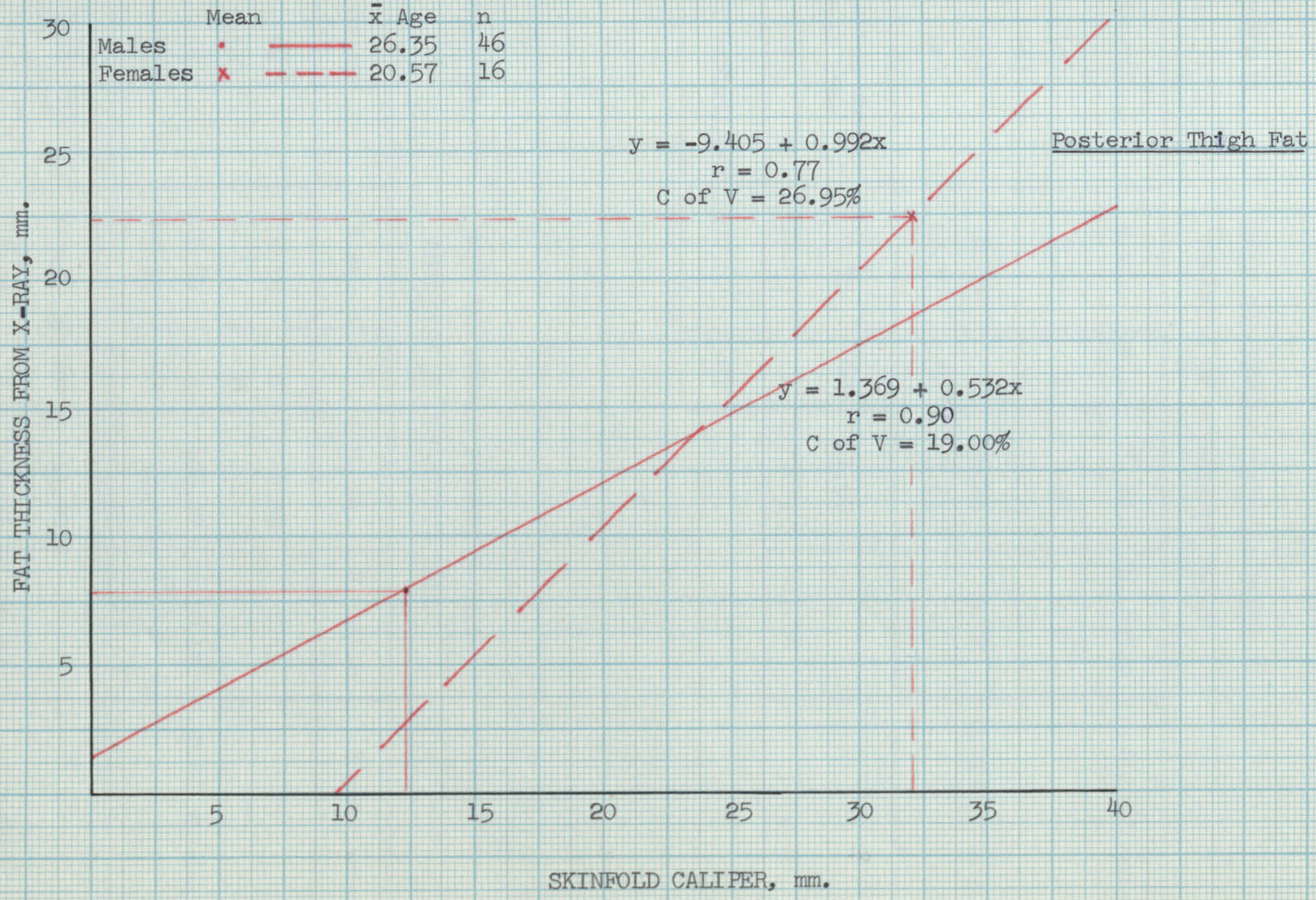


TABLE 11. MALE AND FEMALE ANTERIOR THIGH ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.	M. sq.	F. Ratio	Significance
(c)	0.29	1	0.29	0.18	
(d)	-	0	-	-	
(b)	8.08	1	8.08	5.02	$0.01 < p < 0.05$
(e)	93.37	58	1.61	-	
Deviation about overall line	101.73	60	1.69		
(a)	1470.89	1	1470.89	867.54	$p < 0.001$
Total variation y	1572.62	61			

TABLE 12. MALE AND FEMALE POSTERIOR THIGH ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.	M. sq.	F. Ratio	Significance
(c)	4.29	1	4.29	0.41	
(d)	-	0	-	-	
(b)	106.47	1	106.47	10.14	$0.001 < p < 0.01$
(e)	609.15	58	10.50	-	
Deviation about overall line	719.91	60	11.99		
(a)	3556.54	1	3556.54	296.42	$p < 0.001$
Total variation y	4276.45	61			

Fig. 27. REGRESSION LINES FOR AN INDIVIDUAL LEG SITE IN YOUNG MALES AND FEMALES

X-RAY vs SKINFOLD CALIPER

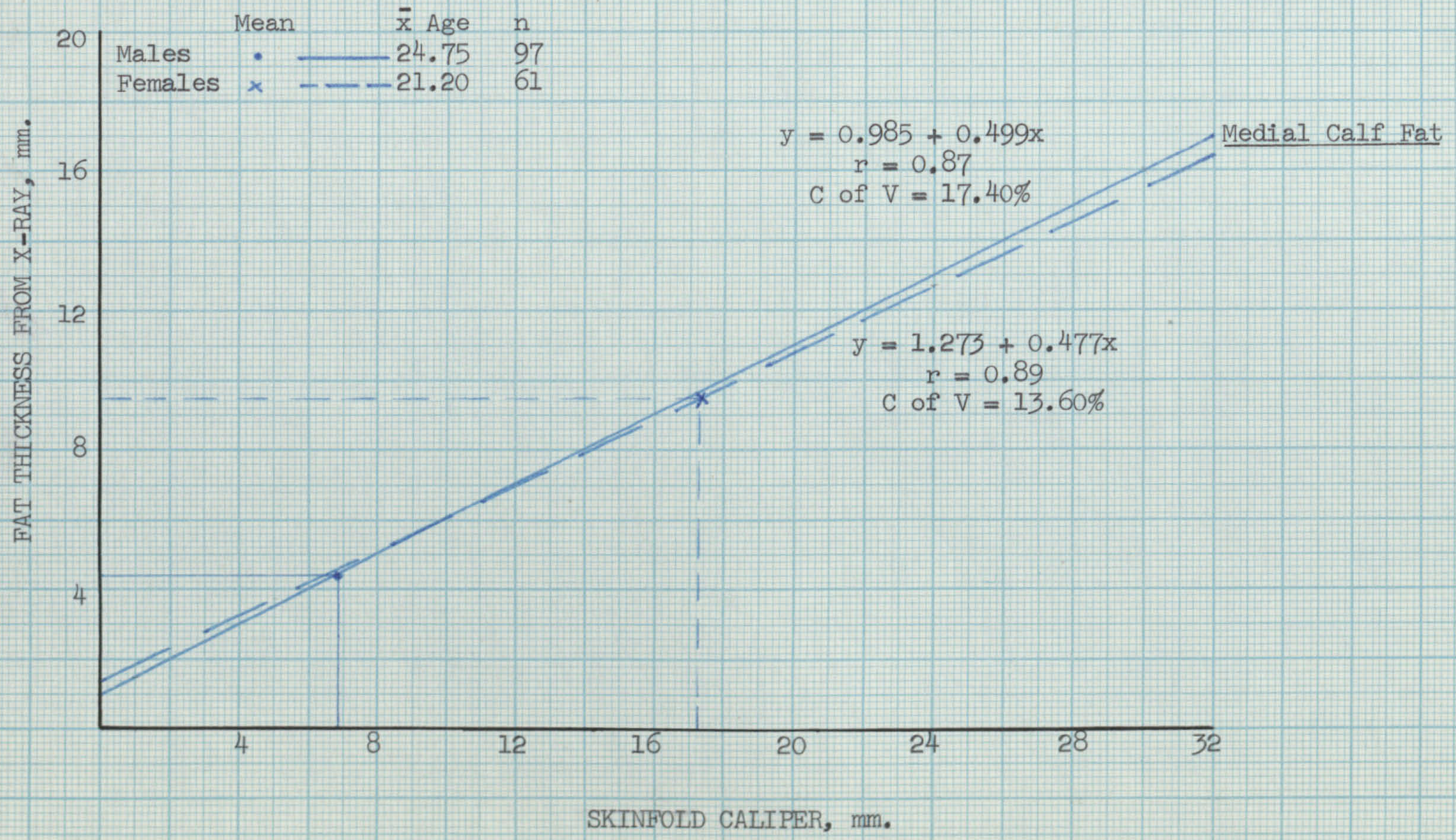


Fig. 28. REGRESSION LINES FOR AN INDIVIDUAL LEG SITE IN YOUNG MALES AND FEMALES

X-RAY vs SKINFOLD CALIPER

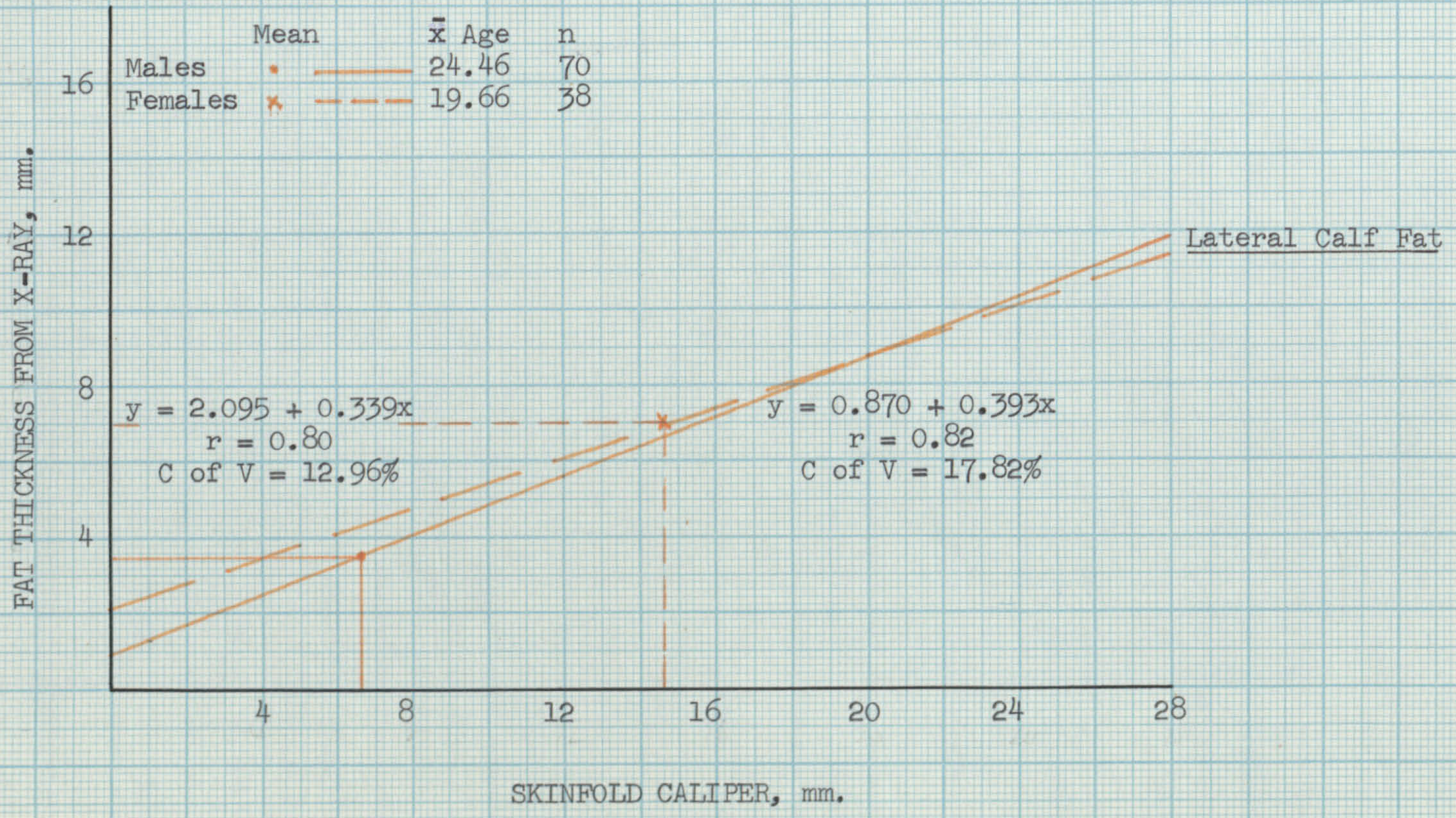


TABLE 13. MALE AND FEMALE MEDIAL CALF
ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.	M. sq.	F. Ratio	Significance
(c)	0.05	1	0.05	0.05	N.S.
(d)	-	0	-	-	
(b)	0.24	1	0.24	0.24	N.S.
(e)	154.12	154	1.00	-	
Deviation about overall line	154.42	156	0.99		
(a)	1549.51	1	1549.51	1565.37	$p < 0.001$
Total variation y	1703.93	157			

TABLE 14. MALE AND FEMALE LATERAL CALF
ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.	M. sq.	F. Ratio	Significance
(c)	4.03	1	4.03	7.48	$0.001 < p < 0.01$
(d)	-	0	-	-	
(b)	0.71	1	0.71	1.32	N.S.
(e)	56.01	104	0.54	-	
Deviation about overall line	60.73	106	0.57		
(a)	413.84	1	413.84	722.37	$p < 0.001$
Total variation y	474.57	107			

Fig. 29. REGRESSION LINES OF FAT THICKNESS BY SOFT-TISSUE ROENTGENOGRAMMETRY ON HARPENDEN SKINFOLD CALIPER READINGS FOR 4 LEG SITES IN YOUNG MALES

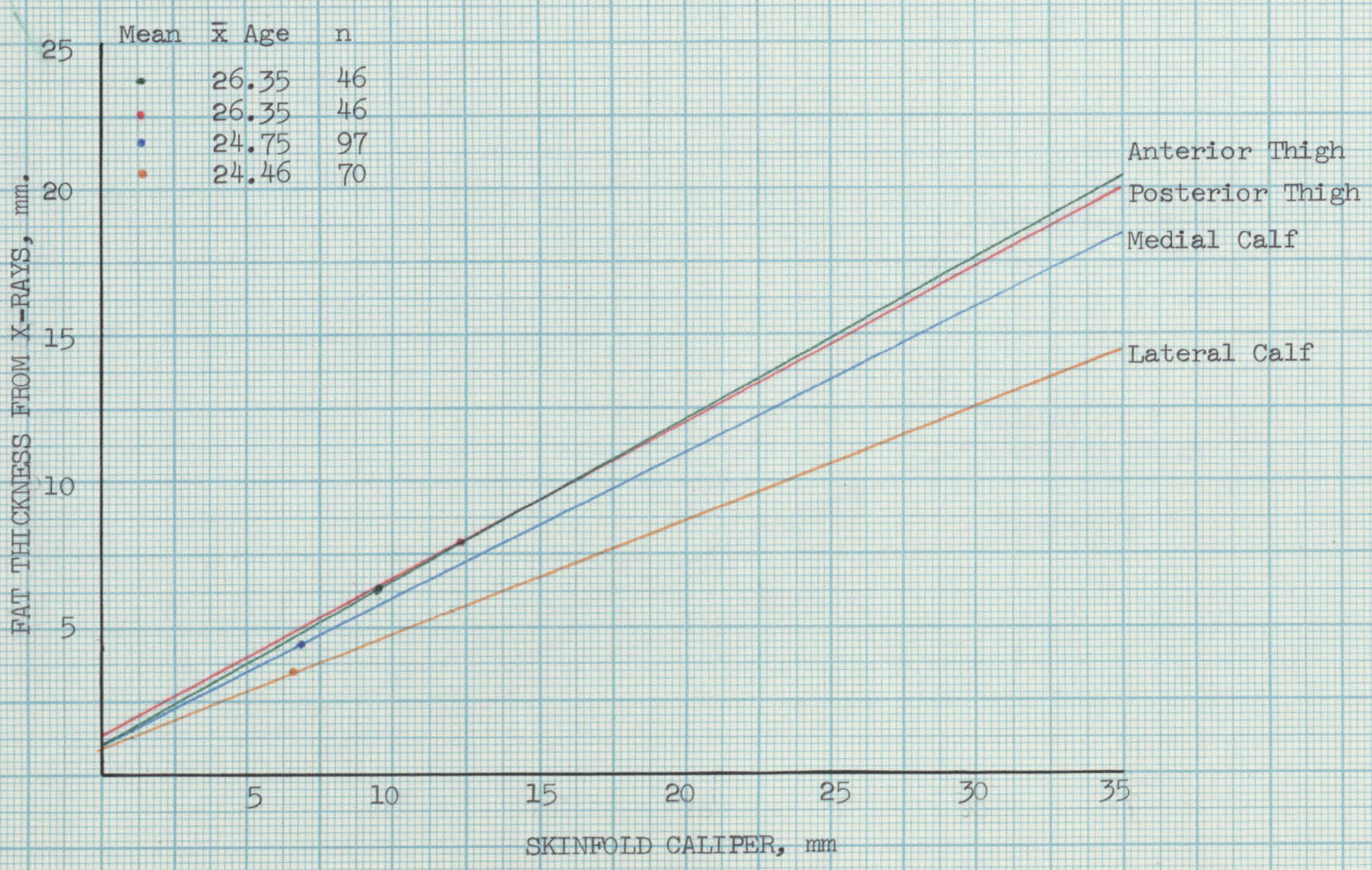


Fig. 30. REGRESSION LINES OF FAT THICKNESS BY SOFT-TISSUE ROENTGENOGRAMMETRY ON HARPENDEN SKINFOLD CALIPER READINGS FOR 4 LEG SITES IN YOUNG FEMALES

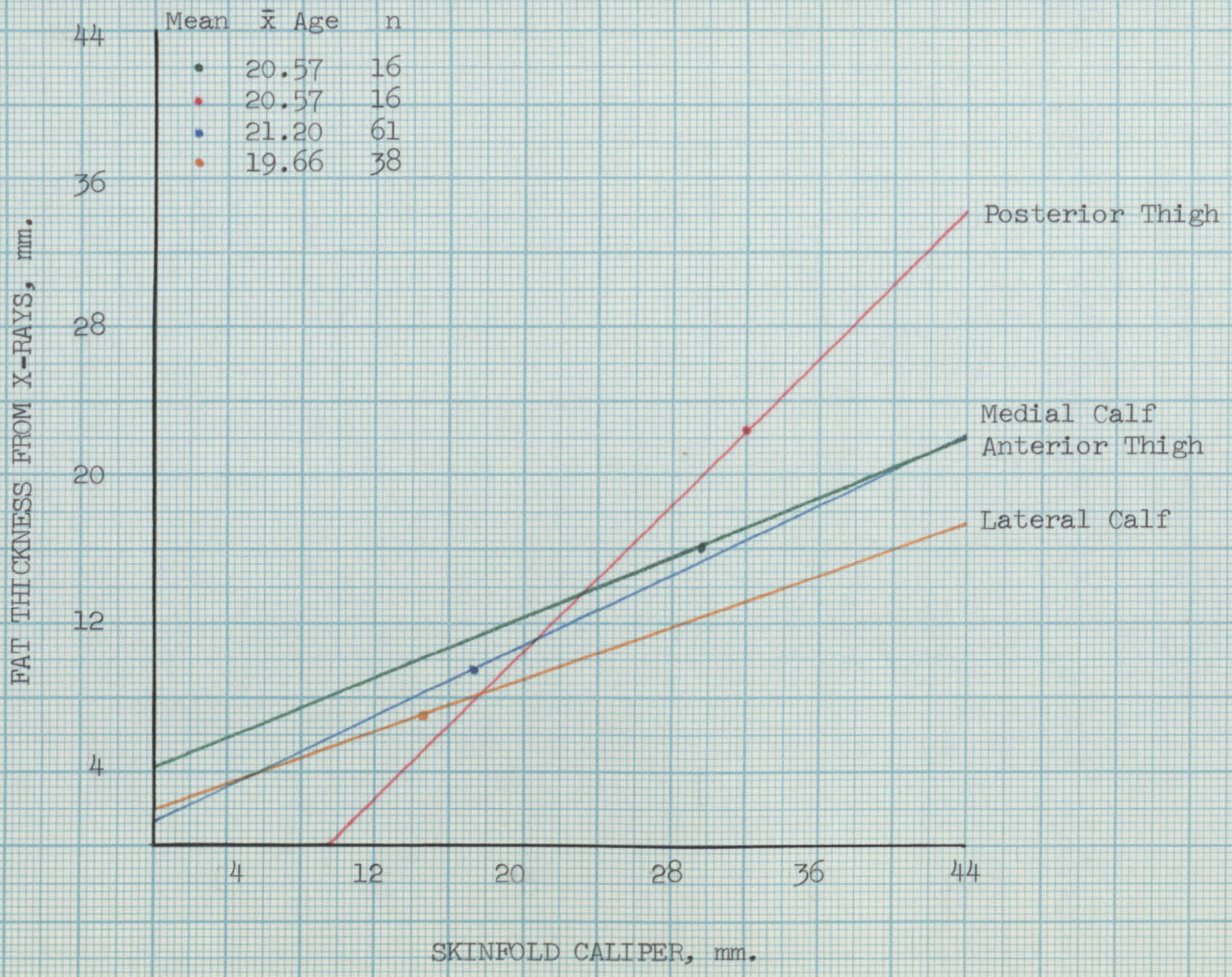


TABLE 15(a). MALE TOTAL GROUPS, ALL 4 LEG FAT SITES

ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.	M. sq.	F. Ratio	Significance
(c)	38.89	1	38.89	45.93	$p < 0.001$
(d)	29.78	2	14.89	17.59	$p < 0.001$
(b)	6.80	3	2.27	2.68	$0.01 < p < 0.05$
(e)	212.53	251	0.85	-	
Deviation about overall line	287.99	257	1.12		
(a)	1465.13	1	1465.13	1307.45	$p < 0.001$
Total variation y	1753.12	258			

TABLE 15(b). FEMALE TOTAL GROUPS, ALL 4 LEG FAT SITES

ANALYSIS OF COVARIANCE TABLE

Source	s.sq.	d.f.	M. sq.	F. Ratio	Significance
(c)	93.02	1	93.02	16.34	$p < 0.001$
(d)	162.33	2	81.17	14.26	$p < 0.001$
(b)	191.22	3	63.74	11.20	$p < 0.001$
(e)	700.19	123	5.69	-	
Deviation about overall line	1146.77	129	8.89	456.73	
(a)	4060.19	1	4060.19		$p < 0.001$
Total variation y	5206.96	130			

significant differences ($F = 45.93$, $p < 0.001$, Table 15a) between the intercepts which eliminates the possibility of using one regression equation for all sites.

It can be seen from Figure 30 that the female regression lines are somewhat randomly dispersed. Their slopes and intercepts have highly significant differences ($F = 11.20$, $p < 0.001$ and $F = 16.34$, $p < 0.001$, Table 15b) and like the male group the 4 sites cannot be combined into a single regression line equation.

Discussion

The mean values for the X-Ray and caliper fat readings show a sex difference with the female having the larger values for all 4 sites, viz. 19.83 mm compared with 8.20 mm for the caliper, and 11.19 mm compared with 5.10 mm for X-Ray. Characteristic differences between medial and lateral calf fat caliper values for females are evident from Table 3.

The ratio of caliper fat to X-Ray fat for all sites combined is 1.61 : 1 for the males and 1.71 : 1 for the females, which demonstrates a higher percentage due to compression in the males, implying that there is a sex variation in the tissue structures with the female exhibiting a firmer overall skinfold layer. Brozek and Kinsey (1960) reported that in women, the skin resiliency as measured by the immediate and total rebound, is higher throughout the age range. Relatively, the females average 2.4 times the amount of caliper fat than do the males and 2.2 times the amount of X-Ray fat for all 4 leg sites. The data has also shown that for the same X-Ray fat thicknesses, the females will demonstrate higher caliper values than males.

These findings are not in agreement with the results of Lee and Ng (1965) who reported relationships between Harpenden skinfold caliper readings and the equivalent sites studies from post-mortem dissections on Chinese males and females, from 1 month to 74 years of age. When Lee and Ng's data are transformed into percentage of actual fat double layer and percentage due to compression, their figures (Table 16) when compared with those from this study, show the exact opposite relationship for the sexes. These contrary findings may be explained by differences in ethnic groups and nutritional factors (Chinese cadavers came from a poor socio-economic class). The large spread over the age range, especially as there were more older rather than younger subjects would account for the decrease in skinfold compressibility with age increase (Brozek and Kinzey, 1960; Garn, 1961). It is also plausible, that because 22 of the females in this present study were Physical Education students and the majority of the other subjects were actively engaged in some kind of recreative sport, their leg muscles would be well developed, causing the subcutaneous layer and skin to be stretched taut; therefore, the skinfold reading would be higher due to less compressibility.

TABLE 16. DATA FROM LEE AND NG (1965), ACTUAL POST-MORTEM FATS VS. CALIPER FATS COMPARED WITH RADIOGRAPHIC AND CALIPER FATS.

	MALES						FEMALES					
	n	Caliper mean mm.	Actual fat mm.	% of actual double fold	% due to Compression	Ratio	n	Caliper mean mm.	Actual fat mm.	% of actual double fold	% due to Compression	Ratio
Lee & Ng, 1965. 9 body sites.	43	7.19	4.85	74.1	25.9	1.48:1	28	9.42	8.00	58.9	41.1	1.18:1
			X-Ray Mean mm.	% of Radio. Double Width					X-Ray Mean mm.	% of Radio. Double Width		
Jones, 1970. 4 sites.	259	8.20	5.10	80.4	19.6	1.61:1	131	19.83	11:19	88.6	11.4	1.77:1
Jones, 1970. 4 sites.	46	8.48	5.42	78.2	21.8	1.56:1	16	23.63	13.85	85.3	14.7	1.71:1

Coefficients of correlation between X-Ray values and Harpenden skinfold caliper are high, the mean r values for the 4 sites are 0.91 and 0.88 males and females respectively. These findings support the published findings of Best and Kuhl (1953); Hammond, (1955); Baker (1955); Garn (1956); Garn and Gorman (1956); Clarke, Geser and Hunsdon (1956); Brozek and Mori (1958); Baker, Hunt and Sen (1958); Tanner, Hughes and Jones (1967); Jones and Pearson (1969).

However, it must be remembered that whilst there are high significant correlations between X-Ray and caliper for the majority of sites, there does not exist a simple conversion factor which is applicable to numerous sites on both of the sexes. Although Hammond's regression (1955) was based on combining the sexes and three fat sites (biceps, triceps and anterior thigh), and later supported by Garn (1961) who mentioned that no adequate data existed to justify separating the effects of age, site and sex, this study has shown that it is not correct to do so.

The covariance analysis results of this present investigation show that there is homogeneous variance amongst the male and female sub-group sample except in the medial calf site where the intercepts are significantly different. This difference may partially be explained by the difficulty experienced by the observer in picking up the lateral skinfolds in the group of physical education students (red regression lines on the graphs), mainly because the tissue was stretched over the well developed calf muscles.

Variations, some only marginal, have been shown in the sub-group sample selections and whilst it can be argued that it "takes all sorts and kinds" to make up a random sample population, discretion should be exercised when taking too many specialists (P.E. students) into making up the normal population sample. Furthermore, it has been shown that there are significant differences within and between the sexes. Therefore, separate regression equations must be used for males and females, also for each site, except the medial calf where the sexes can be combined and a single equation used to express the caliper reading as a true single uncompressed fat thickness (Table 5).

Many reports exist which describe the skinfold values taken by Harpenden calipers as a "true double layer" of subcutaneous tissue. In fact, when lean tissue evaluations are made from limb circumference the correction for the fat is $\frac{1}{2}$ the skinfold value (Best and Kuhl, 1953; Brozek, 1960). When only leg fatfolds are considered, this hypothesis is almost correct for only the lateral calf site, with ratios of 1.91 : 1 for males and 2.07 : 1 for females, but is not applicable to other sites (Table 4).

Conclusion

By accepting that soft-tissue radiographs record accurately, within limits of the technique and observer, the depth of the subcutaneous fat layer at any given part of the body, the values can be treated as absolute measures of the fat thickness. Whereas, any caliper measurement of subcutaneous fat compresses the fold by virtue of the instrument jaws being under pressure, or by stretching due to lifting the skinfold, does not give a true representative double fold. It is considered useful therefore, especially in quantitative tissue component analysis, to have an accurate single measure of a fatfold. Because roentgenogrammetry is not always possible in field studies and some of the chosen body sites are limited and not easily reproducible, it is felt that simple linear regression equations based on previous radiographic studies can predict from skinfold caliper measurements and acceptable single value.

The lateral calf fat site is recommended as being the most reproducible of the 4 leg fat sites in young men and women. In comparison with the other sites it has the lowest standard deviations, is the least affected by compression (Table 3), the ratio of caliper to X-Ray is very nearly 2:1 for both sexes, and the site is easy to pick up and readily accessible. The relationship of the lateral calf and the 3 other leg skinfold sites to total body fat are discussed in Chapter VI.

CHAPTER V

CHAPTER V

ROENTGENOGRAMMETRIC STUDIES ON THE LEG

1. Historical Introduction

In spite of the discovery of X-Rays in 1895 by Wilhelm Conrad von Röntgen, they were not used to measure body composition systematically until some thirty-five years later.

Franzell (1944) noted that there appeared an anonymous report, as far back as 1896, of calcified blood vessels in the "soft-parts". In 1908, Alexander described a picture of the hand showing calcified arteries, for which he offered no explanation. Von Bergen (1909) showed the result of internal bleeding into the subcutaneous tissue following a fracture in the elbow of a child. Although pathological changes in the soft-tissue were slowly being reported, the majority of research at that time was only concerned with the bony skeleton. Interest in subcutaneous fat did not occur until later, and according to Révész (1913) he could see clearly in lateral views of the elbow, blood vessels which he had no reason to believe were pathological. However, he could not discover whether arteries or veins corresponded to the vascular shadows.

Obviously the distinction between the soft-tissues was soon to be defined, for in 1915 Köhler referred to small differences in the tissues in X-Ray densities when studying cases of lipoma. Between 1918 and 1922 Schlayer, Glocker and Nick, when carrying out research in absorption properties of X-Rays, found that fat was much less röntgen opaque than the other surrounding soft-tissues. The first report involving muscle came in 1923 when Laurell showed changes in the muscle widths as well as in the fat, in limbs of children with acute osteomyelitis. At about the same time an anonymous study was conducted on tubercular patients, in which diagnostic tests for oedema were made by distinguishing between changes in thickness of the thoracic fat layer. Apparently the first specific work was that of Nylin (1929) who measured the skin plus subcutaneous fat from radiographs of the chest at the level of the axilla.

Doctor Harold Stuart, a Pediatrician, began the first longitudinal systematic study in 1930 in Boston, where he analysed the components of fat, muscle and bone in soft-tissue radiographs of children's calves (Stuart, 1939; Stuart, Hill and Shaw, 1940; Stuart and Dwinell, 1942; Stuart and Sobel, 1946; Stuart and Reed, 1951). He and his co-workers took measurements at the maximum calf diameter; unfortunately, as we shall discuss later, the antero-posterior radiographs were taken in the supine position with an anode to film distance of only 36 inches (98.4 cm.). In later studies he altered his tube distance to 72 inches (196.8 cm.).

At the Fels Research Institute, Ohio, U.S.A., Sontag and Reynolds modified Stuart's technique by placing the child in the standing position. This avoided distortion of the limb contour which occurred when the weight of the limb was allowed to rest on the surface of the cassette (Reynolds, 1944, 1946, 1950; Reynolds and Grote, 1948). The work at the Fels Institute was extended by Garn and his colleagues, and an aocount of this work, together with at least fifty informative publications on fat shadow work, will be found in a comprehensive review by Garn (1961). Parallel with this, in Spain, Suarez (1953) and his colleagues also used a similar technique in children. They measured across the maximum calf diameter, combining the limb muscle by subtracting the combined medial and lateral fat widths. This technique was first applied to adult studies by Reynolds (1949) and Reynolds and Asakawa (1950), who were interested in the three tissue components, fat, muscle and bone and sex differences.

Work in the United Kingdom was started in 1949 by Tanner and Whitehouse at the Harpenden Growth Study, where similar techniques were introduced in a longitudinal study on children and later on Olympic athletes (Tanner, 1962; Tanner and Whitehouse, 1964). It is these techniques, initiated by Tanner and colleagues, that have formed the basis of the radiographic procedures reported in this thesis.

2. Aims and purposes of the Roentgenogrammetric method

Changes in size or shape being demonstrated solely by parameters such as stature or weight, do not show the changes which take place between the individual tissues, e.g. subcutaneous fat, muscle and bone. Simple anthropometric techniques like the use of skinfold calipers for demonstrating the distribution of fat, limb girths, tell us something about the underlying muscle and bone widths which reveal a trend in skeletal size, but none of these give such a precise tissue component differentiation than soft-tissue roentgenogrammetric techniques. Not only does the method provide a permanent record from which additional checks on the values can be made, it also eliminates some of the errors which show up in traditional anthropometry, e.g. skinfold compressibility associated with age and caliper pressure, (Brozek and Kinzey, 1960) uncertain localization of sites and the inter-observer errors in picking up the skinfolds. Further to this, it appeared that the radiographic method offered an additional parameter - the bony system - which could be measured and isolated from its overlying components. Thus, it was hoped that from the radiographs a technique would be evolved which would not only quantify individually the three tissue components, skin plus subcutaneous fat, muscle and bone, but would provide important information about body composition.

3. The Roentgenogrammetric Technique for limb component widths

Materials and Methods

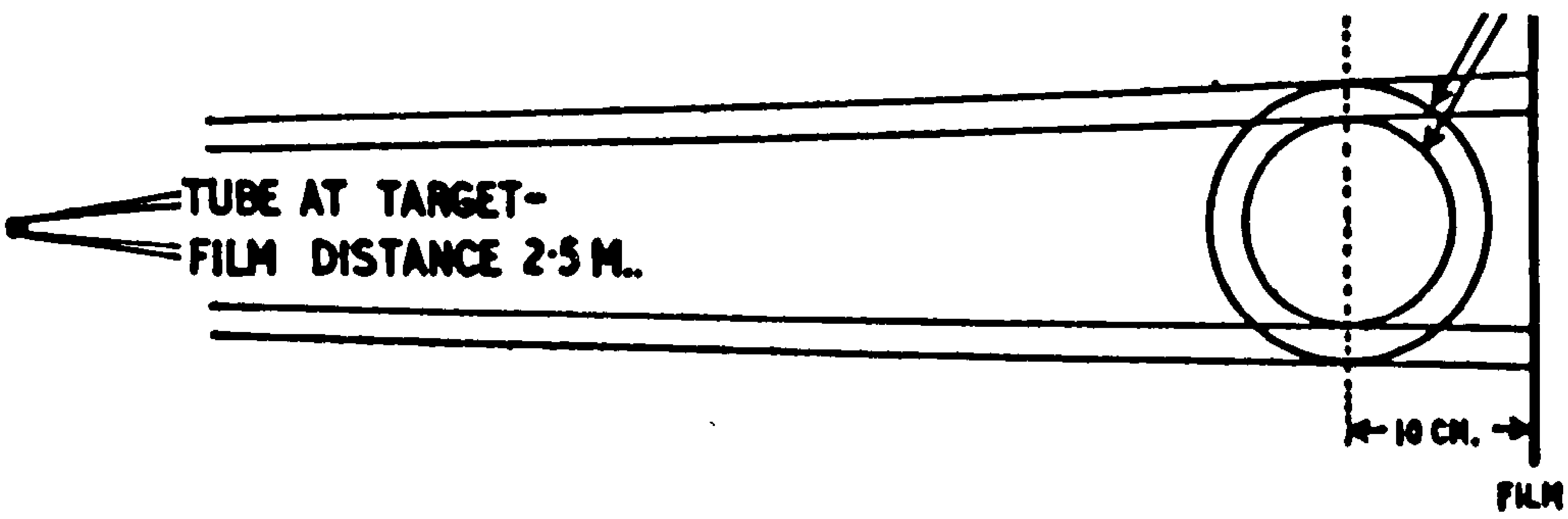
Three soft-tissue radiographs were taken; the left upper arm, the left calf and the left thigh. The arm was placed in a lateral position so that the two epicondyles lay at right angles to the cassette face. The object film distance (i.e. from the vertical central plane of the arm to the film) was measured at exactly 5 cm. (Fig. 31). This technique ensured a constant object enlargement factor which took into account variation

Fig. 31. Roentgenogrammetric pose for the upper arm area.

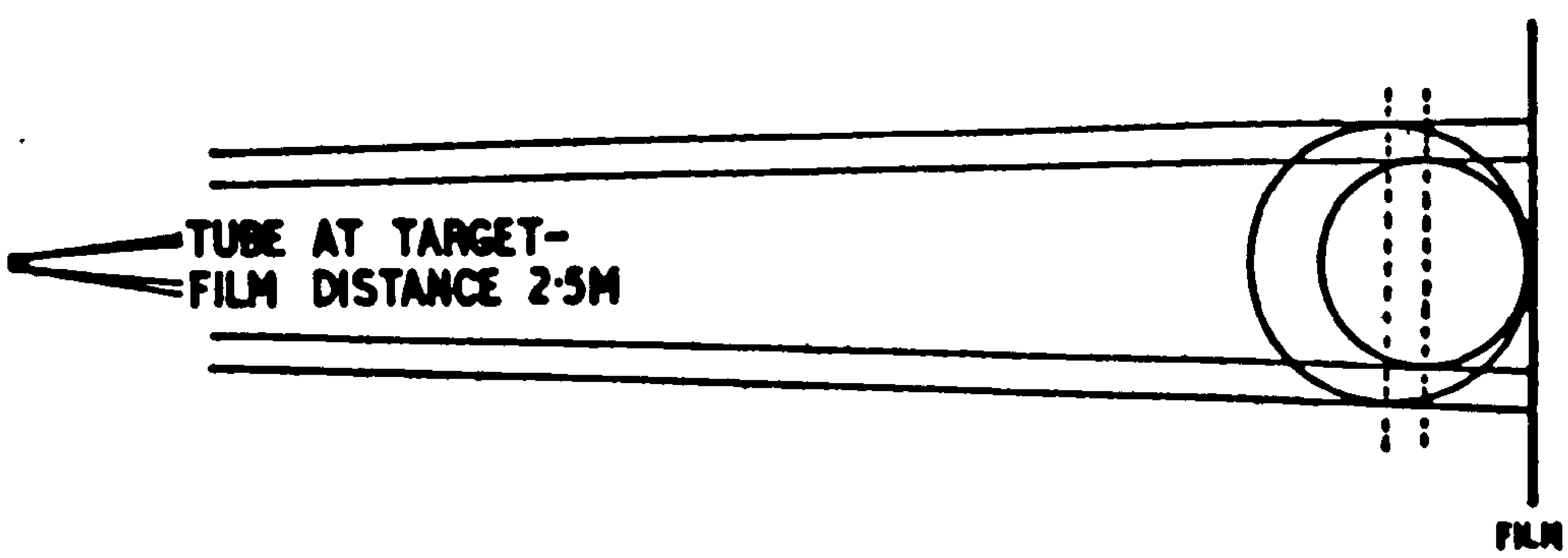
in limb sized (Tanner, 1962)(Fig. 32a). This of course would not be the case should the limb lie in contact with the cassette (Fig. 32b).

The left calf was positioned anteroposteriorly with the body weight evenly distributed over both feet. The foot was placed so that the saggital plane through the malleoli was parallel to the cassette and the central vertical axis (object film distance) at the maximum calf circumference was at 10 cm. (Fig. 33). For the arm and calf exposures, the apparatus, as can be seen in the figures, was designed so that only one half of a 35.6 cm. by 43.2 cm. (14" x 17") cassette divided longitudinally was used for each limb. Not only was this intended from an economical viewpoint, but it facilitates handling and measuring by having two limb shadows on one radiograph. This was accomplished by attaching a perspex sheet one third larger than the cassette to the vertical cassette holder. The outer thirds of the perspex were covered by 1.5 mm. lead sheet, whereas the middle third was clear except for the engraved lines which crossed at the midpoints of the vertical and horizontal axes. These engraved lines were used to facilitate positioning of the limbs and aligning the central ray of the X-Ray beam by means of a light beam delineator attachment.

A spring loaded stop button incorporated in the lower cassette channel ensured that when the cassette was placed in the holder it did not travel beyond the desired location for the first exposure. For the second exposure the stop button was released and the cassette slid through onto a second stop button which ensured that the



a). PERCENT MAGNIFICATION CONSTANT



b). PERCENT MAGNIFICATION VARYING

Fig. 32. Diagram of radiographic technique, to show how keeping the central plane of the limb a constant distance from the casette gives a constant magnification. (From Tanner, *Growth at Adolescence*, 2nd edition, Blackwell Scientific Publications, Oxford).

Reproduced by kind permission of Professor J.M. Tanner.

Fig. 33. Roentgenogrammetric pose for the calf area.

unexposed half of the cassette came within the boundaries of the perspex 'window'.

The left thigh position was with the subject standing astride the cassette stand with the top edge of the cassette placed as high into the groin area as possible. The foot was rotated until the two posterior borders of the femoral condyles were superimposed. This can usually be carried out by palpation. Care needs to be taken to ascertain that the quadriceps femoris muscle is in a relaxed state. The central vertical axis (object film distance) of the thigh, at the 1/3 subischial level, was positioned at 10 cm. from the cassette face (Fig. 34). A perspex rod with suitable engraved rings at one end was calibrated (allowances being made for the thickness of the aluminium cassette face, the tungstate screens together with the perspex sheet) to represent the 5 cm. and 10 cm. object film distance; this was used to determine the exact distance of the central vertical axes of the limbs to the cassette face, as can be seen in the figures.

Since the aim in soft-tissue radiography is to differentiate between the fat plus skin layer and the underlying tissues, only a relatively small exposure is required. Exposure values vary from subject to subject according to their size, structure and sex, likewise the different types of generators and X-Ray tubes vary in output. As a general rule, when using 'Kodak' blue brand film and regular intersifying screens, the exposure values for young adults fell into the following ranges for the two X-Ray machines which were used (Table 17).

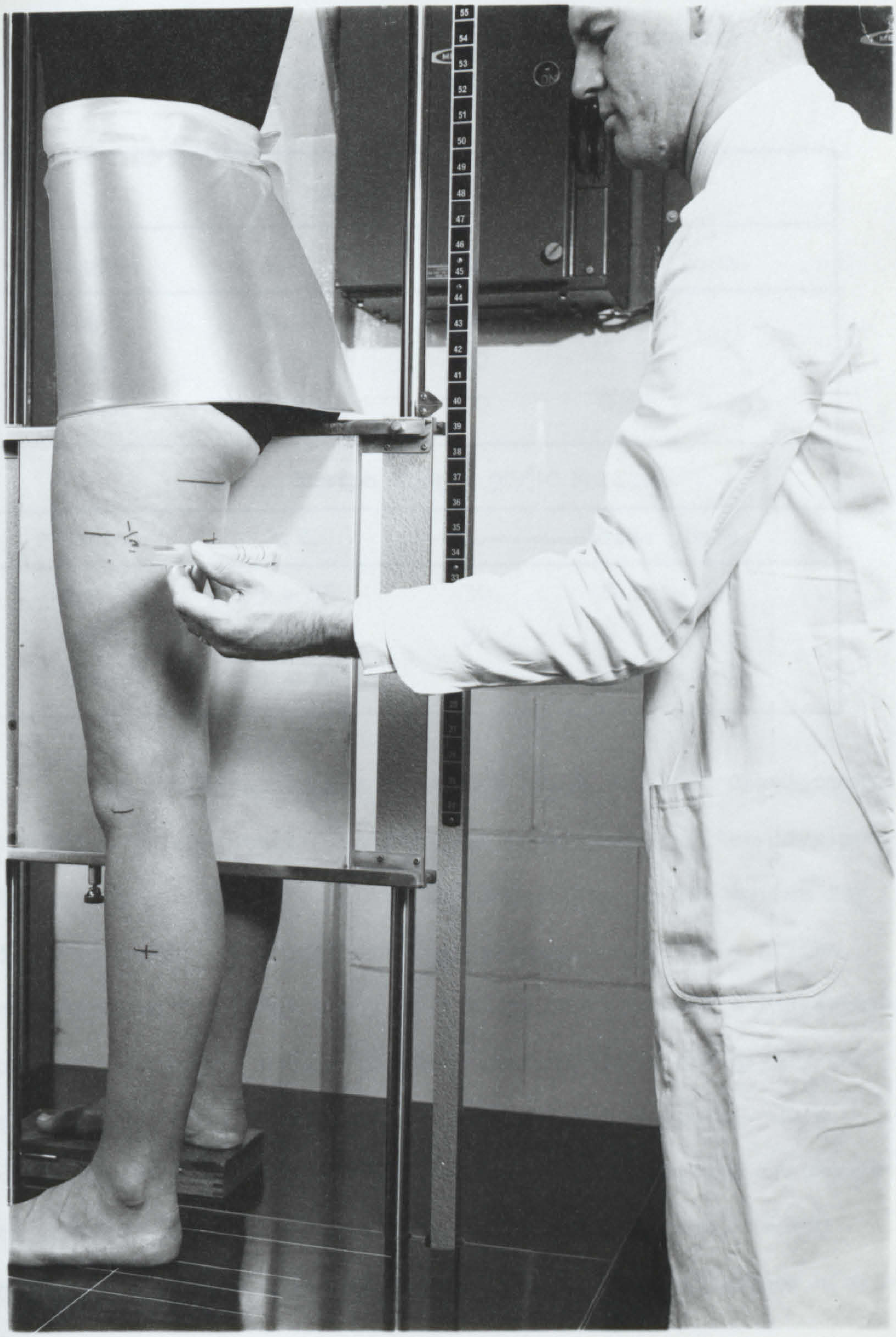


Fig. 34. Roentgenogrammetric pose for the thigh area.

TABLE 17. X-RAY EXPOSURE VALUES FOR SOFT-TISSUE ROENTGENOGRAMMETRY OF THE LIMBS

General Radiological 400			
Region	K.V.	Ma.	Time: Secs.
Arm	48.56	200	0.1
Calf	56.64	200	0.1
Thigh	58.70	200	0.12 - 0.15
Newton Victor 90/30 Mobile			
Region	K.V.	Ma.	Time: Secs.
Arm	45 - 55	30	0.3 - 0.6
Calf	55 - 65	30	0.4 - 0.7
Thigh	65 - 70	30	0.6 - 0.9

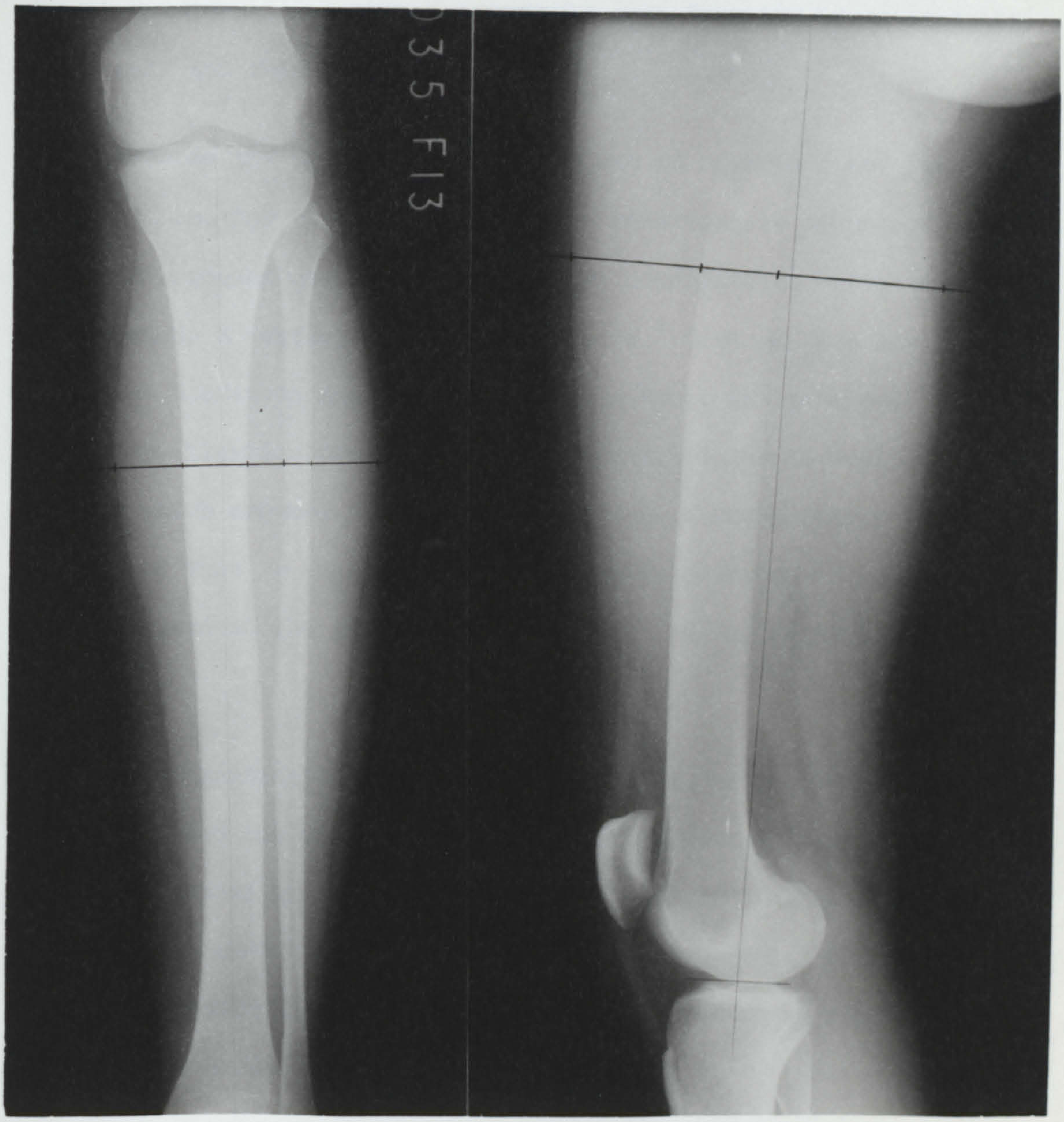
The radiographs were processed using a forced development technique which entailed raising the temperature of the developer to approximately 21.1°C (70°F) and developing by inspection for 3 - 4 minutes. Not only did this process allow for a slight reduction in the X-Ray exposure factors, it produced a radiograph of optimum density around the limb profile which was highly desirable for taking measurements from the radiographs. In a correctly exposed and processed soft-tissue radiograph it should be possible to pick out the individual muscle groups, tendon - muscle linkage and clear distinctions between subcutaneous tissue and muscle.

Radiographic Measurements

One diameter was measured on each radiograph using a specially constructed needle point dial reading caliper (Tanner and Whitehouse, 1955) accurate to 0.1 mm over a range of 1500 mm. (Fig. 16). In the arm radiograph a pencil line was drawn parallel to the long axes of the anterior and posterior surfaces, and a line perpendicular to this was drawn at the level of the lead marker. Along this line the width of the anterior and posterior subcutaneous fat and the humerus (at a level perpendicular to the long axis of the bone shaft) were measured. The muscle width was obtained by subtracting the sum of the fats and bone from the total width.

A line was drawn on the calf radiograph down and parallel to the long axis of the tibia and another line perpendicular to this was drawn at the level of the maximal width. The total width, medial and lateral subcutaneous fat, tibia and fibula, were measured and muscle was obtained by subtraction (Fig. 35a).

The thigh was measured across the maximal width at the level of 1/3 subischial height (stature minus sitting height) as measured up from the lower border of the femoral condyles, on a line that was as nearly parallel to the long axis of the anterior and posterior surfaces as possible (Fig. 35b). This level was chosen by Tanner, not only because it coincides approximately with the greatest antero-posterior thigh muscle diameter in the majority of cases, but it provides a constant landmark when taking into account the growing child.



a).   b).

Fig. 35. a). Anterio-posterior calf radiograph and b). lateral thigh radiograph, showing the horizontal sites from which the tissue component widths are measured.

When width values are measured on radiographs they represent only relative, not absolute figures, since they are taken in a plane of a three-dimensional object, as can be seen from the cross-sections of the calf and thigh (Figs. 36 and 37).

Because the object film distance was as high as 5 cm. for the arm and 10 cm. for the calf and thigh, a considerable amount of object enlargement occurred and therefore necessitated correction. In this study a testing caliper accurate to $\pm$ 0.05 mm. was set up at both these distances and the magnification error was measured. The actual magnification factor closely approximated the theoretical calculation which assumed the X-Ray origin to be a point source (Fig. 38). In practice this is not so, as the origin is represented by the anode target, housed in the shock-proof X-Ray tube, which is usually 1.0 to 3.5 mm^2.

The magnification and distortion discrepancies between the actual size and the size obtained from the measurement can be considerably reduced by careful technique, paying particular attention to the proper anode film distance, critical centering, the object film distance and ensuring that the central X-Ray beam is at right angles to the plane of the film.

By simple geometric principles (Fig. 38) it can be seen how the image size will distort upon the film, in relation to the distance that the X-Ray target (anode) is from the film cassette. Likewise, the greater the image size being radiographed the greater is the distortion. It can be appreciated that the further the X-Ray tube is placed from the film, so the parallax effect becomes less.

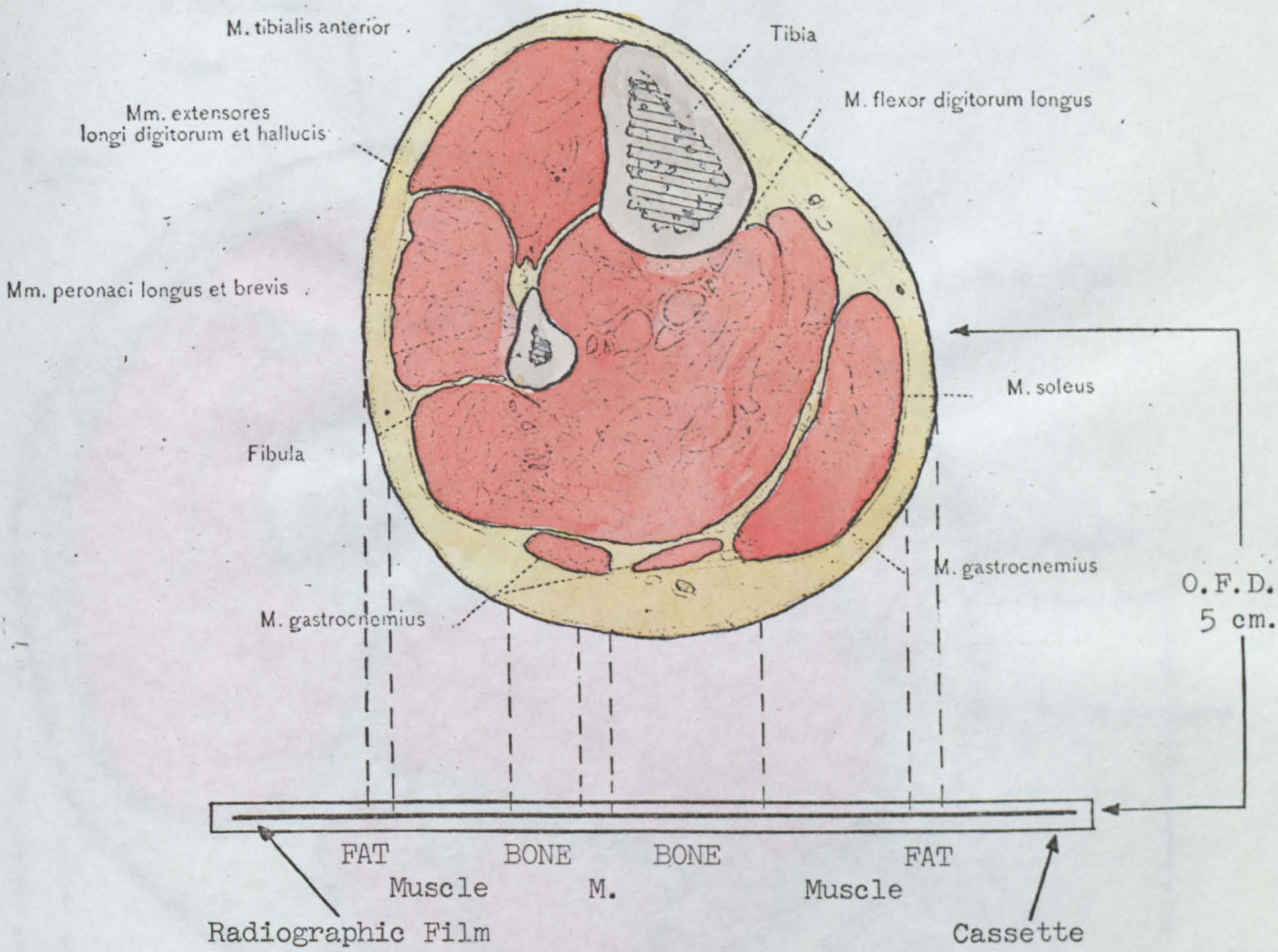


Fig.36. Diagrammatic Interpretation of a cross section of the Calf at the maximum circumference, from a radiograph.

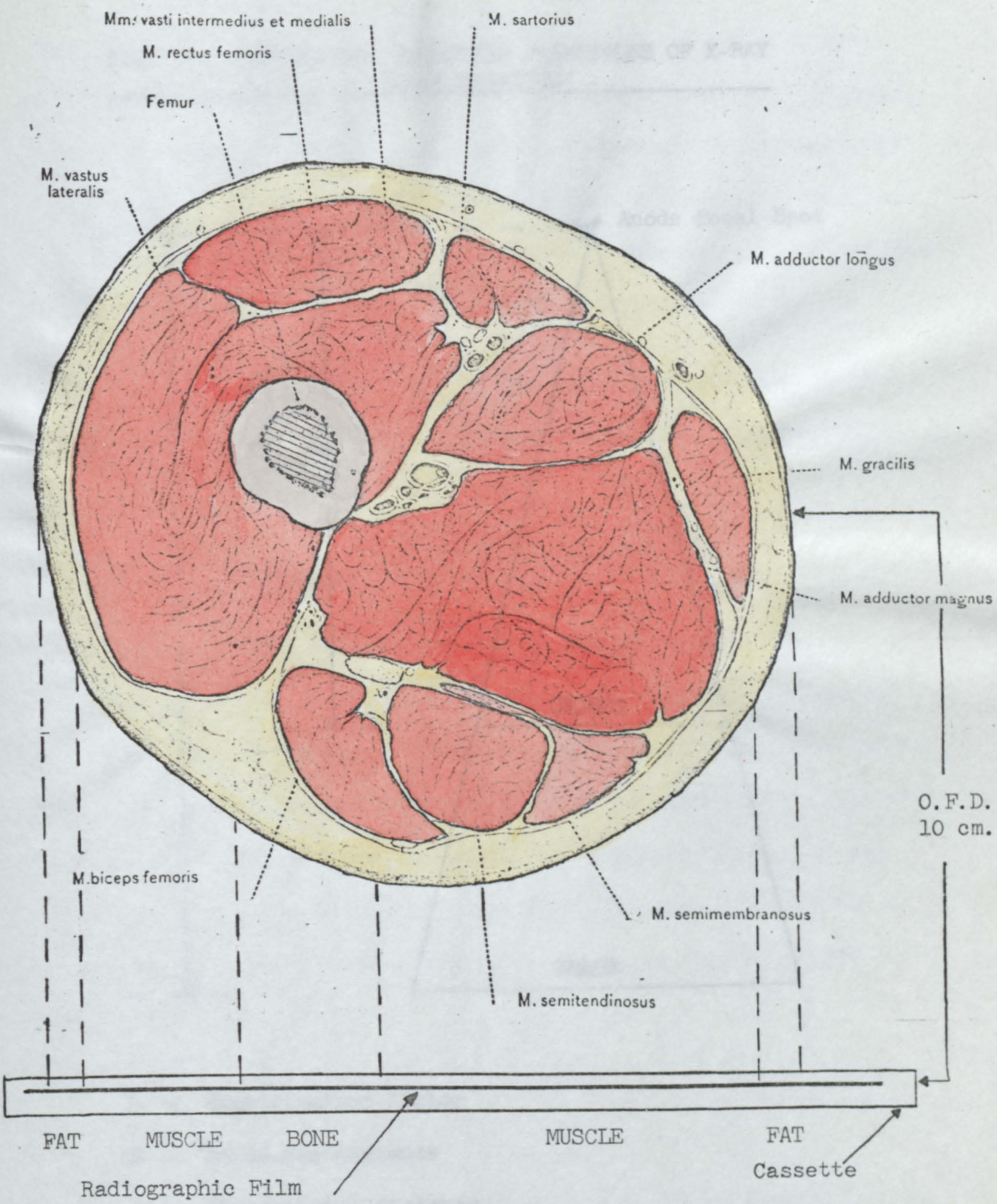
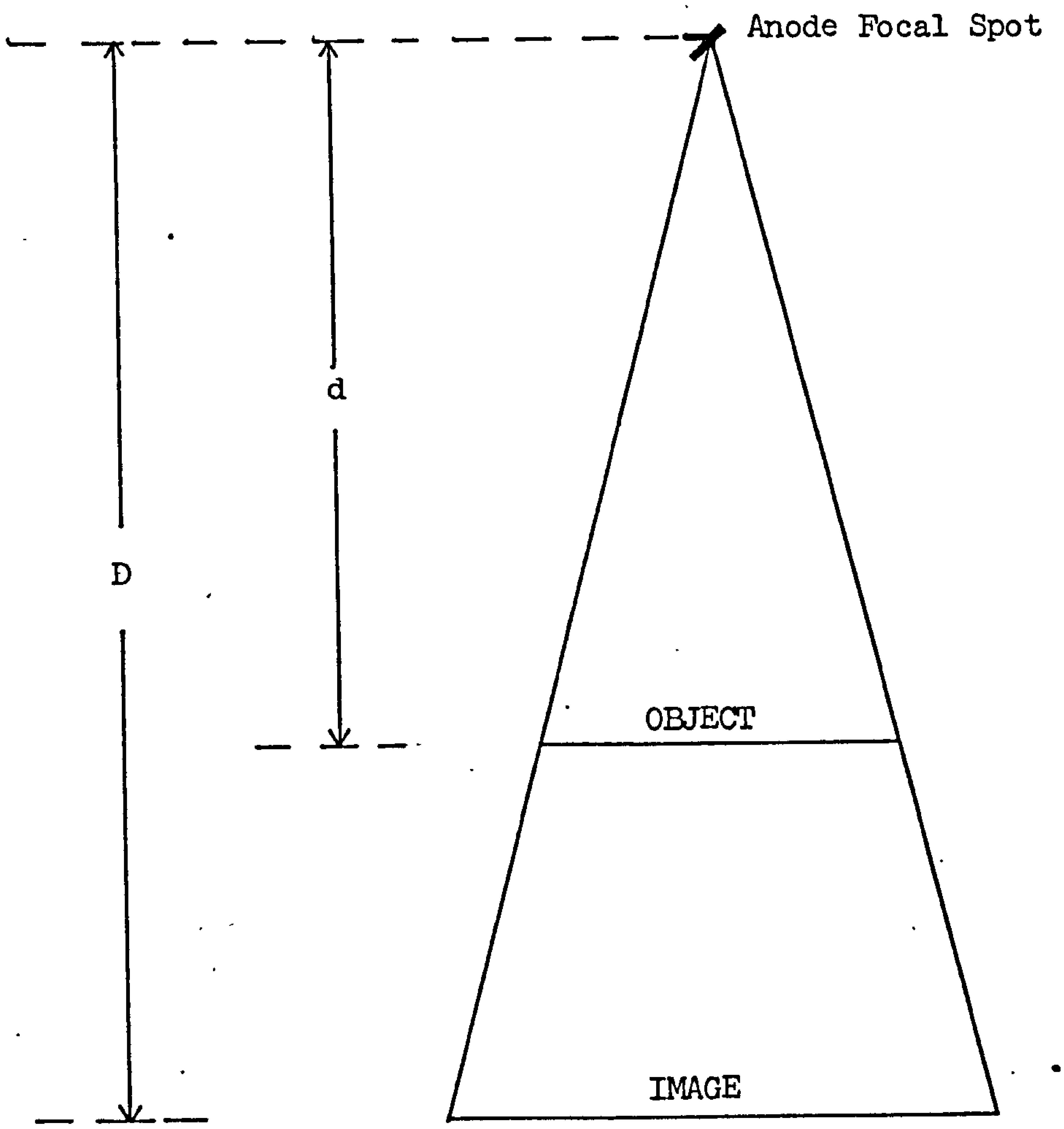


Fig.37. Diagrammatic Interpretation of a cross section of the Thigh at the level of $^1/_3$ subischial height, from a radiograph.

FIG. 38: THEORETICAL GEOMETRIC PRINCIPLES OF X-RAY MAGNIFICATION



I = Magnification factor

D = Focus-fim distance

d = Focus-object distance

Example:-

When using a focus film distance of 2.5 metres and a focus object distance of 2.4 metres, the magnification factor would be:-

$$I = \frac{D}{d} = \frac{2.5m}{2.4m} = 1.041$$

This is also helped by the fact that beyond a distance of 6 feet X-Rays are travelling virtually parallel to one another. However, since the exposure factor alters as the square of the distance, it is necessary to have available X-Ray equipment capable of handling the required higher output. For all the roentgenogrammetric studies an Anode Film Distance of 2.5 metres was adopted.

The magnification error for the two X-Ray sets used in this study were 3.8% and 4.4% and all measurements were adjusted accordingly.

Sources of data

The subjects were 110 healthy young adults, ranging from 18 years to 28 years, including 23 male and 20 female factory workers and three male International athletes, 32 male students of Physical Education and 15 females from a College of Education. The factory workers were taken from an industrial area around Leeds, the men were mainly engaged on fairly heavy work entailing the lifting of heavy castings, whilst the women were mainly on light clerical or laboratory work.

Results

The findings for the investigations of tissue composition in the arm, calf and thigh in males and females are summarized in Table 18. When comparing the total limb widths (Fat + Muscle + Bone) it can be seen that there were remarkably small differences between the sexes; this was particularly evident in the calf and thigh, and when

TABLE 18. MEANS AND STANDARD DEVIATIONS OF TISSUE COMPONENTS, FAT, MUSCLE, BONE AND TOTAL LIMB WIDTH IN THE ARM, CALF, THIGH AND TOTAL LEG CALCULATED FROM RADIOGRAPHS, IN YOUNG MALES AND FEMALES.

	MALES			FEMALES		
	n	Mean	S.D.	n	Mean	S.D.
Age, yrs.	40	24.22	2.78	23	23.73	1.88
	72	25.53	4.37	38	21.94	2.81
Arm						
Total Width, cm.	40	10.37	1.42	23	9.48	1.12
Med. + Lat. Fat	-	1.02	0.41		2.26	0.68
Muscle	-	7.15	1.19		5.35	0.65
Bone	-	2.20	0.26		1.87	0.19
Fat % of Total Width		9.82%			23.84%	
Calf						
Total Width	72	11.84	0.96	38	12.36	0.93
Med. + Lat. Fat	-	0.86	0.30		1.90	0.44
Muscle	-	7.04	0.83		7.05	0.71
Bone	-	3.96	0.33		3.40	0.24
Fat % of Total Width		7.49%			15.41%	
Thigh						
Total Width	72	18.03	1.42	38	17.50	1.37
Med. + Lat. Fat	-	1.50	0.54		4.00	1.16
Muscle	-	13.32	1.19		10.63	0.80
Bone	-	3.21	0.25		2.87	0.18
Fat % of Total Width		8.32%			22.87%	
Total Leg (Thigh + Calf)						
Σ Total Widths	72	29.86	2.24	38	29.86	2.01
Σ Fats	-	2.36	0.80		5.90	1.50
Σ Muscle	-	20.38	1.73		17.69	1.16
Σ Bone	-	7.17	0.52		6.27	0.34
Fat % of 2 Widths		8.14%			19.76%	

they are summed for the total leg (Thigh + Calf), they give identical means. However, when the actual tissue components are compared separately there are marked differences between the sexes. The subcutaneous fat in the limbs of the women were on average more than twice that of the men. Fat as a percentage of the total limb width showed a similar pattern and sex difference. The arm fat was 23.84% of the total width for the women compared with 9.82% for the men; the calf 15.41% for women and 7.49% for men; the thigh 22.87% and 8.32% women and men respectively and for the total leg 19.76% for women compared with 8.14% for the men. On the other hand, the men showed larger muscle thickness in the arm - 7.15 cm - compared with 5.35 cm for women; in the calf muscle the means were almost identical, 7.04 cm and 7.05 cm, and in the thigh 13.32 cm compared with 10.63 cm in the women. The total leg muscle means were 20.38 cm for men and 17.69 cm for women.

Bone also showed a sex difference; the males had larger mean bone widths. The differences were +0.33 cm, +0.56 cm and +0.34 cm for the humerus, tibia plus fibula and femur respectively.

Discussion

A customary technique in Anthropometry is to make body composition comparisons between ages within the sexes and between the sexes by simple measurements such as limb diameters and circumferences. The inherent errors in these usual practices are highlighted by these results which show the importance of revealing the difference between the tissue components which make up the total width or girth of a limb. The circumferences in this study, like the overall diameters, show little difference between the sexes. For example, upper thigh 54.53 cm and 54.84 cm, maximum calf 36.08 cm and 35.29 cm for males and females respectively. If we consider only mean values for the total leg (Thigh + Calf) width we see that there are no differences between the sexes. The men have more muscle (+2.69 cm), more bone (+0.90 cm), but much less fat (-3.54 cm) and this, like the work of Reynolds and Grote (1948), Reynolds (1950), Garn and Saalberg (1953), Tanner (1965) and Malina and Johnston (1967) shows a marked sex dimorphism in the tissue components of the leg in young adults. Although the mean values are not shown in Table 18, the data from this study confirmed the work of Garn and Saalberg (1953), Tanner (1965) using young adults and of Malina and Johnston (1967) using adolescent children, that the subcutaneous fat as measured from radiographs, on the medial aspect of the calf, is thicker relative to the lateral aspect in women, viz. 9.5 mm and 7.0 mm respectively, when compared with the men who exhibit almost equal thicknesses, viz. 4.4 mm and 3.5 mm medial and lateral sites respectively. Likewise, the data from the anterior and posterior subcutaneous fat radiographic sites show a closely related pattern for the female, 16.1 mm and 22.4 mm and for the males 6.3 mm and 7.9 mm anterior and posterior sites respectively.

It is mentioned at the end of the discussion on page 117 that in a present study the thigh has been radiographed in an antero-posterior position. So far as I know, this will be the first occasion when evidence from a population of young adult males and females may show if this different pattern of fat accumulation, as seen on the medial aspect of the lower leg, will extend up into the thigh region. If this is so, it may further substantiate the hypothesis postulated by Garn and Saalberg (1953) that this differential pattern of fat accumulation on the medial aspect of the calf may account for the apparently higher incidence of genu valgum in women.

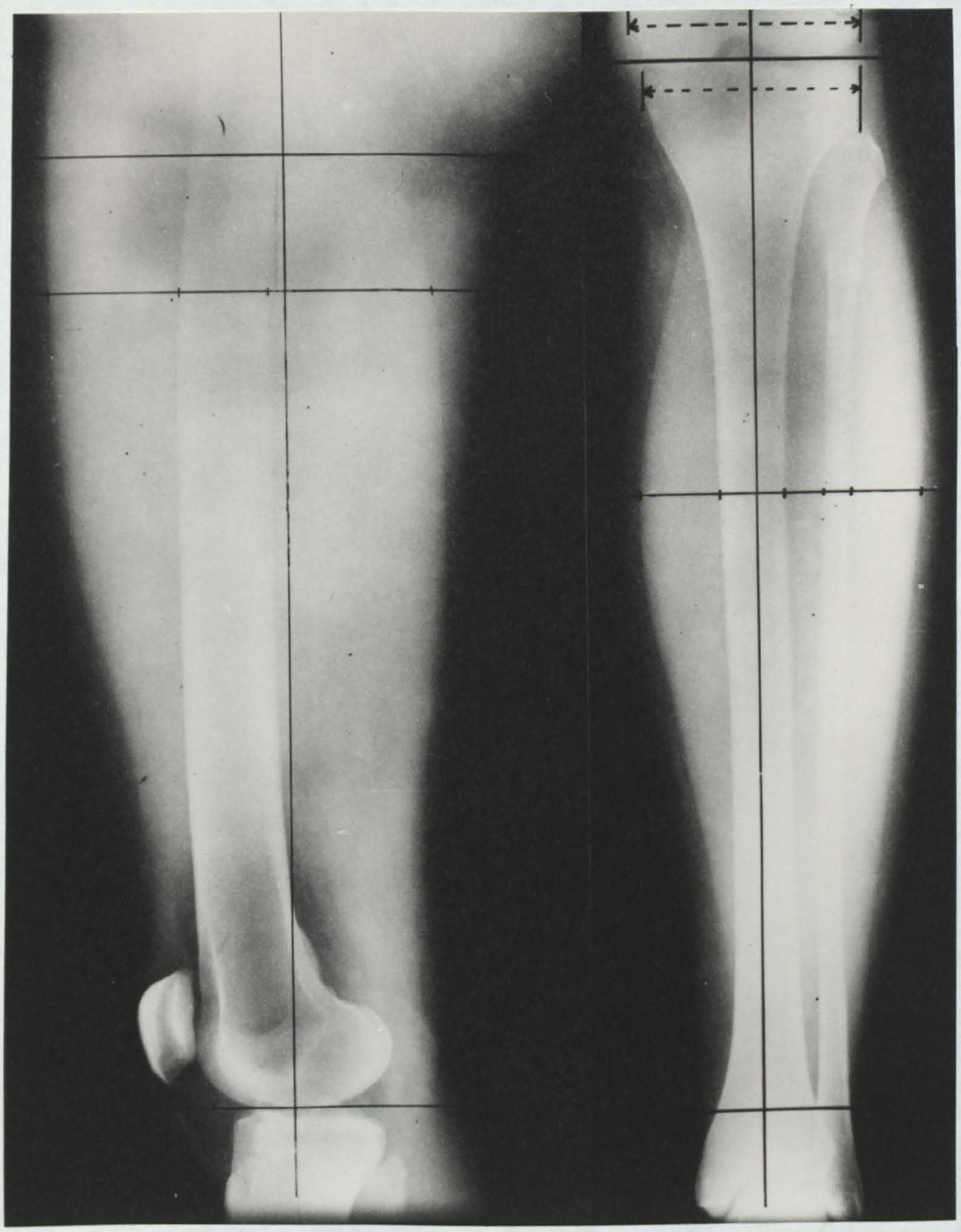
In radiographic studies on limb tissue components, the calf region has been the most studied; however, there appears to be some confusion among research workers when "muscle width" data are reported, because opinions differ on how it should be measured. Stuart et al. (1940, 1942), Reynolds et al. (1948), Cotes et al. (1969), Jones et al. (1970), have excluded the tibial and fibula widths from their muscle data results. Garn et al. (1953a, 1953b); Tanner (1959, 1965) have included them; accordingly care should be exercised when interpreting the results.

4. The roentgenogrammetric technique for limb component volumes

Two soft-tissue radiographs of the left leg were taken; a lateral of the thigh and an anterior-posterior view of the calf. The positioning and radiographic procedure was identical to that previously described for the roentgenogrammetric measurement of the limb widths (Figs. 33 and 34).

The radiographs (Fig. 39a and b) were marked by drawing pencil lines parallel to the long axis of the femur and tibia, and lines at right angles to these at the levels of: the gluteal furrow, one third of the subischial height measured up from the line through the tibial-femoral joint space, the maximum calf diameter, and the minimum diameter of the ankle above the malleoli. Subcutaneous fat thicknesses were taken on the lines at the level of one third subischial in the thigh and at the maximum diameter in the calf.

For the calculation of the bone volumes further lines were drawn at right angles to the tibial-femoral joint line at the maximum bicondylar diameters of the femur and tibia (Fig. 39b). Because the head and neck of the femur and the lower end of the tibia and fibula were outside the boundaries of the 'useful' truncated cones it was necessary to calculate the bone volumes separately. Appropriate bones from three human skeletons were marked at the correct heights and X-Rayed. The true volumes were ascertained by water displacement and the closest estimate to the true volumes were determined. For the femur, the diameter of the shaft at the one third subischial mark (Fig. 39a) was added to the bicondylar femoral diameter and divided by three which gave a "working diameter". For the tibia, the diameter at the maximum calf level was multiplied by four and added to the bicondylar tibial diameter, which was then divided by five. The "working diameters" were used in the calculation of the volume of a theoretical cylinder. No adjustment was found necessary for the fibula, therefore, the calculation was made using the diameter at the same level as for the tibia. The differences between the calculated and actual volumes were, for the femur $\pm$ 20 cm^3,



a). b).

Fig. 39. a). Lateral thigh radiograph and b). anterio-posterior calf radiograph, showing vertical and horizontal sites from which the tissue component volumes are measured.

tibia $\pm$ 12 cm^3, and fibula $\pm$ 5 cm^3. The formula to calculate the volume of a truncated cone was used to compute the gross, and the muscle plus bone volumes of the thigh and calf as described by Jones and Pearson (1969). The "lean" leg volume was obtained by subtracting the two fat readings from each of the diameters in the thigh and calf. It was found that the subcutaneous fat measurements taken at one third subischial and maximum calf level bore the closest relationship to the fat volume as obtained by planimetry.

Verification of subcutaneous fat volume results

It cannot be said with absolute certainty that the results so obtained for the subcutaneous fat volume values are 100% correct. For the proof of the method must wait until direct comparison of X-Ray results can be made against those by dissection; to this end, it is hoped in the near future to carry out this analysis on the legs of cadavers.

However, to overcome this uncertainty a model of a thigh was built and around the "lean mass" shape, a layer of polyzote (an expanded polystyrene material) approximately 2 cm thick was placed to simulate the subcutaneous fatty layer. The model of the thigh was then X-Rayed using the same roentgenogrammetric techniques as already described. From the radiograph the medial and lateral 'polyzote fat' areas were each measured three times with an "Ott" Planimeter accurate to 0.2% and the summation of the two areas were multiplied by the mid-circumference (i.e. the level at which the X-Ray tube was centred) to give the volume. The difference between the known volume of the polyzote and the volume from the radiographs by planimetry was < 0.01 litres (see Appendix II for experimental results).

Having established that the results obtained from the radiographs by planimetry were highly reliable (Fig. 40), direct comparison could be made against the fat volume values obtained from the Anthropometric and Radiographic method, that is, from frustum of cones, outer volume minus inner volume (Table 2, p. 27)

Many different combinations of fat thickness levels and sites in the thigh and calf radiographs were computed to find the values which bore the closest relationship to the accepted standard method by planimetry. This was found to be at the 1/3 subischial and maximum circumferences of the thigh and calf respectively. Some results of these experiments can be found in the appendices.

Statistical treatment

A computer programme was used to calculate a linear regression analysis, the mean, standard deviation, correlation coefficient and standard error of the estimate. Student's 't' test (two-tailed) was used to determine the significance of difference between the related sample means.

Results

Table 19 shows the validation of the soft-tissue roentgenogrammetric techniques by comparing the computed volumes with those

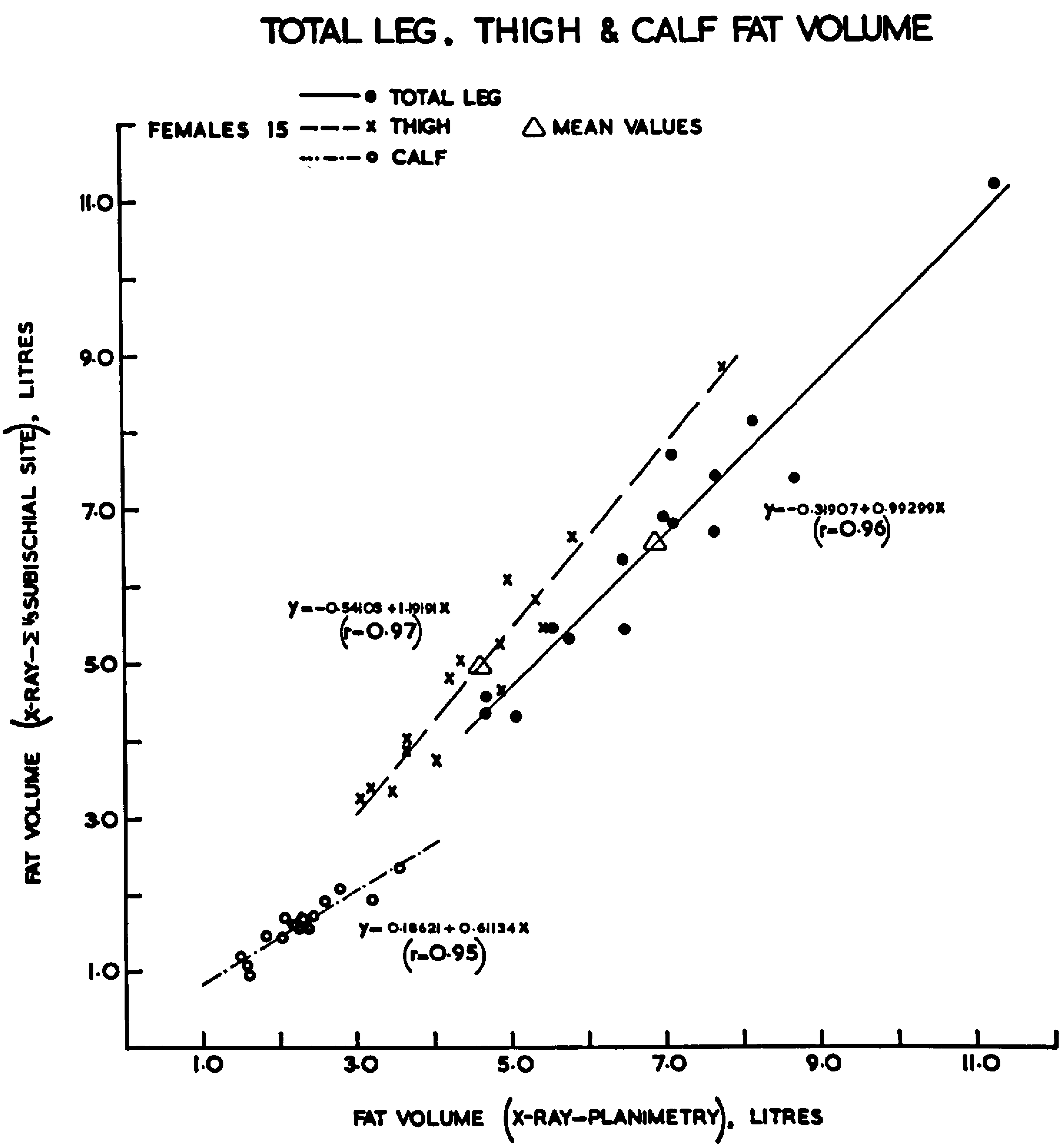


Fig. 40. The relationship between two methods for calculating the total leg, thigh and calf subcutaneous fat volume in young women. Soft tissue X-Rays by planimetry vs soft tissue X-Rays by medial and lateral fats at $\frac{1}{3}$ subischial site.

TABLE 19. COMPARISON OF RESULTS OBTAINED BY (1) WATER DISPLACEMENT AND (2) X-RAY METHOD

		MALES				FEMALES			
Body Component Volume		Mean (1.)	S.D. (1.)	Correlation Coefficient	Matched Pairs	Mean (1.)	S.D. (1.)	Correlation Coefficient	Matched Pairs
Total Leg	(1) (2)	16.34 17.45	2.43 2.64	0.96	-1.11*	15.84 16.27	2.13 2.03	0.93	-0.43
Thigh	(1) (2)	10.75 12.84	1.60 2.10	0.94	-2.09*	10.67 11.28	1.68 1.53	0.83	-0.61
Calf	(1) (2)	5.37 5.08	0.82 0.85	0.95	+0.29*	5.14 4.99	0.61 0.70	0.92	+0.15

*Significant difference of the mean values (by matched pairs t-test) $P < 0.05$.

obtained by water displacement for men and women. In all cases the coefficients of correlation are highly significant ($p < 0.001$) and the differences between the means are significantly different for the males (by matched pairs 't' test $p < 0.05$) and for the females are non-significant. In the regression equations for X-Ray values compared with the water displacement values, the regression coefficients do not differ significantly from 1.

Table 20 presents the means and standard deviations for the subcutaneous fat, muscle and bone volume values for the Total Leg, Thigh and Calf.

The gross volumes for the calf show little difference between the sexes with mean values of 5.02 litres for males and 4.99 litres for females. However, there are marked differences in the Thigh, the male being the larger by +1.68 litres.

When separate comparisons are made of the tissue components there are marked differences between the males and females for fat, muscle and bone. The subcutaneous fat volume in the calves of the women when expressed as a percentage of total limb volume is more than twice that of the men, 31.85% and 14.58%, and in the thigh it is even higher still, 43.68% for women and 16.79% for the men. For muscle volume we have a similar situation as shown for the widths, the men showing an increase of 0.68 litres in the calf over the women, and a very large increase of 4.23 litres in the thigh. The bone volume in the calf includes the fibula; it can be seen that the males have larger bones than the females, 0.80 litres compared with 0.59 litres. This also holds true for the thigh where the mean

TABLE 20. MEANS AND STANDARD DEVIATIONS OF TISSUE COMPONENTS, FAT, MUSCLE, BONE AND TOTAL LIMB VOLUME, CALCULATED FROM RADIOGRAPHS, IN THE CALF, THIGH AND TOTAL LEG OF YOUNG MALES AND FEMALES.

	MALES			FEMALES		
	n	Mean	S.D.	n	Mean	S.D.
Age, yrs.	43	25.80	5.32	15	19.18	1.38
Calf						
Total Volume, litres		5.02	0.83		4.99	0.70
Fat		0.73	0.26		1.59	0.37
Muscle		3.49	0.56		2.81	1.25
Bone		0.80	0.14		0.59	0.05
Fat % of Total Volume		14.58%			31.85%	
Thigh						
Total Volume		12.96	2.04		11.28	1.53
Fat		2.18	0.92		4.93	1.50
Muscle		10.01	1.51		5.78	0.98
Bone		0.78	0.12		0.57	0.05
Fat % of Total Volume		16.79%			43.68%	
Total Leg (Thigh + Calf)						
Total Volumes		17.98	2.78		16.27	2.03
Fat		2.85	1.14		6.52	1.79
Muscle		13.08	1.75		8.59	0.95
Bone		1.58	0.25		1.16	0.09
Fat % of Total Volume		15.87%			40.05%	

values for the femur are 0.78 litres and 0.57 litres for men and women respectively.

Figure 40 shows the relationship between the two methods of calculating the volume of subcutaneous fat in the thigh and calf region of young females from radiographs; one method, by the summation of the fat widths at the 1/3 subischial level, and the other by planimetry of the fat areas. The correlation coefficients - 0.97 and 0.95 for the thigh and calf respectively - are highly significant ($p < 0.001$) with standard errors of the estimate about the regression lines of $\pm$ 0.37 and $\pm$ 0.13. When the thigh and calf fat volume values are added together, the resultant total leg r value is 0.96 S.E. $\pm$ 0.49, the regression line is not significantly different from 1.

Discussion

The published literature on estimating volumes from radiographs is extremely sparse. Stuart, Hill and Shaw (1940) cite Weinbach in a personal communication, for developing a method for estimating volumes from linear measurements of shadows in X-Ray films by a "Method of Frustums". Although this work was carried out in a normal child development study at the College of Physicians and Surgeons, Columbia University, in the 1940's, to date, no published reference can be located. Also Baker, Hunt and Sen (1958) cite Webster, of the Naval Medical Research Laboratory, who utilized the geometric model of frustums of elliptical conic sections in studies on the forearm. Unfortunately no references are given or can be obtained.

Best and Kuhl (1953) derived several formulae based on physical and roentgenologic measurements. They suggested the most accurate method would be to integrate cross-sectional muscle areas over the entire length of the limb and a slightly less accurate approximation would be to split the extremities into cylinders and frustums of cones. In spite of the suggestion they decided to use an extremely arbitrary system which assumes the brachium to be a series of concentric cylinders, with the outer walls limited by the periosteum, outer muscle and the skin surface. On this basis they arrived at the following formulae:

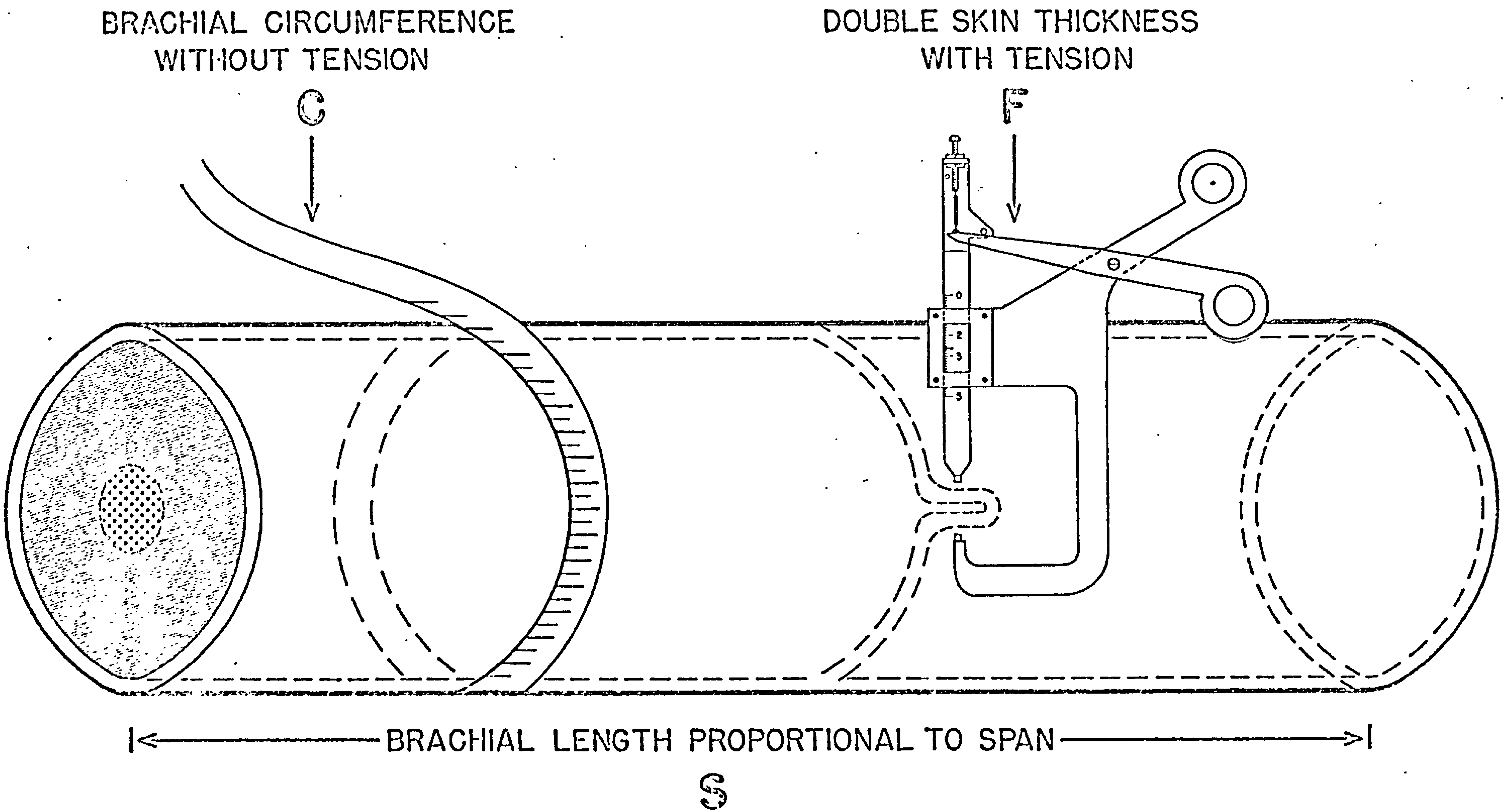
1) Approximate brachial muscle mass $+\pi$ (muscle radius^2 - bone radius^2) x bone.

2) Lean brachial mass = π (muscle radius^2) x bone length.

3) Lean brachial index = Span (brachial circumference - 4.7 x dorsal arm skinfold)^2 x 10^{-5}.

In the third formula the arm circumference is divided by 2 to determine the arm radius and the muscle radius is then arm radius minus $\frac{3}{4}$ of the skinfold thickness by caliper measurement (refer Table 4, p. 45). Therefore, the figure 4.7 in the equation equals $\frac{3}{4} \times 2\pi$ (Fig. 41). The factor 10^{-5} has only been introduced to bring the decimal point into a convenient place.

From Table 4, it can be seen that the mean values from Best and Kuhl for the medial and lateral caliper skinfolds differ considerably, as do the caliper and radiographic ratios. Therefore,



LEAN BRACHIAL INDEX $= S(C - 4.7F)^2$

Fig. 4I: Data from Best & Kuhl, 1953.

one cannot assume the brachium cylinder to have a concentric layer of subcutaneous fat. Whilst Best and Kuhl have rightly stated that the skin is not of a uniform thickness around the entire circumference, their argument falls down when they mention that the dorsal skinfold is, however, easy to measure and appears to be representative for most of the circumference. This technique could have had considerably more validity had they taken a mean value for the corrected medial and dorsal skinfold caliper values.

The first experimental validation of radiographically determined volumes is reported by Garn and Gorman (1956). They determined the actual water displacement of a 33 cm length of thigh and compared the measured volume to the volume obtained by planimetry from standard anterio-posterior radiographs of the left leg. Their results showed that the relationship between the gross thigh volumes and the computed volumes are fully rectilinear and when the radiographic measurements are corrected for magnification, deviations of less than $\pm$ 200 cm^3 in 5000 cm^3 may be expected. Furthermore, Garn pointed out that on this basis, fat, muscle and bone may also be obtained by planimetry. Garn (1961) states that fat volume calculated from leg cylinders may possibly provide a better indication of total fat, but such volumes may over-estimate or under-estimate the true value unless the limb is treated as a number of truncated cones.

It can be seen from Table 21 that the results show a close agreement in spite of two different methods being presented. However, from a practical consideration the method of planimetry is time-consuming and laborious, especially in view of having to make at

TABLE 21. COMPARISON OF THE EXPECTED DEVIATIONS BETWEEN GROSS THIGH VOLUMES BY WATER DISPLACEMENT AND COMPUTED THIGH VOLUMES IN YOUNG WOMEN FROM TWO DIFFERENT STUDIES.

	Jones U.K. 1970	Garn and Gorman U.S.A. 1956
Mean computed Thigh volumes, cm^3	5.405	5.000
Deviation between gross and computed volumes	±0.235	±0.200
Range	4,520 - 7,540	2,900 - 6,315
Weight, Kg. range of subject	52 - 77	61 - 109
Mean thigh length, cm.	30.4	33.0

least three measurements of each parameter, because the chances of getting the same reading twice with the planimeter on a hardened gloss cellulose nitrate X-Ray film base is remote.

It appears from the results that the roentgenogrammetric method slightly over-estimates the gross thigh volume for the males and females. This may be due to taking into the calculation an insufficient number of truncated cones. Whilst this, in theory, is relatively simple, in practice, it adds further complications and time to the method, when bearing in mind that for population studies the methods should be reasonably uncomplicated, yet yield reliable results.

In a present study, with the thigh placed in an anterio-posterior position, it is hoped to reduce considerably this over-estimation.

The gross limb volume values, determined by the roentgeno-grammetric technique (Jones, 1969) discriminate between the sexes more clearly than do the limb tissue width techniques without having to go further and examine the underlying components. Yet the actual degree of dimorphism is only correctly revealed when the tissue composition is examined separately. If we consider the total leg (thigh + calf), the men have larger gross volumes, 17.98 litres compared with 16.27 litres for women. They also have more bone volume and an enormous muscle difference, 13.08 litres in comparison to 8.59 litres for women. The situation is completely reversed when the fat values are examined, with the women having

2.3 times more than men. It is interesting to express the fat in the legs of males and females as a percentage of their mean total body fat (calculated from $\Sigma 4$ fat skinfolds after Durnin and Rahaman, 1967) and for men it is approximately 29% and strikingly, 37% for women.

Advantages of soft-tissue Roentgenogrammetry

One of the major advantages of the roentgenogrammetric technique is that it can yield independent measures of fat, muscle and bone (cortex and medulla). The radiographic technique is extremely useful for evaluating the thickness of subcutaneous fat from sites which may prove difficult to pick up and accurately locate with skinfold calipers, especially in areas which show sex dimorphism, e.g. posterior thigh, calf, iliac and mid-trochanteric sites. The quantification of bone from X-Rays has mainly been from the measurements of widths and areas (Stuart, Hill and Shaw, 1940; Stuart and Dwinell, 1942; Reynolds and Grote, 1948; Lombard, 1950; Garn and Saalberg, 1953; Tanner at al., 1959; Tanner, 1962 and 1965; Maresh, 1963; and Malina and Johnston, 1967), but the data derived from volumes are virtually lacking apart from Stuart and his colleagues (1940) who cut and weighed the separate areas in the leg X-Ray shadows. It has been questioned by Garn (1961) whether information from bony widths provides useful indicators of the general skeletal mass, and it may well be that with the additional contribution of length and area, the volume of bone may provide additional knowledge of the mineral mass in a healthy population. The estimation of the bone volume in this research was primarily aimed at separating the compartments of bone and muscle.

In particular, the roentgenogrammetric technique provides the opportunity for multi-disciplinary studies on body composition where estimates of total body fat, muscle mass and skeletal weight may be fairly accurately predicted from single sites such as the arm, calf or thigh. Whilst the area of total body fat prediction from radiographic sites has received considerable attention (Garn, 1957a, 1957b, 1957c; Brozek and Mori, 1958; and Brozek, Mori and Keys, 1958), the study of the intercorrelation of relative muscularity with the total body muscle to an acceptable degree of accuracy is in its infancy.

In addition, radiographs present permanent records and a quick visual appraisal of the relative amounts of fat, muscle and bone; also it has its attractions when a rapid system of classification is called for.

Disadvantages

These are set out and discussed on page 120 under the heading "Problems arising from Soft-Tissue Radiography".

Reliability

Possible sources of error occur through bad technique in positioning the limbs to be radiographed and taking measurements from the X-Ray films. However, these errors have been reduced to a minimal level by employing a single experienced observer. The differences between experienced and inexperienced workers was tested in a measurement trial by examining two films which had been inserted into single cassettes. There were differences which, although relatively small, were mainly due to the inexact location with the caliper needle point, of the neighbouring compartments of fat, muscle and bone. Because of this, all measurements were made by one experienced observer.

Problems arising from soft-tissue radiography

1) Equipment - Some of the major important factors making the use of X-Ray equipment somewhat prohibitive are:- the availability of suitably qualified staff (Code of Practice 1969), expense, suitable rooms or laboratories which require special ventilation and protection for operators as well as personnel outside the buildings. For non-portable, fully rectified apparatus special earthing and a 3-phase 440 volt supply, operating and material costs are high. Most important of all the hazards of X-Radiation.

2) Radiation Hazards - So far as this study is concerned, these arise from machines and apparatus which emit penetrating ionizing radiations. X-Rays are of heterogeneous quality in a broad spectrum, but in general terms two types of irradiation may be identified: (a) X-Rays of a relatively long wavelength are known as "soft" rays and have a marked biological effect upon the skin and

superficial tissues, and (b) the X-Rays of short wavelength which are known as "hard" rays and which are responsible for the penetration of the deeper and more dense tissue. To prevent the "soft" rays striking the tissues and so giving up their energies, which are absorbed and are damaging, an aluminium filter is placed beneath the aperture of the X-Ray tube. The filter absorbs the "soft" rays and allows mainly the "hard" homogeneous beam to be transmitted through the tissues without giving up their energies.

The hazards of exposure to X-Rays are great, not only for the operator, because the dose is cumulative, but for the subject. Therefore, great care is exercised in their control and use. The International Commission on Radiological Protection (1960) gave particular significance to the general effects of radiation of the body in particular to the blood-forming organs, e.g. production of anaemia and leukaemia, and the gonads, e.g. gene mutation, chromosomal aberrations. It is with this particular reference in mind that special attention has been paid to gonadal and skin protection.

3) Protection and Clothing - During the preliminary stages of this investigation the protection of the gonads was provided by overlapping lead scales contained in a specially designed flexible garment - *"Armadillo" (Tanner, Whitehouse and Powell, 1958), in the form of a jockstrap for the males and an apron for the females. Subsequent observation (Clark, personal observation, and Jones, 1970)

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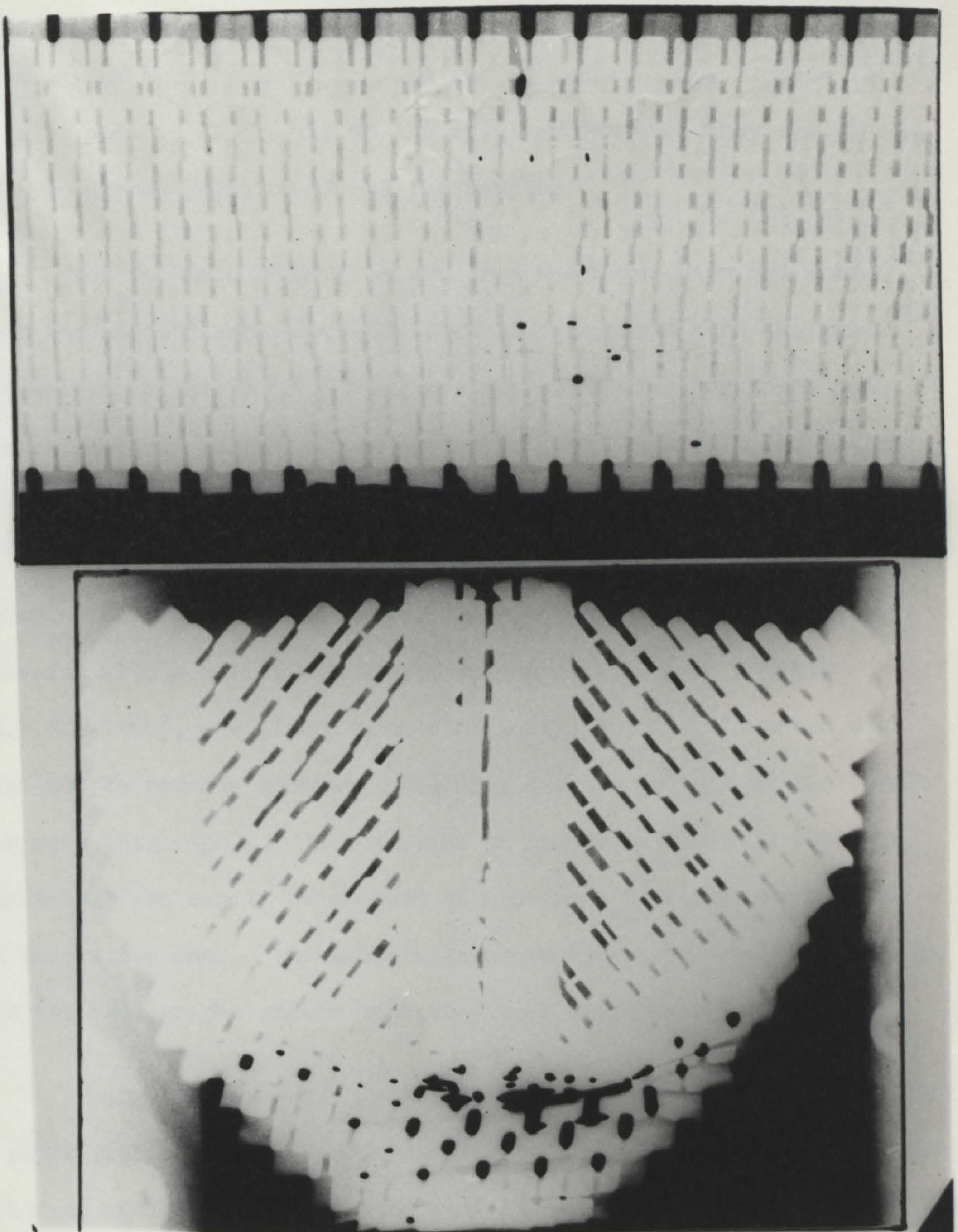
*The word "Armadillo" is a registered trade mark.

showed that after continuous use some of these garments became permeable to X-radiation, as was demonstrated when a film badge, placed behind a male "Armadillo" protector, was shown to have an excessively high reading of approximately 20 mrad. As this dose had resulted from peripheral radiation and not from the primary beam, doubt was cast on the effectiveness of the protector and an immediate investigation was set up to look at skin and gonad doses together with the effectiveness of a new gonad protector during soft-tissue radiography.

5. The Investigation on Skin and Gonad dosages during Soft-tissue Roentgenogrammetry.

Current information of gonad protection, skin and gonadal doses during investigative radiography has been limited to the work of Tanner et al. (1958) and Garn et al. (1957, 1963, 1964 and 1967). Although much published data exist on radiographic studies of body composition they do not state what measures, if any, were taken to ensure adequate protection to the subjects, or levels of radiation received (e.g. Malina and Johnston, 1967).

To make certain of the doubt cast on the effectiveness of the male and female "Armadillo" they were X-Rayed in the position to be encountered when wearing them. The prints from radiographs (Fig. 42) reveal defects in the metallic lead "scales" and in their overlap, allowing primary radiation to pass. Leaks in the garments occur through handling, such as throwing on to a table top after use,



a).

b).

Fig. 42. Radiographic prints demonstrating radiation leaks in the a) Female and b) Male "Armadillo" protective garments.

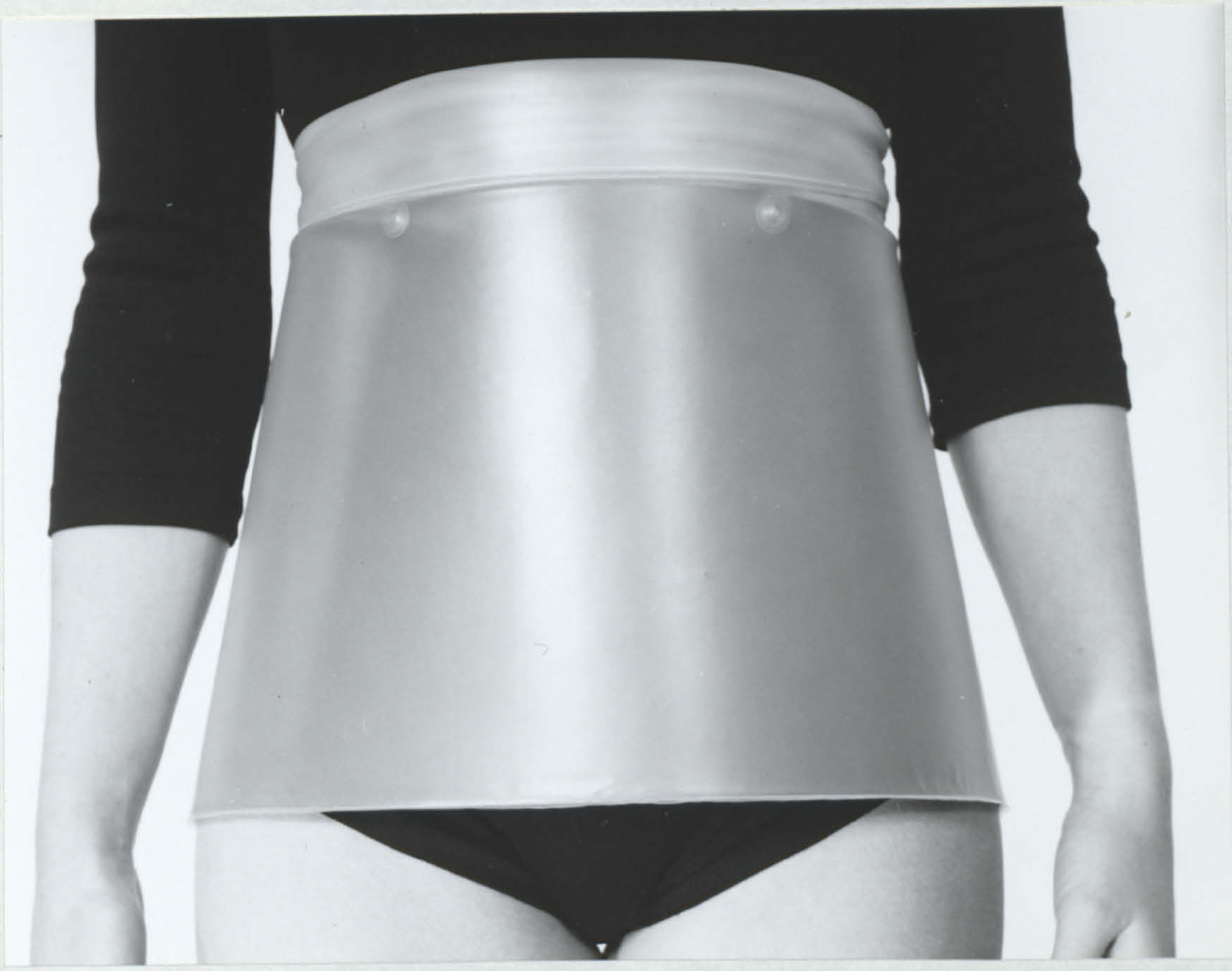
causing the lead "scales" to bend out of shape. The "scales" also tend to open up especially in the male garment when they are placed in the desired position around the scrotum.

For the next studies on men from the Royal Navy and women from the Cardiff area, two new protective garments were designed. The male lead shield (Fig. 43a) was approximately 1 mm thick and was attached to an underlying strong polythene mould for retention of shape and rigidity. The lead shield was placed into a pouch in a "jock strap" which was easily cleaned or sterilised with organic chlorine compounds. Tan grade "protoled", a lead-loaded plastic material with a metallic lead equivalent of 0.5 mm at 150 kVp (R.P.S., 1966), was placed inside a special P.V.C. belt which was designed to provide adequate shielding for the ovaries of the female subjects (Fig. 43b). In the event of damage to the belt the "protoled" can easily be removed by undoing a fastener and placing it into a new one. The two new garments were irradiated at 125 kVp, and the radiographs showed that they were completely radiopaque.

Using the new gonad protectors, an experiment was set up with a water filled phantom, used to simulate the scattering effect of a subject, whilst measurements of radiation dose in millirads in air were made.

A portable X-Ray dosemeter E.I.L. model 37.C in conjunction with a 35 cm^3 ionization chamber was used to measure the radiation dose. The minimum dose detectable with this instrument is 0.01 mrad.

a).



b).

Fig. 43. New types of gonad X-Ray protectors, a). for males and b). for females.

The gonad dose was measured by placing the ionization chamber on the surface of the phantom nearest to the X-Ray tube, directly over the positions which would be occupied by the gonads (Fig. 44a). However, the radiation dose figures given for the female gonads were measured with the ionization chamber at the level of the iliac crest in two positions, viz. (a) for the calf exposure: on the anterior surface in the midline, (b) for the thigh exposure: on the lateral surface in the midline. No attempt was made to calculate the actual ovary dose by interpolation, using a computer programme, as was reported by the Adrian Committee (1960).

The skin dosages were measured with the ionization chamber taped to the phantom in a central position, marked by a light beam centering device, of the part to be radiographed (Fig. 44b).

It was realised that during radiography of the arm, the female gonads would lie behind the cassette, whereas the male gonads could lie either behind or below the cassette depending upon the stature of the subject. Consequently, measurements were made under conditions which simulated both these cases (Table 22).

The X-Ray diagnostic set used was a General Radiological 125 kVp, 400 mA fitted with a Mullard rotating anode, with effective focal spot sizes of 1.2 mm^2 and 2.0 mm^2. Inherent filtration in the tube was 0.7 mm aluminium with a further 1.0 mm aluminium added, which together with the 1.5 aluminium filter in the light beam delineator attachment made a total filtration of 3.2 mm aluminium-equivalent.

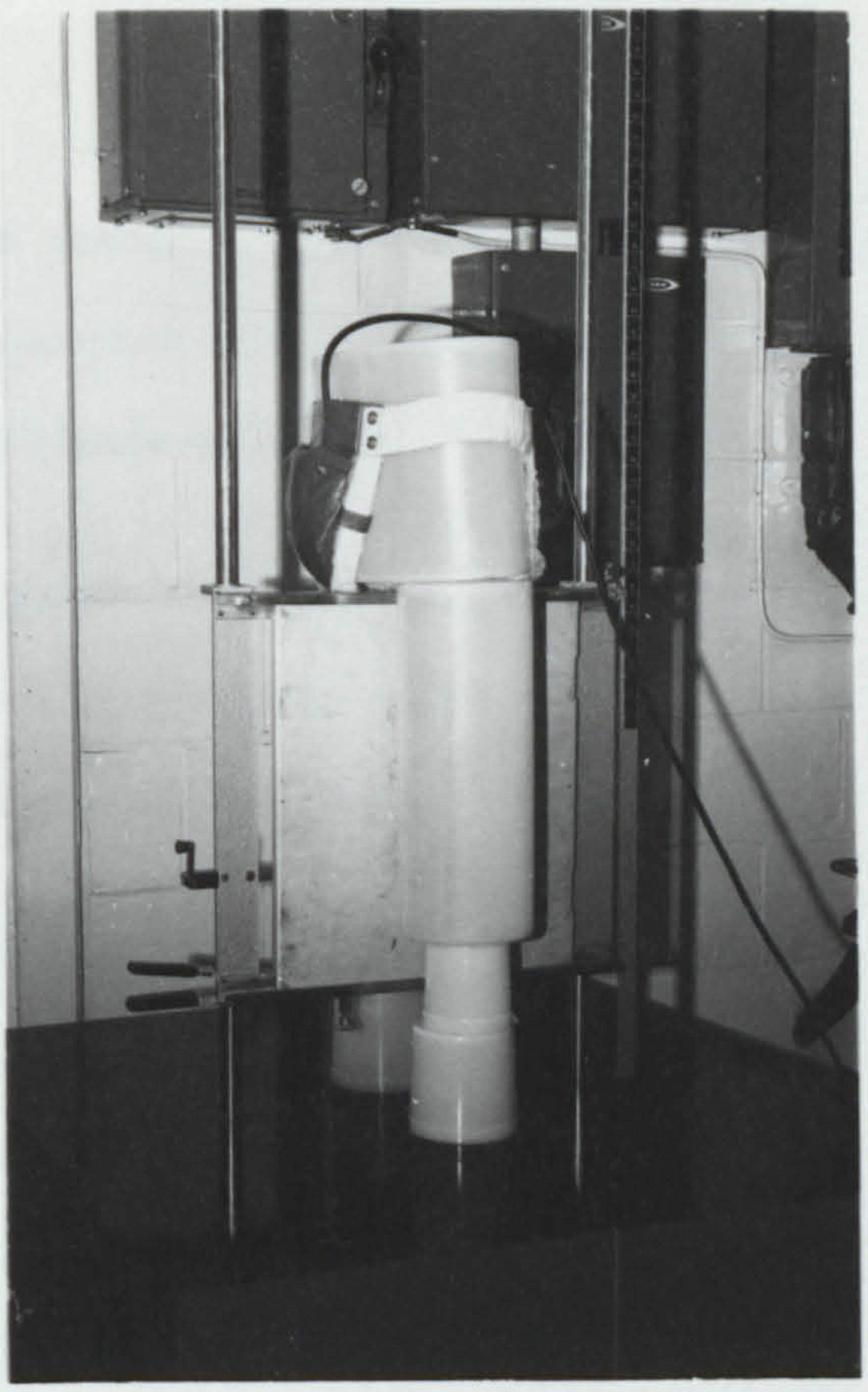


Fig. 44a).
Measurement of the radiation dose to the gonads, behind the male protector.

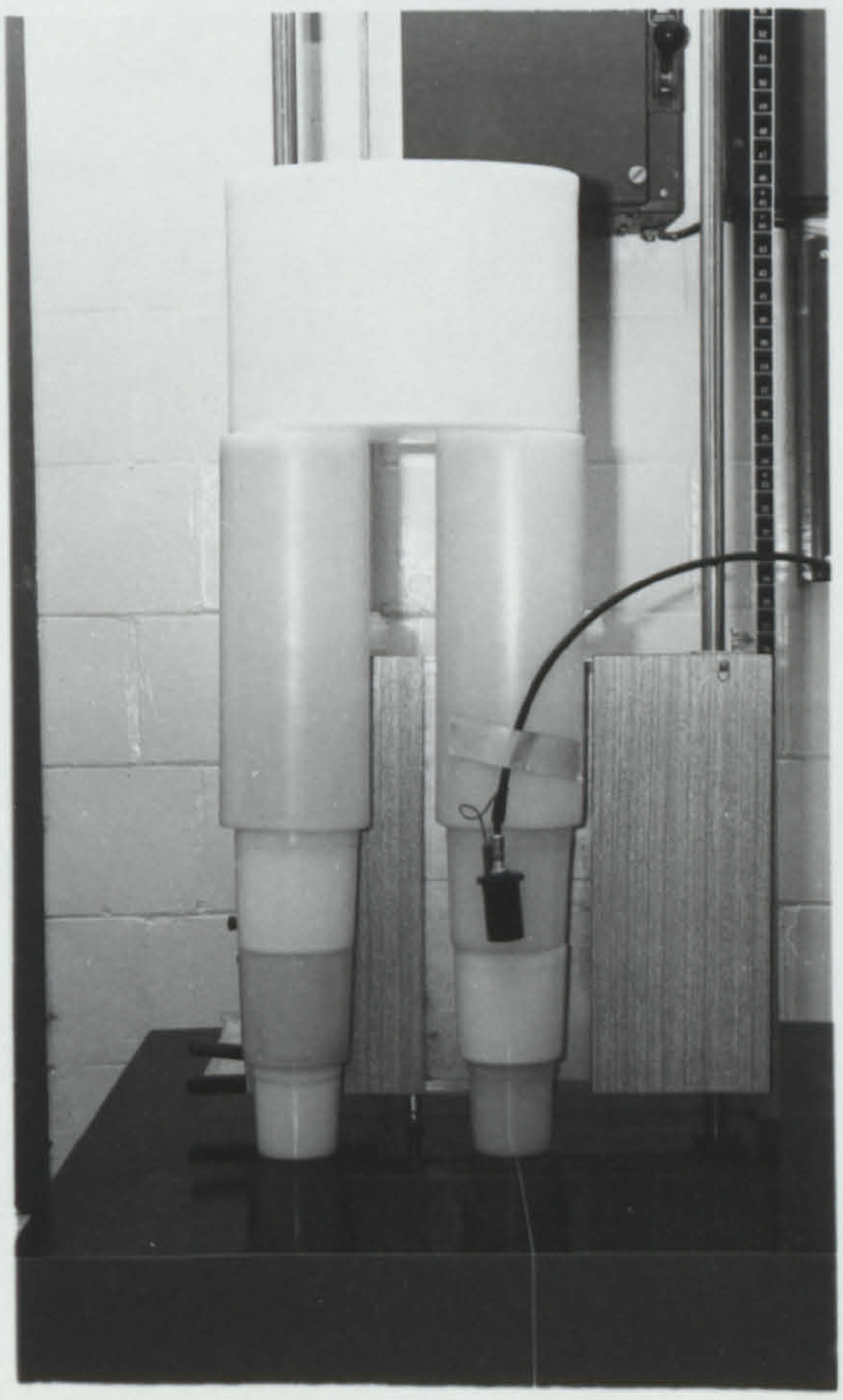


Fig. 44b).
Measurement of the radiation dose to the skin on the thigh of a phantom.

Prior to the radiation measurements being made. the X-Ray service engineers carried out calibration tests on the synchronous motor timer and milliampere meter.

Fast film (Kodak blue brand), fast itensifying screens (Kodak Standard) and forced development enabled the exposure values to be kept low, so minimising the levels of radiation.

The exposure values varied with the physique of the subject and the part of the body being examined. However, for this experiment the maximum values that would be encountered were used. These criteria were based on a large male subject whose weight fell around the 95th. percentile (76.2Kg). They were: arm 55 kVp at 20 mA seconds; calf 65 kVp at 20 mA seconds and for the thigh 75 kVp at 25 mA seconds, and in all cases the anode to film distance was kept constant at 2.5 metres (98.43 inches). At the time of aligning the central beam on the object, great care was taken to adjust the light beam diaphragms so that the useful beam did not overlap the area of the cassette, viz. 17" by 7" for the arm and calf, and 17" x 14" for the thigh.

Results

As shown in Table 22 the skin dose as measured in the primary beam (average of three determination) was 12 mrads for the arm, 23 mrads for the thigh and 16 for the calf - a total of 51 mrads.

The gonadal doses as measured behind the protectors ranged from 0.01 mrad to 0.13 mrad, depending upon the position of the gonads

TABLE 22. RADIATION DOSAGE (MRAD) TO THE SKIN AND GONADS IN YOUNG MALE AND FEMALE ADULTS, DURING SOFT-TISSUE ROENTGENOGRAMMETRY.

Position of Measurement and Conditions (Using water filled phantom)	No. of Exposures	Total Dose (mrad	Dose for one exposure (mrad)
1. <u>Radiography of Arm</u>			
Skin dose (arm, mid shaft of humerus)	1	12	12
Approximate position of gonads (male and female, <u>behind</u> cassette, <u>with</u> gonad shield).	5	<0.01	<0.01
Approximate position of gonads (male and female, <u>behind</u> cassette, <u>without</u> shield.	4	0.06	0.02
Approximate position of gonads (male, <u>below</u> cassette, with shield).	3	0.3	0.1
2. <u>Radiography of Thigh</u>			
Skin dose (thigh, 1/3 subischial height)	1	23	23
Gonad position (male, with shield)	3	0.4	0.13
Gonad position (female, i.e. at the iliac crest level, with shield)	2	0.2	0.1
3. <u>Radiography of Calf</u>			
Skin dose (calf, at maximum circumference)	1	16	16
Gonad position (male, with shield)	4	0.06	0.02
Gonad position (female, with shield)	3	0.02	0.01

TABLE 23. MEASUREMENTS OF RADIATION DOSE TO THE MALE AND FEMALE GONADS WITHIN THE USEFUL X-RAY BEAM.

Position of Measurement	Exposure		Dose for one Exposure (mrad)
	kVp	mAS	
Male gonads) with Female gonads) shield	75	24	0.15 0.2

at the time of exposure. It should be emphasised that the reading of 0.13 mrad was obtained for the male shield, with the phantom in the lateral position, and some difficulty was encountered in completely covering the large 35 cm^3 ionization chamber.

Further measurements were made to estimate the gonad dose should they lie within the useful beam, a condition which could occur through inaccurate centering of the X-Ray tube. The results are shown in Table 23.

Discussion and conclusion

A combination of fast films, moderately fast intensifying screens, adequate filtration (not less than 3 mm al. Garn, 1963, 1967), light beam delineators and forced development, make it possible to reduce skin and gonadal dosages to an extremely low level. Tanner (1962 and 1965) reported a total skin dose for his three procedures of about 66 mrad with the gonad dose being too small to be measured.

His figures of 66 mrad which are for children, at an exposure which implies a dose of about 100 mrad for an adult the size of ours, can probably be explained by the techniques and equipment available in the nineteen-fifties. Thus the new equipment and procedures lead to a saving of 50%, although it should be emphasised that there may be discrepancies in these figures due to variations in output between X-Ray tubes and in the calibration between generators.

Garn (1967) published figures of 16.8 mrad for a large muscular adult anterio-posterior leg using exposure factors of 62 kVp, 40 mAs at 6 ft. anode film distance. Because the tube filtration of 3 mm was similar to ours, comparisons can be made when the anode film distance is altered to 2.5 metres (98.43 ins.). To obtain a radiograph of equal density at this distance an exposure of 75 mAs would have to be given. It can be seen that this value is very nearly four times that of our calf exposure (20 mAs), yet a figure obtained for the skin dose was similar (16 mrad). Having consulted the tube rating charts for the given kVp, mAs, filtration and anode film distance factor (I.C.R.P.3, 1960), it was found that a theoretical calculation of 18.5 mrad agreed favourably with that of our dosemeter reading of 16.0 mrad. Discrepancies in these figures may be due to variations in output between tubes and in the calibration between generators.

It has been mentioned that a variation in the male stature could cause the gonads to lie below the level of the lead lined cassette, although still reasonably protected by virtue of being outside the boundaries of the useful beam. Because this possibility exists the pose for the arm has been modified so that the subject now adopts a kneeling position with the left side of the body against the vertical cassette stand.

In considering the total of the three measurements made on the phantom with the male gonad protector, it should be remembered that the values are probably too high. Firstly, owing to the size and shape of the ionization chamber, considerable difficulty was experienced in securing the shield in position and completely covering the chamber. Secondly, because the measurements were taken on the surface of the phantom they may be biased towards a higher reading through the lack of considerable attenuation that would be encountered in the surrounding body tissues. In the three soft-tissue radiographic procedures the actual dose received by the gonads, especially in the female, will therefore, be less than the reading of 0.17 mrad. The maximum permissible dose to the gonads as stipulated in the Code of Practice (H.M.S.O., 1964) for non-designated persons is 1.5 rems (1,500 mrems) per year, which gives a large safety margin when reporting dosages in fractions of a mrad. However, Garn et al. (1967) points out that because of the ethics involved with volunteer subjects the gonadal doses should be kept at below 1 mrad per year, and local skin dosages to a fraction of the natural background radiation (100 to 300 mrad per year). For these reasons it would appear, therefore, that the techniques described, using suitable apparatus and the new protective garments, keep levels of penetrating radiation to the skin and gonads to an extremely low level.

There is evidence from the first study, which suggests that the "Armadillo" garment is unsatisfactory and that its use should be discontinued. The new gonad protectors appear from the results to be entirely satisfactory and may provide an alternative for investigation and normal diagnostic radiological procedures.

Researchers are ethically obliged to discipline themselves in strict radiation hygiene rules particularly in the use of proper gonadal protection.

CHAPTER VI

CHAPTER VI

PREDICTING TOTAL BODY FAT FROM RADIOGRAPHIC FAT TISSUE WIDTHS, VOLUMES AND LEG SKINFOLD CALIPER MEASUREMENTS.

1. Introduction.

Brozek, (1956) has shown that measurements of thickness of subcutaneous fat can be used for estimating man's fatness, and from percentile norms the relative fatness of an individual can be judged. However, it is desirable for most purposes to have absolute measures of body fat rather than relative ones and considerable literature exists on how this has been accomplished (Garn, 1961). The majority of studies have calculated the total body fat, by estimating the body density, the whole body volume having been obtained by under water weighing or water displacement, with correction made for the residual air in the lungs and respiratory passages (Buskirk, 1961). Estimates of fat made from densitometry have been used to predict percentage body fat from simpler measurements like skinfold caliper values (Keys and Brozek, 1953; Pascale et al., 1956; Sloan et al., 1962; Sloan, 1967; Durnin, and Rahaman, 1967; Durnin and Womersley, 1969 and Haisman, 1968). Equations for predicting body density, hence, total body fat, from radiographic estimates of fat widths have been made by Garn (1957), Brozek, Mori and Keys (1958).

In this study the total body fat was estimated by the method of Durnin and Rahaman (1967). Their separate regression equations for men and women, aged 18 to 33 years, predict the density value D from the sum of 4 skinfold measurements (Biceps, triceps, subscapula and suprailiac).

The percentage of body fat was calculated from Siri's (1956) formula:

$$\% \text{ fat} = \left(\frac{4.95}{D} - 4.5\right) \times 100$$

2. Results and Recommendations.

a) Prediction from fat widths and volumes.

In Table 24 the findings relate fat width and fat volume in the thigh, calf and total leg of 32 male and 15 female young adults to total body fat. It can be seen that for men, the total leg (i.e. Σ 4 fat widths from the Thigh + Calf) shows the best positive relationship with a significant r value of 0.82 ($p < 0.001$) s.e. of estimate 1.95%, Coefficient of Variation 14.6%. For women, the thigh (Σ2 fat widths) offered the highest correlation with body fat r = 0.51 ($0.05 < p < 0.02$) which is not highly significant, and the s.e. of estimate 3.59%, is almost twice that for men. The results also show very similar values for the fat volume estimates and when the correlation coefficients for the difference between correlated samples were tested (i.e. male and female fat widths 'r' vs Fat vol. 'r') the 't' values were non-significant.

It appears that the two techniques are equally good when used for the prediction in men of total body fat, but it is recommended that the width technique is to be preferred due to its simplicity, and accuracy in prediction. Neither of the techniques are recommended for women.

b) Prediction from leg skinfold caliper measurements.

Harpenden skinfold caliper measurements from 4 leg sites viz. anterior and posterior thigh, medial and lateral calf have been related to total body fat %. Table 25 shows the coefficients of correlation for the individual sites, together with the thigh and calf sites summed and then a combination of all four regions. The highest coefficients of correlation were found in the anterior thigh site for men $r = 0.83$ ($p < 0.001$), but in anterior and posterior thigh sites combined for women, $r = 0.75$ ($p < 0.001$).

The data show that total body fat can be estimated with a reliability of $\pm$ 1.84% for men and $\pm$ 2.91% for women by using simple and convenient methods such as skinfold caliper measurements. For men, the anterior thigh site at the 1/3 subischial level is recommended and for women, a summation of the anterior and posterior thigh skinfold values.

TABLE 24. COEFFICIENTS OF CORRELATION, STANDARD ERROR OF THE ESTIMATE AND COEFFICIENTS OF VARIATION ARE GIVEN FOR THE TOTAL LEG, THIGH AND CALF FAT WIDTHS AND VOLUMES FROM RADIOGRAPHS VS % TOTAL BODY FAT.*

	Fat Width X-Ray						Fat Volume X-Ray					
	Males			Females			Males			Females		
	r	S.E. of Est.%	C of V %	r	S.E. of Est.%	C of V %	r	S.E. of Est.%	C of V %	r	S.E. of Est.%	C of V %
TOTAL LEG	0.82	1.95	14.6	0.48	3.65	13.0	0.78	2.13	15.9	0.44	3.73	13.3
THIGH	0.80	2.07	15.5	0.51	3.59	12.8	0.77	2.20	16.5	0.47	3.68	13.1
CALF	0.71	2.40	17.9	0.26	4.02	14.3	0.74	2.29	17.1	0.25	4.04	14.1

* Calculated from 4 skinfold measurements after Durnin and Rahaman (1967)

TABLE 25. LEG SKINFOLD CALIPER SITES FOR YOUNG MALE AND FEMALE ADULTS CORRELATED WITH TOTAL BODY FAT, (ESTIMATED BY THE METHODS OF DURNIN AND RAHAMAN, (1967)).

	n	Anterior Thigh	Posterior Thigh	Thigh Sites	Medial Calf	Lateral Calf	Calf Sites	Total Leg 4 Caliper Sites
Males	32	0.84***	0.50**	0.72***	0.43*	0.59***	0.52**	0.70***
Females	15	0.71**	0.61**	0.72***	0.55**	0.24	0.46	0.69**

Levels of Significance *** $p < 0.001$

** $p < 0.01$

* $p < 0.05$

CHAPTER VII

CHAPTER VII

THE CONTRIBUTION OF INDICES OF LIMB MUSCLE TO MAXIMAL OXYGEN UPTAKE AND WHOLE BODY POTASSIUM (^{40}K)

1. Introduction.

The capacity for exercise of normal subjects may be described as the maximal uptake of oxygen (VO_2 Max) that the subject can sustain during progressive exercise, when an increase in the work load does not cause an increase in the oxygen consumption. It is during this sustained period of maximal exercise, which is about two minutes, that the gas sample values for oxygen should not vary by more than 5%. The overall function of the oxygen transport system of the body is reflected in the VO_2 Max, and in spite of the transport of oxygen being a function of numerous physiological variables. The concern of this chapter is to estimate the amount of active muscle capable of utilizing that oxygen.

The indices of limb muscle were obtained by soft-tissue Roentgenogrammetry, Anthropometry and the Total Body Potassium.

The prime requirement is to relate indices of muscle to maximal oxygen uptake and to whole body potassium. As a consequence the merits of alternative muscle indices must be compared and practicability of measuring the volume of the muscle as opposed to the width be studied. A second requirement is to indicate which muscle index would be most appropriate to use in routine population studies.

2. The Measurement of Maximal Oxygen Uptake.

Materials and Methods.

The exercise was performed using a Müller cycle ergometer. The subjects were allowed to become accustomed to this procedure by cycling at 450 kpm/min. for 4 minutes which also served as a warm-up period, after which they rested for 10 minutes. Initially, the period of exercise was for 6 minutes at a work load of 450 kpm/min. (73.5 watts), this again was followed by a rest period of approximately 8 minutes or until the heart rate had returned to within 5 beats/min. of the frequency at the initial resting period. The male and female subjects next cycled for a further 6 minutes at a higher work load- 900 kpm/min. (147 watts) and 720 kpm/min. (118 watts) respectively. Another rest period ensued, after which the maximum oxygen uptake was assessed using a continuous work load after the method of Binkhorst and Van Leeuwsen (1963). On this procedure the work load was increased at 2 minute intervals from a starting point determined from the subjects response to submaximal exercise.

The subjects inspired through a low resistance valve (Bannister and Cormack, 1954) and the expired gas was collected over the last 2 minutes of the exercise in a 'Plysu' non-diffusable Douglas bag via a short length of corrugated 'Dacron' tubing. The Douglas bag, suspended to reduce its resistance, was subsequently emptied through a Parkinson Cowan CD4 dry gas meter. The mixed expired gas sample, collected in 2-litre polyvinyl gas sample bags, was analysed for oxygen and carbon dioxide using a Servomex 101A meter and a Cambridge Indicator (Kathometer) respectively. These gas analysers were calibrated against a Haldane-Lloyd gas analysis apparatus (Lloyd, 1958).

The expired air samples and volumes were corrected to standard temperature and pressure for dry gas (STPD).

3. The measurement of Total Body Potassium.

Introduction.

Since radiation counters built for health physics survey work have become more refined and made more sensitive it has been possible to detect low level naturally occuring radioactivity in the human body. As a result, in vivo measurements of total body potassium utilizing whole-body radiation counters have made an important contribution to the investigation of body composition.

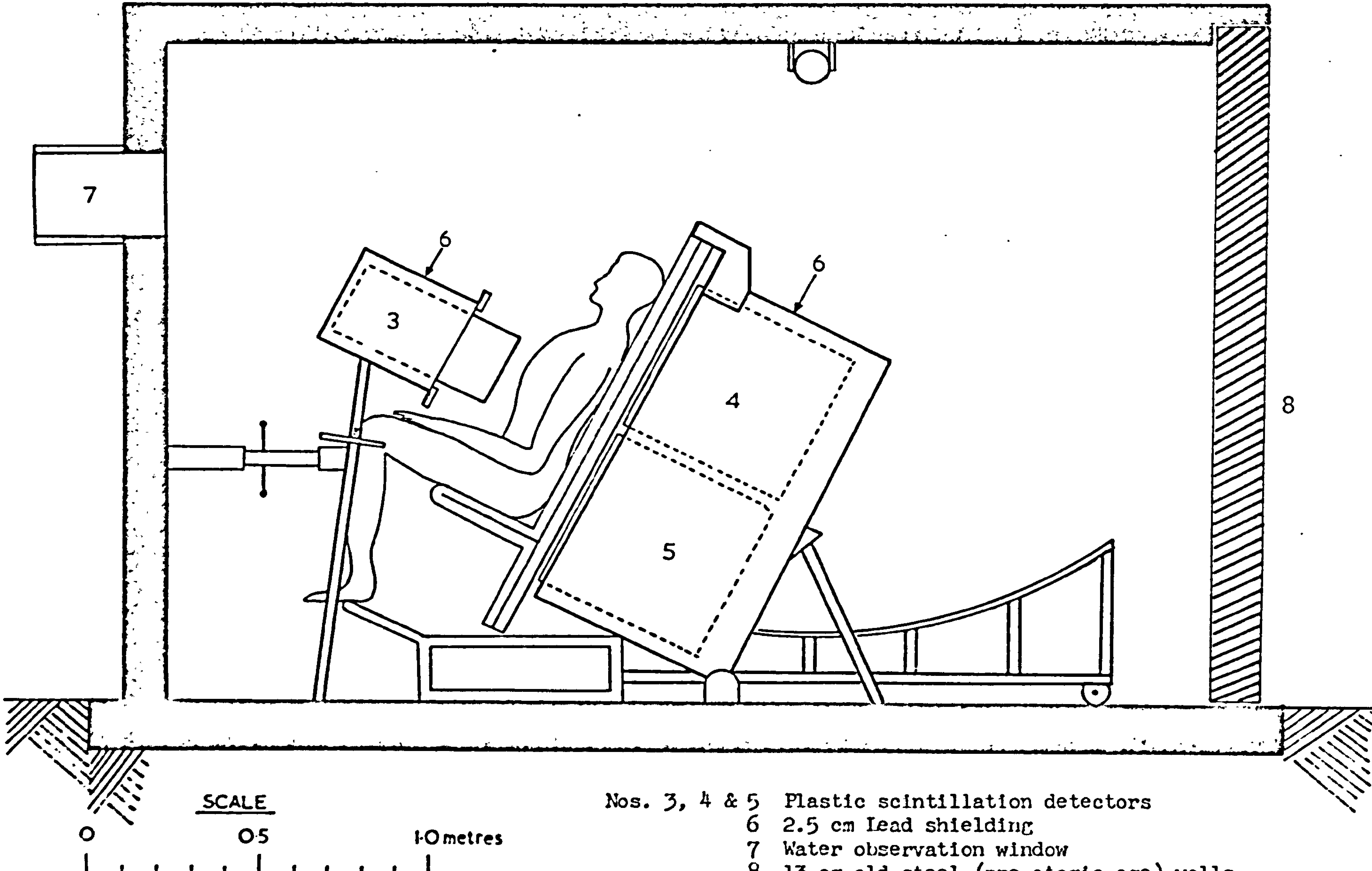
In two separate papers by Burch and Spiers (1953) and Reines et al. (1953) came the first reports of in vivo measurements of total body potassium by counting the naturally occuring potassium isotope ^{40}K. Anderson (1957) described an improved counter which gave a coefficient of variation of the potassium estimate of 6%, at the same time he confirmed the linear relationship between body potassium and lean body mass. Allen et al. (1960) and Anderson (1963) published detailed quantitative data comparing lean body weights obtained from potassium, water and body density measurements. In a study on over 4,000 cases Burmeister (1965) showed a high correlation when examining the increase of total potassium with body weight in males and females. The relationship also demonstrated a sex difference which Burmeister believed was attributed to a difference in body composition.

Reba, Cheek and Leitnaker (1968) in a chapter on "body potassium" and "lean body mass" summarise their findings by stating that lean body mass (LBM) differs in composition depending on the sex. The potassium concentration in the LBM was significantly higher in the male. That there is a difference in the LBM of boys and girls highlights the possibility that boys have a higher percentage of muscle cells relative to visceral cells. Further, it appears that muscle cells have a higher concentration of potassium than do visceral cells.

The stable pool of potassium, which is an essential constituent of human tissues, contains only a small fraction (0.0119%) of the naturally occuring radio isotope ^{40}K. It emits β-particles and γ-rays of 1.46 Mev. and is highly stable with a half-life value of 10^{9} years. The isotope emits approximately 330 γ-rays per second in a typical body potassium content of 100g, and a proportion of these can be detected by sensitive, sodium iodide or plastic scintillation whole-body counters placed around the body.

Materials and Methods.

The subject, having showered (to remove any environmental radiation) and donned a light cotton gown, reclines in a chair housed in a room with steel walls 13 cm, thick, lined with 2.5 cm. of lead in the method of Burkinshaw and Spiers (1967). Surrounding the chair are grouped three large plastic scintillation detectors (Fig. 45).



Nos. 3, 4 & 5 Plastic scintillation detectors
6 2.5 cm Lead shielding
7 Water observation window
8 13 cm old steel (pre-atomic age) walls.

Fig. 45. Whole body potassium monitoring in a special counting chamber.

Gamma ray activity in the ^{40}K photo peak is recorded by a multichannel pulse height analiser for 20 minutes. The observed counting-rate is a measure of the amount of ^{40}K present in the body, minus a correction for the background radiation pre-recorded for 60 minutes. The nett counting rate was multiplied by a calibration factor, which is a linear function of the ratio of the subject's weight and height (Burkinshaw, 1967). The calibration was achieved by administering a small oral dose of the isotope ^{42}K, which is short lived (half-life value 12.5 hours) and has similiar energies (1.52) Mev.) to ^{40}K, moreover, after absorption, the macroscopic distribution in the body is almost identical to that of natural potassium (Hughes, 1963; Wilson, 1964). Therefore, the counting rate from ^{42}K is very nearly equal to that of natural potassium which emits γ-rays at the same rate.

In this study, using Burkinshaw's calibration factor F (gK/count per min.) the coefficient of variation of the potassium estimates about the regression line is $\pm$ 4%.

4. <u>Inter relationship of the indices with total body potassium.</u>

a) VO_2 Max vs. ^{40}K.

Because the VO_2 Max is related to the amount of muscle which can be brought into use during most forms of exercise, it should be related to the total amount of body muscle. Body potassium (^{40}K) being mainly intracellular (Reba et al. 1968), it can provide an estimate of the body cell mass and indirectly a measure of total body muscle as well as the capacity for exercise. Figure 46 shows these two variables ^{40}K and VO_2 Max to be highly correlated in the male sample $r = 0.82$ ($p < 0.001$), whilst for the female group the value $r = 0.44$ ($p < 0.05$) is reduced. The VO_2 Max measurements, made on a young group of male Physical Education teachers and on a group of female student teachers, can be used for predicting the amount of potassium in the body of young male and female adults with a coefficient of variation of 9.1% s.d. $\pm$ 13.8 gm and 7.9% s.d. $\pm$ 7.7 gm.

In the 1966 study for the International Biological Programme (I.B.P.), Cotes (1969) and co-workers showed values of $r = 0.69$ ($p < 0.001$) and $r = 0.77$ ($p < 0.001$) males and females respectively, between ^{40}K and VO_2 Max. These measurements were made on 23 male and 20 female healthy factory workers and when the oxygen values were used to predict the potassium levels in these groups they showed coefficients of variation for males and females $\pm$ 10.7% and $\pm$ 10.9% respectively.

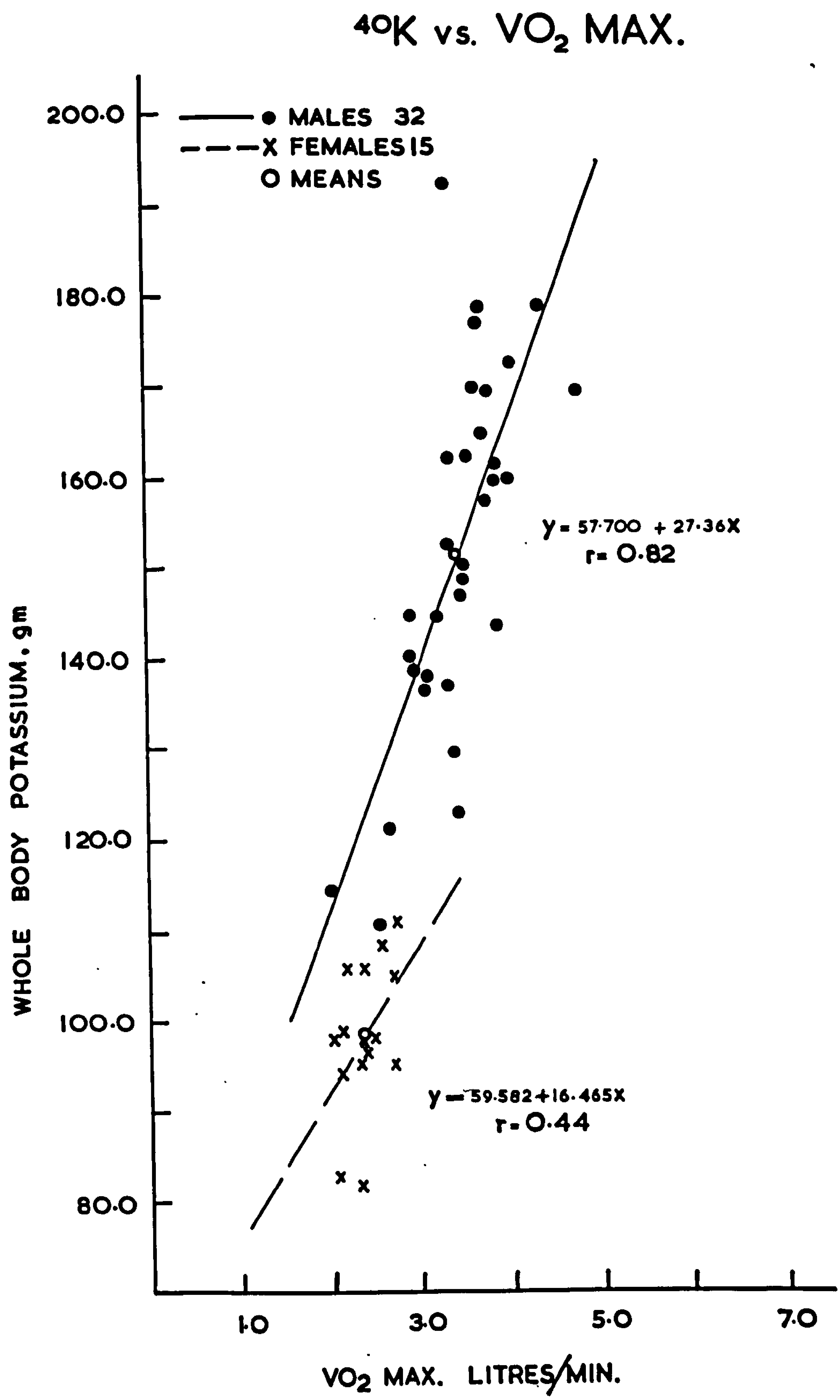


Fig. 46. The regression of ^{40}K on VO_2 Max. for male and female young adults.

b) ^{40}K vs Limb muscle widths (X-Rays).

As previously reported the skeletal muscle was assessed indirectly for the whole body by monitoring the total body potassium and directly by soft-tissue roentgenogrammetry, for the arm, calf and thigh. The results of the 1966 study showed that the summation of these 3 muscle widths was highly correlated with the ^{40}K, respectively for men and women, r = 0.72 and 0.58. As a percentage of the overall muscle width the thigh muscle accounts, on average, for almost half (47%) and contributes most to the relationship with ^{40}K. When the arm muscle width and to a lesser extent the calf, is taken out of the analysis no significant difference is made to the relationship (Table 26).

The present study also shows (Fig. 47) that ^{40}K is highly correlated with the total leg muscle width (Thigh + Calf), for men r = 0.75 and r = 0.78 for women (Table 27). It also shows that the total body potassium can be estimated indirectly from radiographic leg muscle widths with s.e. of the estimate of $\pm$ 13.3 gm, coefficient of variation 8.8%, and $\pm$ 5.4 gm, coefficient of variation 5.5%, for men and women respectively. Table 27 also shows that when the bone is added to the regression in the form of a "lean tissue" (X-Ray) variable, no improvement is seen, in fact, the s.e. of the estimates for men and women are higher. Furthermore, it can be seen that it is possible to omit the calf muscle width from the relationship and prediction of ^{40}K without loss of accuracy, in fact, for women there is a marginal improvement when the thigh alone is taken. This finding is in

TABLE 26. REGRESSION OF TOTAL BODY POTASSIUM (K) ON INDICES OF LIMB MUSCLE WIDTH (ARM, THIGH AND CALF) FROM ROENTGENOGRAMMETRY.

Males	n = 29	K = -10.44 + 0.055 x Thigh + Calf + Arm muscle width.	S.E.	11.8 g.	C.V.	8.2%
		K = -41.13 + 9.25 x Thigh + Calf muscle width	S.E.	10.4 g.	C.V.	7.2%
		K = -31.94 + 13.58 x Thigh muscle width	S.E.	10.2 g.	C.V.	7.1%
Females	n = 23	K = 38.44 + 0.023 x Thigh + Calf + Arm muscle width.	S.E.	5.9 g.	C.V.	6.5%
		K = 28.34 + 3.75 x Thigh + Calf muscle width	S.E.	5.8 g.	C.V.	6.4%
		K = 28.17 + 0.060 x Thigh muscle width	S.E.	5.5 g.	C.V.	6.1%

Data from IBP Study 1966.

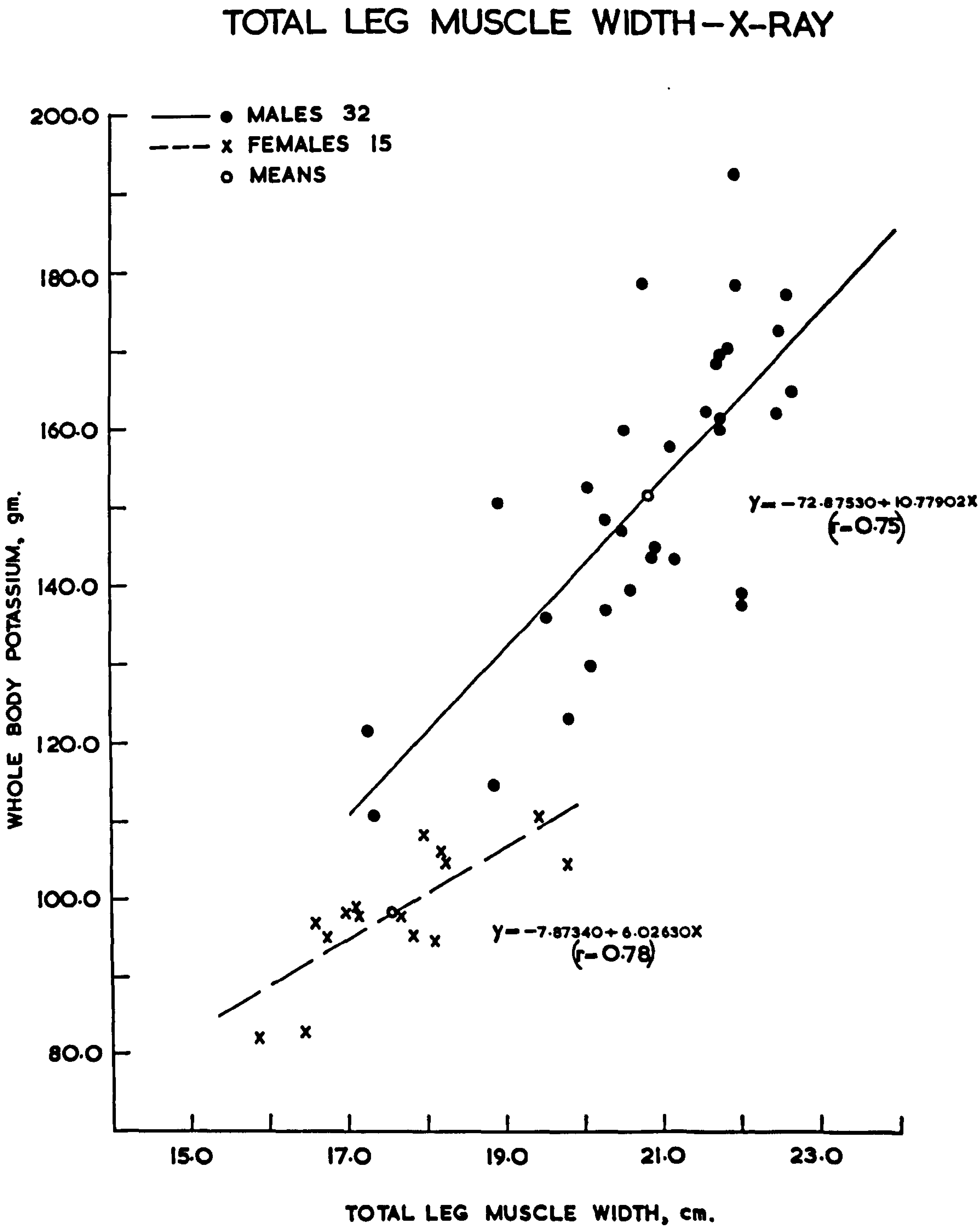


Fig. 47. The regression of ^{40}K on total leg muscle width for male and female young adults.

TABLE 27. REGRESSION OF TOTAL BODY POTASSIUM (^{40}K) ON LIMB MUSCLE AND MUSCLE PLUS BONE WIDTHS AND VOLUMES FROM X-RAYS AND BY ANTHROPOMETRY.

		Whole Body Potassium (^{40}K) (Dependant Variable)					
		MALES n = 32			FEMALES n = 15		
Muscle and Lean Leg (Independant Variable)	Limb Compartment	r	S.E. of the Estimate g	Coefficient of Variation %	r	S.E. of the Estimate g	Coefficient of Variation %
Muscle plus Bone Volume Anthropometry	Total Leg	0.82	11.66	7.68	0.48	7.56	7.70
	Thigh	0.74	13.48	8.88	0.51	7.41	7.55
	Calf	0.72	12.68	8.35	0.30	8.21	8.37
Muscle plus Bone Volume X-Ray	Total Leg	0.83	11.16	7.35	0.68	6.35	6.47
	Thigh	0.73	13.70	9.03	0.61	6.81	6.93
	Calf	0.78	12.54	8.25	0.18	8.48	8.63
Muscle plus Bone Width X-Ray	Total Leg	0.84	10.97	7.23	0.79	5.25	5.35
	Thigh	0.79	12.29	8.10	0.87	4.30	4.38
	Calf	0.70	14.48	9.54	0.38	7.96	8.11
Muscle Volume X-Ray	Total Leg	0.83	11.26	7.42	0.67	6.44	6.56
	Thigh	0.73	13.82	9.11	0.60	6.92	7.05
	Calf	0.76	13.08	8.62	0.13	8.55	8.71
Muscle Width X-Ray	Total Leg	0.75	13.29	8.76	0.78	5.40	5.50
	Thigh	0.73	13.76	9.07	0.80	5.13	5.23
	Calf	0.50	17.41	11.47	0.32	8.16	8.31

agreement with the results reported by Cotes et al. (1969).

It is practicable to obtain estimates of relative musculature from soft-tissue radiography, and this index of limb muscle has been obtained by measuring the width of the muscle at specified points in the leg. If estimates of absolute muscularity (as far as interpretation of muscle shadow in radiographs is concerned) in the legs could be obtained in the form of volumes, would this prove to be a more informative index?

c) ^{40}K vs Limb Muscle volume (X-Rays).

Limb muscle volume data, obtained from soft-tissue roentgenogrammetry, were collected on 32 male students of Physical Education and 15 female students from a College of Education and a University of Technology. Fig. 48 shows the relationship of the muscle volume with the ^{40}K. It can be seen that for both sexes there is a good fit about the regression line with an improvement in the s.e. of the estimate for the males (Table 27), compared to the width. The correlation coefficient r = 0.83 and the coefficient of variation 7.42% is also improved. For the females all the three values are slightly lower for the muscle width values: r $\doteq$ 0.67, s.d. 6.4 gm, coefficient of variation 6.6%.

These two muscle indices, X-Ray muscle width and X-Ray muscle volume, for males and females against ^{40}K were statistically tested for the significance of the difference between two correlation coefficients for correlated samples. In the male and female groups

TOTAL LEG MUSCLE VOLUME – X-RAY

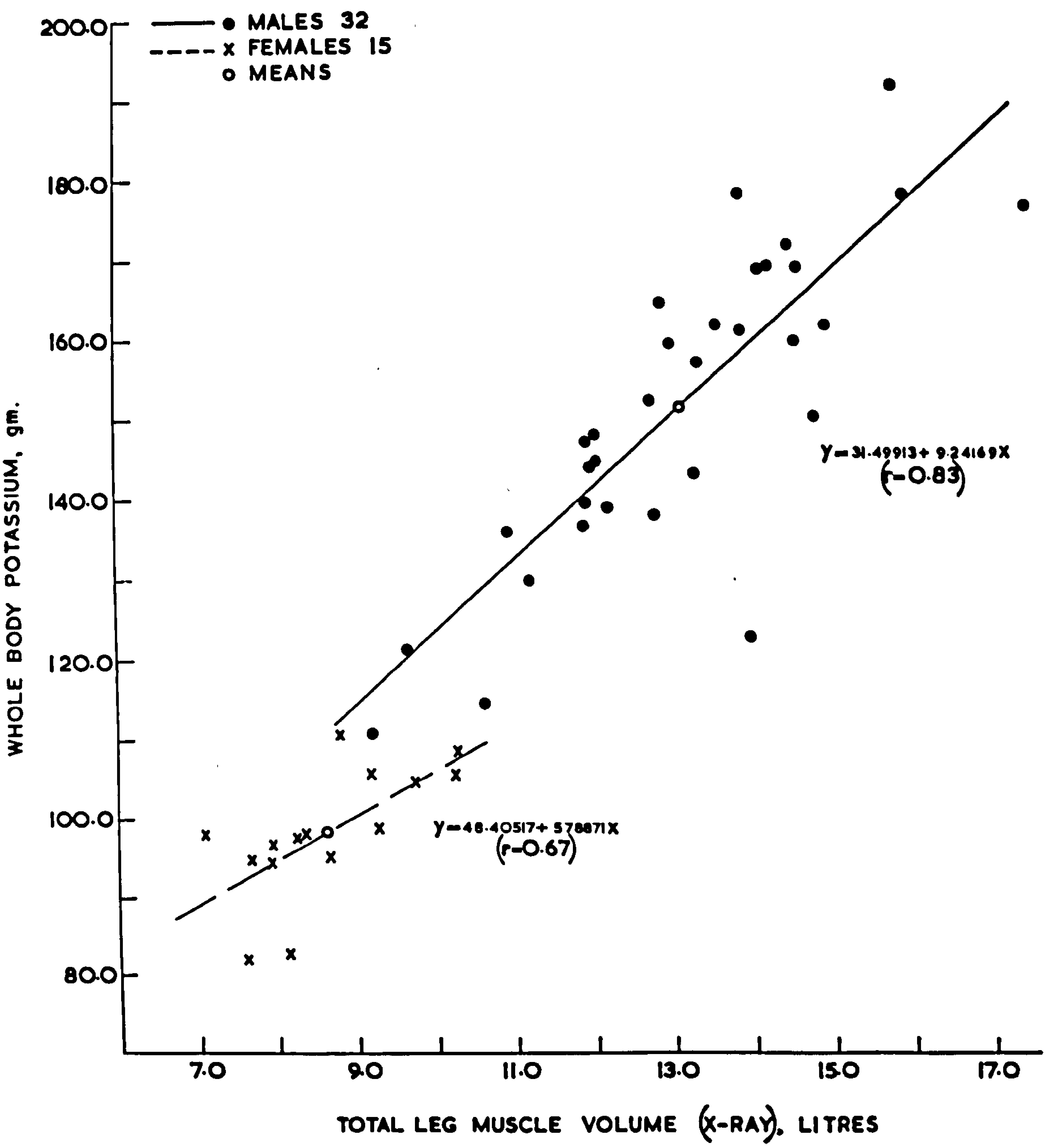


Fig. 48. The regression of ^{40}K on total leg muscle volume for male and female young adults.

the difference between width vs ^{40}K and volume vs ^{40}K were not significant ($t = -0.85$, $p < 0.20$) and ($t = 0.74$, $p < 0.20$). Therefore, it can be concluded that for men, the total leg muscle volume is a better index of overall muscularity as assessed from measurements of ^{40}K than is the muscle width. The improvement in the description of total body potassium in terms of the coefficient of variation is approx. 3%. In females the overall muscularity is best described by an index of leg muscle (Thigh + Calf) width. When only the "lean leg" muscle volume is estimated from roentgenogrammetry there is no material improvement in the regression for the description of ^{40}K (Table 27) in either men or women.

d) Thigh muscle width (predicted from Anthropometric variables).

The measurements of muscle by soft-tissue radiography is acceptable in most adult studies where cross-sectional data only are required, it is not satisfactory for serial studies on longitudinal measurements on healthy subjects, because of the cumulative effects of radiation. As an alternative to roentgenogrammetry for the estimation of limb muscle, an empirical approach was adopted using multiple regression equations of width of X-Ray thigh muscle on the circumference of the thigh (measured at the 1/3 subischial site) minus the anterior thigh caliper skinfold value. (Jones et al., 1970; Burkinshaw et al. 1970). The results appear in Table 28 and show a coefficient of variation about the best fit regression line for male subjects 3.9% and for female subjects 6.3%. These results suggest, that

TABLE 28. PREDICTION OF THIGH MUSCLE WIDTH FROM THIGH CIRCUMFERENCE AND ANTERIOR THIGH CALIPER FAT IN YOUNG MALE AND FEMALE ADULTS BY MULTIPLE REGRESSION EQUATIONS.

Data Source	Sex	N	Equation	S.E. of Estimate	C.V.	Observed Thigh Mus. Width X-Ray	S.D. mm	Predicted Value, data from other sources.
I.B.P. Leeds 1968 P.E. Students	M	32	TM = 0.23370 TC(cm) - 0.62768 AF(cm) + 1.48064	0.522	3.90%	13.3847	0.94	(data from another source not yet available)
LUT/MRC Study Nov. 1968 University Student		11						
Matlock Coll. Ed. P.E. Students		23						
Total =		66						
I.B.P. Leeds 1968 P.E. Students	F	13	TM = 0.10840 TC(cm) - 0.50724 AF(cm) + 6.90386	0.709	6.29%	11.26973	0.75	Females M.R.C. P.R.U. Data n = 48. 11.2613
LUT/MRC Study Nov. 1968 University Students		2						
Matlock Coll. Ed. P.E. Students		22						
Total =		37						

TM - Thigh Muscle, cm.
TC - Circumference, cm.
AF - Anterior Thigh Caliper Fat, cm.

for young adults it is possible to describe an index of thigh muscle width without material loss of accuracy in terms of thigh circumference and anterior thigh skinfold.

It is also possible to obtain similar relationships for the prediction of calf muscle width by using the maximum calf circumference minus the medial caliper skinfold which show coefficients of variation of 5.0% approximately.

e) Thigh muscle volume (predicted from Anthropometric variables).

An alternative to estimating limb muscle volume from roentgenogrammetry has been sought. Initially the multiple regression equations were constructed using the same terms as for the muscle width, i.e. the thigh circumference and anterior thigh skinfold. They were for men:-

Thigh Muscle Volume = 0.272 T. Circ. - 1.240 Ant. Fat - 4.377 Constant. s.d. 1.36, Coefficient of Variation 15.2%.

And for women:-

Thigh Muscle Volume = 0.094 T. Circ. - 0.635 + 2.308 Constant. s.d. 0.73, Coefficient of Variation 13.2%.

The prediction of thigh muscle volume using these independant variables is not good, the multiple correlation coefficients are low r = 0.55 for men and r = 0.42 for women and the coefficients of variation are not acceptable when comparing them with the equations for the prediction of thigh muscle width.

For the next multiple regression equation, the length of the thigh (measured from the gluteal furrow to the knee joint space) was added to the equation resulting in, for men:-

Thigh Muscle Volume = 0.280 T. Circ. + 0.295 h - 1.176 Ant. Fat - 14.229 Constant. s.d. 0.84, coefficient of variation 9.0%.

And for women:-

Thigh muscle volume = 0.105 T. Circ. + 0.205 h - 0.504 Ant. Fat - 4.865 Constant, s.d. 0.70, coefficient of variation 12.5%.

It can be seen that by adding the length of the thigh to the equation the prediction of thigh muscle volume is improved considerably. This is true especially for men where the coefficient of variation is down to 9.0% and the multiple correlation coefficient has risen to $r = 0.80$. There is only marginal improvement for the women.

f) ^{40}K vs Muscle plus bone (lean leg) volume by Anthropometry.

Because it has been shown previously that when the two techniques for measuring "Lean" leg volume by anthropometry and roentgenogrammetry are compared they are almost linear, the anthropometric relationship with whole body potassium is virtually the same as for the X-Ray method (Table 27).

As a further substitute for the radiographic technique, a multiple regression equation has been constructed to predict ^{40}K in terms of the gross leg volume by water displacement and the sum of the 4 leg skinfolds thicknesses. The equations are given below:-

Men - $^{40}K = 6.277$ (Leg Volume H_2O litres) - 1.362 ($\Sigma 4$ leg fats) + 39.639 Constant. s.d. 12.2 g, coefficient of variation 8.0%. The multiple correlation coefficient is of the same magnitude r = 0.80, when compared with total leg muscle plus bone volume by X-Ray, r = 0.81 and anthropometry (truncated cones) r = 0.79.

Women - ^{40}K = (Leg Volume) 2.078 - 1.937 (ΣFats) + 80.595 Constant. s.d. 7.7 g, coefficient of variation 7.9%, multiple r = 0.51.

This technique, for women, shows no material improvement over other methods already described.

Summary of the findings.

There are no material differences between the relationship of the volume of muscle or muscle plus bone, as determined by roentgenogrammetry or anthropometry, to whole body Potassium (^{40}K). Each is equally good so the choice between the methods can be made on grounds of convenience. However, muscle volume or muscle plus bone volume has a better relationship with ^{40}K than does the X-Ray muscle width, for men, but not for women, where the X-Ray muscle width is best. Thigh muscle width can be predicted from multiple regression equations for both sexes without material loss of accuracy and because of this the width of the muscle mass, determined from

a) 1st. choice - soft-tissue roentgenogrammetry and
b) 2nd. choice - anthropometry (Thigh circ. - Ant. Fat)

of the thigh is highly satisfactory.

5. Inter relationship of the indices with Maximal Oxygen Uptake.

Maximal oxygen uptake (VO_2 Max.) reflects the overall function of the oxygen transport system of the body together with the amount of skeletal muscle which can effectively be brought into use. Because the subjects exercised on a cycle ergometer the effective muscles were mainly those of the thigh and calf, therefore, it is not surprising that VO_2 Max is significantly and positively correlated with the measurements of ^{40}K ($r = 0.82$ for males and $r = 0.44$ for females), which reflects total body muscle, as is shown in Figure 46.

For a simpler and probably better muscle index the width and volume have been estimated radiographically and the muscle plus bone using anthropometry.

a) VO_2 Max vs Muscle width (X-Ray).

Figure 49 shows the regression of maximal oxygen uptake on total leg muscle width. There is a significant correlation for men, $r = 0.63$ ($p < 0.001$) and for women $r = 0.56$ ($p < 0.02$) and the lines of best fit have slopes significantly different ($p < 0.001$) from zero. Values for the thigh and calf together with the standard errors of the estimate and coefficients of variation are shown in Table 29.

These data confirm the relationship, shown by Cotes et al. (1969) between VO_2 Max and the index of muscle width estimated by soft-tissue roentgenogrammetry. However, the female subjects in this present study showed a reduced coefficient of variation over the female industrial group studied in 1966, when comparing the thigh muscle width against the VO_2 Max, 9.07% with 11.23%. The values for the males were similar 13.0% with 12.8%.

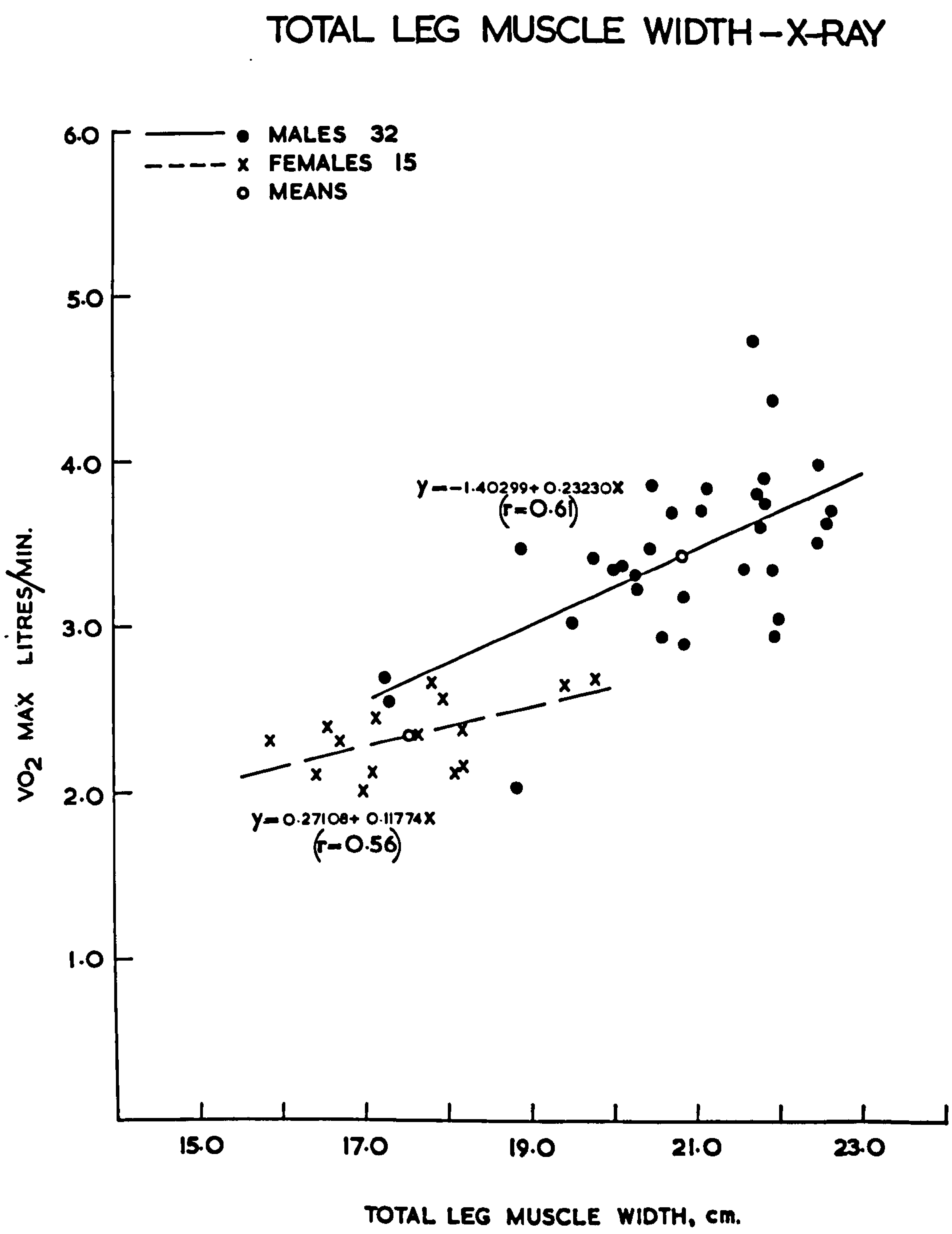


Fig. 49. The regression of VO_2 Max. on total leg muscle width for male and female young adults.

TABLE 29. REGRESSION OF MAXIMUM OXYGEN UPTAKE (VO_2 MAX) ON LIMB MUSCLE AND MUSCLE PLUS BONE WIDTH AND VOLUME FROM X-RAYS AND BY ANTHROPOMETRY.

		MALES n = 28			FEMALES n = 15		
		r	S.E. of Est.	Coeff. of Variation	r	S.E. of Est.	Coeff. of Variation
Muscle plus bone volume Anthropometry	Total Leg	0.70	0.41	12.00	0.35	0.22	9.31
	Thigh	0.68	0.91	9.98	0.36	0.91	15.21
	Calf	0.58	0.58	12.75	0.39	0.37	11.13
Muscle plus bone volume X-Ray	Total Leg	0.74	0.39	11.28	0.26	0.23	9.61
	Thigh	0.68	0.42	12.18	0.07	0.23	9.92
	Calf	0.58	0.47	13.54	0.48	0.20	8.75
Muscle plus bone width X-Ray	Total Leg	0.68	0.42	12.30	0.67	0.17	7.40
	Thigh	0.66	0.43	12.59	0.45	0.21	8.90
	Calf	0.54	0.49	14.10	0.71	0.16	6.96
Muscle Volume X-Ray	Total Leg	0.74	0.39	11.30	0.21	0.23	9.71
	Thigh	0.68	0.42	12.25	0.05	0.23	9.93
	Calf	0.57	0.48	13.79	0.40	0.21	9.12
Muscle Width X-Ray	Total Leg	0.63	0.45	13.04	0.56	0.19	8.22
	Thigh	0.62	0.45	13.04	0.41	0.21	9.07
	Calf	0.41	0.52	15.21	0.50	0.20	8.63

These findings show that the choice of site for the estimate of muscle width should be in the thigh for the men and the calf for the women. The probable explanation why the calf should prove to be the best region for women, was that the ratio of muscle width to overall width was slightly higher for the calf than for the thigh.

b) VO_2 Max vs Muscle Volume (X-Ray).

In the present series of men the coefficient of variation of VO_2 Max was 16. 2%. However, this was reduced to 11.3% by use of the linear regression on total leg muscle volume (Fig. 50), which shows a positive significant correlation $r = 0.74$ ($p < 0.001$) and a standard error about the estimate of 0.39. It can be seen from Table 29 that the coefficients of correlation, s.e. of estimates and coefficients of variation all show improvement for the muscle volume indices over those for muscle widths. For women, there is no significant correlation ($p > 0.1$) between leg muscle volume and VO_2 Max. Of the two segments, the calf shows the best relationship, $r = 0.40$ (n.s.).

c) VO_2 Max vs Muscle and Bone Volume (X-Ray and Anthropometry).

The results in Table 29 also show, for men and women, that when the bone volume is added into the muscle volume for a regression on VO_2 Max, the values are virtually unaltered, apart from the thigh muscle plus bone volume by anthropometry which shows an improved correlation coefficient $r = 0.36$ (n.s.).

An analysis of the data for VO_2 Max vs X-Ray muscle width in men and women was carried out to test the significance of the

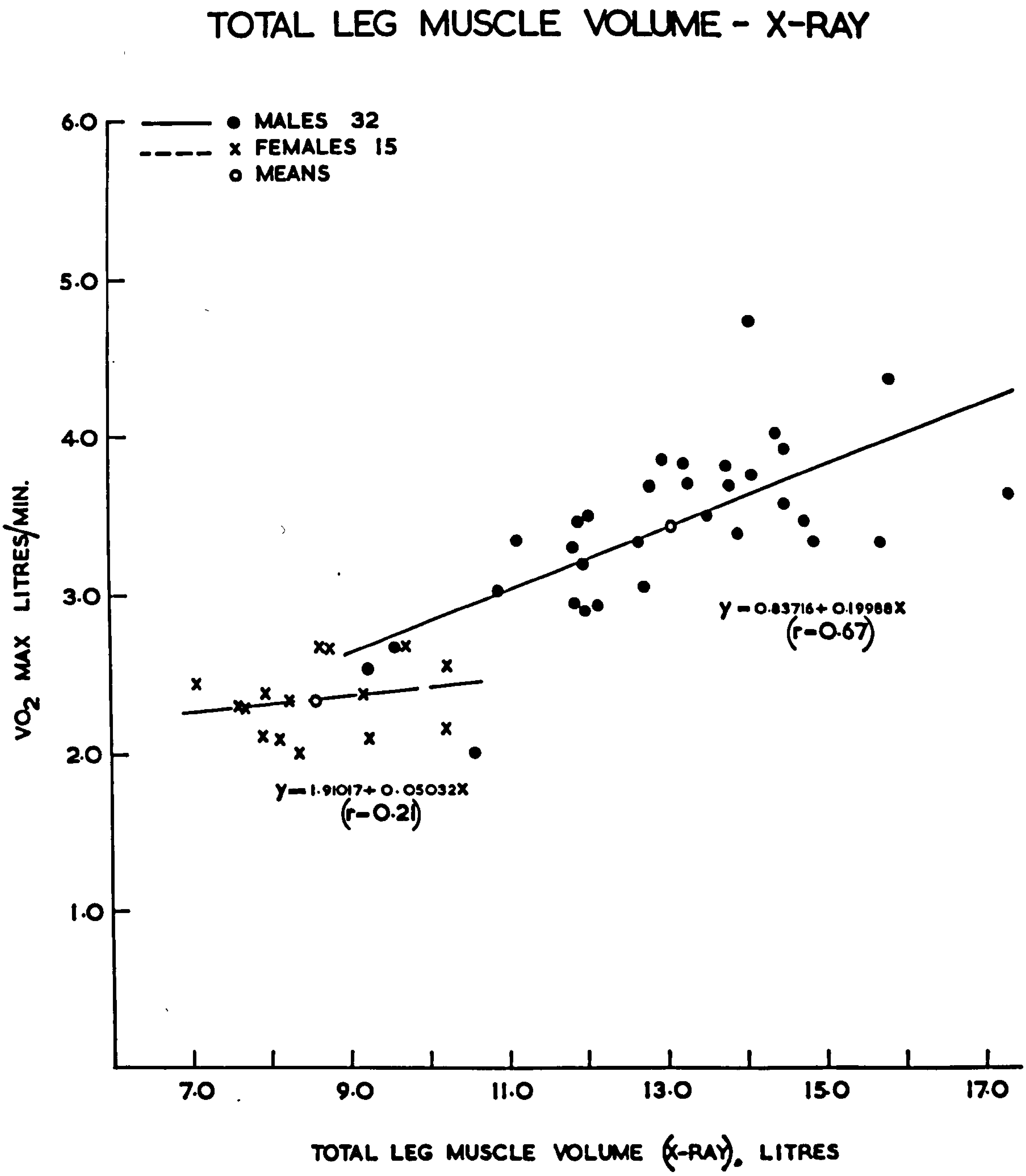


Fig. 50. The regression of VO_2 Max. on total leg muscle volume for male and female young adults.

difference between two correlation coefficients for independant samples i.e. males and females. The differences were non-significant ($t = 0.31, < 0.8\ p < 0.7$). This procedure was also carried out for the muscle volume data between men and women and for these independant samples the differences between the two coefficients of correlation $r = 0.74$ and $r = 0.21$ were significant ($t = 2.10, < 0.05\ p < 0.02$).

A further analysis for the difference between two correlations was made for correlated samples i.e. VO_2 Max vs X-Ray muscle width and VO_2 Max vs X-Ray muscle volume for men and women. The results showed that between the width and volume there was a non-significant difference $t = -1.27$ ($< 0.2\ p < 0.3$) for men and $t = 1.64$ ($< 0.2\ p < 0.1$) for women.

6. Discussion and Summary.

In the present series of VO_2 Max values for 15 women the coefficient of variation was $\pm$ 9.6%, s.d. $\pm$ 0.22 l/min. By introducing the total leg muscle width (X-Ray) into the regression on maximal oxygen uptake the variation was reduced to $\pm$ 8.2% and the s.d. to $\pm$ 0.19 l/min. Similar figures were obtained for the regression on total leg muscle plus bone width from soft-tissue roentgenogrammetry. The findings have shown that for description of VO_2 Max in a group of male subjects the variation can be reduced by making allowance for muscle or "lean tissue" volume. This, however does not apply to young females, where the best description was gained from muscle or "lean tissue" widths. It has been demonstrated that the muscle bulk expressed as "lean leg volume" determined by anthropometric methods as described by Jones and Pearson (1969), correlated highly, r = 0.83, with the maximal oxygen uptake in a group of 32 young highly athletic female physical education students (Hamley and Watson, 1969; Watson, 1969). Because both studies have used a cycle ergometer, the musculature involved in rotating the crank pedal was mainly that of the thigh and calf (Houtz and Fischer, 1959), therefore, some pertinent observations may be made. The age groups were similar, the samples were different, one was highly athletic whilst the other was only moderately active. The mean maximal oxygen uptake values were similar 2.34 l/min (present study) and 2.39 l/min (Watson), but the standard deviations differ, $\pm$ 0.45 l/min with a coefficient of variation of 18.7%, which was virtually twice the value given here. In this study the mean lean leg volume determined from anthropometry was 9.75 litres, s.d. $\pm$ 1.04, Watson's figure was 8.54 litres, s.d. $\pm$ 1.32. Contrary findings have been demonstrated in these two studies and further reasoning for these differences are suggested. The VO_2 Max values in 6 of the P.E. women were under 2.0 l/min, range 1.34 - 1.67 l/min and when these are taken out of the data for a regression on lean leg volume the coefficient of correlation drops from r = 0.83 to r = 0.72 ($p < 0.001$). However, the most plausible explanation for the differences are in the composition of the tissues. It would be expected that due to training and exercise the 'athletic' women would exhibit higher lean leg volume values, but they do not, there is a difference of -1.21 litres. Frantzell and Ingelmark (1951) have shown from radiological studies of the leg that for a constant muscle volume the amount of true muscular tissue in a muscle diminishes and is largely replaced by adipose tissue as age increases and exercise decreases. This implies that the present group of 15 female College and University students had a high proportion of interstitial fat in their 'lean leg' volumes. Because the oxygen consumed during exercise is dependant upon the load in the muscles, and also on the mass of muscle at work (Astrand and Saltin, 1961), it would appear that the VO_2 Max values would be greatly influenced by the size and variation in the leg muscle composition.

Not only have the determinations of leg muscle volumes indicated that the work capacity was related to the musculature involved, they have also shown a sex difference, which was shown up in the coefficients of correlation. This relationship was positively correlated for young men ($r = 0.74$, $p < 0.001$) and to a lesser extent for young women ($r = 0.2$, $p > 0.1$). In an attempt to explain this phenomenon it is of interest to look at some investigations of other research workers. Frantzell and Ingelmark (1951) have carried out a morphologic and radiologic investigation on the occurence and distribution of fat in human muscles. Their findings indicate that the frequency of interstitial fat in the legs was significantly higher in women than in men, also women's legs often contain more subfascile fat than men's. Cheek (1968) discussing muscle cell growth in normal children, points out that it is not just the increase in the number of muscle cells which accounts for the larger muscle mass in males, but the continued linear increase in muscle cell size which may take place until 25 years of age. The difference between males and females in the number of muscle cells was in the order of 3:2. Therefore, it may be reasonably stated; that this sex-linked difference was a result of a difference in muscle mass composition. The men exhibited larger and more muscle cells per unit muscle volume which could effectively be brought into use, resulting in a highly significant relationship with the aerobic maximal oxygen uptake.

A sex difference has also been shown in the whole body potassium values (Burkinshaw et al., 1967; Cotes et al., 1969) when predictions have been made from measurements of thigh muscle and lean body mass. Flear and Florence (1963), have also shown that the potassium content of muscle tissue may differ because of differences in the fat and water content of the muscle. However, Cotes et al., (1969) point out that prediction equations for maximal oxygen uptake on whole body potassium and a limb or thigh muscle may be combined irrespective of sex, which suggests that the component measurements are to a large extent interchangeable. The evidence is not unequivocal, especially when considering that approximately 50% of the whole body potassium count is represented in the muscles. Added to this is the uncertainty of how much lower leg muscle is counted by the scintilators when they are grouped around an inclined chair (Fig. 45 refers). For further clarification on this issue Burkinshaw and Jones are attempting to isolate the measurements for the upper thigh region from the buttocks using large leaded shields. This will enable accurate potassium counts to be made using a linear scan technique which can be accurately related to the volume of muscle or muscle plus bone in the thigh and calf regions of males and females.

In conclusion, this study shows that variation in describing maximal oxygen uptake can be diminished by making allowance for the composition and distribution of body muscle. It demonstrates that body muscle can be obtained from anthropometric or roentgenogrammetric techniques or by monitoring total body potassium (^{40}K). Some techniques exhibit advantages over others but generally speaking all are interchangeable, therefore, the choice of method can be made on grounds of suitability and convenience. For large population studies the width of the muscle mass of the thigh is quite satisfactory when predicted from thigh circumference minus anterior caliper skinfold measurement. Thigh muscle width is further recommended as the premier index for describing body muscle in young male and female adults living in the United Kingdom.

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APPENDICES

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APPENDIX I

EXPERIMENT TO VALIDATE THE VOLUME OF THE FOOT BY ANTHROPOMETRIC TECHNIQUES COMPARED WITH THE KNOWN VOLUME BY WATER DISPLACEMENT.

Foot volume by water displacement

To the minimum ankle circumference level = 999 cc. Multiplied by 2 for the volume of 2 feet = 1.998 litres.

To the bimalleolar diameter level = 745 cc. Multiplied by 2 for the volume of 2 feet = 1.490 litres.

Calculated volume by anthropometry

The foot was regarded as three different shapes (Figs. 1, 2, & 3):-

1) A wedge

2) A wedge and a rectangle

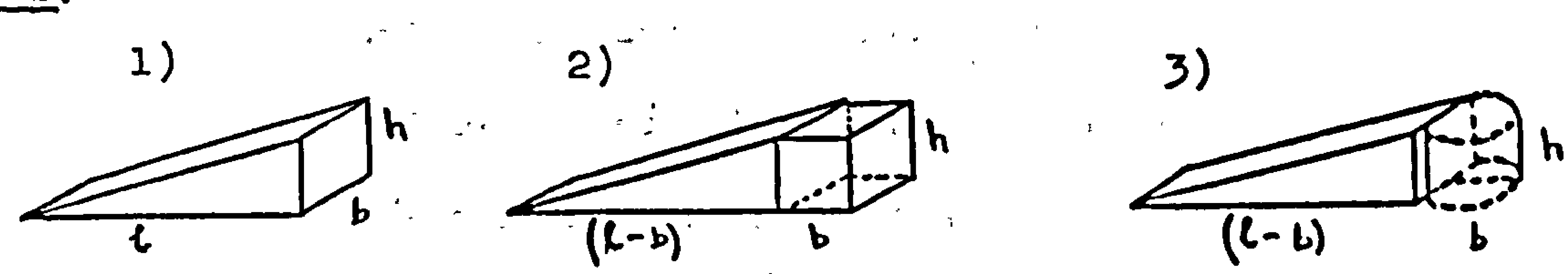
3) A wedge and a cylinder.

The volume was calculated to two different heights:-

A) The minimum ankle circumference level

B) The bimalleolar diameter level.

Figures:



Measurements of A - 1 = 25.1, b = 6.9, h = 11.1

Measurements of B - 1 = 25.1, b = 6.2, h = 5.9

where 1 = length, b = breadth, h = height.

For reference calculation A1) will be the wedge shaped foot volume to the minimum ankle circumference level.

A1) $\frac{1}{2}(25.1)(11.1)(6.9) = 961.20$ cc. Multiplied by 2 for two feet $=$ <u>1.922 litres.</u>

A2) $(6.9)(6.9)(11.1) + \frac{1}{2}(25.1 - 6.9)(11.1)(6.9)$

$= 528.47 + 696.99 = 1225.44$ cc. $=$ <u>2.451 litres.</u>

A3) $\pi\left(\frac{6.9}{2}\right)^2 11.1 + \frac{1}{2}(25.1 - 6.9)(11.1)(6.9)$

$= 414.85 + 696.99 = 1111.82$ cc. $=$ <u>2.224 litres.</u>

B1) $\frac{1}{2}(25.1)(5.9)(6.2) = 459.08$ cc. $=$ <u>0.918 litres.</u>

B2) $(6.2)(5.9)(6.2) + \frac{1}{2}(25.1 - 6.2)(5.9)(6.2)$

$= 226.80 + 345.68 = 572.48$ cc. $=$ <u>1.145 litres.</u>

B3) $\pi\left(\frac{6.2}{2}\right)^2 5.9 + \frac{1}{2}(25.1 - 6.2)(5.9)(6.2)$

$= 178.03 + 345.68 = 523.71$ cc. $=$ <u>1.047 litres.</u>

<u>Conclusion</u>

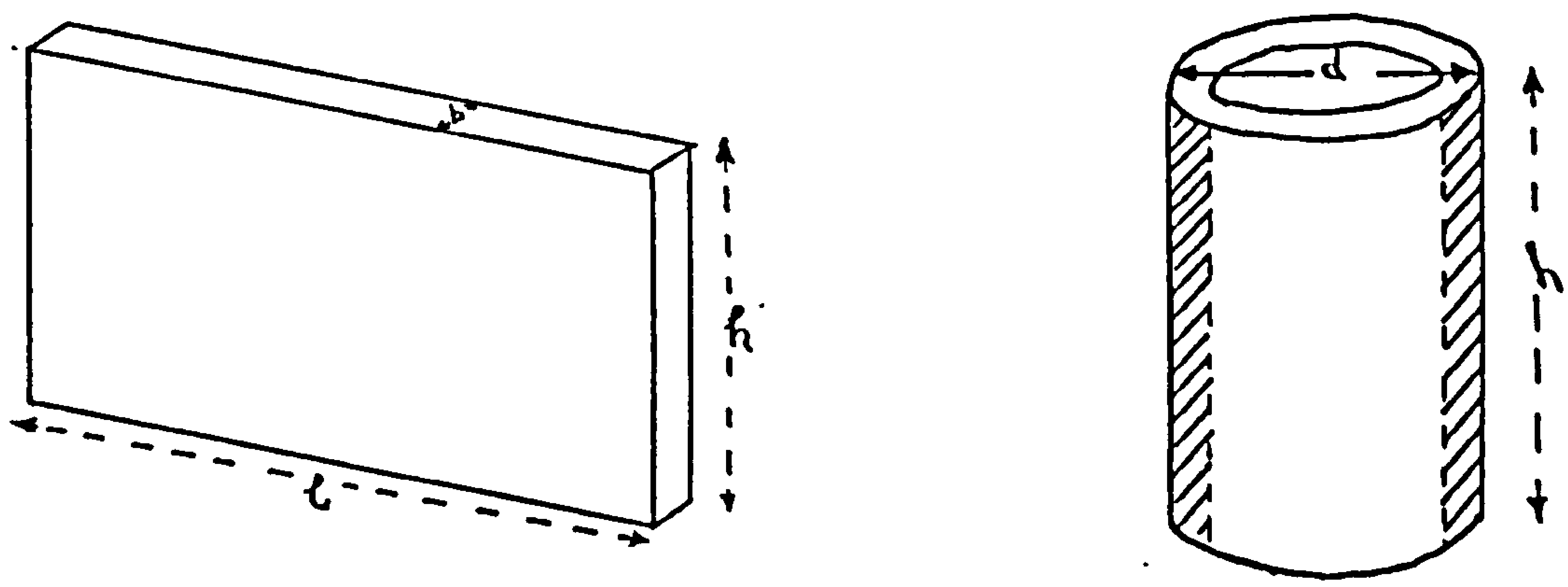
When anthropometric measures are taken from the foot for the purpose of estimating the volume, the most accurate results are obtained (comparisons being made against a known volume by water displacement), when the foot is assumed to be wedge shaped. Where l = length of foot, b = breadth (calculated as the diameter of the minimum ankle circumference) and h is the height - ground to minimum ankle circumference.

The standard deviations of the differences between known water displacement volume and that calculated by anthropometry for 60 male and 45 female subjects were 0.15 and 0.10 respectively.

APPENDIX II

EXPERIMENT TO VALIDATE AREAS BY PLANIMETRY (FROM RADIOGRAPHS) TO GIVE VOLUMES, COMPARED WITH KNOWN VOLUMES

A model thigh made of polyzote (an expanded polystyrene material), was X-Rayed to ascertain whether the actual volume equalled the volume arrived at by planimetry.



Polyzote Model of Thigh

Actual Volume

The actual volume = length x breadth x height

where length	=	70.5 cm
breadth	=	1.91 cm.
height	=	34.2 cm.

$$\text{Actual volume} = 70.5 \times 1.91 \times 34.2$$
$$= \underline{4605.20\ cm^3}$$

Volume by planimetry

Volume by planimetry = measured shaded area corrected for magnification x mean circumference.

Measured shaded area = 10.82 sq. ins. Multiplied by 6.4516 to convert to sq. cm. = 69.81 sq. cm.

Corrected for magnification factor of 6.8% = $\frac{69.81}{1.068}$ = 65.24 sq. cm.

Mean circumference = actual overall length.

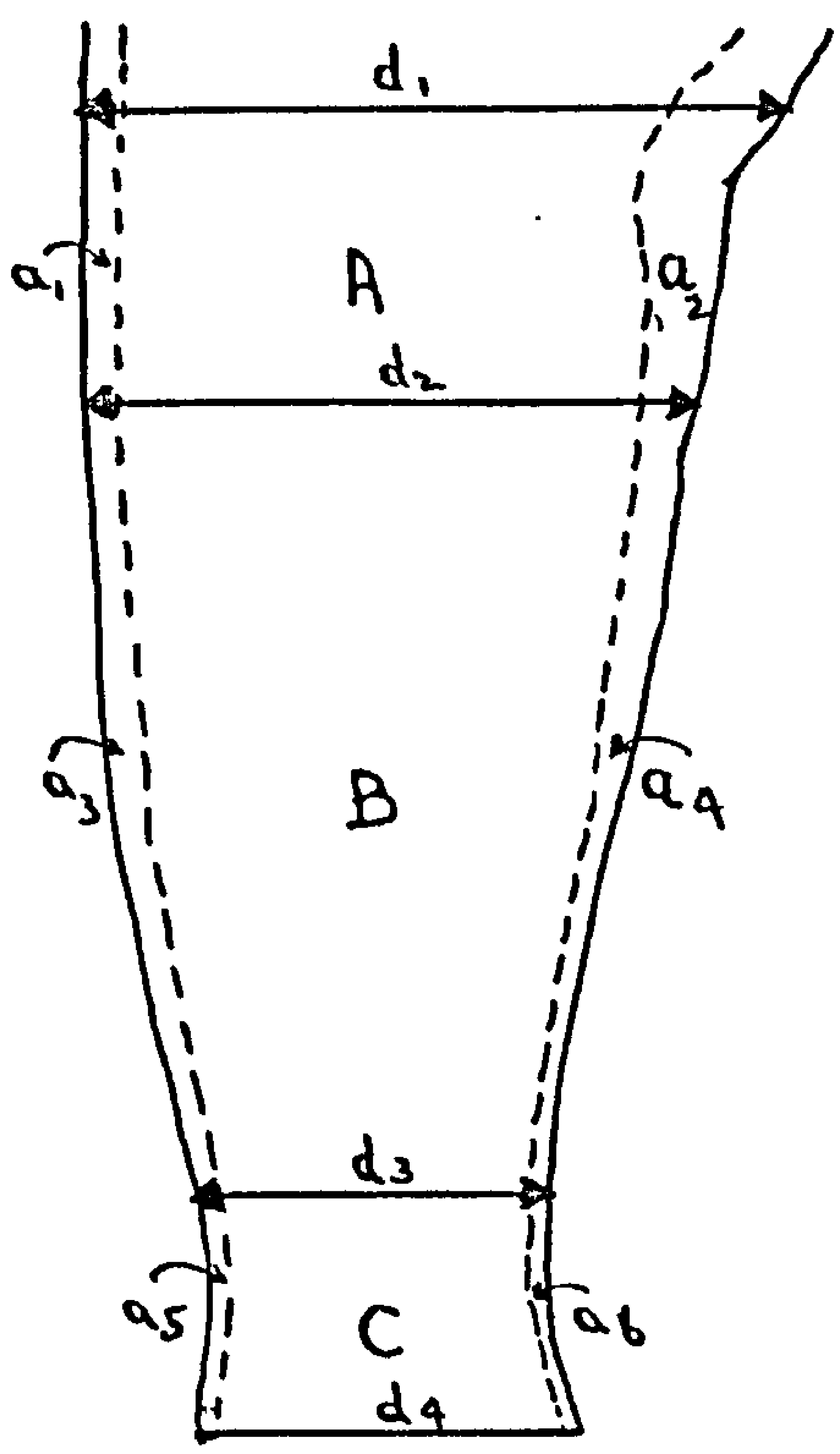
Volume by planimetry = 65.24 x 70.5

= <u>4599.42 cm^3</u>

Difference between the methods = 5.78 cm^3 = <u>0.13%</u>

APPENDIX III(a)

CALCULATION OF FAT VOLUME OF THE THIGH BY PLANIMETRY OF THE INDIVIDUAL SEGMENTS USING TRUNCATED CONES (METHOD 1).



d = diameter of the thigh in cm.

d_1 = 18.62

d_2 = 16.58

d_3 = 12.90

d_4 = 12.46

a = areas of fat in sq. ins.

a_1 = 1.60

a_2 = 2.37

a_3 = 4.15

a_4 = 3.25

a_5 = 1.79

a_6 = 0.97

c = circumference.

<u>In truncated segment A</u>

Σ Areas of fat from planimetry = $a_1 + a_2$ = 1.60 + 2.37 sq. ins.

= 3.97 sq. ins.

Multiply by 6.4516 to convert into sq. cm. = 25.61 sq. cm.

As the area taken is the sum of 2 fat sites, the mean must be used for the actual calculation. Therefore, area of fat

$= \frac{25.61}{2}$

= <u>12.81 sq. cm.</u>

Total Volume of fat = Total area x Mean circumference.

$c_1 = d_1\pi$ = 18.62 x 3.142 = 58.50 cm.

$c_2 = d_2\pi$ = 16.58 x 3.142 = 52.09 cm.

Mean circumference = $\frac{110.59}{2}$ = <u>55.30 cm.</u>

Therefore, Total Volume of fat = 12.81 sq. cm. x 55.30 cm.

= <u>708.39 cm^3</u>

<u>In truncated segment B</u>

Σ Areas of fat from planimetry = $a_3 + a_4$ = 4.15 + 3.25 sq.in.

= 7.40 sq. ins.

Multiply by 6.4516 to convert to sq. cm. and divide by 2 for

actual fat volume = $\frac{47.74}{2}$ sq. cms. = <u>23.87 sq. cm.</u>

Total Volume of fat = Total area x Mean circumference.

$c_2 = d_2\pi$ = 16.58 x 3.142 = 52.09 cm.

$c_3 = d_3\pi$ = 12.90 x 3.142 = 40.53 cm.

Mean circumference = $\frac{92.62}{2}$ = <u>46.31 cm.</u>

Therefore, Total Volume of fat = 23.87 sq. cm. x 46.31 cm.

= <u>1105.42 cm^3</u>

<u>In truncated segment C</u>

Σ Areas of fat from planimetry = $a_5 + a_6$ = 1.79 + 0.97 sq.ins.

= 2.76 sq. ins.

Multiply by 6.4516 to convert to sq. cm. and divide by 2 for

actual fat volume = $\frac{17.81}{2}$ sq. cm. = <u>8.91 sq. cm.</u>

Total Volume of fat = Total area x Mean circumference.

$c_3 = d_3 \pi = 12.90 \times 3.142 = 40.53$ cm.

$c_4 = d_4 \pi = 12.46 \times 3.142 = 39.15$ cm.

Mean circumference $= \frac{79.68}{2} = \underline{39.84 \text{ cm.}}$

Therefore, Total Volume of fat = 8.91 sq. cm. x 39.84 cm.

$= \underline{354.97 \text{ cm}^3}$

By adding total fat volume of segments A, B and C the Total Thigh Fat Volume can be calculated = 708.39 + 1105.42 + 354.97 cm^3.

$= \underline{2168.78 \text{ cm}^3}$

Multiply by 2 for total thigh fat volume in 2 legs

$= \underline{4337.56 \text{ cm}^3}$

APPENDIX III(b)

CALCULATION OF FAT VOLUME OF THE THIGH BY PLANIMETRY OF THE OVERALL FAT AREA, USING A SINGLE TRUNCATED CONE (METHOD 2)

d = diameter of thigh as before.

a = area of thigh fat as before.

c = circumference.

Total thigh area of fat = a. = 1.60 + 2.37 + 4.15 + 3.25 + 1.79 + 0.97.

= 14.13 sq. ins.

Multiply by 6.4516 to convert to sq. cm. and divide by 2 for actual fat volume = $\frac{91.16}{2}$ sq. cm. = 45.58 sq. cm.

Total Volume of fat = Total Area x Mean circumference.

$c_1 = d_1\pi =$ 18.62 x 3.142 = 58.50 cm.

$c_2 = d_2\pi =$ 16.58 x 3.142 = 52.09 cm.

$c_3 = d_3\pi =$ 12.90 x 3.142 = 40.53 cm.

$c_4 = d_4\pi =$ 12.46 x 3.142 = 39.15 cm.

Mean circumference = $\frac{190.27}{4}$ = 47.57 cm.

Total Volume of fat = 45.58 sq. cm. x 47.57 cm.

= 2168.24 cm^3

Multiply by 2 for total thigh fat volume in 2 legs,

= 4336.48 cm^3

APPENDIX IV

CALCULATION OF FAT VOLUME OF THE THIGH BY FRUSTUMS OF A CONE FROM RADIOGRAPHS

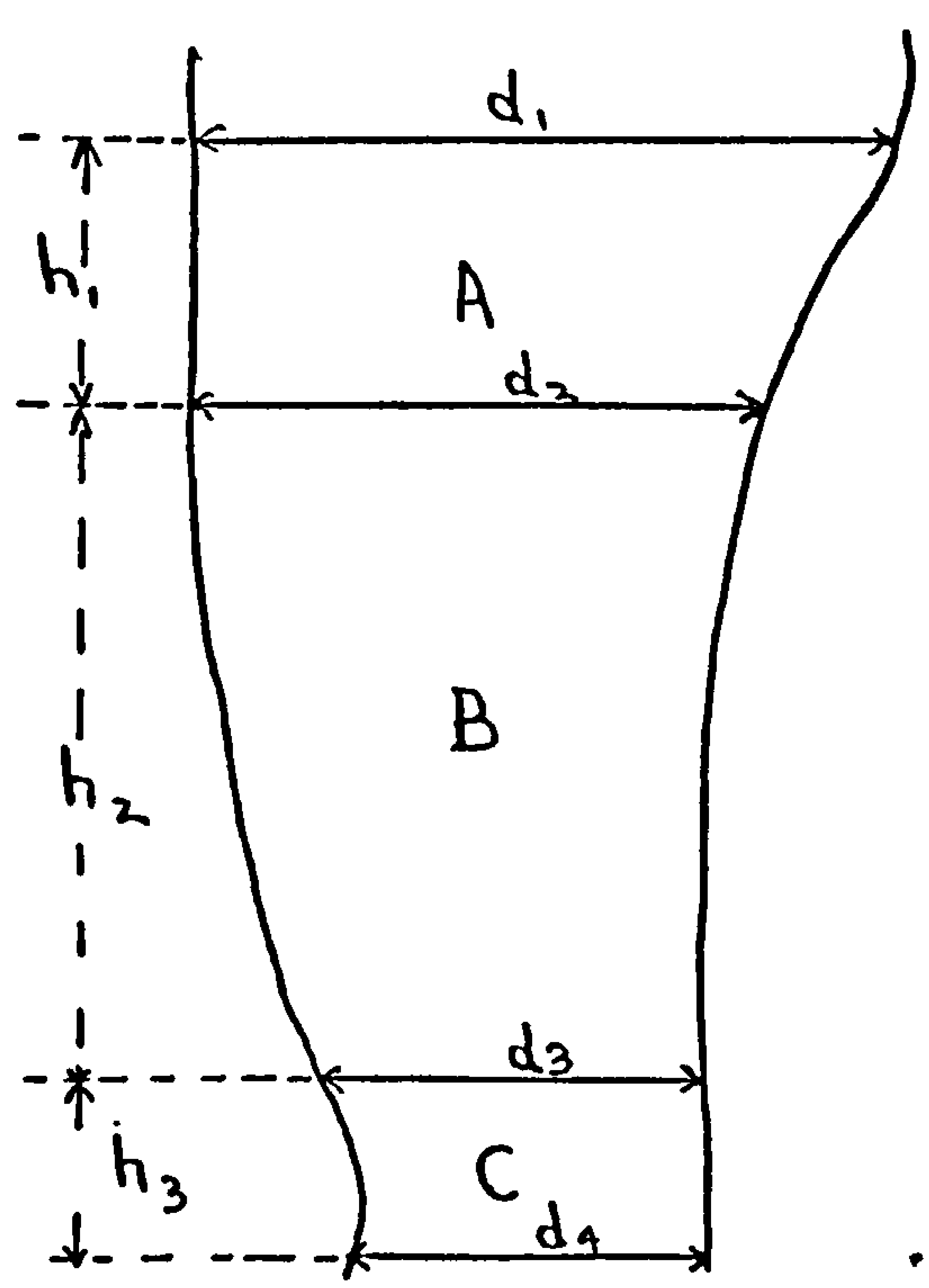
The object of this calculation is to find the volume of the total thigh using the following formula:-

$$\frac{h}{3}\left(a + \sqrt{ab} + b\right)$$

where a and b are the areas of 2 parallel surfaces.

Then by subtracting the volume of the muscle plus bone (inner cone) from the gross (outer cone) the volume of the total thigh fat is derived.

Outer Cone (Total thigh)



d = diameter of the thigh in cm.

d_1 = 18.62

d_2 = 16.58

d_3 = 12.90

d_4 = 12.46

h = height of each segment in cm.

h_1 = 6.75

h_2 = 18.04

h_3 = 8.07

r = radius of thigh in cm.

Segment A

Diameter = 18.62 r = 9.31 h = 6.75
16.48 r = 8.29

$$\text{Volume} = \frac{6.75}{3}\left((9.31)^2\pi + (8.29)^2\pi + (9.31)(8.29)\pi\right)$$

$$= 2.25\ (272.34 + 215.93 + 242.50)$$

Volume of A = 1644.23 cm^3

Segment B

Diameter = 16.58 r = 8.29 h = 18.04
12.90 r = 6.45

$$\text{Volume} = \frac{18.04}{3}\left((8.29)^2\pi + (6.45)^2\pi + (8.29)(6.45)\pi\right)$$

$$= 6.01\ (215.93 + 130.72 + 168.00)$$

Volume of B = 3093.05 cm^3

Segment C

Diameter = 12.90 r = 6.45 h = 8.07
12.46 r = 6.23

$$\text{Volume} = \frac{8.07}{3}\left((6.45)^2\pi + (6.23)^2\pi + (6.45)(6.23)\pi\right)$$

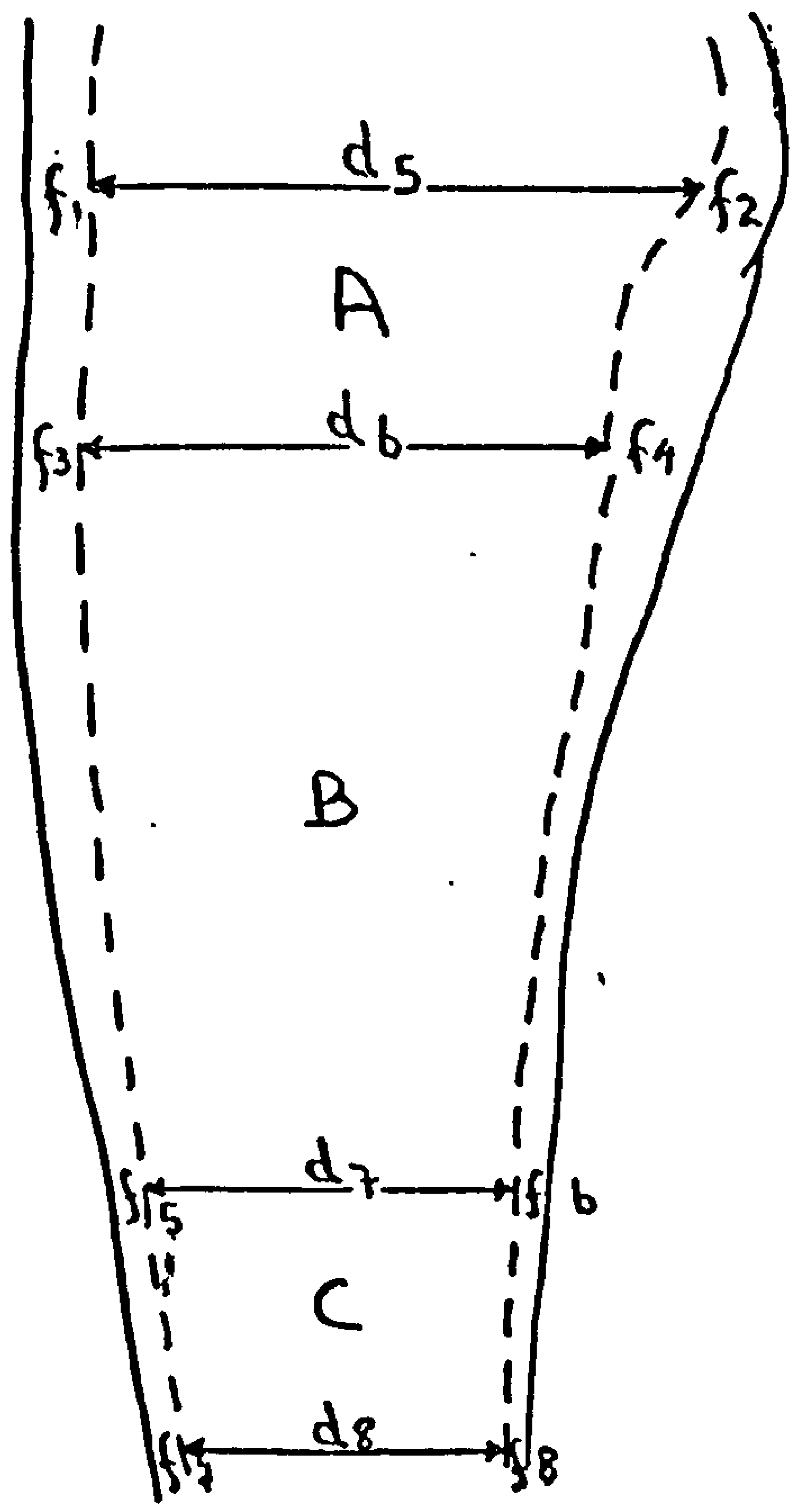
$$= 2.69\ (130.72 + 121.95 + 126.26)$$

Volume of C = 1019.32 cm^3

Total Volume of A, B and C = 1644.23 + 3093.05 + 1019.32 cm^3

= 5756.60 cm^3

Inner Cone (Muscle plus bone)



f = diameter of thigh fat in cm.

$f_1 = 1.54$ $f_2 = 3.88$

$f_3 = 1.52$ $f_4 = 1.50$

$f_5 = 2.09$ $f_6 = 1.00$

$f_7 = 1.30$ $f_8 = 0.50$

d = diameter of muscle plus bone in cm. calculated by subtracting diameter of fat from the total thigh diameter in the outer cone.

$d_5 = d_1-(f_1+ f_2) = 18.62-5.42 = 13.20$

$d_6 = d_2-(f_3+ f_4) = 16.58-3.02 = 13.56$

$d_7 = d_3-(f_5+ f_6) = 12.90-3.09 = 9.81$

$d_8 = d_4-(f_7+ f_8) = 12.46-1.80 = 10.66$

h = height as in the outer cone in cm.

$h_1 = 6.75$

$h_2 = 18.04$

$h_3 = 8.07$

r = radius of muscle plus bone in cm.

Segment A

Diameter = 13.20 r = 6.60 h = 6.75
= 13.56 r = 6.78

Volume $= \frac{6.75}{3} ((6.60)^2\pi + (6.78)^2\pi + (6.60)(6.78)\pi)$

$= 2.25\ (136.87 + 144.43 + 140.60)$

Volume of A = 949.28 cm^3

Segment B

Diameter = 13.56 $r = 6.78$ $h = 18.04$
= 9.81 $r = 4.905$

$$\text{Volume} = \frac{18.04}{3}\left((6.78)^2\pi + (4.905)^2\pi + (6.78)(4.905)\pi\right)$$

$$= 6.01\ (144.43 + 75.59 + 104.49)$$

Volume of B = 1950.31 cm^3

Segment C

Diameter = 9.81 $r = 4.905$ $h = 8.07$
= 10.66 $r = 5.33$

$$\text{Volume} = \frac{8.07}{3}\left((4.905)^2\pi + (5.33)^2\pi + (4.905)(5.33)\pi\right)$$

$$= 2.69\ (75.59 + 89.26 + 82.14)$$

Volume of C = 664.40 cm^3

Total Volume of A, B and C = 949.28 + 1950.31 + 664.40 cm^3.

= 3563.99 cm^3

Therefore, Total Volume of thigh fat = 5.756.60 - 3563.99 cm^3.

= 2192.61 cm^3

Multiply by 2 for the total thigh fat volume in 2 legs:

= 4385.22 cm^3