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THE PROPOSAL, VALIDATION AND APPLICATION OF A CALIPER TECHNIQUE FOR THE ESTIMATION OF UNCOMPRESSED SKINFOLD THICKNESS.

by

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ABSTRACT

The technique of using spring calipers to predict percentage body fat has been somewhat suspect because of variations in skinfold compression under constant pressure. Before this study expensive laboratory techniques for the measurement of uncompressed subcutaneous fat depth existed in the form of radiography and ultrasound, however no quick, reliable, non-invasive field technique existed for the estimation of uncompressed skinfold thickness. The purpose of this study was to produce a caliper technique for the estimation of uncompressed skinfold thickness and make applications in problem solving; specifically to investigate the phenomenon of skinfold compressibility with respect to skinfold thickness, sex of subject and site of skinfold.

First, skinfolds at seven sites on 15 females and 13 males were measured with three Harpenden skinfold calipers which exerted different pressures (5, 10, 15 $\times 10^{4} Nm^{-2}$: application being in this order at one minute intervals) and an extrapolated prediction of skinfold thickness at zero caliper pressure (ZT) was made. Validity of this three caliper technique was tested using both ultrasound and radiography as criteria of uncompressed subcutaneous fat depth. It was found that the three caliper technique gave a

reliable estimation of uncompressed skinfold thickness although it may have underestimated at very large skinfold thicknesses.

Next, the relationship between skinfold compressibility and skinfold thickness was investigated. Two procedures for quantification of compressibility were carried out.
1) conventional compression percentages were determined by calculating the percentage decrease from an uncompressed estimate of skinfold thickness to a caliper measure of skinfold thickness. This calculation assumes that compression percentage is independent of skinfold thickness.
2) DT; the difference between the three caliper uncompressed skinfold thickness estimate and the thickness measured by the caliper with the pressure of 10 $\times 10^4$ Nm^{-2} was calculated. Allometric analysis showed that the compression percentage procedure was not independent of skinfold thickness. The derived DT values were however found to be linearly related to skinfold thickness, thus an analysis of covariance of DT with ZT as a covariate (DT/ZT) was proposed as an improved procedure for the study of compressibility phenomena.

Finally, the effects of sex of the subject and site of the skinfold on the phenomenon of skinfold compressibility were investigated. Forty males and 30 females were measured at 3 sites with the three caliper technique. Using the DT/ZT criterion there was no significant difference in compressibility due to either sex of the subject or site of the skinfold. However, the conventional compression percentage analysis on the same data yielded the same kind of spurious differences as were obtained in previous studies where thickness of the skinfold was not considered in claims of a sex difference in compressibility.

In view of the foregoing findings it was recommended that the DT/ZT relationship should be used when considering differences in compressibility otherwise thickness effects could masquerade as compression differences. Contrary to claims in the literature, females in this study were shown not to have greater skinfold compression than males. Indeed although not significant, the absolute values indicated the female skinfolds to be less compressible than males. It appeared from this study that a general statement about quantitative sex and site differences in skinfold compressibility may not be possible because of sample specificity.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION.

The determination of body fat has been a matter of general interest for scientists in Human Biology for many years, and has immediate practical applications in the health professions. Various laboratory methods for determining the proportion of body fat have been developed, but these techniques require elaborate and expensive equipment and sometimes invasive techniques. Therefore the technique of using calipers to measure skinfold thickness was developed to provide a quick, convenient, reliable, and non-invasive technique for the assessment of subcutaneous body fat. Brozek and Keys (1951) greatly accelerated the use of this non-invasive technique by developing predictive equations to estimate fat from body density. Following their initial studies many other workers developed similar equations following the same rationale. (Pascale et al. 1956, Parizkova 1961, Steinkamp et al. 1965, Durnin and Rahaman 1967, Haisman 1970, Bugyi 1971, Adam et al. 1962, Best 1953, Chinn and Allen 1960, Edwards and Whyte 1962, Sloan 1967, Wilmore and Behnke 1969, Sloan et al. 1962, Katch et al. 1968, Lohman et al. 1975, Durnin and Womersley 1969). Thus skinfold measurents became accepted as a reliable field technique.

Despite its acceptance and widespread use the technique of caliper measurement of skinfold thicknesses, has several inherent limitations. These limitations include:

a) The predictive regression equations produced are sample specific.

b) The measurement procedures are prone to both intra- and inter-observer error.

c) The procedures rely on the assumption that the ratio of subcutaneous to internal fat is constant in all individuals.

d) There are variations in the amount of compression exhibited by different skinfolds under the same caliper pressure.

The aim of this study was related to these limitations and was specifically concerned with developing techniques to reduce variation in skinfold measurements due to skinfold compressibility.

There is general acceptance that at least four factors affect compressibility of skinfolds, ie. Age, Site, Sex, and Hydration level (Brozek and Kinsey 1960, Clegg and Kent 1967). No single comprehensive study has been carried out to test the contribution of all four factors to the phenomenon of skinfold compression. Although several studies have been carried out on the effect some of these factors have on skinfold compressibility. However none of these have proposed a way to eliminate or account for differences in compressibility. Brozek & Kinsey (1960) showed that there were significant changes in compressibility due to age and site of skinfold. Clegg & Kent (1967) showed site differences, and a sex difference, but proposed that there might well be a relationship between thickness and compressibility and that the differences shown might possibly have been confounded with thickness differences. However of the investigations carried out on skinfold compressibility only Jones (1970) and Lee and Ng (1965) have taken into account skinfold thickness when looking at differences due to site, sex and age.

Because of the apparent errors inherent in the use of skinfold calipers, due to lack of consideration of the aforementioned factors, a study was organised in three parts to develop new instrumentation and methods to compare with conventional methods and to examine sex and site phenomena as follows:

I) The development of a caliper technique for the estimation of uncompressed skinfold thickness and also a comparison of ultrasonic scanning and radiography as criterion measures of uncompressed subcutaneous fat depth.

II) An investigation of the relationship between skinfold compressibility and skinfold thickness.

III) Investigation of the effects of sex and site of skinfold on compressibility.

I) A caliper technique for the estimation of uncompressed skinfold thickness.

This part of the study dealt with the development and validation of a new technique for the estimation of uncompressed skinfold thickness. The technique featured the use of 3 skinfold calipers, each of which exerted different pressures over constant surface area. Standardised measurement of skinfolds with the three calipers were obtained, and a comparison of these measurements with both ultrasonic and radiographic estimations of uncompressed skinfold thickness was made. The hypotheses to be tested were:

a) That no difference existed between an estimate of uncompressed skinfold thickness, as measured by a 3-caliper technique, and an ultrasonic measurement of subcutaneous fat depth.

b) That no difference existed between ultrasound and radiographic estimates of subcutaneous fat depth.

II) Skinfold compressibility and skinfold thickness.

The second part of this study dealt with the investigation of the relationship between skinfold compressibility and uncompressed thickness of the skinfold. The hypotheses tested were:

a) That skinfold compression percentage was independent of skinfold thickness.

b) That an absolute change in skinfold thickness (DT) was related to skinfold thickness.

III) Effects of sex and site on skinfold compressibility.

This part of the study made use of the compressibility/thickness relationship to investigate the effects of sex and site on skinfold compressibility at 3 skinfold sites in 30 female and 40 male subjects. The hypotheses tested in this part of the study were that:

a) Skinfold compressibility did not differ at different sites.

b) Skinfold compressibility did not differ between the sexes.

LITERATURE REVIEW.

THE TECHNIQUE OF SKINFOLD MEASUREMENT.

a) As a predictor of percentage body fat.

Brozek and Keys (1951) were the first to develop equations for the prediction of specific gravity of the body from skinfold measurements. Abdominal, Chest, Back, Upper Arm and Thigh skinfolds were used in simple regression equations to predict specific gravity. Correlation coefficients varied from -0.749 to -0.857 for younger men, and -0.538 to -0.681 for older men. When several skinfolds were combined in a multiple regression equation, multiple correlation coefficients of -0.876 for younger and -0.744 for older men were obtained. The authors pointed out a need for more complete predictive equations covering the complete range of ages for both sexes. Brozek and Keys had selected skinfold sites for their techniques using the following criteria;

a) Representation of regions known to show large variations in subcutaneous fat thickness.

b) Representation of the extremities.

c) Ease of precise location.

Other workers apparently were influenced by Brozek and Keys. Numerous small sample studies appeared in the following decades, each expounding a predictive equation for body density or percentage body fat based on regression analysis comparing numerous anthropometric measurements to body density. There was general agreement among these studies that the correlation coefficient between body density and the specific anthropometric measures selected was in the region of 0.8 to 0.9 (Pascale et al. 1956, Parizkova 1961, Steinkamp et al. 1965, Durnin and Rahaman 1967, Haisman 1970, Bugyi 1971, Adam et al. 1962, Best 1953, Chinn and Allen 1960, Edwards and Whyte 1962, Sloan 1967, Wilmore and Behnke 1969, Sloan et al. 1962, Katch et al. 1968, Lohman et al. 1975, Durnin and Womersley 1969).

Damon and Goldman (1964) carried out an investigation into the validity of ten of these anthropometric equations predicting body fat. They found that the closest predictions of densitometrically determined fat were obtained from the equations of Pascale et al. (1956) and that of Brozek and Keys (1951) in both studies the two standard skinfold sites, triceps and subscapular were used. The difference between predicted and densitometric fat percentages averaged ±2% for the Pascale formula. Individuals whose fat was predicted poorly were at the extremes of age, height, and weight for the sample.

The use of skinfold calipers as a practical technique for the estimation of percentage body fat has been investigated extensively and the technique has a generally assumed validity for most applications.

B) RELIABILITY AND LIMITATIONS OF SKINFOLD MEASUREMENTS.

Despite general acceptance of skinfold thickness measurements as a valid anthropometric field technique, there appeared to be at least four limitations of the technique which might be summarised under the following headings:

i) SAMPLE SPECIFIC.

Equations relating skinfold thicknesses to body density tended to be sample specific. Equations could only be valid as predictors of percentage body fat, if applied to a sample which was similar to the population from which they were derived (Wilmore and Behnke 1969, Damon and Goldman 1964, Haisman 1970). Large errors were obtained when equations were applied to samples diverse in age, sex, ethnic group and level of fitness (Durnin and Rahaman 1967, Durnin and Womersley 1969 & 1974)

However there was evidence to suggest that perhaps some equations might be applied to populations from different origins without significant errors. The regression equation of Durnin et al. 1969 derived from Europeans, has been successfully applied to Chilean males (Apud, Benavides and Jones 1977). However this same equation produced significant errors when applied to Gurhka Indians (Jones, Bhadradwaj, Bhatia and Malhotra 1977). This tended to indicate some body compositional difference, maybe in bone mineralisation. The diversity in valid predictability of percentage body fat from regression equations would suggest that great caution must be used when applying predictive equations to samples different from those from which they are derived.

ii) OBSERVER ERROR.

There have been many studies carried out on the various types of calipers, to ascertain the level of repeatability of the technique. Valid measures subsume a rigorous protocol and adequate training of the investigator. Several investigators have shown that when standardised techniques such as those found in the International Biological Program handbook were employed both intraobserver and interobserver error were minimised (Burkinshaw, Jones, Krupowicz 1973).

Burkinshaw et al. (1973) showed that if the skinfold sites were marked on the skin there was no significant difference between measures by experienced and relatively inexperienced measurers at various sites. When sites were not marked the inexperienced measurers were found to be measuring higher than the experienced measurers by about

2mm.

Durnin and Womersley (1973) in a similar study showed variability between measurements and advocated highly standardised techniques.

iii) VARIATIONS IN THE RATIO OF SUBCUTANEOUS TO INTERNAL FAT.

One of the assumptions made when creating equations that predict the total body fat from skinfold thickness measurements, is that there is a constant ratio of subcutaneous to internal fat. This assumption however has been questioned by various authors. Keys and Brozek (1953) pointed out that although one could measure subcutaneous fat thickness and its distribution, one could not from this data determine total fat mass because of the variation of ratio of subcutaneous to internal fat for different individuals of different sexes and ages. Skerlj, Brozek and Hunt (1953) using densitometric criteria showed that the ratio of subcutaneous to total body fat was 0.26 in women aged 18-30 years and another group 31-45 years, but was 0.22 in a group of women aged 46-67 years.

Chen (1953) and Young, Blondin, Bensusan and Fryer (1963) found a decrease in ratio of subcutaneous to internal fat in women over 50 years of age. Studies by Parizkova (1963, 1977), Rahaman (1967) and Durnin and Womersley (1969, 1974) all provided further evidence to support the contention that the ratio of subcutaneous to internal fat varied as a function of sex and age.

This variation is very important when considering predictive equations. However when considering skinfold compressibility the most important factor is not the ratio but the absolute thickness of fat situated subcutaneously. Thus no further discussion of the variation of ratio of subcutaneous to internal fat will be made.

iv) VARIATIONS IN SKINFOLD COMPRESSIBILITY.

The first investigations into the possibility of variations in the degree of compression of skinfolds under the application of calipers were carried out by comparing caliper skinfold measurements with an estimate of uncompressed subcutaneous fat thickness. This estimation of subcutaneous fat depth was normally radiographically determined. Since a skinfold consisted of a double thicknesss of skin plus subcutaneous fat, and radiographic estimations were of a single thickness of skin plus subcutaneous fat, it was necessary to compare the skinfold thicknesses to 2 x Radiographic thicknesses. Correlation coefficients between the two estimates varied for each sex and at different sites, but the range was between 0.8 and 0.9 (Brozek and Mori 1958, Garn 1956, Garn and Gorman 1956, Hammond 1955, Jones 1970, Kurimoto and Yoshigi 1976, Edwards 1955).

The degree of compression of the skinfold in these studies was quantitatively expressed as the percentage change from radiographic to caliper measures. Hammond (1955) showed by measurements taken at two sites a mean compression percentage of 43%, using a Harpenden caliper exerting a constant pressure of 10 $\times 10^4 Nm^{-2}$. There being negligible difference between sites. Garn and Gorman (1956) in a similar study used a Lange caliper which exerted a constant pressure of 10 $\times 10^4 Nm^{-2}$ but over a smaller surface area of 30 mm^2 as compared to 90 mm^2 of the Harpenden caliper. Their sample, composed of young adult males, had a mean skinfold thickness of 9.3 mm at the midaxillary site. They found a mean compression percentage of 35%.

Edwards et al. (1955) also compared caliper measurements to radiographic measures and found a better correlation with a caliper exerting 15 $\times 10^4 Nm^{-2}$, than with a caliper exerting 10 $\times 10^4 Nm^{-2}$. However some subjects complained of pain when measured with the higher pressure caliper. It was also noted that the higher pressure caliper gave a lower skinfold thickness measurement due to the greater pressure exerted. For these reasons the authors recommended that the lower pressure of 10 $\times 10^4 Nm^{-2}$ be accepted as standard for caliper pressure.

Pascale et al. (1956) compared 2 calipers of different design which exerted the same pressure (10 $\times 10^4 Nm^{-2}$) on pressure plates of 25 mm^2 and 40 mm^2 respectively. The calipers with the larger contact area were found to correlate worse than the calipers with the smaller contact area when related to specific gravity of the body, thus suggesting an intervening variable.

Brozek and Mori (1958) carried out a similar study to that of Garn and Gorman (1956), but on a sample of 126 men between the ages of 52 and 62 years. They found a mean compression percentage of 16%. These two studies considered jointly would tend to indicate a decrease in compressibility with increasing age, if indeed compression percentage is an unbiased estimate of degree of tissue compression by the caliper.

In a study on age changes in skinfold compressibility Brozek and Kinzey (1960) measured men between the ages of 20 and 69. They were measured with calipers with 3 different pressures (5, 10, 20 $x10^{4}Nm^{-2}$). Thirty minutes was left between each measurement so that the skinfold could return to normal after compression. They showed that compression percentages decreased with age and that there were site differences in compression percentages. This site difference was more evident in older men. They obtained a mean compression of 16%, which is lower than the 43% of Hammond and the 35% of Garn. This difference may be attributable to the different mean skinfold thicknesses of the three groups, if the thickness of the skinfold affects the compressibility, since the mean thickness for the groups decreased with age.

Lee and Ng (1965) in a study on male and female cadavres, compared caliper measurements (10 $x10^{4}Nm^{-2}$) with direct fat thickness measurements made via incision at the site. They showed a lower caliper reading on females compared to males for the same fat thickness as measured by incision. Clegg and Kent (1967) measured young adults with calipers of four different pressures (5, 10, 15, 20 x10^{4} Nm^{-2}) at four sites (triceps, subscapular, costal margin, iliac crest). They came to the following conclusions based on compression percentage means not controlled for thickness:

a) Skinfold compressibility varies at different sites.

b) Compressibility varies between different individuals.

c) Compressibilities are generally greater in females than in males.

Clegg and Kent also indicated that there may be a relationship between thickness of the skinfold and compressibility. They suggested that in the male compressibility increases with increasing thickness of skinfold. However a similar relationship was not found in the female sample tested. They found the lack of relationship between skinfold thickness and compressibility in women interesting, and observed that these were the sites with greatest mean thicknesses, and proposed that possibly above a certain value, increases in skinfold thicknesses may not be accompanied by increased compressibility.

The indications from these studies were that compressibility was indeed different between the sexes, with female skinfolds being more compressible than those of males. However Jones (1970) in a comparison of radiographic with caliper measurements at four sites on the leg (Anterior and posterior thigh and medial and lateral calf) found that the ratio of caliper fat to radiographic fat was 1.61:1 for men, and 1.71:1 for women when the four leg sites were combined. This study took account of the thickness of fat and showed that male sites were more compressible than female sites for the same fat thickness. This would tend to conflict with evidence from the other studies. Efforts have been made to explain the discrepency in terms of sample differences, in that the females measured by Jones were physical education students with well developed musculature causing increased skin tension. There were also ethnic, nutritional and age differences in the samples. However it is important for comparative purposes that in any analysis skinfold thickness is controlled for in a similar manner to that of Jones.

Compression percentage is a ratio of two linear measurements or lengths and thus should be dimensionless, and independent of skinfold thickness, however Clegg and Kent (1967) proposed a possible relationship between compression percentage and skinfold thickness which would seem cotradictory and mutually exclusive. If compression percentage is related to thickness then simple comparison of mean compression percentages between males and females is not a valid test of a sex difference in compressibility since females tend to have higher mean skinfold thicknesses than males. However, the technique of Jones (1970), where thickness was taken into account, was a valid test of a sex difference in compressibility. This method of analysis could also be applied to differences due to site and age.

Summary:

1) Skinfold measurements have become accepted as a valid anthropometric field technique.
2) Skinfold thicknesses have been related to body density in order to predict percentage body fat.
3) Predictive equations tend to be sample specific.
4) The prediction of percentage fat from predictive equations is poorest in subjects exhibiting extremes of age, height, and weight for the population.
5) Highly standardised techniques must be employed to reduce intra- and interobserver error.
6) Marking the site of a skinfold increases the accuracy of repeated measures.
7) The ratio of subcutaneous to internal fat is not constant in all individuals.
8) Mean compression percentage varies according to the population under study.
9) A 15 $\times 10^4 Nm^{-2}$ caliper measurement correlated better to radiographic measures than did a 10 $\times 10^4 Nm^{-2}$ caliper.
10) There was a decrease in compressibility with age when judged by mean compression percentages.
11) A lower caliper reading was found in females compared to males for the same actual fat thickness.

12) Skinfold compressibility was found to vary at different sites.

13) Compression percentages were generally larger in females than males.

14) There may be a relationship between skinfold thickness and compression percentage.

15) Male skinfolds were found to be more compressible than female skinfolds when skinfold thickness was taken into account.

16) Compression percentage is dimensionless and thus should be

independent of skinfold thickness.

RADIOGRAPHIC AND ULTRASONIC TECHNIQUES FOR ESTIMATION OF SKINFOLD THICKNESS.

One of the first uses of ultrasonic estimation of subcutaneous fat depth was as an alternative method of assessing back fat in pigs. It was used as a method of determining fat in vivo in animal body composition studies (Temple et al. 1956) and was proposed as a possible technique for fat thickness assessment in human subjects (Stouffer 1963). The apparent lack of side effects of the technique has lead to the increasing use of it as a technique in human research.

The technique features the use of an ultrasonic scanner, which converts electrical energy into high frequency sound energy. This sound energy is transmitted into the body as short pulses. When these waves strike perpendicularly onto the interfaces between two tissues of different acoustical properties, a small portion of the energy is reflected back to the transmitter probe. Here it is changed back into electrical energy. This can be seen on an oscilloscope screen as a vertical deflection from the horizontal time base. The distance along the time base from zero point to vertical deflection is proportional to the time taken for ultrasonic waves to traverse from the interface and back to the probe. If the velocity of sound is known then this time can be converted to fat depth. Ultrasonic scanning in this mode is called A-scanning. The use of A-scan ultrasound measurement of adipose tissue in humans has been examined in several studies (Booth, Goodard and Patton, 1966; Bullen, Quade, Olsen and Lund, 1965; Hawes, Albert, Healy and Garrow, 1972; Sloan, 1967, Whittingham 1962, Haymes et al., 1975). When ultrasonic measurements have been compared to caliper skinfold thickness measurements, by means of simple regression analysis, correlation coefficients of 0.80 and above have been found (Booth et al., 1966; Bullen et al., 1965; Sloan, 1967) I contrast, when Haymes et al. (1975) carried out a similar study comparing these two techniques, correlation coefficients for ultrasonic measurements and caliper skinfold thickness for males were lower than 0.8 at all four sites used, but greater than 0.8 for their female sample. It was believed that this difference was primarily due to the greater range in subcutaneous fat thicknesses in the female sample. A spuriously high correlation coefficient was obtained for the female data. However as recognised by the authors the effects of variation in tissue composition and skin tension could not be discounted.

In a test of reliability of ultrasonic measurement Haymes et al. (1975) found correlation coefficients of between 0.87 and 0.98 for test-retest on the four sites used, compared to 0.98 - 0.99 for test- retest correlation coefficients when the four sites were measured by skinfold caliper. This was accepted as showing that the ultrasound technique was a valid, reliable technique for the estimation of uncompressed subcutaneous fat depth. Bullen et al. (1965) produced ultrasonic measurement test-retest correlation coefficients of between 0.985 and 0.994, and stated that they were of the same magnitude as those reported for the most reliable of comparable anthropometric measurements (Tanner and Weiner 1949). The thickness range in this study was 3 to 40 mm of tissue, whereas the range in the study by Haymes et al (1975) was 5 - 30 mm which may partially account for the higher correlation in the earlier study.

Correlation coefficients of between 0.7 (Suprailiac) and 0.88 (Mid-triceps) were obtained for comparisons of ultrasound measures with x-ray measures at the same sites by Haymes et al (1975). However Hawes et al. had reported poor correlations between ultrasound and x-ray measurements at the iliac crest and greater trochanter.

Summary:

1) Correlation coefficients of 0.80 and above have been found betweenultrasonic and caliper measurements of subcutaneous fat.

2) The ultrasound technique has been validated against radiography as a reliable measure of uncompressed subcutaneous fat depth.

BIOPHYSICAL PROPERTIES OF SKIN.

A skinfold is composed of a double layer of skin plus subcutaneous tissue. The characteristics of the skinfold under application of a caliper exerting constant pressure are determined by the biophysical properties. These biophysical properties are dependent on both the properties of the skin and those of the underlying subcutaneous tissues. Unfortunately, isolated subcutaneous adipose tissue does not lend itself to physical tests involving deformation, due to the problems of attaching samples to any apparatus. However the skin itself is a medium that can, and has been experimented on extensively. Skin has been studied in deformation by stretching and compression under various conditions of sex, age, and level of hydration. Knowledge of the properties of the skin may help in the interpretation of results found in this thesis, since skin is included in a caliper measurement of subcutaneous fat thickness.

The stress/strain relationship and the tensile strength of uniformly loaded strips of human skin have been studied extensively. Ridge and Wright (1965, 1966, 1966) carried out uniaxial extension on excised skin samples. They produced a three part force/extension diagram:

1) An initial extension phase corresponding to the straightening out of the collagen fibres.
2) A second phase of stiffening extension of the oriented collagen fibres.
3) A final yielding phase as individual fibres break.

Rothman (1954) recognised that skin was under forces of tension in vivo, and would contract upon incision. Dupuytren as reported by Cox (1942) first observed that there were direction effects in skin tension. A circular bladed stilletto caused an oval incision when wounding the skin of a cadavre. Langer as reported by Ma and Cowdry (1950) carried out further experiments and produced a series of lines on the body, relating to directions of principle tension. These lines followed the direction of preferential orientation of fibres in the dermis (Cox 1942), this was again shown by Wright (1966). These lines were termed Langer lines. The stress/strain curve of specimens of skin along and across Langer lines, were found to be different. The skin would extend more across the Langer line, since the skin could extend a long way before the fibres became oriented parallel to each other.

It was the belief of this author that this variation in skin tension at different areas of the body, may be contributing towards the site differences in skinfold compressibility that have been found in the literature.

Deformation in parallel with Langer lines requires greater force than at right angles. This was found by Gibson (1969) when measuring biaxial deformation in vivo on human subjects, with the use of a simple device which rested on the skin and recorded the force required to stretch a rectangular segment of skin. This finding was important in a discussion of skinfold technique, since it would mean that at any given site, different measurements, due to the change in skin tension might be elicited merely by rotating the caliper through an angle of 90 degrees. This highlights the need for standardised landmarking and orientation of the caliper at the skinfold sites.

Biaxial deformation of skin was studied under conditions of compression. The rate at which a circular plate of skin reduced its thickness under a constant load was measured as a function of compression. It was supposed that water rapidly left the compressed tissues at a diffusion-limited rate. The rate of compression, therefore was set by the viscosity of the fluid held in the fibrous connective tissue. This was an important finding, in that it threw light on the time interval required between skinfold measures. When a skinfold has been measured some period of time should be left before remeasurement, to allow the skinfold to return to normal, ie. for the expulsed water to return. The recovery time that should be allowed before remeasurement has been debated. Brozek and Kinzey (1960) proposed that as long as 30 minutes should be allowed between measurements.

The tensile strength of female skin was found to be less than that of male skin (Wenzel 1949), and also female skin has been found to be more extensible than male skin (Ridge and Wright 1965). These findings relate to the histologic findings of Lindholm (1931) in that elastic fibres were more numerous in female than male skin. Wenzel (1949) found that shrinkage of excised skin was greater in males than in women, indicating that male skin was under greater tension in vivo. These findings would tend to back the theory that female skinfolds would be more compressible.

With age there is a decrease in skinfold compressibility (Brozek and Kinzey 1960). There is increasing elastic stiffness of skin after the age of 40 in man (Kennedi et al. 1963). This is attributable to the fact that with increasing age there is an increase in the number of cross-linkages in the collagen fibres. Thus, the fibres cannot slide across each other under conditions of stress. This is supported by the fact that the tensile strength of skin increases with age (Rollhauser 1950). Grahame (1969) found that there was an increase in the modulus of elasticity of skin with age in both sexes. All these findings would tend to indicate a decrease in skinfold compressibility with age.

Summary:

1) There is a three part force/extension curve for uniaxial extension of a strip of excised skin.

2) In vivo the skin is under tension.

3) Langer lines exist on the body, which relate to directions of principle tension in the skin and follow the direction of preferential orientation of the fibres in the dermis.

4) Stress/strain curves across and along Langer lines are different.

5) Skin tension varies at different sites.

6) The rate of compression of skin is dependent on the viscosity of the water held in the fibrous connective tissue.

7) Female skin is more extensible than male skin.

8) In vivo male skin is under greater tension than female skin.

9) There is increasing elastic stiffness with age.

DIMENSIONALITY THEORY.

Bridgeman (1931):

"The purpose of dimensional analysis is to give certain information about the relations which hold between the measurable quantities associated with various phenomena."

When a relationship exists between two variables X and Y, the relationship can be represented by the expression Y = F(X) where F is a function. In this relationship Y is considered to act as the dependent variable and X is the independent variable. Variables may be expressed in terms of quantities according to the particular set of rules of operation, which are regarded as fundamental and of irreducible simplicity. In physical terms, these fundamental quantities are Mass, Length, and Time. The dimension of a quantity is represented by square brackets [ ] as suggested by Ellis (1966). Thus the dimension of Mass is represented as [M].

If a variable is composed of a combination of the primary quantities it is said to be a secondary quantity. Any secondary quantity can thus be expressed in terms of primary quantities. Such a secondary quantity in a geometrical similarity system where shape and composition are constant is Density. Density is expressed as mass per unit volume or mass/volume. The dimension of Mass is [M], and the dimension of volume, since volume is proportional to the cube of length, is $[L]^3$. Therefore the dimension of Density is $[M]/[L]$ or $[M][L]^{-1}$. The system of mechanics uses mass, length, snd time as primary quantities, but this is merely an arbritrary selection. The selection of primary being made according to the particular kind of physical system being dealt with. In the physiological dimensional system there is only one primary quantity, and that is length. The dimension of length is $[L]^1$. Mass can be expressed as $[L]^3$ since it is proportional to volume. Time has the dimension $[L]^1$. Density in the physiological system now has the dimensions of $[L]^0$, meaning that density is independent of length.

In the area of human growth dimensional analysis has been used in forming metaphorical models, or similarity systems from general premises which can then be used to interpret empirical results. The most commonly used similarity model in the study of human biology has been the geometrical similarity model. In the geometrical similarity model it is assumed that volume is proportional to L^3, and Density is constant therefore Mass/Volume is constant and M is proportional to Volume or $M \propto L^3$. Also $T \propto L^1$ since one assumes that all values are in constant proportions independent of size. Therefore velocities L/T of an L must be constant. If L/T is constant then $L \propto T$.

For bodies which are geometrically similar, area $\propto L^2$ or area has the dimension $[L]^2$, and Volume $\propto L^3$ or has the dimension $[L]^3$. These relationships were appreciated as long ago as 300 B.C. by Euclid, and 287-212 B.C. by Archimedes. Galileo (1638) had applied such a model to the study of human and animal locomotion. Since then many authors have applied geometrical similarity models in an attempt to gain insight into human structure and function.

It is now possible having defined the primary quantities of a system to use that system to predict relationships between variables. This will be done in an attempt to show that the concept of compression percentage is not independent of thickness of skinfold as would be predicted by dimensionality theory.

DEFINITIONS OF TERMS USED IN THIS THESIS.

3 - caliper technique	Use of three Harpenden skinfold calipers, each exerting a different pressure, to measure the same skinfold. A linear regression is then carried out between log10 skinfold thickness values and caliper pressure. The antilog of the intercept calculated from this regression is regarded as the uncompressed skinfold thickness prediction (ZT).
ZT	Predicted uncompressed skinfold thickness from the three caliper technique.
H(5)	The skinfold thickness as measured by the Harpenden skinfold caliper exerting $5 \times 10^4 Nm^{-2}$.
H(10)	The skinfold thickness as measured by the Harpenden skinfold caliper exerting $10 \times 10^4 Nm^{-2}$.
H(15)	The skinfold thickness as measured by the Harpenden skinfold caliper exerting $15 \times 10^4 Nm^{-2}$.
C(Z/10)	A compression percentage calculated by subtraction of H(10) from ZT and then division by ZT.

DT — A compressibility measure produced by subtraction of H(10) from ZT.

UT — Subcutaneous fat depth as measured by ultrasonic scanning.

RT — Subcutaneous fat depth as measured by radiography.

Throughout this thesis the units of caliper pressure used have been $\times 10^{4}\ Nm^{-2}$. This was preferred to the more traditional units of $gm\ mm^{-2}$ used in the literature, in order to come in line with the SI unit system.

PART 1.

THE PROPOSAL AND VALIDATION OF A 3-CALIPER TECHNIQUE FOR THE ESTIMATION OF UNCOMPRESSED SKINFOLD THICKNESS.

INTRODUCTION.

The measurement of skinfolds by use of a spring caliper to estimate subcutaneous fat thickness has long been accepted as a valid anthropometric technique despite the several limitations previously mentioned. This study was concerned with looking at the variation in the amount of compression of different skinfolds under constant pressure. Even when jaw surface area, and pressure exerted by the caliper are kept constant, the degree of compression of different skinfolds varies. Factors such as site and sex may influence the degree of compression for the same thickness of skinfold. The influences of these factors were investigated in parts II and III of this thesis.

The ideal measurement of thickness of fat plus skin would be one taken when no pressure was exerted on the surface of the skin. This would give an estimate of uncompressed thickness and as such would negate our need to worry about the effects of variations in compressibility. Subcutaneous fat depth can indeed be measured in an uncompressed state, by both radiographic and ultrasonic scanning techniques. However both require expensive and sophisticated equipment and are thus not used extensively in research and clinical application. Radiography has the added disadvantage that it is time consuming and also carries with it the hazards associated with the use of radiography. To date no quick, convenient field technique for the estimation of uncompressed skinfold thickness has been developed. The aim of this study was to develop and show application of a three caliper technique for the estimation of uncompressed skinfold thickness by extrapolation from compression at different pressures. The three caliper technique and the conventional single caliper procedure were compared to an ultrasonic skinfold thickness which served as an uncompressed thickness criterion.

METHODS AND MATERIALS.

It was the purpose of this study to develop a technique to reduce variation due to compressibility differences in skinfolds. To avoid the problem of compression the best measure of skinfold thickness would be an uncompressed thickness (Garn 1956, Brozek and Mori 1958, Tanner, Hughes and Jones 1966, Clegg and Kent 1967). This can be achieved by use of soft tissue radiography, and also by ultrasonic scanning techniques. Many studies have been carried out to show the variation in compressibilities of skinfolds by comparison of either radiographic or ultrasonic measures of skinfold thickness to caliper measurements (Booth et al. 1966, Garn 1956, Hawes et al. 1972, Garn and Gorman 1956, Brozek and Mori 1958, Jones 1970). There is however no quick, convenient field technique for the estimation of uncompressed skinfold thickness. The aim of this study is to fill this hiatus, and produce a three caliper technique for the estimation of uncompressed skinfold thickness.

The 3 Caliper Method for the Estimation of Uncompressed Skinfold Thickness.

Three standard Harpenden skinfold calipers were modified in order to produce one caliper which exerted a constant pressure of 5 $\times 10^{4}$ Nm^{-2}, one of 10 $\times 10^{4}$ Nm^{-2}, and the third to produce 15 $\times 10^{4}$ Nm^{-2}. When a graph of skinfold thickness measured by the caliper, versus pressure exerted by the caliper, for any individual skinfold was plotted, a curve similar to that in Fig. 1a was produced. Details of how the calipers were changed and how they were subsequently calibrated can be found in Appendix 1.

The ideal caliper measurement for minimal or no compression would be one taken at zero caliper pressure.

However this was quite obviously impossible to achieve with a caliper, since it must exert a certain amount of pressure on the skinfold in order to make a measurement. A theoretical zero caliper pressure thickness could be achieved by extrapolation of the thickness/caliper pressure curve back to zero caliper pressure. In practice this has limitations in that if the 10 $x10^4 Nm^{-2}$ reading is slightly high (as may sometimes occur due to observer error) the curve produced by a standard least squares curve fitting routine, tended to give a predicted zero pressure thickness lower than the 5 $x10^4 Nm^{-2}$ reading, as depicted in Fig. 1b. To correct for this, and to ensure that the predicted zero pressure thickness always was greater than the 5 $x10^4 Nm^{-2}$ readings, the log10 of the thickness was calculated and plotted against caliper pressure. A simple regression analysis was carried out on these points and the intercept on the log10 thickness axis was calculated. The antilog of the intercept was calculated and this was the zero caliper pressure thickness prediction ZT (Fig. 1c).

Fig. 1: Graphical representation of the three caliper technique

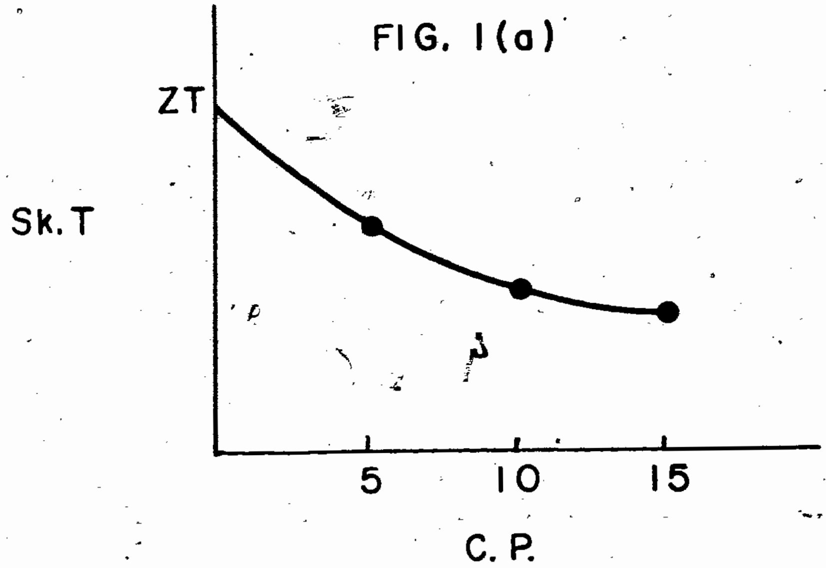


FIG. 1(a)

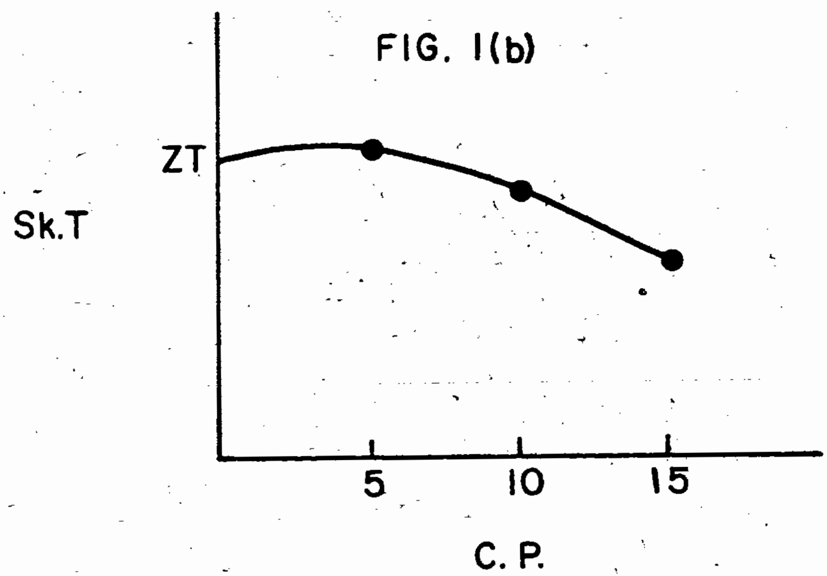


FIG. 1(b)

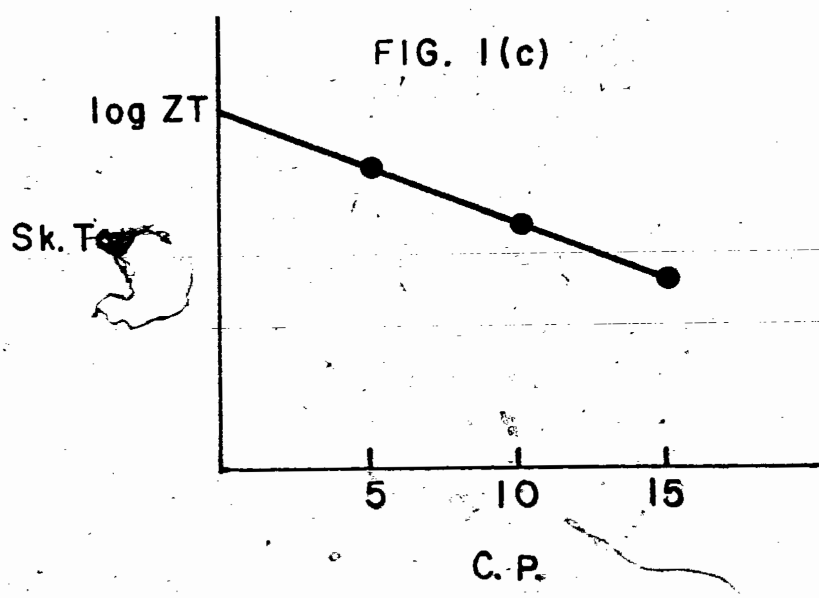


FIG. 1(c)

If this method was to become an accepted technique which other workers might use to determine uncompressed skinfold thickness, then it must be standardised. The site was clearly marked so that each caliper was applied to the same skinfold exactly. The technique would fail if the site of application was different for the three calipers, or if the skinfold was picked up in a different manner each time. Having marked the skinfold carefully, the skinfold was measured with the 5 $\times 10^4 Nm^{-2}$ caliper, after a pause of one minute the skinfold was measured with the 10 $\times 10^4 Nm^{-2}$ caliper, and after a pause of another minute the 15 $\times 10^4 Nm^{-2}$ caliper was used. This was defined as the standardised technique, and was from now on be referred to as the 3 - caliper technique. The implications and problems associated with this technique were discussed at the end of this thesis. Details of the pilot study to determine order of application of the calipers, and the final form of the 3-caliper technique are given in Appendix 2.

GENERAL PROCEDURE

Twenty eight subjects were used in this study, 15 females age range 7.1-29.5 yrs., average age 22.0 yrs., and 13 males age range 8.2-30.2 yrs., average age 23.2 yrs. The subjects were selected from students and friends at Loughborough University. An attempt was made to ensure that the sample had a fairly large variation in skinfold types, in order to provide a wide range for the 3 - caliper technique.

Seven skinfold sites were selected for use in the study. All subjects were measured on the right-hand side of the body. The seven sites used were:-

TRICEPS - The vertical fold on the midline of the back of the arm, midway between acromiale and radiale.

SUBSCAPULAR - The natural oblique fold below the inferior angle of the scapula.

MIDAXILLARY - The vertical fold at the side of the chest, on the midaxillary line, midway between axilla and iliac crest.

SUPRAILIAC - The natural oblique fold 5 to 7 cm upwards on an imaginary line from anterior iliac spine to axilla.

BICEPS - The vertical fold on the front of the arm at the same level as the triceps skinfold.

MEDIAL CALF - The vertical fold on the medial aspect of the calf at the level of the maximum calf girth.

LATERAL CALF - The vertical fold on the lateral aspect of the calf at the level of the maximum calf girth.

The skinfold sites are illustrated in Figure 2.

Fig 2: Skinfold sites.

(1) Triceps

(2) Subscapular

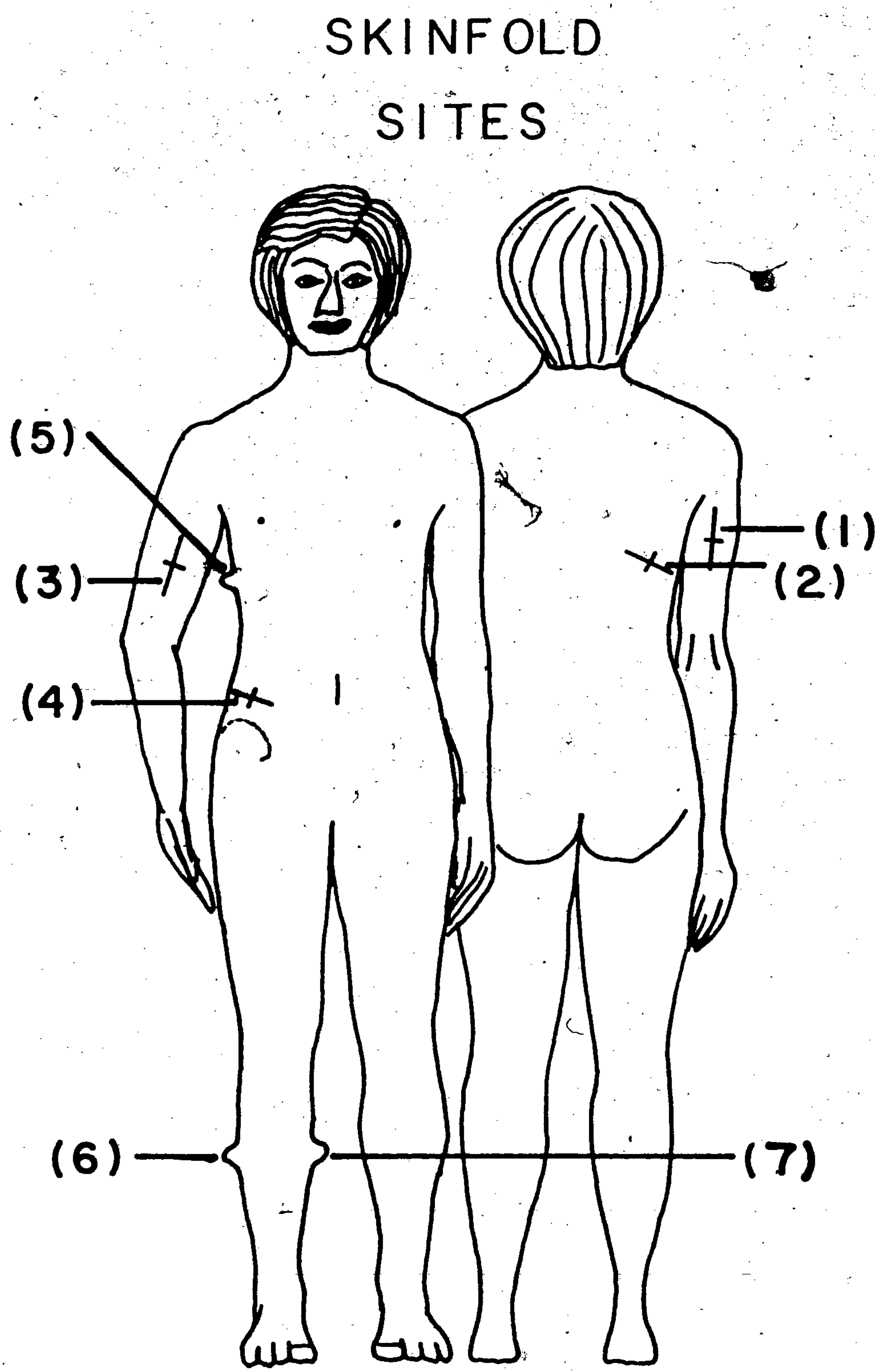
(3) Biceps

(4) Suprailiac

(5) Midaxillary

(6) Lateral Calf

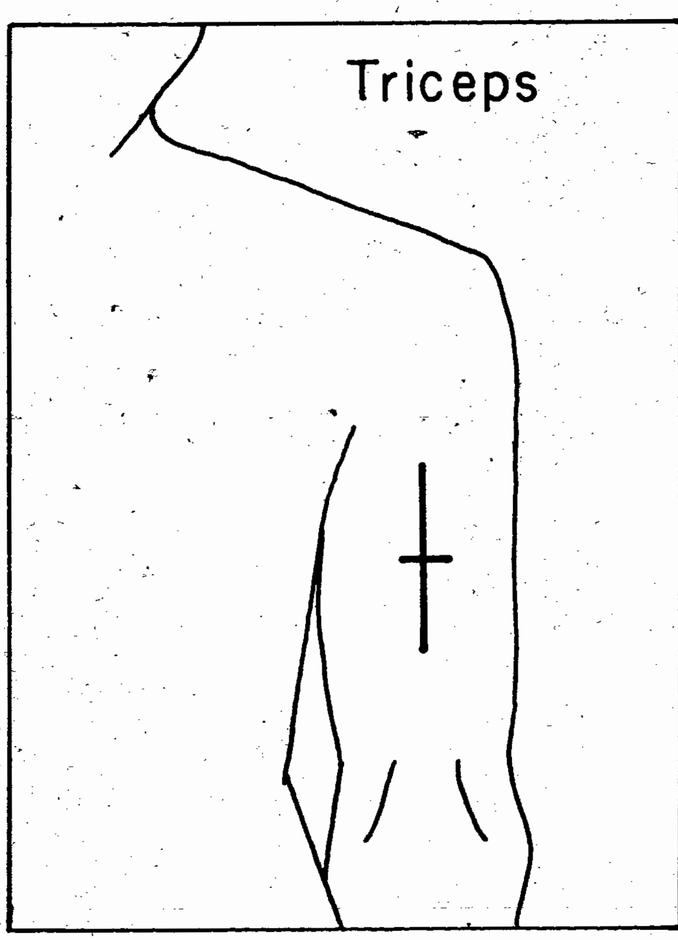
(7) Medial Calf


SKINFOLD
SITES
(5)
(3)
(4)
(6)
(1)
(2)
(7)

The skinfold sites were clearly marked on each subject by use of a dermagraphic pen. A long mark was made along the crest of the skinfold, so that the same skinfold was picked up each time. A cross mark on this line was made at the point of application of the caliper, so that position of caliper application could be standardised. (Fig. 3) The subjects were initially measured using an ultrasonic scanner to record the uncompressed subcutaneous fat depth at each of the seven sites. The subjects were then measured by use of the 3 - caliper technique at each of the seven sites. A period of 5 minutes was allowed before the skinfolds were remeasured using the 3 - caliper technique. Seven of the 28 subjects were also measured using a radiographic technique at four of the seven sites. The four sites used were; Triceps, Biceps, Medial Calf, Lateral Calf. These four sites were chosen because of their accessibility to the radiographic technique. The technique of Jones (1970) was employed.

Fig 3: Skinfold marking technique.

SKINFOLD MARKING TECHNIQUE



ULTRASONIC TECHNIQUE.

In this study an estimate of uncompressed subcutaneous fat depth was obtained by use of an ultrasonic scanner. The scanner used was a SKI Ekoline 20A with a 5.0 MHz. transducer. Measurement of fat depth with the scanner was made before skinfold measurement with the 3-caliper technique. The thickness was measured first with the scanner to avoid any compression effects that might have been elicited by previous use of the calipers.

The experimenter practised with the ultrasonic scanner until reliable and reproducible results were being obtained. This practice was necessary for the production of reliable results in the actual study. If undue pressure was placed on the transducer when it was in position on the skin, a certain amount of local compression of the subcutaneous tissues occured. Thus, a fairly light touch was required with the transducer, although enough pressure was required to elicit good acoustic conduction. Conduction of the sound waves was aided by the use of a standard acoustic coupling gel. It was necessary for the sound waves to strike the tissue interfaces at right angles for there to be reflection of the waves back to the transducer, thus gentle manipulation of the transducer was required to provide a clear and correct trace. An explanation of what was meant by a slight pressure and how this was standardised to give repeatable measures was explained in Appendix 3.

The depth estimate was recorded on an ultraviolet paper recorder. However before the reading from the trace could be used, certain corrections had to be made. It has been shown that sound waves travel faster in water than they do in fat, and thus a correction for this difference had to be made. This was necessary since the transducer was calibrated through a water medium.

$$\text{Correction Factor} = \frac{\text{Velocity of sound through fat}}{\text{Velocity of sound through water}} = \frac{1456 \text{ ms}}{1480 \text{ ms}}$$

Correction Factor = 0.9797

Therefore each measurement from the trace was initially multiplied by 0.9797. This is a correction factor commonly used in ultrasound measures of fat thickness. The horizontal scale of the scanner's oscilloscope could be altered to give a clearer display. The scale was changed on each subject so that the trace occupied almost all of the screen. Thus a correction due to this change needed to be made. Scale markers which represented 1 cm. appeared on the trace. The distance between these markers could be measured from the trace and the appropriate conversion factor calculated. A final correction was made from the results of calibration of the transducer. The transducer was calibrated by use of a perspex block with a well bored into it (as depicted in Fig. 4). This well had a larger diameter at the top and a shoulder midway down where the diameter was less. This block was made to specific dimensions as shown in Fig. 4. The well was completely filled with distilled water. Depth measurements to the bottom of the well and to the shoulder were made. From these readings a correction factor was calculated. The correction factor tended to change from time to time. It was mainly due to the positioning of the transducer in the plastic holder. This holder was necessary since the transducer had a diameter of only 8.0 mm and thus would quite easily cause local compression of the subcutaneous tissues. A plastic rim of 48.0 mm diameter was placed around the transducer and this allowed application of the transducer with negligible local compression. The transducer was thus calibrated before each subject was measured.

RADIOGRAPHIC TECHNIQUE.

On seven of the subjects soft tissue radiographs were taken of the lateral aspect of the upper arm, and the anterior aspect of the lower leg. This allowed for estimation of subcutaneous fat depth to be made at the triceps and biceps sites, and at the lateral and medial calf sites. The subjects were volunteers from the 28 subjects measured by ultrasound; four females and three males being measured.

Positioning of the subjects was as shown in Fig. 4. The upper arm was allowed to hang freely in front of the x-ray film cassette. The midpoint at one half the acromiale-radiale distance on the back of the upper arm was positioned exactly 10 cm perpendicularly away from the front surface of the cassette. The arm was placed so that the limb was not deformed by compression against the cassette casing, and the limb was in a standard position. The arm was supported in position by use of small foam pads. After positioning the subject was asked to remain completely still. The positioning was quickly checked, and the radiograph exposed. The cassette was then moved over in its mounting since only one half of the cassette was exposed at any one time. The subject was then asked to stand in front of the cassette as in Fig. 5. The leg was positioned such that the mid-point of both lateral and medial aspects of the calf were 15 cm perpendicular from the front surface of the cassette. The subject was then asked to remain perfectly still. The positioning was rechecked, and the radiograph exposed.

Fig 4: Arm positioning for radiography.

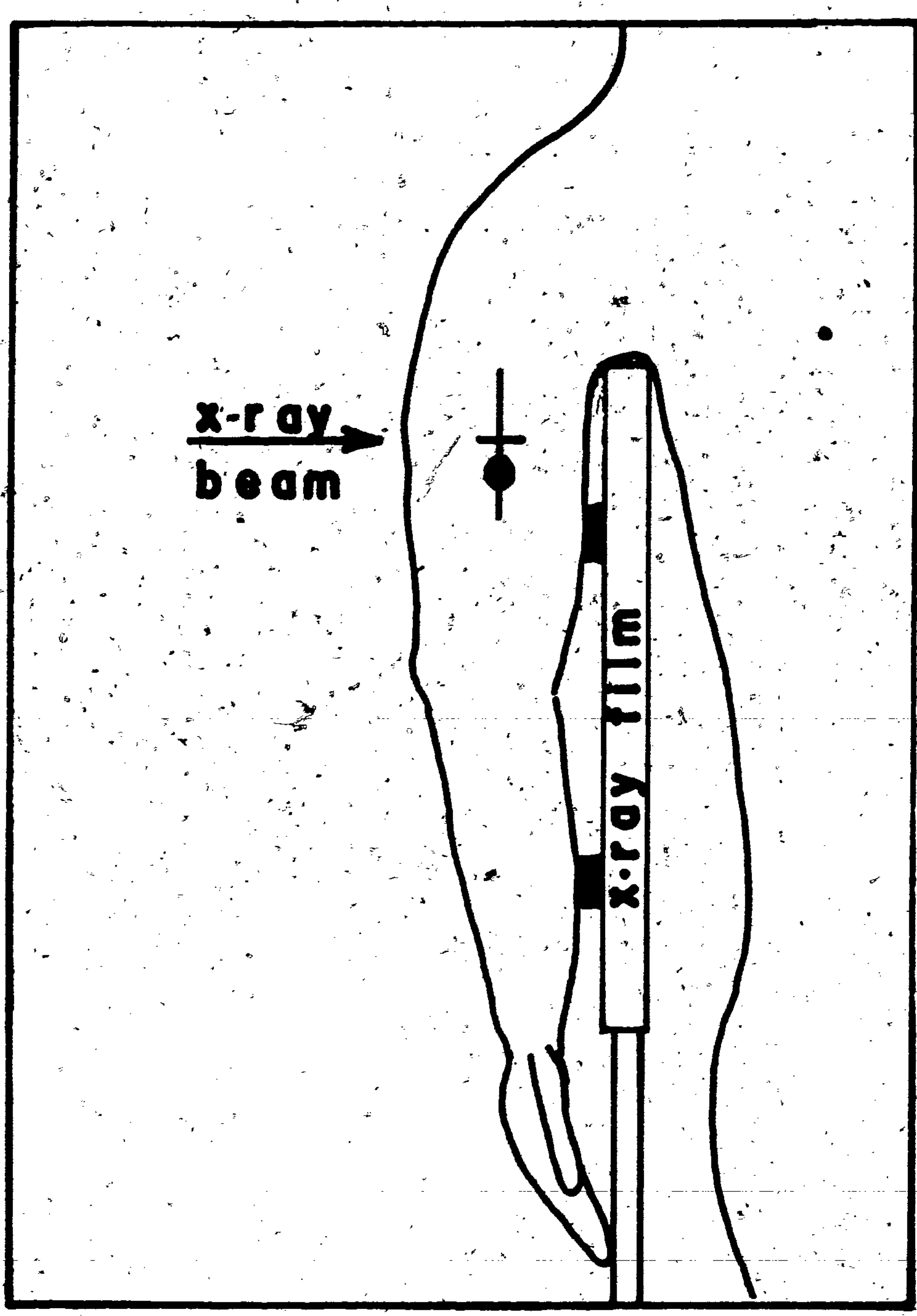
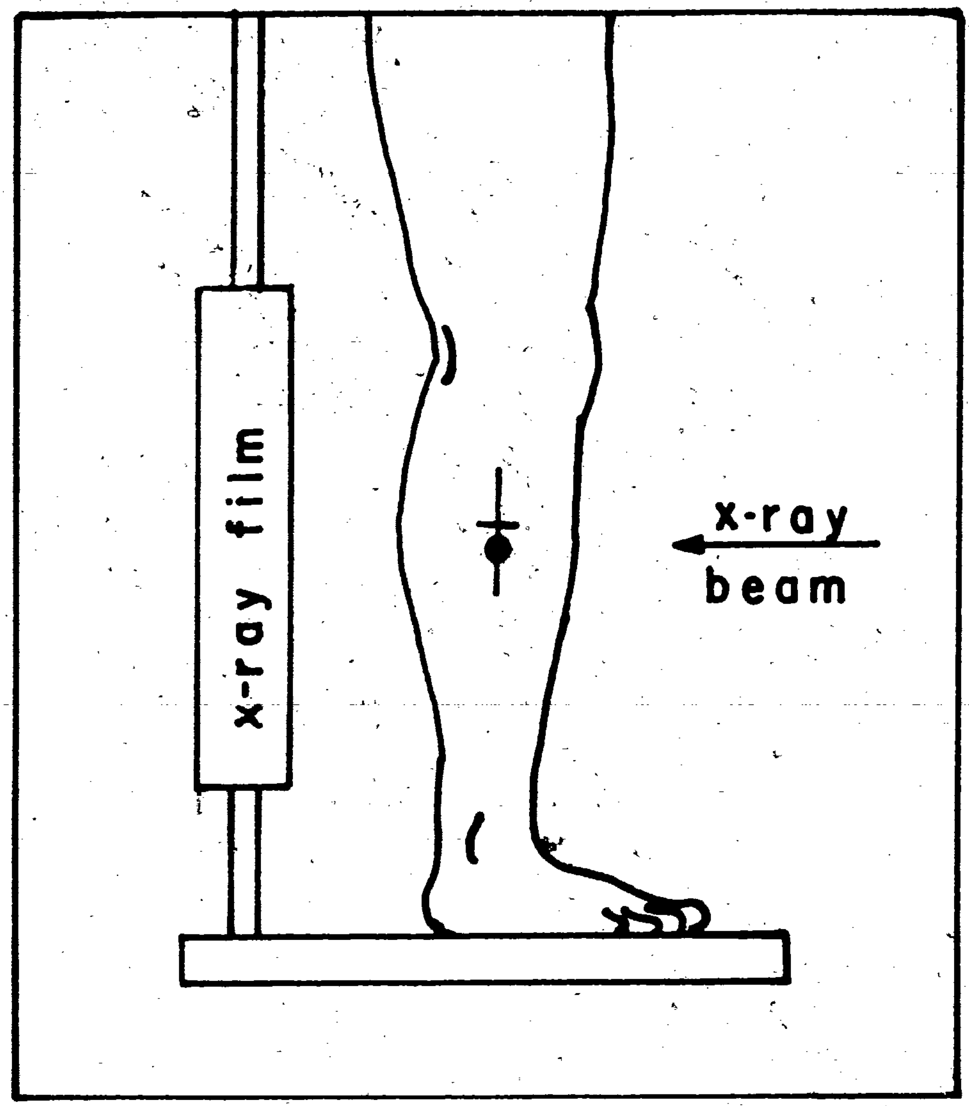

x-ray
beam
x-ray film

Fig 5: Calf positioning for radiography.


x-ray film
x-ray
beam

It was necessary to mark the skinfold so that the experimenter could tell where to measure the fat thickness on the radiograph. This was done by taping an English penny to the surface of the skin, 1/2 cm below the skinfold mark. The penny had the added advantage that it could be used as the magnification correction factor measure, since the penny was exactly 2 cm in diameter, and when viewed from the edge was 2 cm from any angle.

The fat depth was measured from the radiographs by use of a standard radiograhic caliper. The measurement was taken perpendicular to the skin surface at a point 1/2 cm above the edge of the coin. The length of the coin was measured in order to calculate the magnification factor. The caliper reading was then multiplied by this magnification factor. Readings were taken to the nearest 0.1 mm.

RESULTS AND ANALYSIS.

ULTRASOUND vs. X-RAY.

Radiography is an accepted laboratory method for the estimation of subcutaneous fat depth. However this method has several limitations. It is only applicable at certain sites; it is a time consuming process, and it has possible deleterious side-effects with overuse. Ultrasonic measurement because of the lack of the aforementioned limitations of radiography has become accepted as a valid technique for subcutaneous fat depth estimation. For these reasons in this study the ultrasonic method was used as the criterion measure of uncompressed subcutaneous fat depth. As a cross-check of the validity of the ultrasound technique, 7 of the subjects were measured using the radiographic technique at four of the sites measured by ultrasonic scanning. This produced 28 individual skinfold measurements by both radiography and ultrasonic scanning. A correlation coefficient of 0.865 was found between the two techniques. The mean for the radiographic thicknesses was found to be slightly greater than that for ultrasonic thicknesses, (Table 1) although no significant difference was found between the means for the two techniques at the 95% level of significance. These findings agree with those found in the literature, where correlations between the two techniques varied from 0.76 - 0.98, dependent on the sites used and sex of the subjects involved. Radiographic thicknesses have been found to be slightly higher than ultrasonic measures. These findings would tend to justify the selection of ultrasonic measurements as a criterion of uncompressed skinfold thickness in this study, since ultrasonic measures correlate well with radiographic measures, and ultrasound does not have the deleterious side effects that radiography could have when used incorrectly.

Table 1: Simple regression analysis between Radiographic Thickness measurements (RT), and Ultrasonic Thickness measurements (UT) on seven subjects at four sites.

	RT(mm)	UT(mm)
Mean	8.68	8.27
S.D.	5.03	4.71

Regression equation:

$$UT = 0.791(RT) + 1.4$$

$$S.E.E. = 2.57 \text{ mm}$$

$$r = 0.865$$

$$n = 28$$

COMPARISON OF ZT AND H(10) vs. ULTRASOUND.

The aim of this study was to produce a technique for the measurement of skinfold thickness which minimised the effects of differences in compressibility. It has been claimed that a portion of the variance in a relationship between a caliper technique and radiography (a criterion measure of uncompressed thickness) is due to the variation in compressibility in different skinfolds. If the 3-C technique gave better correlation with a criterion measure than the skinfold measured with the Harpenden $10 \times 10^4 Nm^{-2}$ caliper H(10) alone, then this would tend to indicate that the technique had accounted for some of the variance due to compressibility differences. Table 2 shows the results of this analysis. $10 \times 10^4 Nm^{-2}$ is the internationally accepted pressure for skinfold calipers. It could be seen that there is a better correlation between ZT (the estimate of uncompressed skinfold thickness from the 3-caliper technique) and UT (uncompressed thickness by ultrasonic scanning) than between H(10) and UT, at five of the seven sites used. The correlation coefficients between ZT and UT when all sites are considered are 0.904, and between H(10) and UT 0.869. Therefore an extra 6.2% of the total variance in the relationship has been explained by the new 3 - caliper technique. Fig. 6, and Fig. 7 show the regression lines for these relationships. If the site showing the greatest variation in compressibility is considered, that is the suprailiac site since it showed the greatest range in compression percentages (Table 3), it is found that the correlation coefficient between H(10) and UT is 0.789, and that this is increased to 0.895 between ZT and UT, thus an extra 17.85% of the total variance is explained. These results indicate that in five of the seven sites used, the 3 - caliper technique accounted for a portion of the variance due to differences in compressibility.

Table 2: Correlation coefficients between Ultrasonic Thickness (UT) and Skinfold Thicknesses H(5), H(10), H(15) and ZT.

SITE	H(5)	H(10)	H(15)	ZT
All sites	0.889	0.896	0.865	0.904
Triceps	0.914	0.908	0.905	0.920
Biceps	0.890	0.902	0.909	0.873
Lat. Calf	0.869	0.867	0.865	0.869
Med. Calf	0.946	0.954	0.952	0.932
Midaxillary	0.825	0.756	0.749	0.839
Subscapular	0.948	0.943	0.948	0.949
Suprailiac	0.823	0.789	0.777	0.895

Fig 6: Graph of H(10)/UT regression line for all sites.

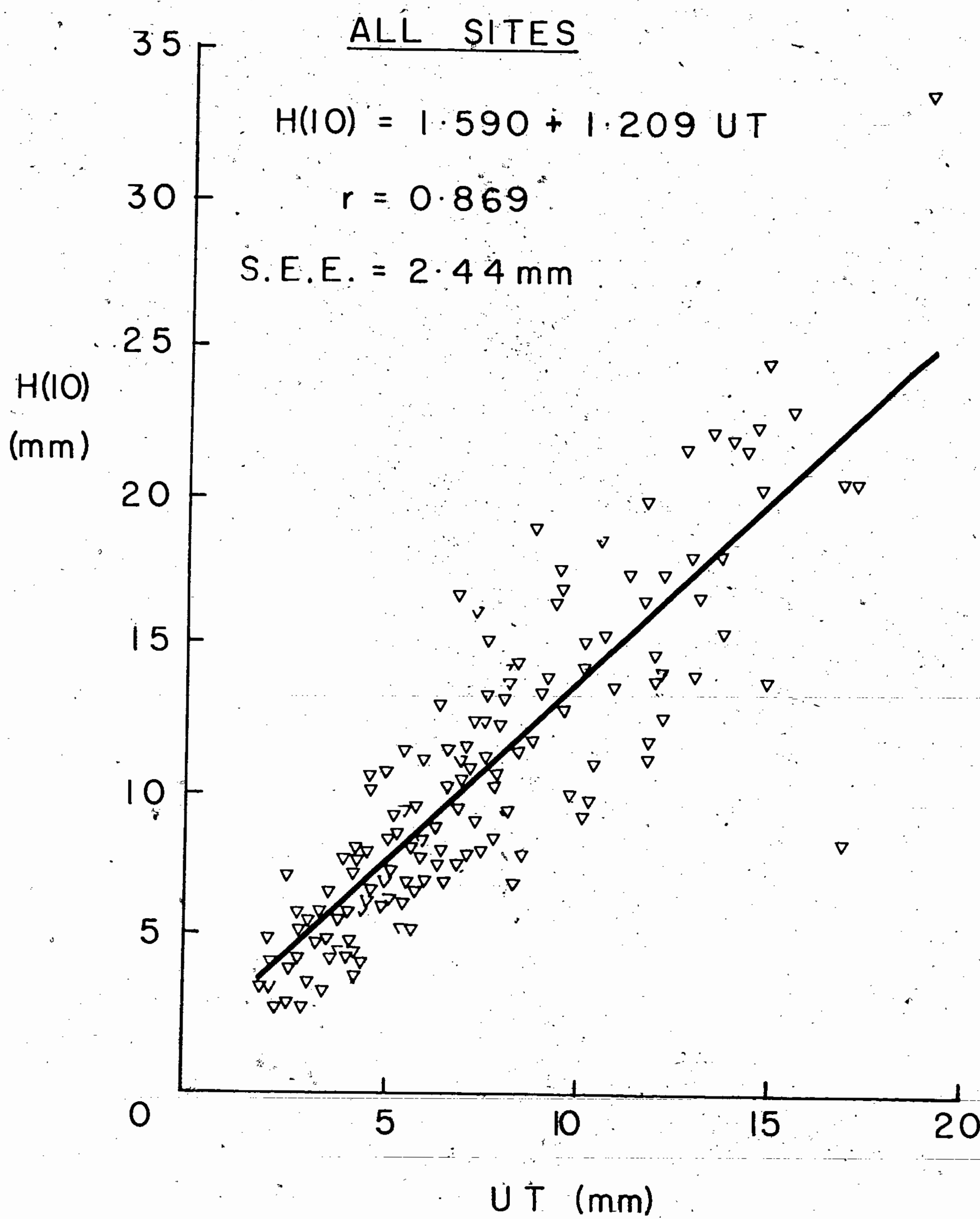
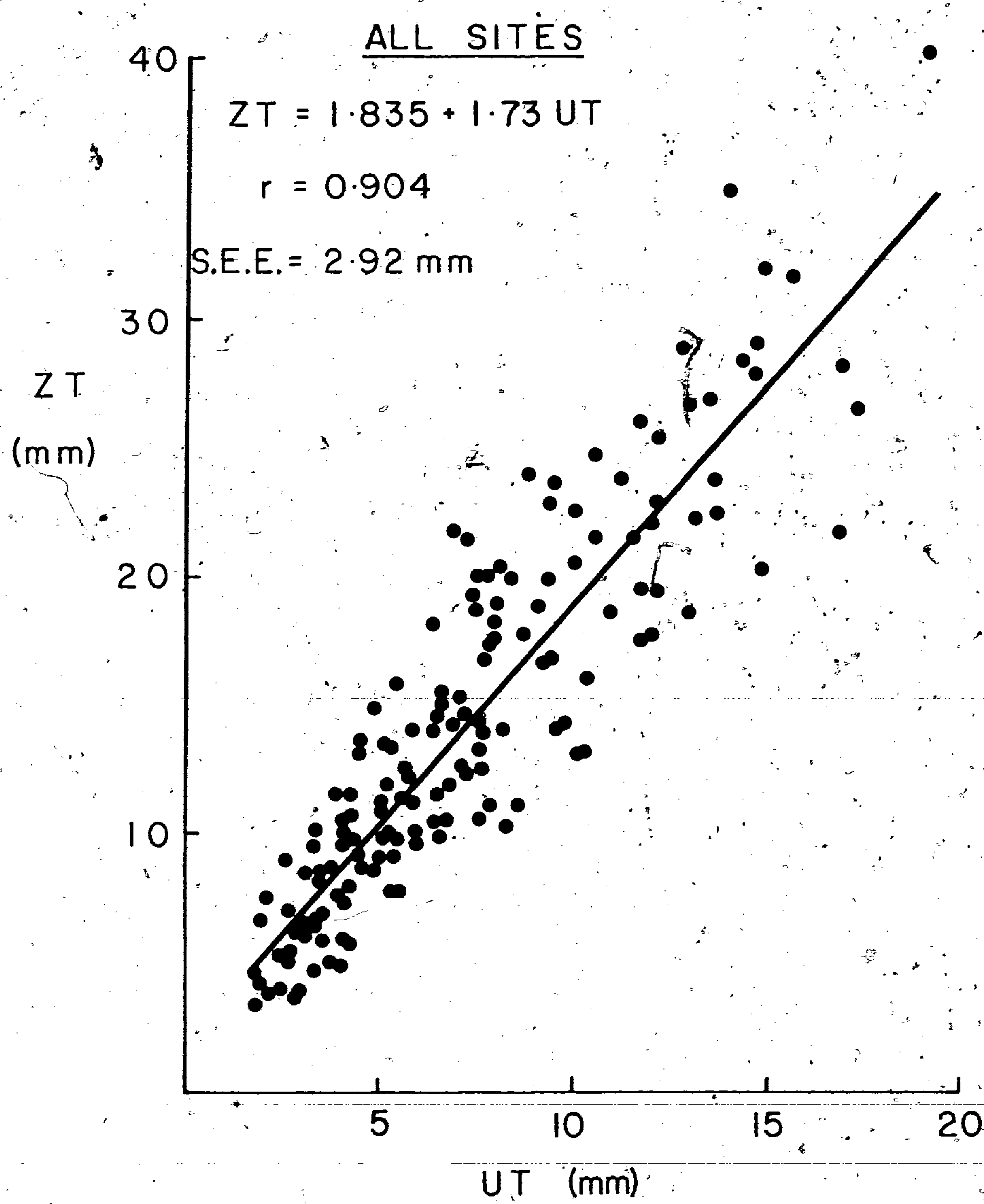

ALL SITES
H(10) = 1·590 + 1·209 UT
r = 0·869
S.E.E. = 2·44 mm
35
30
25
20
15
10
5
0
H(10)
(mm)
5
10
15
20
UT (mm)

Table 3: Mean compression percentages C(Z/10).

SITE	SEX	Max.	Min.	Range	Mean	S.D.
Biceps	M	37.3	5.9	31.4	24.6	8.7
	F	44.1	20.2	23.9	32.4	8.1
Triceps	M	35.9	21.6	14.3	27.9	4.3
	F	32.2	17.6	14.6	25.5	3.8
Midaxillary	M	32.3	8.5	23.8	21.6	7.6
	F	45.9	17.5	28.4	27.2	7.7
Subscapular	M	29.3	11.5	17.8	21.0	5.0
	F	32.3	15.0	17.3	25.2	5.1
Suprailiac	M	36.3	22.3	14.0	29.4	3.7
	F	61.3	22.8	38.5	34.9	9.6
Lat. Calf	M	37.5	16.5	21.0	28.1	5.9
	F	28.0	15.8	12.2	22.9	3.6
Med. Calf	M	35.7	11.9	23.8	27.0	8.5
	F	34.2	23.4	10.8	27.7	3.7

Fig 7: Graph of ZT/UT regression line for all sites.


ALL SITES
ZT = 1·835 + 1·73 UT
r = 0·904
S.E.E. = 2·92 mm
ZT
(mm)
40
30
20
10
5
10
15
20
UT (mm)

TEST OF DIFFERENCE BETWEEN ZT AND 2 X ULTRASOUND.

Having determined that at five of the sites there was greater correlation between ZT and UT, than between H(10) and UT (Table 2), it was necessary to find out whether ZT and ultrasound values were predicting the same uncompressed thickness. To this end a t-test on the difference between means of ZT and 2 x UT was carried out for each site (Table 4). 2 x UT was used since ZT is a measure of a double uncompressed thickness. It is generally accepted that statistical tests which assume a normal distribution are not valid when applied to raw skinfold measurements. This is due to the positive skewness which normally occurs in samples of skinfold measurements. The raw data in the sample in this study were tested for skewness. The distribution of the sample was found to approximate well to the t-distribution, thus making application of a t-test on the difference between sample means a valid test to use. The lack of skewness normally found in skinfold data was probably due to the limited sample in this study, in that no excessively obese subjects were used. When the total sample was considered no significant differences were found between the means of ZT and 2 x UT except for suprailiac and lateral calf sites. When the data were divided into male and female groups at each site it was found that in 11 of the 14 groups there was no significant difference between means. Table 4 showed the results of this analysis. A significant difference between the means was accepted if the probability of a difference was less than 0.05; that is acceptance at the 95% confidence level. The results showed that there were significant differences between means at two sites (Suprailiac and Lateral Calf).

Table 4: T-tests on the difference between means of ZT and UT.

Site	Sex	ZT Mean	ZT S.D.	2xUT Mean	2xUT S.D.	t	p
Biceps	Both	8.4	4.4	8.3	3.7	0.148	0.88
	Male	5.7	3.1	6.1	2.4	-0.767	0.46
	Female	10.7	4.1	10.3	3.5	0.725	0.48
Triceps	Both	17.9	7.7	17.4	7.9	0.948	0.35
	Male	13.1	5.1	12.6	5.1	0.722	0.48
	Female	22.0	7.2	21.4	7.7	0.649	0.53
Subscapular	Both	13.5	6.2	13.2	6.1	0.748	0.46
	Male	10.9	2.4	10.8	2.8	0.245	0.81
	Female	15.7	7.7	15.3	7.5	0.706	0.49
Midaxillary	Both	10.9	4.8	11.2	5.1	-0.545	0.59
	Male	9.8	4.3	9.0	2.7	1.185	0.26
	Female	11.9	5.2	13.1	6.0	-1.798	0.09
Suprailiac	Both	14.2	6.1	16.9	7.8	-3.884	0.00
	Male	12.7	6.6	12.9	6.3	-0.497	0.63
	Female	15.5	5.5	20.3	7.6	-5.145	0.00
Med. Calf	Both	15.9	7.3	16.3	8.1	-0.744	0.46
	Male	10.8	5.0	9.8	3.9	1.988	0.07
	Female	20.4	6.0	21.9	6.3	-2.327	0.04
Lat. Calf	Both	15.2	5.5	13.5	5.3	3.360	0.00
	Male	12.6	4.9	10.4	2.9	3.290	0.01
	Female	17.6	5.0	16.1	5.6	1.770	0.10
All Sites	Both	13.7	6.7	13.8	7.1	--	--

CORRELATION OF H(5), H(10), AND H(15) TO ULTRASOUND.

It has been stated by various workers that 10 $\times 10^4 Nm^{-2}$ is the optimum pressure to be exerted by a skinfold caliper. In general it was claimed that 15 $\times 10^4 Nm^{-2}$ was too strong, and therefore could cause pain in some subjects, whereas 5 $\times 10^4 Nm^{-2}$ has been criticised as being too light, thus causing unreliable measurement. Correlation analyses were carried out to find out which of the caliper measurements related best to the ultrasound values. Table 2 shows the correlation coefficients for the comparisons H(5) vs. UT, H(10) vs. UT, H(15) vs. UT, for individual sites and also for all sites combined. From this it can be seen that in 5 of the 7 sites the H(5) value relates better to UT than either H(10) or H(15). At the same 5 sites H(15) was the value with the lowest correlation to UT. When all sites were considered together H(5) relates best to UT, and H(15) has the poorest relationship.

DISCUSSION.

By comparison to radiographic measurements on 25% of the subjects the ultrasonic scanning technique was found to be a valid method for the estimation of uncompressed subcutaneous fat depth. Radiographic measurements have always been regarded as the criterion measure of uncompressed fat depth, however with the sophistication of the ultrasonic scanning technique it too may be accepted as a valid alternate measure. It is however a technique that requires rigorous training to provide reliable and reproducible measures. As demonstrated in this study, ultrasonic scanning can be justified for use as a criterion measure of uncompressed skinfold thickness.

The main aim of this study was to develop a technique that would overcome the problems of variations in skinfold compressibility. If the 3 - caliper technique was going to account in some way for variations in compressibilities then the ZT from the three caliper technique would correlate better to the ultrasonic value than would the Harpenden 10 $x10^4\ Nm^{-2}$ value. This was indeed found to be the case in 5 of the 7 sites. The most striking example was that of the Suprailiac site where the correlation coefficient increased from 0.789 to 0.895, explaining an extra 15% of the total variance. The midaxillary site also displayed a large increase of 0.757 to 0.839, an extra 17% of the total variance now explained by variation in compressibility. When all sites were considered together the correlation coefficient for H[10] vs. UT was 0.869 and for ZT vs. UT was 0.904. This showed that the technique had cut down the variance due to compressibility, although it is not claimed that it completely erradicated the problem.

It was also shown that the technique gave a good estimate of uncompressed thickness when compared to 2 x UT. Tests for the significance of the differences of means for correlated data yielded insignificant differences between uncompressed thickness and 2 x UT, at five of the seven sites as shown in Table 4. When the data was broken down by sex only three of the fourteen groups showed a significant difference. Those sites were Suprailiac (female), Medial Calf (female) and Lateral Calf (Male) and it was also noticeable from Table 3 these were also sites with high mean compression percentages. This may indicate that the 3 - caliper technique may have slightly underestimated uncompressed thickness in highly compressible skinfolds.

An interesting finding was that the Harpenden 5 $x10^4 Nm^{-2}$ caliper related better to the ultrasonic measurement than each of the other two pressures. In the literature it has been claimed that 5 $\times 10^4 Nm^{-2}$ is too slight a pressure to obtain reliable results. The reason for the 5 $\times 10^4 Nm^{-2}$ caliper showing a better relationship was probably that since the caliper did not squeeze the skinfold as much as the other two pressures then the differences in compressibility did not become so apparent. However it was not proposed that the 5 $\times 10^4 Nm^{-2}$ be used as the standard pressure replacing the 10 $\times 10^4 Nm^{-2}$ pressure.

In the measurement of skinfold thicknesses by spring calipers, a matter that is of prime consideration is that of time between measurements. Brozek and Kinzey in their study on skinfold compressibility and age, allowed 30 minutes between application of different calipers. This was to allow full recovery of the skinfold, since during measurements there was expulsion of water from the tissues under compression. It will be noted that there is only one minute allowed between successive measurements, and also that this time interval must be strictly adhered to. During extensive pilot studies it shown that this standardised technique was the best of many combinations of time intervals, and order of application of calipers that were tried. Even though the skinfold was not given sufficient time to recover between trials, the proposed technique was based on the assumption that the recovery phenomenon was systematic. During this study subjects were remeasured 5 minutes later. Since there was still a residual effect of the compression the predicted uncompressed thickness was lower during the second measurement than the first. It was proposed from this result, and from results of pilot studies, that at least 20 minutes be left between first measurement with the 3-caliper technique and the remeasurement.

Subject to the acceptable limitations given above it was decided that the 3 - caliper technique yielded valid estimates of uncompressed skinfold thickness taking into account variation in compressibility. Thus it was accepted that the 3-caliper technique was a satisfactory method for the subsequent purpose of this study in studying skinfold compressibility phenomena.

PART II.

THE RELATIONSHIP BETWEEN SKINFOLD COMPRESSIBILITY AND SKINFOLD THICKNESS.

INTRODUCTION.

It was the aim of this study to determine if there was a relationship between the amount of compression of a skinfold and the uncompressed thickness of that skinfold. In past studies in the literature the degree of compression of a skinfold has been expressed as some form of percentage decrease in thickness. In studies where radiography or ultrasonic scanning was employed, as well as skinfold thickness measurement by a caliper of one type or another, compression percentage was expressed as the percentage decrease from twice the radiographic, or ultrasonic value, to the caliper measurement.

$$C.P. = \frac{(2 \times \text{Radiographic Thickness}) - \text{Caliper thickness}}{(2 \times \text{Radiographic Thickness})} \times 100$$

In studies where measurements were made with calipers of different jaw pressures, the compression percentage is expressed as the percentage difference from skinfold thickness measured with a low pressure caliper to one measured with a higher pressure caliper. Thus

$$C.P. = \frac{\text{Low Caliper Thickness} - \text{High Caliper Thickness}}{\text{Low Caliper Thickness}} \times 100$$

These concepts of compression percentages have been used in an attempt to look at the differences between sexes and also to investigate the effects of other factors on skinfold compressibility, such as age (Brozek and Kinzey, 1960). In the study by Clegg and Kent (1967) compression percentages in young adult males and females were computed and mean values compared. They found that the female means at individual sites were greater than the male means, and thus concluded that female skinfolds were more compressible. Ostensibly this was an expected finding since female skin is generally regarded as much softer and delicate than that of males. However, in this study mean skinfold thickness at the various sites were larger in the females. Thus it could not be discounted that there was a contamination effect due to thickness of skinfold. Clegg and Kent (1967) in fact conceeded this by pointing out that there may be some sort of relationship between compression percentage and skinfold thickness.

If one examines this relationship from a dimensionality theory standpoint, an interesting problem arises. The concept of compression percentage is a linear measurement divided by a linear measurement therefore by dimensionality theory it has a dimension of $[L]^0$, that is it is independent of size. If you plot a measure with dimension $[L]^0$ against a measure with dimension $[L]^1$ one would expect to obtain a line which was a horizontal straight line indicating that the $[L]^0$ measure was independent of size. Compression percentage is a measure with dimension $[L]^0$ and uncompressed skinfold thickness is a measure with dimension $[L]^1$, thus one would expect a horizontal straight line when one plotted compression percentage against skinfold thickness, if the theory held true and compression percentage was unrelated to skinfold thickness. If this was found to be the case, and compression percentage was independent of thickness then Clegg and Kent were correct in their conclusion that female skinfolds were more compressible than male skinfolds due to their higher mean compression percentages. If however there was found to be a relationship between compression percentage and skinfold thickness, then they are in error in their conclusion, since they have not taken account of thickness and the females measured in this study had a greater mean skinfold thickness.

If one returns to dimensionality theory a measure with dimension [L]1 should give a linear relationship to skinfold thickness. Such a measure would be skinfold thickness measured with a low pressure caliper minus the thickness measured with a higher pressure caliper, ie. the difference between the two caliper measurements. This would give a measure with dimension [L]1, and should in theory be linearly related to thickness. It may well be, if this is the case, that this is a better method of representing the amount of compression of a skinfold.

This part of this thesis looked at the concepts of compression percentage and absolute thickness change, and their relationship to skinfold thickness. The data used in this portion of the study were those collected in the Loughborough study, thus methods and materials are the same as for Part I of this thesis. From these data a compression percentage C(Z/10) was calculated, and a change in thickness DT was calculated. The relationship between these and uncompressed thickness as measured by ultrasonic scanning and zero uncompressed thickness (ZT) was investigated.

METHOD.

The sample was identical to that in Part I of this thesis. From the data a compression percentage C(Z/10) for each skinfold was calculated using the relationship:

$$C(Z/10) = ((ZT - H[10])/ZT) \times 100$$

where ZT is the predicted uncompressed skinfold thickness from the 3-caliper technique and H[10] is the thickness of the skinfold measured by the standard Harpenden $10 \times 10^4 Nm^{-2}$ caliper.

Another measure of compressibility DT was calculated using the relationship:

$$DT = ZT - H[10]$$

DT was merely the change in thickness from ZT to H[10]. This has the dimension [L]1 and thus should have been linearly related to skinfold thickness. Allometric analysis was applied to each of these measures to establish their relationship to skinfold thickness.

RESULTS.

Due to the heterogeneous nature of the sample no attempt was made to divide the data into groups by sex and site. It was felt by the author that since the aim of this portion of the study was to show a relationship between compression and thickness of skinfolds, it would be preferable to show that a relationship could be proven even when the relationship contained the extra variance due to differnt sex and sites.

The values for compression percentage C(Z/10) and compressibility DT were calculatd for each skinfold. A simple regression analysis was carried out between C(Z/10) and ultrasonic thickness UT, and for between DT and UT. Similar analyses were carried out using ZT in place of UT. The results of these analyses are shown in Tables 5. It can be seen that C(Z/10) correlated poorly with both UT and ZT, correlation coefficients of 0.261 and 0.227 respectively. However both relationships show significantly positive slopes. DT correlated well with both UT and ZT, correlation coefficients of 0.837 and 0.877, with significantly positive slopes. Thus DT increased with increasing skinfold thickness, but so too did C(Z/10) which should dimensionally have been independent of thickness. In order to determine the exact dimensional relationships between C(Z/10) and UT or ZT, and between DT and UT or ZT, allometric analysis was applied to the data. This is summarised in Tables 6. B values of 0.204 and 0.219 were found for comparisons of Log10[C(Z/10)] against Log10UT and Log10ZT respectively. These were both found to be significantly greater than zero. When the data was arbitrarily split into two groups by the criterion of a ZT of 20 mm and also by UT of 10 mm, allometric analysis was reapplied to find b values for the lower range and also for the upper range of skinfold thicknesses.B values of -0.319 and -0.689 were found for UT and ZT respectively when ZT was greater than or equal to 20 mm and UT was greater than or equal to 10 mm The ZT b value was found to be not significantly different from zero. When the group where ZT was less than 20 mm, or UT was less than 10 mm, b values of 0.264 and 0.330 were found for UT and ZT respectively. These were both found to be greater than zero with a probability of 0.0000. The regression lines for these analyses were shown in figures 8 and 9.

Tables 5: Simple regression analyses of C(Z/10) and DT versus UT and ZT.

Table 5(a). Simple Regressions of C(Z/10) versus UT and ZT.

$$C(Z/10) = 0.247\ (ZT) + 23.526$$

r = 0.227 S.E.B = 0.0758 S.E.E. = 7.099

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	534.07	534.07	10.60	0.0013
Residual	194	9777.85	50.40		

Table 5(b). Simple regression of C(Z/10) versus UT.

$$C(Z/10) = 0.536\ (UT) + 23.208$$

r = 0.261 S.E.B. = 0.1422 S.E.E. = 7.037

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	703.88	703.88	14.21	0.0002
Residual	194	9608.04	49.53		

Table 5(c). Simple regression of DT versus ZT.

DT = 0.2856 (ZT) + 0.116

r = 0.877   S.E.B. = 0.0112   S.E.E. = 1.051

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	715.67	715.67	648.28	0.0000
Residual	194	214.17	1.10		

Table 5(d). Simple regression of DT versus UT.

DT = 0.5158 (UT) + 0.2389

r = 0.837   S.E.B. = 0.0242   S.E.E. = 1.197

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	651.94	651.94	455.12	0.0000
Residual	194	277.90	1.43		

TABLES 6. ALLOMETRIC ANALYSIS OF C(Z/10) AND DT.

Table 6(a).

Allometric analysis of C(Z/10) with UT criterion of thickness.

All UT values.

$$\text{Log10 } C(Z/10) = 0.204 \ (\text{Log10 UT}) + 1.252$$

r = 0.346   S.E.B. = 0.0397   S.E.E. = 0.122

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	0.391	0.391	26.4	0.0000
Residual	194	2.873	0.015		

UT greater than or equal to 10 mm.

$$\text{Log10 } C(Z/10) = 1.819 - 0.3188 \ (\text{Log10 UT})$$

r= 0.224   S.E.B. = 0.2381   S.E.E. = 0.102

Analysis of variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	0.019	0.019	1.79	0.1894
Residual	34	0.353	0.010		

UT less than 10 mm.

$$\text{Log10 } C(Z/10) = 0.264 \ (\text{Log10 UT}) + 1.2125$$

r = 0.341   S.E.B. = 0.0580   S.E.E. = 0.124

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	0.321	0.321	20.74	0.0000
Residual	158	2.446	0.015		

Table 6(b).

Allometric analysis of C(Z/10) with ZT criterion of thickness.

All ZT values.

$$\text{Log10 C(Z/10)} = 0.219\ (\text{Log10 ZT}) + 1.175$$

r = 0.367 S.E.B. = 0.0399 S.E.E. = 0.121

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	0.439	0.439	30.16	0.0000
Residual	194	2.824	0.015		

ZT greater than or equal to 20 mm.

$$\text{Log10 C(Z/10)} = 2.408 - 0.6897\ (\text{Log10 ZT})$$

r= 0.439 S.E.B. = 0.2351 S.E.E. = 0.098

Analysis of variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	0.083	0.083	8.60	0.0058
Residual	36	0.348	0.010		

ZT less than 20 mm.

$$\text{Log10 C(Z/10)} = 0.330\ (\text{Log10 ZT}) + 1.069$$

r = 0.433 S.E.B. = 0.055 S.E.E. = 0.120

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	0.517	0.517	35.98	0.0000
Residual	156	2.241	0.014		

Table 6(c).

Allometric analysis of DT with UT criterion of thickness.

All UT values.

Log10 DT = 1.099 (Log10 UT) + 0.365

r = 0.831 S.E.B. = 0.0528 S.E.E. = 0.162

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	11.351	11.351	432.85	0.0000
Residual	194	5.088	0.026		

UT greater than or equal to 10 mm.

Log10 DT = 0.605 (Log10 UT) + 0.1616

r= 0.397 S.E.B. = 0.2396 S.E.E. = 0.103

Analysis of variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	0.067	0.067	6.37	0.0164
Residual	34	0.358	0.011		

UT less than 10 mm.

Log10 DT = 1.185 (Log10 UT) - 0.421

r = 0.763 S.E.B. = 0.0798 S.E.E. = 0.171

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	6.466	6.466	220.60	0.0000
Residual	158	6.631	0.029		

Table 6(d).

Allometric analysis of DT with ZT criterion of thickness.

All ZT values.

$$\text{Log10 DT} = 1.219\ (\text{Log10 ZT}) - 0.825$$

r = 0.910 S.E.B. = 0.0399 S.E.E. = 0.121

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	13.615	13.615	935.15	0.0000
Residual	194	2.824	0.015		

ZT greater than or equal to 20 mm.

$$\text{Log10 DT} = 0.3103\ (\text{Log10 ZT}) + 0.408$$

r= 0.215 S.E.B. = 0.235 S.E.E. = 0.098

Analysis of variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	0.017	0.017	1.74	0.1952
Residual	36	0.348	0.010		

ZT less than 20 mm.

$$\text{Log10 DT} = 1.330\ (\text{Log10 ZT}) - 0.9315$$

r = 0.889 S.E.B. = 0.0549 S.E.E. = 0.119

Analysis of Variance.

	D.F.	S.S.	M.S.	F	p
Regression	1	8.412	8.412	585.54	0.0000
Residual	156	2.241	0.014		

Fig 8: Regression lines of allometric analysis of C(Z/10) versus UT.

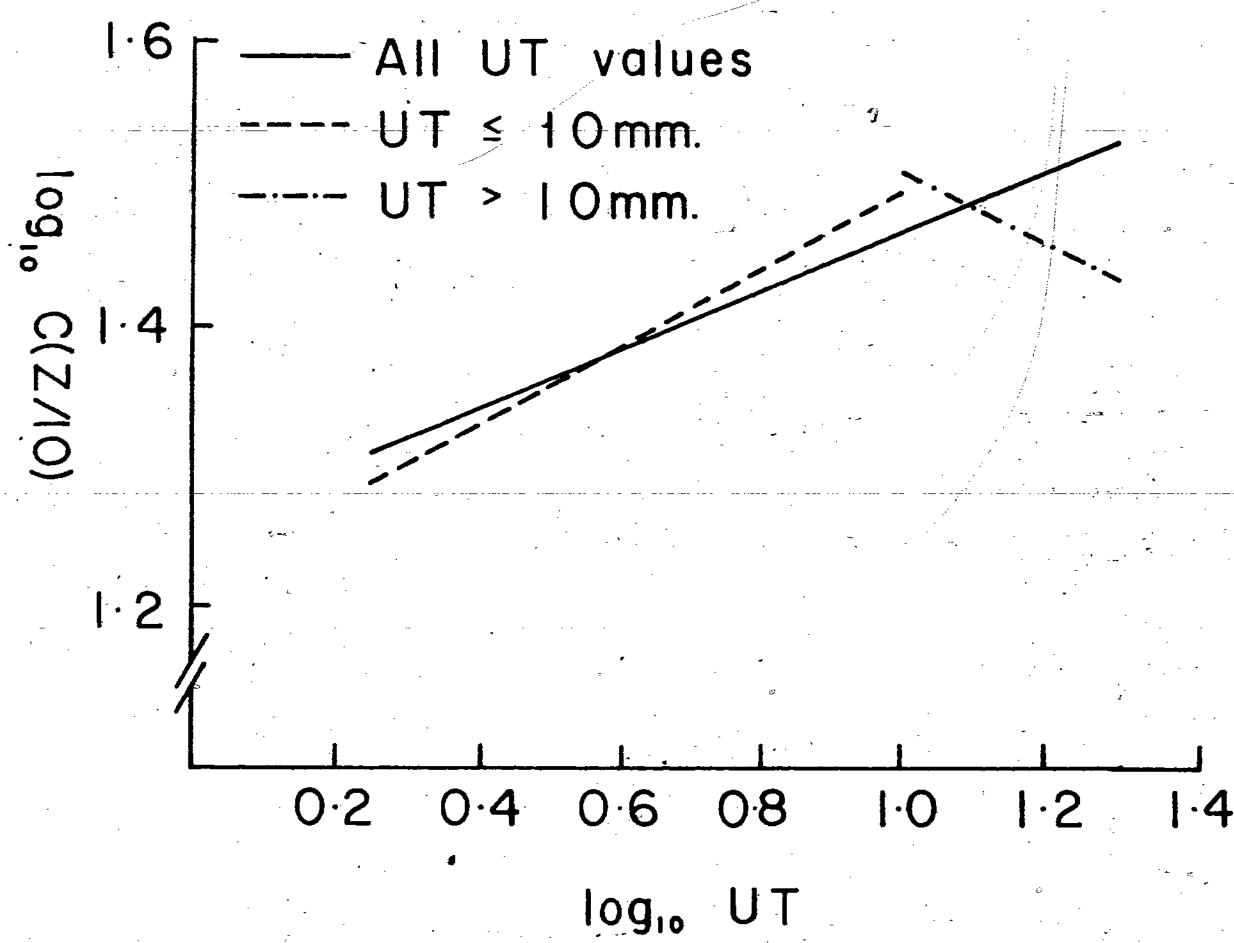
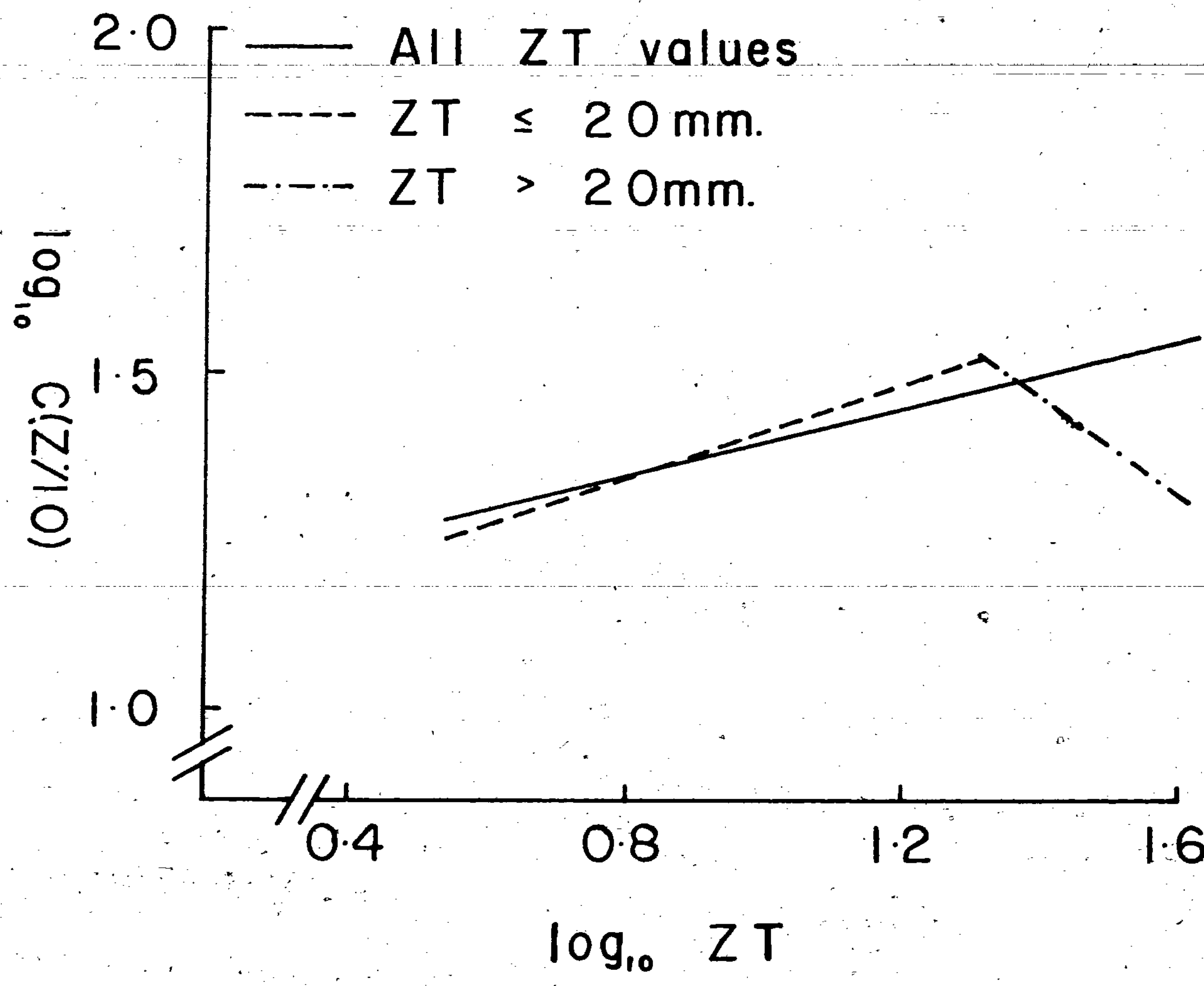

1·6
1·4
1·2
All UT values
UT ≤ 10mm.
UT > 10mm.
$\log_{10}$ C(Z/10)
0·2
0·4
0·6
0·8
1·0
1·2
1·4
$\log_{10}$ UT

Fig 9: Regression lines of allometric analysis of C(Z/10) versus ZT.


All ZT values
ZT ≤ 20 mm.
ZT > 20mm.
2·0
1·5
1·0
log₁₀ C(Z/10)
0·4
0·8
1·2
1·6
log₁₀ ZT

DISCUSSION.

When allometric analysis was applied to compression percentages in relation to uncompressed skinfold thickness as measured by UT (the ultrasonic thickness) and ZT (the 3-caliper uncompressed skinfold thickness) it was shown that compression percentage was not independent of skinfold thickness. Significant exponent b values of 0.204 and 0.219 were obtained for comparisons to UT and ZT respectively. A b value of 0.00 would be predicted by dimensionality theory since compression percentage was a ratio of two linear measurements thus had dimension $[L]^0$, ie. it was dimensionless and thus independent of skinfold thickness. These b values were found to be significantly greater than zero with a probability of 0.0000 for UT and 0.0000 for ZT. Observation of these data seem to indicate an increase in compression percentage with increasing skinfold thickness. However at high levels of skinfold thickness the compression percentage plateaued and even became smaller in some cases. To test for this the data were arbitrarily divided into two sets. All measurements where UT was less than 10 mm, and all measurements where UT was greater than or equal to 10 mm. A similar division was made by the criterion of a ZT value of 20 mm The ZT criterion of 20 mm was twice that of UT, since

ZT was a skinfold thickness, and UT was a single thickness of skin plus subcutaneous fat. The same analysis as before was now applied to each group of data. The analyses showed that b values of 0.264 and 0.330 existed for UT and ZT respectively, for skinfolds less than UT = 10 mm and ZT = 20 mm respectively. These b values were significantly greater than zero with probabilities of 0.0000 for UT and 0.0000 for ZT. However for values greater than or equal to UT = 10 mm and ZT = 20 mm, b values of -0.319 for UT and -0.689 for ZT were obtained. The b value for ZT was found to be significantly less than zero with a probability of 0.0058, however the UT b value was not found to be significantly less than zero with a probability of 0.1894. It can be seen that rather than being independent of skinfold thickness, or even positively linearly related to skinfold thickness, compression percentage has a complex relationship to skinfold thickness. The exact relationship of compression percentage to skinfold thickness is not an important issue here. Therefore the fact that the data dividing points of 10 and 20 mm were purely arbitrary is of no concern. The important point being that it was shown that compression percentage was not independent of skinfold thickness.

The implications of this finding are far reaching. All studies carried out on skinfold compressibility, that have used compression percentage as a criterion of compressibility, have made decisions on sex, age and site differences merely by comparison of mean compression percentages without taking into account mean skinfold thicknesses. This would be valid if compression percentage was independent of skinfold thickness. However,in this study this was shown not to be the case. This therefore throws all the conclusions of these previous studies into doubt. Clegg and Kent (1967) showed a sex difference where female skinfolds were more compressible than male skinfolds, since females showed a higher mean compression percentage. However they also had a higher mean skinfold thickness. Thus, the sex difference may merely have been a thickness difference. No more can be said about the study without further analysis of the raw data to take into account skinfold thickness.

The question now was what should be used as a criterion of compressibility, and how could skinfold thickness be taken account of in any analyses. A concept of absolute thickness change from ZT to skinfold thickness measured with the $10 \times 10^4 Nm^{-2}$ caliper was adopted. This was termed DT. DT has the dimension [L]1, and thus should be linearly related to skinfold thickness. When simple regression analyses were carried out between DT and UT, and ZT, correlation coefficients of 0.837 and 0.877 respectively were obtained. When allometric analysis was applied to each relationship b values of 1.099 and 1.219 respectively were found, compared to a b value of 1 as expected from dimensionality theory.

Thus DT is a measure that was found to be linearly related to skinfold thickness. Two samples e.g. samples of different sex, may be compared by use of this relationship. If it can be shown that the two sexes have different regression lines, then it can be said that there is a sex difference. The same form of analysis can be applied to age and site differences. This was indeed carried out in part III of this thesis, where the effects of sex, age, and site on compressibility were investigated.

PART III.

THE INVESTIGATION OF THE EFFECT OF SEX AND SITE ON SKINFOLD COMPRESSIBILITY.

INTRODUCTION.

Skinfold compressibility is a subject that has received only cursory attention in kinanthropometric research. Several authors have carried out small scale studies, and raised many interesting questions, however they did not follow up with further studies. Brozek and Kinzey (1960) in a study on age changes in skinfold compressibility stated:

> "We cannot offer a straightforward interpretation of the mechanisms underlying the observed changes in skinfold compressibility with age. The authors do not maintain that the differences are accounted for by changed elastic properties of the adipose tissue alone. Obviuosly skin is involved. The hydration of tissues is likely to vary with age, and to affect tissue elasticity."

However Brozek and Kinzey did not follow up this study in order to explore the contributions of the factors outlined. Clegg and Kent (1967) carried out a study on skinfold compressibility, and came up with the conclusions that:

a) Skinfold compressibility varies at different sites.

b) Compressibility varies between different individuals.

c) Compressibilities are generally greater in females than in males.

Also they pointed out that there may be a relationship between thickness and compressibility. Clegg and Kent gave an explanation of the sex difference that they found, by way of consideration of the different thicknesses of the skinfold between the sexes. Jones (1970) showed that female skinfolds were less compressible than male skinfolds when thickness of skinfold was taken into account. However Clegg and Kent also made reference to the work of Lee and Ng (1965), who compared $10 \times 10^{4} Nm^{-2}$ caliper readings with actual fat thicknesses and found that males gave larger caliper readings than females for the same true fat thickness. Lee and Ng proposed that the difference might be caused by a combination of three possible factors:

a) Differences in the thickness of the skin proper.

b) Differences in compressibility.

c) Different degrees of tension of the skin and subcutaneous tissues.

When a skinfold is pinched up between thumb and fore-finger the aim would be to produce a thickness comprised of two parallel layers of skin plus underlying adipose tissue, which could then be measured to give an estimate of the amount of underlying adipose tissue. Thus, present in this skinfold would be two thicknesses of tissue that have great variations in composition. It is the variation of proportion and mechanical characteristics of these various components that cause the differences in compressibility of the skinfolds. Therefore it is necessary to consider the anatomical structure of the skinfold. Half a skinfold, as previously stated, is comprised of a layer of skin plus an adipose tissue layer. The composition of these two layers is very different. The skin is subdivided into the outer epidermis and the underlying dermis. The epidermis is an epithelial layer whose main component is keratin. It is a form of epithelium designed to be resilient to damage and bacterial invasion, also it prevents diffusion of water out of the body. The mechanical properties of the epidermis are largely unknown. The dermis is composed primarily of collagen. The structure of the dermis changes as one moves down through its layers. The superficial layer contains relatively more blood vessels, is a looser type of connective tissue, is more easily distorted carries little or no load when the whole skin is under tension. The main part of the dermis is made up of bundles of collagen fibrils aranged in a three-dimensional weave pattern. This gives a shear- resistant structure. Also present in varying amounts are elastin fibres, which tend to be more prominent in the most superficial and deepest layers of the dermis. The elastin would appear to be under tension in normal skin, and probably accounts for the fact that skin contracts in area when removed from the body. Skin from different areas of the body exhibits this phenomenon to different degrees, due to the varying amounts of elastin present at each particular site. In contrast the subcutaneous layer, the hypodermis, is composed of a loose areolar connective tissue, containing varying numbers and sizes of fat cells. These fat cells probably play a large part in determining the mechanical properties of this tissue, since there may be many small cells, or a few small cells, or many large cells, in fact there are many combinations of cell types and numbers posible, and each would presumably elicit different mechanical propoerties.

There are many factors which may influence the phenomenon of skinfold compressibility. Each of the folowing factors has been cited as possibly influencing the degree of compression. Sex, site of measurement of skinfold, age of subject, skin tension level of habitual activity, level of hydration of skinfold, before or after exercise, after large change in body weight by either dieting or overeating, ratio of size to number of fat cells in the subcutaneous adipose layer, diurnal variation. Some of these factors are interdependent, and thus it can be seen that the phenomenon of skinfold compressibility is very complex and any investigation into the effects of any one factor on it would require very careful planning if all intervening variables were to be controlled for. In this part of the study this author investigated the effects of sex and site. This selection left many intervening variables that shuold be controlled for. However an experiment where all of these intervening variables were controlled would require very expensive equipment, invasive techniques and prohibitive time constraints. The factors that could be controlled easily would be effect of exercise, the effect of a large change in body weight, and diurnal variation. Measuring at the same time of day to overcome effects of diurnal variation becomes restrictive when a large number of subjects is required. Thus subjects were measured at the time they were available and it was assumed that there was a random distribution of time of measurement of subjects across the sample.

There were intervening variables however that were impractical to control, for instance level of hydration of skinfold, skin tension ratio of fat cell size to fat cell number in subcutaneous fat layer, and level of habitual activity. It would be impractical to try to assess the level of hydration of the subcutaneous tissues. One might carry out a total body water analysis by the isotopic dilution principle, or one might carry out an invasive biopsy of the subcutaneous tissues. Either way would involve a large time commitment, techniques which are not totally sociably acceptable, and results that have an inherently large variance. Skin tension is another uncontrollable intervening variable. One method of measuring skin tension would be to mark out a square of skin of known dimensions, then excise that piece of skin. The skin contracts on excision and a remeasurement of dimensions can be made, the change in dimensions being proportional to skin tension. Another method would be to puncture the skin with a circular stiletto blade and measure the size of the resultant oval wound. The wound is oval due to the presence of Langers lines, which are lines of varying tension, due to the orientation of collagen fibres in the dermis. However these methods are both sociably unacceptable and thus untenable as research techniques on human subjects. The ratio of fat cell size to number is a problem that would require an invasive fat biopsy. It is probable that the mechanical properties of the subcutaneous tissues would change dependent on number and size of fat cells present. However it is debatable whether comparison with a caliper technique which is at best working to an accuracy of 5% of skinfold thickness, would show any significant differences.

Thus for this part of the study sex and site effects were investigated. The effects of large body weight changes, and exercise effects were controlled for. However diurnal variation effects, tissue hydration effects, skin tension effects, fat cell size to number ratio effects, and habitual activity effects were not controlled for, and their effects were pooled into the total variance due to error.

In part II of this thesis it was shown that there was a relationship between skinfold compressibility as denoted by DT = ZT - H(10), and uncompressed skinfold thickness ZT. The objective of this part of the study was to show that the DT/ZT relationship changes with sex and site of skinfold. This was achieved by an analysis of covariance on the data with sex and site as grouping factors and uncompressed thickness as a covariate.

Clegg and Kent (1967) showed that female skinfolds were more compressible than male skinfolds by comparison of mean compression percentages, however the error of this conclusion was pointed out in part II of this thesis. The question that this author tried to answer was "does a sex difference in compressibility exist or is it merely a thickness difference?". A sample of young adults between the ages of 20 and 30 years were measured at 3 sites. The data obtained on this sample were tested for any effects on compressibility of site or sex of skinfold.

METHOD AND MATERIALS.

A sample of young adult subjects between the ages of 18 and 32 years were measured at 3 sites (Triceps, Subscapular, Midaxillary, Suprailiac and Medial Calf) using the 3-caliper technique. These three sites were chosen partly because they are three of the easier skinfolds to measure but also so that a skinfold from each of the arm, leg and trunk was measured. There were 70 subjects in this sample, 40 males mean age 25.65 years, and 30 females mean age 24.98 years.

The subjects were selected as healthy adults who had not undergone recent substantial weight loss. The subjects were mainly students and their friends from Simon Fraser University.

From the caliper measurements ZT and DT were calculated using the afore mentioned equations. Analyses of covariance were then carried out to investigate the effect of site and sex on these measurements. Analyses of covariance where DT was the dependent variable, sex and site were grouping factors and ZT was a covariate, were carried out on the group data.

Compression percentages C(Z/10) were also calculated in order to display the way in which site and sex differences have been observed in the literature. Mean compression percentages were calculated for each of the sex and site groups. Analyses of variance were carried out on the data to determine if there were any differences in compression percentages due to sex and site of skinfold.

RESULTS

Compression percentages were calculated for each of the skinfolds measured. The mean compression percentages and standard deviations were calculated for each sex at each of the three sites. Analyses of variance were carried out to test the difference in compression percentages with respect to sex and site. The results were as shown in Tables 7. When The total group was considered and sex and site were used as grouping factors it was found that there was no significant differences due to sex ($p = 0.712$), but that there was a significant difference due to site of skinfold ($p = 0.014$). Means and standard deviations for compression percentages were shown in Table 8.

When the data was broken down into individual sites, and analyses of variance with sex as a grouping factor were carried out, it was found that there were no significant sex effects at any of the three sites (Triceps $p = 0.441$, Subscapular $p = 0.984$, Medial Calf $p = 0.930$). The results of these analyses are shown in Tables 11.

Tables 7: Anova of C(Z/19) at all sites.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG OF F
Main Effects	460.073	3	153.358	2.949	0.034
Sex	7.128	1	7.128	0.137	0.712
Site	452.945	2	226.473	4.355	0.014
2-Way Interactions	20.346	2	10.173	0.196	0.822
Sex Site	20.346	2	10.173	0.196	0.822
Explained	480.422	5	96.084	1.847	0.105
Residual	10609.742	204	52.009		
Total	11090.164	209	53.063		

Table 8. Means and Standard Deviations for Compression Percentages.

	Mean C(Z/10)	S.D.	N
MALES (All Sites)	28.5	8.5	120
FEMALES (All Sites)	28.7	7.4	90
TRICEPS (Male)	29.6	7.3	40
TRICEPS (Female)	28.3	5.8	30
SUBSCAPULAR (Male)	26.1	7.1	40
SUBSCAPULAR (Female)	26.1	6.4	30
MEDIAL CALF (Male)	29.3	9.0	40
MEDIAL CALF (Female)	29.5	6.4	30

Analyses of covariance were carried out on the data where ZT and DT had been calculated. In these analyses DT was the dependent variable with sex and site as grouping factors and ZT as a covariate. Figures 10, 11 and 12 show the regression lines between DT and ZT for both sexes at each site. The analysis of covariance tests for a significant difference between these regression lines. Figures 13 and 14 show the regression lines displayed according to sex of subject.

The initial analysis was carried out on the total group data (Table 9). This showed that there were no significant sex and site effects. However they came close to acceptance at the 0.05 level, p = 0.077 and p = 0.064 respectively. Analyses of covariance were then carried out on the data from each of the three sites separately, in order to determine where any sex differences were occurring. At the 95% confidence level there was no significant sex difference at any of the three sites (Triceps p = 0.389, Subscapular p = 0.776 and Medial Calf p = 0.061) as shown in Tables 10.

Fig 10: Regression lines of DT versus ZT for each sex at the Triceps skinfold site.

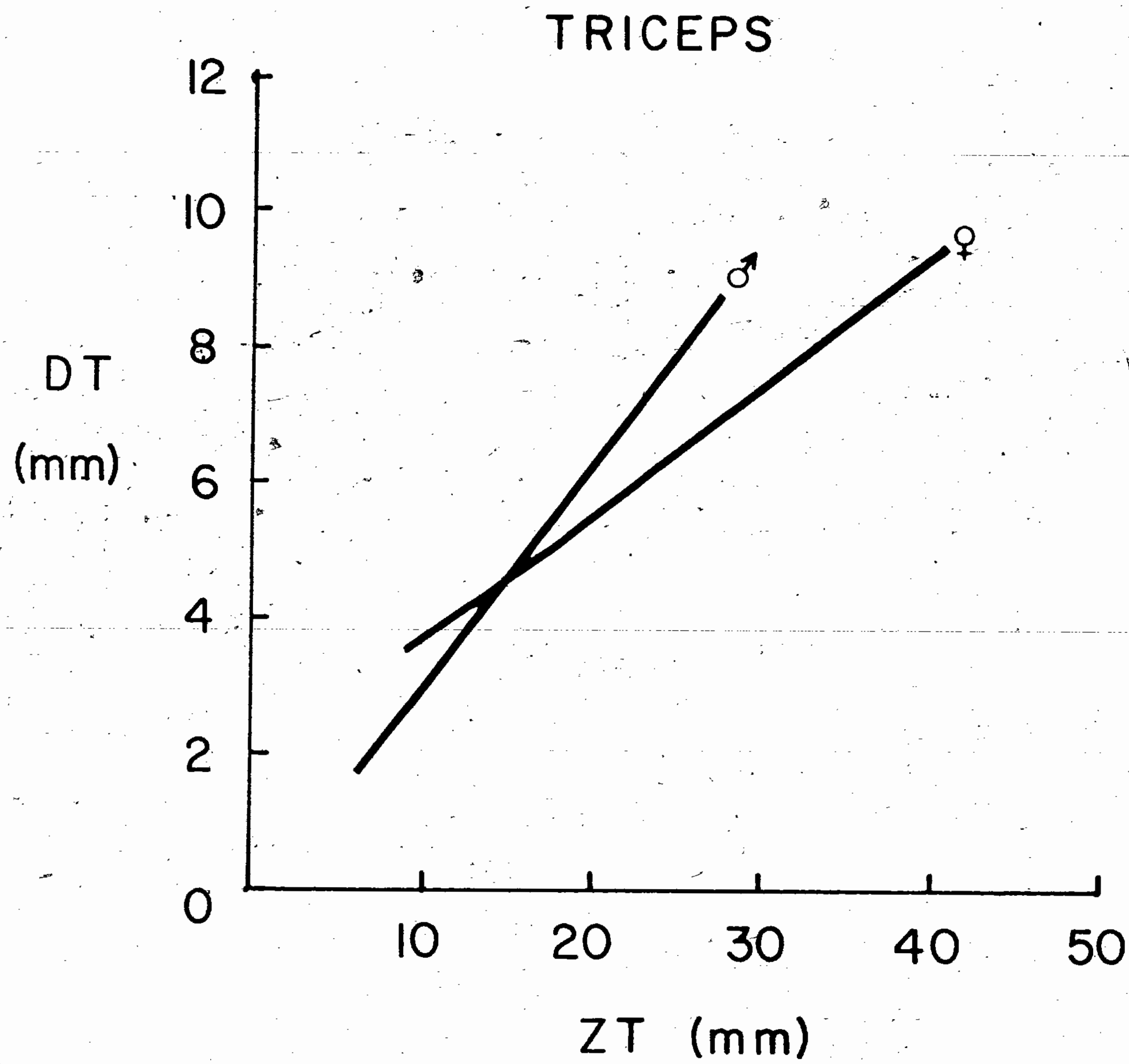

TRICEPS
DT
(mm)
0
2
4
6
8
10
12
10
20
30
40
50
ZT (mm)
♂
♀

Fig 11: Regression lines of DT versus ZT for each sex at the Subscapular skinfold site.

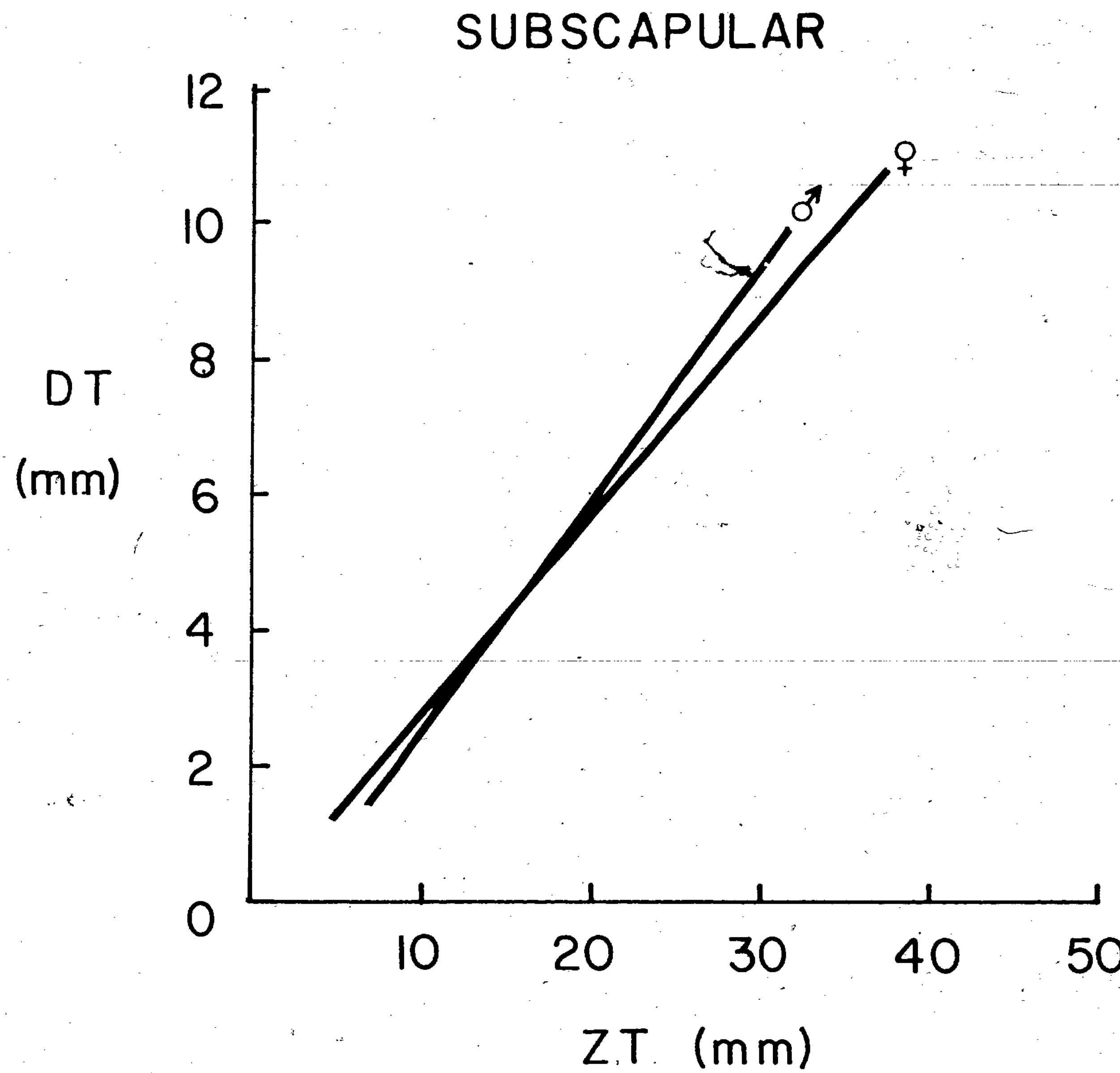

SUBSCAPULAR
DT
(mm)
12
10
8
6
4
2
0
10
20
30
40
50
Z.T. (mm)
♂
♀

Fig 12: Regression lines of DT versus ZT for each sex at the Medial Calf skinfold site.

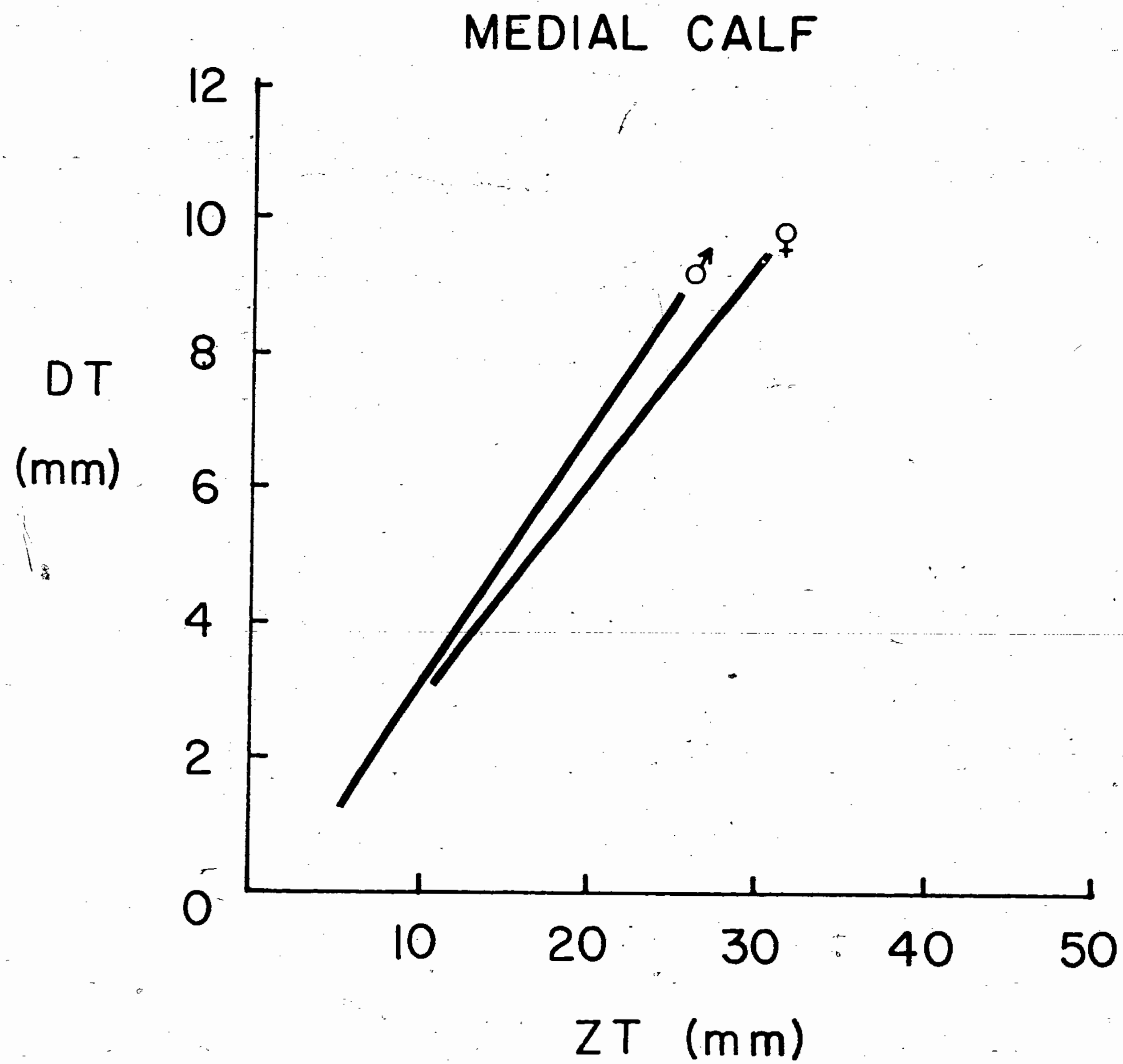

MEDIAL CALF
DT (mm)
12
10
8
6
4
2
0
10
20
30
40
50
ZT (mm)
♂
♀

Fig 13: Regression lines of DT versus ZT for each site in Male subjects.

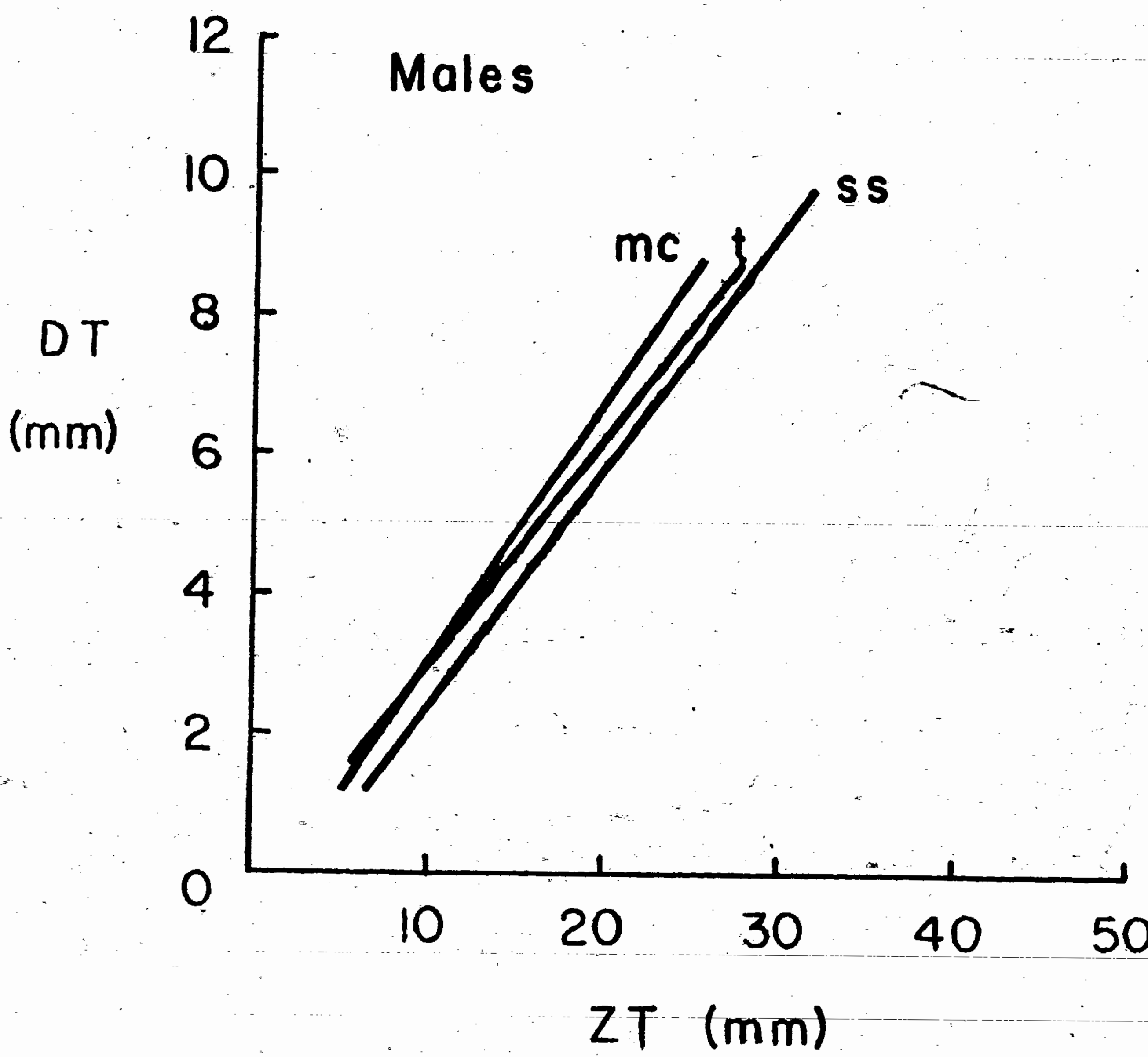

Males
DT
(mm)
12
10
8
6
4
2
0
mc
t
ss
10
20
30
40
50
ZT (mm)

Fig 14: Regression lines of DT versus ZT for each site in Female subjects.

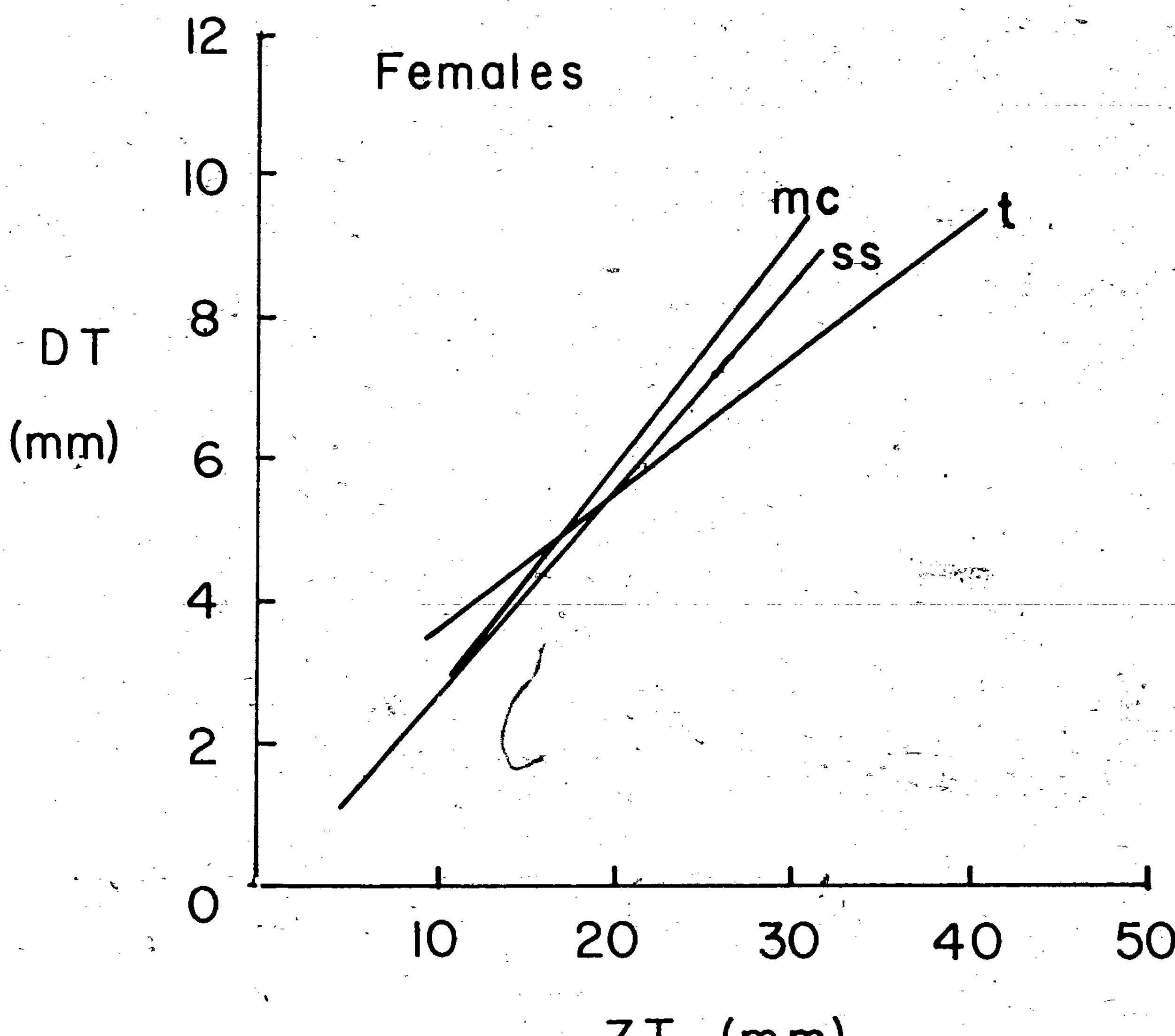

Females
DT
(mm)
12
10
8
6
4
2
0
mc
ss
t
10
20
30
40
50
ZT (mm)

Table 9: Ancova of DT at all sites combined.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG OF F
Covariates	802.531	1	802.531	689.16	0.000
ZT	802.531	1	802.531	689.16	0.000
Main Effects	10.464	3	3.488	2.99	0.032
Sex	3.679	1	3.679	3.160	0.077
Site	6.480	2	3.240	2.782	0.064
2-Way Interactions	2.059	2	1.030	0.884	0.415
Sex Site	2.059	2	1.030	0.884	0.415
Explained	815.054	6	135.842	116.65	0.000
Residual	236.396	203	1.165		
Total	1051.450	209	5.031		

Tables 10: Ancova of DT at individual sites.

Table 10(a): Ancova of DT at Triceps.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG OF F
ZT	207.638	1	207.638	140.69	0.000
SEX	1.111	1	1.111	0.75	0.389
Explained	208.750	2	104.375	70.72	0.000
Residual	98.883	67	1.476		
Total	307.633	69	4.458		

Table 10(b): Ancova of DT at Subscapular.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG OF F
ZT	254.427	1	254.427	312.12	0.000
SEX	0.066	1	0.066	0.08	0.776
Explained	254.494	2	127.247	156.10	0.000
Residual	54.616	67	0.815		
Total	309.110	69	4.480		

Table 10(c): Ancova of DT at Medial Calf.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG OF F
ZT	309.731	1	309.731	277.55	0.000
SEX	4/041	1	4.041	3.62	0.061
Explained	313.772	2	156.886	140.59	0.000
Residual	74.768	67	1.116		
Total	388.540	69	5.631		

In the literature differences in compressibility due to sex and site have been determined by comparison of compression percentages. To test if different results would be obtained if compression percentages were considered, analyses of variance where C(Z/10) was the dependent variable and sex was a groupind factor were carried out on the data from each site (Table 11). It was shown that there were no significant differences due to sex at any of the three sites (Triceps p = 0.441, Subscapular p = 0.984 and Medial Calf p = 0.930). By this method of analysis there was found to be no difference in compressibility between the sexes at the medial calf site, but there was a difference with p = 0.061 when the analysis was carried out in terms of DT taking thickness ZT into account as a covariate.

Jones (1970) had expressed compressibility as a ratio of radiographic to caliper thickness measurements. In this study the equivalent ratio is that of ZT/H10. Table 12 showed mean ZT and H10 values for each site and also the resultant ZT/H10 ratio. This was carried out in order to compare these data with the findings of Jones.

Tables 11: Anova of C(Z/10) at individual sites.

Table 11(a): Ancva of C(Z/10) at Triceps.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG OF F
SEX	26.935	1	26.935	0.599	0.441
EXPLAINED	26.935	1	26.935	0.599	0.441
RESIDUAL	3055.157	68	44.929		
TOTAL	3082.092	69	44.668		

Table 11(b): Anova of C(Z/10) at Subscapular.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG OF F
SEX	0.020	1	0.020	0.000	0.984
EXPLAINED	0.020	1	0.020	0.000	0.984
RESIDUAL	3179.126	68	46.752		
TOTAL	3179.146	69	46.075		

Table 11(c): Anova of C(Z/10) at Medial Calf.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIG OF F
SEX	0.499	1	0.499	0.008	0.930
EXPLAINED	0.499	1	0.499	0.008	0.930
RESIDUAL	4375.727	68	64.349		
TOTAL	4376.227	69	63.424		

Table 12: Mean ZT and H10 values, with resultant ZT/10 ratio.

	Mean ZT	Mean H10	ZT/H10 ratio
Triceps (M)	13.8	9.6	1.42
Triceps (F)	20.2	14.6	1.38
Medial Calf (M)	12.0	8.2	1.46
Medial Calf (F)	18.7	13.2	1.42
Subscapular (M)	13.5	9.8	1.38
Subscapular (F)	13.8	10.1	1.38
Male (All Sites)	13.1	9.2	1.42
Female (All Sites)	17.6	12.6	1.40

DISCUSSION

The error of the use of comparison of compression percentages as a criterion of differences in compressibility of skinfolds was shown in part II of this thesis. It was shown that compression percentage was not independent of skinfold thickness, thus a technique which took into account skinfold thickness had to be employed. In this part of the thesis the aim was to show whether or not differences in compressibility occurred dur to sex or site of skinfold. It must be borne in mind tthat any conclusion as to sex or site differences may well be specific to the sample measured. The onus for further generalisations on sex or site differences in the human population awaits further study.

The data in this thesis was initially analysed in a manner similar to that which previous studies in the literature have used. The data was analysed in terms of compression percentages. Comparison of the mean compression percentages for each site (Table 8) showed very little differences between the sexes at each site. Comparison of the mean ZT values (Appendix VI) however showed that the female means were higher at each site. Part II of this thesis showed a relationship between compression percentage and skinfold thickness, thus it could not be stated on the strength of the evidence supplied by the comparison of mean compression percentages that there was no difference in compressibility between the sexes.

An analysis of variance on the compression percentages showed that there was no sex effect, but that there was a site effect, significant at the 0.05 level. However when the data was analysed in terms of DT with ZT as a covariate, different results were obtained. When the analysis of covariance was carried out on the DT data it was found that there was no sex and site effects significant at the 0.05 level. Thus when skinfold thickness (Zt) was taken into account there were found to be no significant differences, although a site difference had been found when compression percentages were analysed. It was also noticeable that although no significant sex effects were found by either analysis the probability of a difference was radically different in each case. When compression percentages were analysed a p = 0.712 was found for a sex difference. However using the DT/ZT relationship analysis the probability of a difference was p = 0.077. Thus when skinfold thickness was taken into account the sex effect nearly reached an acceptance level.

When the data was broken down into the three individual sites a similar discrepency in results was found. When compression percentages were considered it was found that there was no sex difference in any of the sites, but that at the medial calf site when skinfold thickness was taken into account p = 0.061 for a sex difference. With compression percentage analysis p = 0.930 for the sex difference. Thus it can be seen that markedly different results can be achieved with the two techniques.

From these findings this author wished to stress the need for the consideration of skinfold thickness when interpreting skinfold compressibility data and recommended that the DT/ZT relationship technique be used rather than the compression percentage method.

By consideration of the DT/ZT regression lines for each site (Figures 10, 11 and 12), it could be seen that there was a general trend for the female skinfolds to be less compressible than the male skinfolds ie. there is a lower DT value for any particular ZT value. However the difference between male and female regression lines was not significant at any of the sites. The general conclusion from most of the studies carried out in the literature was that the female skinfold was more compressible than the male skinfold. These studies utilised versions of the compression percentage as a criterion of difference. On such study was that of Clegg and Kent (1967). However in the study by Jones (1970), where skinfold thickness was taken into account, it was found that male skinfolds were more compressible than female skinfolds. Jones expressed compressibility in terms of a ratio of radiographic to caliper fat measurements. He found that when the sum of four leg sites were considered the male ratio was 1.61:1 and the female ratio was 1.71:1. It was possible to express the data from this study in similar terms to that of Jones. A ratio of uncompressed skinfold thickness (ZT) to skinfold thickness measured with a standard Harpenden caliper (H10) was considered equivalent, although not equal to the ratio used by Jones. The results of the analysis were shown in Table 12. It was seen that at Medial Calf and Subscapular sites the ratio was slightly larger for females but that this was reversed at the triceps site. When all the sites were considered simultaneously a ratio of 1.42:1 was was found for males, and a ratio of 1.40:1 for females. Therefore there was a trend for male skinfolds to be slightly more compressible. However this is not a significant difference.

In the study by Jones he had tried to explain his finding that his male skinfolds were more compressible than the female skinfolds by pointing out that the females in his sample were physical education students and thus comparatively more muscular in the legs than an average female population. The sample in this author's study was of a similar age to that of the sample in the Jones study, however they were not physical education students, although some of the females in the sample were athletes of various types. In this author's study a sex effect had been found although only significant at the 0.10 level, thus not accepted as a significant difference. Jones found male skinfolds to be more compressible than female skinfolds. The majority of other studies have found that female skinfolds are more compressible, although by the dubious analysis of compression percentages. It is therefore the contention of this author that whether or not a sex effect is found and in which direction this effect is oriented, depends on the male and female samples measured. Muscularity causing increased skin tension will decrease compressibility thus a muscular female group compared with an inactive male group would probably show female skinfolds to be less compressible than male skinfolds, and vice versa. The main concern should be that the data is handled correctly, ie. by taking account of skinfold thickness in analysis, and couching any statements as to sex differences in terms of the samples measured.

In consideration of the site differences incompressbility, it was found that there was a significant site difference when compression percentage analysis was applied. However when DT/ZT analysis was applied the difference was found not to be significant at the 0.05 level (p = 0064). Figures 13 and 14 show the regression lines for DT versus ZT for each site for males and females respectively. By the study of these lines it could be seen that there was a trend for differences in compressibility at each site. In both males and females the medial calf site was the most compressible; that is there is a higher DT for any given ZT value. In the case of site differences it was also the contention of this author that any investigation into compressibility should take into account the effects of skinfold thickness.

CONCLUDING DISCUSSION

The main aim of this thesis was to determine the feasibility of developing a caliper technique for the estimation of uncompressed skinfold thickness. By its very nature a skinfold caliper had to exert a finite pressure on the skin in order to make a reading. However this caused a problem in that different skinfolds responded in different ways to the same pressure. It has been acknowledged in the literature that there was variation in the degree of compression in skinfolds. This variation in compressibility was one of the accepted criticisms of estimation of subcutaneous fat by skinfold caliper measurement. This author set out to develop a caliper measurement technique that would take into account variations in skinfold compressibility and produce an estimate of uncompressed skinfold thickness. To this end a standardised 3 caliper technique was developed. The standardised 3 caliper technique involved the measurement of a skinfold with three Harpenden skinfold calipers which exerted three different pressures, ie. 5, 10, 15 $x10^4 Nm^{-2}$. The skinfold was measured firstly with the 5 $x10^4 Nm^{-2}$ caliper, and then after a one minute period was measured with the 10 $x10^4 Nm^{-2}$ caliper. After a further one minute delay the skinfold was measured with the 15 $x10^4 Nm^{-2}$ caliper. From this data a simple regression analysis was carried out between log10 skinfold thickness and caliper pressure. The antilog of the intercept of this line was termed ZT, and represented the estimated uncompressed skinfold thickness.

In the development of this technique several factors had to be taken into account:

1) A finite time was required for the skinfold to return to normal after measurement with a caliper, due to water expulsion during measurement.
2) The order of application of the calipers may have affected the caliper readings.
3) Reproducibility of skinfold measurements was better when sites were marked.

The skinfolds were clearly marked with a cross-mark made at the point of application of the caliper. This was to ensure that the same skinfold was measured by each of the three calipers.

One would have to have allowed about 20 minutes for the skinfold to recover after each caliper application. Thus the technique would have required one hour to measure one skinfold. This obviously would not have been a very practical time constraint. Thus to keep the length of time spent on each subject to a minimum and also to acknowledge the timing effect on measurements, a standard one minute was allowed between each measurement. Thus this author acknowledged that the skinfold had not fully recovered when the next caliper was used. However one minute was allowed for recovery after each measurement, thus standardising the effect on measurements.

It was decided that the order of presentation of calipers would be 5 then 10 then 15 $x10^4 Nm^{-2}$, however the author acknowledged that there might be an effect due to order of measurement and thus carried out a small pilot study to test for this effect. It was found that there was no significant differences between measurements and thus this author decided that the most sensible order of presentation would be to use the lightest pressure first and the heaviest last. Thus the author adopted 5, 10, 15 as the standardised order.

Having taken the previously mentioned factors into account, the 3 caliper technique was standardised. From the 3 caliper technique an estimate of uncompressed skinfold thickness was made. Before any technique can be used in research it must be validated against a criterion technique. In Part I of this thesis the validity of the uncompressed skinfold thickness was tested. The criterion measure used was that of ultrasonic scanning estimation of subcutaneous fat depth (itself being validated by radiography). Ultrasonic scanning is becoming accepted as a valid technique for fat thickness estimations in humans. Since the calipers measure a double thickness of skin plus subcutaneous fat, the uncompressed skinfold thickness was compared to twice the ultrasonic thickness. It was found that the uncompressed skinfold thickness prediction (ZT) was indeed a valid measure of fat thickness when compared to twice the ultrasonic estimation of subcutaneous fat depth. Therefore the author proposed that the 3 caliper technique may be used to predict uncompressed skinfold thickness.

The internationally accepted caliper pressure was $10 \times 10^4 Nm^{-2}$ as proposed by Edwards et al (1950). As pointed out earlier, one criticism of a single caliper measurement was that it was subject to error due to variations in skinfold compressibility. In order to establish if the 3 caliper technique had reduced this error in skinfold thickness estimation, ZT was correlated with ultrasonic subcutaneous fat depth (UT). The thickness measured by the $10 \times 10^4 Nm^{-2}$ caliper H(10) was also correlated with UT. It was found that ZT correlated better to UT than did H(10); this would indicate a reduction in variance due to skinfold compressibility had occured, at least in part. Thus the author concluded that the 3 caliper technique gave a valid estimate of uncompressed skinfold thickness and did so having taken account of some of the variance due to skinfold compressibility .

Part II of this study was directed at the investigation of the relationship between compressibility and skinfold thickness. Clegg and Kent (1967) had proposed that there may be a relationship between compression percentage and skinfold thickness. Compression percentage should have been independent of thickness according to dimensionality theory, however it was shown that compression percentage was indeed related to skinfold thickness. The relationship was shown to be curvilinear. This indicated that any conclusions from previous studies based on the premise that compression percentage was independent of thickness were now vulnerable to criticism.

A new measure of compressibility was proposed as being the difference between ZT and the skinfold thickness measured by the Harpenden 10 $\times 10^{4}$ Nm^{-2} caliper. It was termed DT. It was shown that there was a good relationship with skinfold thickness. This was then used in the third part of the thesis to investigate the effects of site and sex on skinfold compressibility.

In part III however it was the author's intention to show that the discrepencies in results that could occur by analysis of results by the traditional compression percentage technique and the newly proposed DT/ZT relationship technique, rather than to come to any conclusion on sex and site differences.

The study showed that there was no significant sex differences however the data were analysed, There was found to be no significant site effect with the DT/ZT technique. But the site effect was found to be significant when the data were analysed with regard to compression percentages. Thus it was the final conclusion of this author that any investigation into differences due to sex or site should be analysed by the DT/ZT method. Also any conclusions about sex or site differences should be phrased in terms of the sample measured.

APPENDIX I

TIME ALLOWANCE BETWEEN REMEASUREMENTS WITH THE THREE CALIPER TECHNIQUE (PILOT STUDY).

A question that has been discussed in the literature is that of the time that should be allowed between remeasurements of skinfolds to give reproducible results. Brozek and Kinzey allowed 30 minutes between skinfold measurements at the same site, claiming that this was the time period required for the skinfold to return to normal. In undocumented pilot studies the experimenter observed that a period of 20 minutes appeared to be long enough for the measurements to be reproduced.

The 3 caliper technique is standardised so that each caliper measurements are made one minute apart. The experimenter acknowledged that each measurement will be affected by the previous one, however a standardised technique was adopted and validated against ultrasonic measurements. This standardised technique incorporates this timing effect.

In order to test the reproducibility of skinfolds with two different time delays between measurements the following two experiments were carried out.

1) Twenty minute period between remeasurements.

Six male subjects, average age 21.655 d. yrs., age range 19.772 - 24.493 d. yrs., were measured with the 3 caliper technique at 5 sites; Subscapular, Triceps, Midaxillery, Suprailiac and Medial Calf. After a period of 20 minutes during which they rested quietly the subjects were remeasured with the three caliper technique. An analysis of variance on skinfold thickness with 1st or 2nd reading as a grouping factor was carried out. The results of the analysis were as follows:

Anova of skinfold thickness by reading.

	S.S.	D.F.	M.S.	F	Sig
Reading Effect	1.460	1	1.460	0.114	0.736
Residual	2282.941	178	12.826		
Total	2284.401	179	12.762		

An F statistic of 0.114 is produced by this analysis. This gives a probability of 0.736 of there being a difference between 1st and 2nd readings of skinfold thickness. Thus there is no significant difference between skinfold measurements when a period of 20 minutes is allowed between testings.

2) Five minute period between 3 caliper technique readings.

On another sample of 6 males, average age 22.910 d. yrs., age range 19.430 - 26.871 d. yrs., 5 minutes was allowed between 1st and 2nd readings with the 3 caliper technique. The same five skinfolds were used. Again analysis of variance was carried out on the data and the results were as follows.

Anova of skinfold thickness by reading.

	S.S.	D.F.	M.S.	F	Sig
Reading Effect	0.591	1	0.591	0.084	0.772
Residual	1247.757	178	7.010		
Total	1248.348	179	6.974		

An F statistic of 0.084 was found showing that again there was no significant difference between 1st and 2nd readings with the 3 caliper technique.

The experimenter thus concluded that there was no significant difference between repeated measurements with the 3 caliper technique when either a 5 or a 20 minute period was allowed between measurements. However when all subsequent data was collected a 20 minute period was allowed between remeasurements.

APPENDIX II

MODIFICATION AND CALIBRATION OF THE THREE SKINFOLD CALIPERS

Three standard Harpenden calipers were purchased. These calipers exerted a constant pressure of 10 $\times 10^{4} Nm^{-2}$ over the jaw surfaces. This pressure was exerted by two coil springs. On one of the calipers, one of the springs was removed. This spring was then added to the third caliper. It was necessary for an extra long post to be machined for attachment of the third spring. The experimenter now had three calipers, one with one spring one with two springs and one with three. It was now necessary to calibrate the calipers to determine the pressures exerted by them. This was carried out in the Human Biology Laboratory of Loughborough University of Technology, utilising their standard procedure for caliper calibration.

The caliper was clamped horizontally on a retort stand. A light tin dish suspended on four threads was hooked over the lower jaw surface of the caliper. This dish of known weight acted as the scale pan to hold weights taken from a chemical balance. Weights were added to the pan until the jaw surfaces first opened. The total weight of scale pan plus weights was recorded. The pressure of the caliper was described in terms of x10^{4} Nm^{-2} of jaw surface area. The surface area of the jaws was 90 mm^{2}, since they were 15 x 6 mm rectangular plates. Thus to determine caliper pressure the weight required to open the jaws is divided by the jaw surface area (90 mm^{2}). Each caliper was calibrated three times as a check against error. The three calipers were found to exert pressures of 4.9, 10.0 and 15.1 x10^{4}Nm^{-2} respectively. All three were within the allowable bounds of error such as they could now be said to exert pressures of 5, 10, and 15 x10 Nm .

APPENDIX III

STANDARDISATION OF ULTRASONIC MEASURES

A great deal of practice was required before the experimenter became proficient at gaining repeatable measurements of subcutaneous fat depth with the ultrasonic scanner. When taking a measurement it was necessary to press firmly enough with the transducer to ensure good acoustic conduction, yet lightly enough so that no compression of the subcutaneous tissue occurred. This was achieved by observation of the trace on the oscilloscope during measurement. The trace appeared as a series of spikes rising vertically from a base line. Each spike represented an interface between two tissues with differing acoustic properties. The first spike on the left is the 'main bang' or zero point, representing the surface of the skin. The next spike to the right is the skin/subcutaneous fat interface, the next is the fat/muscle interface. If the experimenter pressed fairly hard on the transducer the fat thickness would appear to be reduced yet the muscle thickness would be unaltered. When a reading was taken the fat was slightly compressed then allowed to return to normal by releasing the pressure on the transducer. If the pressure was reduced too much acoustic conduction was destroyed and the trace broke up thus the reading was taken at a point in release of pressure just prior to the loss of acoustic conduction. This ensured that the minimum possible pressure was being exerted by the transducer.

APPENDIX IV

THE EFFECT OF ORDER OF PRESENTATION OF CALIPERS IN THE 3 - CALIPER TECHNIQUE (PILOT STUDY)

In the standardised technique the skinfold is first measured with the 5 $\times 10^4 Nm^{-2}$ caliper, then with the 10 $\times 10^4 Nm^{-2}$ caliper and finally with the 15 $\times 10^4 Nm^{-2}$ caliper, each with a one minute interval. In order to show if the order of presentation of the calipers affected the measurements a small pilot study was carried out.

Two female subjects were measured at 5 skinfold sites; Triceps, Biceps, Subscapular, Suprailiac and Abdominal. Each subject was first measured with the standardised 3 caliper technique. The subject was then remeasured one hour later using the 3 calipers, except that this time the calipers were presented in reverse order. Thus the 15 $\times 10^4 Nm^{-2}$ caliper was used first, followed by the 10 $\times 10^4 Nm^{-2}$ and then the 5 $\times 10^4 Nm^{-2}$ caliper with a one minute interval between them.

Using paired t-tests the caliper readings with the standardised technique and those with the reversed routine were compared. There were no significant differences found between the caliper readings with the standardised technique and with the reversed routine.

APPENDIX VI

S.F.U. SAMPLE MEANS AND STANDARD DEVIATIONS.

40 Males - Mean Age 25.65 yrs.

30 Females - Mean Age 24.98 yrs.

	ZT		DT		CZ	
	Mean	S D	Mean	S D	Mean	S D
MALES						
ALL SITES	13.1	5.8	3.9	2.2	28.4	8.0
TRICEPS	13.8	5.9	4.2	2.2	29.6	7.3
MEDIAL CALF	12.0	5.7	3.7	2.3	29.3	9.0
SUBSCAPULAR	13.5	5.8	3.7	2.2	26.2	7.1
FEMALES						
ALL SITES	17.6	6.5	5.0	2.1	28.0	6.3
TRICEPS	20.2	6.0	5.6	1.7	28.3	5.8
MEDIAL CALF	18.7	5.2	5.6	2.1	29.5	6.4
SUBSCAPULAR	13.8	6.5	3.7	2.0	26.1	6.4
ALL DATA	15.0	6.5	4.4	2.2	28.2	7.3

	H5		H10		H15	
	Mean	S D	Mean	S D	Mean	S D
MALES						
ALL SITES	11.6	5.0	9.2	3.9	8.7	4.3
TRICEPS	12.2	5.0	9.6	4.1	9.0	3.5
MEDIAL CALF	10.5	4.9	8.2	3.6	7.7	3.6
SUBSCAPULAR	12.1	4.9	9.8	3.9	9.3	3.5
FEMALES						
ALL SITES	15.7	5.8	12.6	4.8	11.8	4.5
TRICEPS	18.0	5.5	14.5	5.0	13.6	4.6
MEDIAL CALF	16.7	4.7	13.1	3.8	12.2	3.7
SUBSCAPULAR	12.5	5.8	10.1	4.7	9.6	4.3
ALL DATA	13.3	5.7	10.7	4.7	10.0	4.3

APPENDIX V

LOGHBOROUGH SAMPLE MEANS AND STANDARD DEVIATIONS.

13 Males - Mean Age 23.2 yrs.

15 Females - Mean Age 22.0 yrs.

	ZT		CZ		DT	
	Mean	S D	Mean	S D	Mean	S D
MALES						
ALL SITES	10.8	5.1	25.7	7.0	2.9	1.8
BICEPS	5.7	3.1	24.7	8.8	1.6	1.4
TRICEPS	13.1	5.1	27.9	4.2	3.8	1.9
LATERAL CALF	12.7	4.9	28.1	5.9	3.6	1.8
MEDIAL CALF	10.8	5.0	26.9	8.7	3.1	1.9
MIDAXILLARY	9.8	4.3	21.6	7.6	2.3	1.5
SUBSCAPULAR	10.9	2.4	21.0	4.9	2.3	0.9
SUPRAILIAC	12.7	6.6	29.4	3.7	3.8	2.3

FEMALES						
ALL SITES	16.3	6.9	28.0	7.3	4.5	2.2
BICEPS	10.7	4.0	32.4	8.2	3.6	1.9
TRICEPS	22.0	7.2	25.6	3.8	5.5	1.5
LATERAL CALF	17.6	5.0	22.9	3.6	4.0	1.1
MEDIAL CALF	20.4	6.0	27.7	3.7	5.7	1.9
MIDAXILLARY	11.9	5.2	27.2	7.6	3.5	2.4
SUBSCAPULAR	15.7	7.7	25.2	5.2	4.1	2.3
SUPRAILIAC	15.5	5.5	34.9	9.6	5.5	2.7
ALL DATA	13.7	6.7	26.9	7.3	3.8	2.2

	H10		H5		H15	
	Mean	S D	Mean	S D	Mean	S D
MALES						
ALL SITES	7.9	3.4	9.6	4.4	7.4	3.0
BICEPS	4.1	1.8	5.1	2.5	3.8	1.5
TRICEPS	9.3	3.3	11.6	4.2	8.7	2.8
LATERAL CALF	8.9	3.3	11.1	4.1	8.3	2.8
MEDIAL CALF	7.7	3.2	9.6	4.3	7.2	3.0
MIDAXILLARY	7.5	2.8	8.9	3.8	7.1	2.8
SUBSCAPULAR	8.6	1.7	10.0	2.0	8.2	1.5
SUPRAILIAC	8.8	4.4	11.2	5.6	8.2	3.9

FEMALES						
ALL SITES	11.7	5.3	14.4	6.2	10.9	4.9
BICEPS	7.2	2.5	9.2	3.1	6.5	2.0
TRICEPS	16.5	6.1	19.8	6.7	15.5	5.7
LATERAL CALF	13.6	4.1	15.8	4.5	12.5	3.7
MEDIAL CALF	14.7	4.4	18.1	5.5	13.7	4.3
MIDAXILLARY	8.5	3.2	10.6	4.3	8.0	2.8
SUBSCAPULAR	11.6	5.5	14.1	6.8	10.9	5.0
SUPRAILIAC	10.0	3.9	13.3	4.7	9.3	3.5
ALL DATA	9.9	4.9	12.2	5.9	9.3	4.5

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