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An investigation into the validity of percentage body fat estimations by a commercially available bioelectrical impedance analyser

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the degree of Master of Science

August 1995

A. G. Williams

An investigation into the validity of percentage body fat estimations by a commercially available bioelectrical impedance analyser

Abstract

The present investigation examined the validity of bioelectrical impedance analysis (BIA) and selected skinfolds (Sum 4) when estimating percent body fat (% fat) in young, physically active adults (MEAN ± SEM = 18.3 ± 1.2 % fat) by comparing the estimates with values obtained from densitometry (D). Thirty-five Caucasian volunteers (21 males, 14 females; MEAN ± SEM = 22.9 ± 0.4 yr) served as subjects. The statistical analysis involved calculation of the bias and 95% limits of agreement. The results indicated that the Bodystat 1500 BIA system agreed better with D (bias and 95% limits = 0.7 ± 7.4 % fat) than Sum 4 (bias and 95% limits = 2.2 ± 8.5 % fat). However, the error observed for both predictive methods was too large to recommend use in assessing % fat in a young, physically active population, unless only a general estimation of % fat is required for work such as epidemiological studies.

Keywords: body composition, bioelectrical impedance analysis,
skinfolds, densitometry, agreement.

This work is original and has not been previously submitted in support of a degree, qualification or other course.

Signed.....

Date.........

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CHAPTER 1

INTRODUCTION

INTRODUCTION

The methodology of assessing body composition has received great scientific interest due to the importance of body fat when related to both health status and sporting performance. The validity of bioelectrical impedance analysis (BIA) as a measure of body composition is a complex matter given the dependence of the values obtained on each manufacturer's regression equation. The published research concerning one popular model - the Bodystat 1500 - is rather limited, and additional validation studies are required. Major advantages of BIA include its non-invasive, quick and relatively easy to perform application. Thus, the main potential of this technique, which relies on the different conductivity of tissues to define body composition, is as a possible replacement for the use of BMI and skinfold measurements which have certain limitations.

Numerous studies have evaluated the accuracy of some commercially available BIA systems, often focusing on the apparatus produced by RJL Systems of Detroit, USA - e.g. Ross, Leger, Martin, and Roy (1989), Brodie and Eston (1992), Stout, Eckerson, Housh, Johnson, and Betts (1994). However, just three recent papers have attempted to address the lack of research concerning the Bodystat model.

Smye, Sutcliffe, and Pitt (1993) found little difference between the measurements obtained from three of the four models they compared - two of which were the RJL and the Bodystat systems (mean difference in impedance value 0.6% ($p<.03$)). However, no validation against a criterion method was attempted.

Fuller, Sawyer, and Elia (1994) cleverly assessed the predictive value of the various equations utilised by differing BIA systems by manually inputting a standard impedance value. Their findings suggested that the Bodystat equation was more suitable (approximately ± 7 % fat when compared to reference methods) than that utilised by other BIA systems (or, indeed, skinfold methodology) when a population of obese women was studied. Thus, the relative importance of the regression equation utilised as opposed to the physical apparatus itself can be appreciated.

Maughan (1993) evaluated the validity of the Bodystat apparatus against densitometry as a criterion method. However, as the author readily admits, procedures were not performed in full accordance with the manufacturer's instructions (Bodystat Ltd., 1994) - notably, a lack of control over the subjects' prior behaviour (little emphasis was placed on this point), and hence hydration levels, was present. This factor has been previously identified by Hutcheson, Latin, Berg and Prentice (1988) and Thompson *et al* (1991) as a pre-requisite to accurate body composition measurements by BIA. Furthermore, Maughan (1993) refers to "...the relative inexperience of the operator with this technique" (p.66) as a possible source of error concerning the relatively poor reproducibility of the BIA measurements performed in that study. Nevertheless, the results suggested less difference between skinfold measurements and densitometry than between BIA and densitometry.

Evidently, there is a need for further validation studies of the Bodystat 1500 BIA system if the users of this commercially available product are to have a degree of confidence in the measurements obtained. Furthermore, statistical analysis should be performed in full accordance with the method described by Bland and Altman (1986) for the comparison of two methods of clinical measurement. These authors explain the limitations and false assumptions common to similar studies which often mis-use the Pearson product-moment correlation and ANOVA techniques. For example, the correlation 'r' between two variables plotted on a graph will be considered to be perfect if the points lie along any straight line. However, the agreement will only be perfect if the points lie along a line of equality.

Therefore, the aim of the current study is to assess the validity of the Bodystat 1500 apparatus when used to measure body fat level, using densitometry as a criterion measure. As many previous validation studies have also assessed other established estimates of body composition for comparison with a new method, this trend will be continued with skinfolds taken at four upper-body sites, and the transformation developed by Durnin and Womersley (1974) used to estimate body composition.

CHAPTER 2

METHODOLOGY

METHODOLOGY

Subjects.

35 physically active adult volunteers recruited from the student population of Chester College of Higher Education participated in this study, all of whom had signed informed consent forms. Weight was recorded to the nearest 0.1kg, and height to the nearest 0.01m. Descriptive data are given in Tables 1 and 2.

Procedures.

All measurements were carried out by the same experienced investigator. In order to accord with the Bodystat manufacturer's instructions and ensure normal hydration of the subjects, each subject was requested to conform to the desired conditions (Bodystat Ltd., 1994) prior to assessment - namely :-

No eating or drinking 4-5 hours prior to the test.

No exercise 12 hours prior to the test.

No alcohol or caffeine consumption 24 hours prior to the test.

Testing sessions in the morning proved to be most agreeable with the subjects as a result, and all body composition analyses of a particular subject were performed on one occasion.

BIA. All measurements were made with the subjects in a comfortable, supine position, having removed the right shoe and sock and any other clothing/jewellery obstructing the right hand/foot. The BIA measurements were made with the model Bodystat 1500 (Bodystat Ltd., Douglas, Isle of Man), and were in accordance with the procedures explained by the manufacturer (Bodystat Ltd., 1994).

Skinfolds. Body composition was estimated from skinfold thicknesses via the use of equations established by Durnin and Womersley (1974) for 4 upper body sites. The sites were identified as those described by Harrison *et al* (1988), and measurements were made in triplicate to the nearest mm, with the median value taken at each site.

Densitometry. Residual lung volume (RV) was determined by the closed-circuit oxygen dilution method described by Wilmore, Vodak, Parr, Girandola, and Billing (1980), with the subject seated in the water tank and immersed to the level of the neck. The external pressure on the torso was previously found to have a significant effect on measured body composition by Gibbons, Jessup and Bunting (1985). The complete method of RV determination involved the use of a Vitalograph spirometer (Vitalograph, Ltd., Buckingham, UK), oxygen gas analyser (Servomex, model 570A), carbon dioxide gas analyser (Servomex, infra-red PA404) and a 9-litre classic bell spirometer. Two or three trials of RV determination were performed until two observed values were within 100ml of each other. The mean of these two values was then calculated as RV.

Body density was determined by hydrostatic weighing in a cylindrical tank (height 127cm, diameter 91cm) in which a swing seat was suspended from a 40-kg scale with digital display (Novatech: Hastings, UK). The subjects submerged beneath the surface of the water while expiring maximally and remained as motionless as possible at the point of maximal expiration for roughly 5s, while underwater weight was recorded. After several practice trials to familiarise the subjects with the test procedure, at least 5 further trials were performed until consistent values were obtained. The average of the two heaviest weighings was taken to be underwater weight, and used in the equation of Siri (1961) to determine body composition.

Repeatability. All body composition measurements were repeated on a sub-sample of 10 subjects between 24 hours and 2 weeks after the first test session. This was in order to allow an estimate of the test-retest reliabilities of each of the procedures carried out in this particular study.

Analysis of Data. All statistical analyses were undertaken with the use of the SPSS for Windows (V. 6.1) software (SPSS Inc., 1994). The method of assessment of test-retest reliability was that described by Bland and Altman (1986). The coefficient of repeatability they describe is simply ± 2 standard deviations of the mean of the differences between trials for each subject. The method of comparison between methods was also that described by Bland and Altman (1986) which examines the differences between the two methods for individual subjects. Specifically, the bias (mean difference) and 95% limits of agreement (± 2 standard deviations) between densitometry and the alternative prediction techniques were calculated. This statistical approach does not involve any preconceived assumptions about which method is correct, thereby taking account of the fact that no 'reference method' such as densitometry can be said to represent the 'true' value of body composition. Furthermore, the ability of either of the prediction techniques (BIA and skinfolds) to acceptably reproduce estimates obtained by using the existing assessment method of densitometry could be considered. Thus, the agreement between two methods was evaluated, as opposed to the strength of the relation between them (as obtained from Pearson product-moment correlations). Bland and Altman (1986) also state that regression analysis is inappropriate for comparison of methods - however, the technique is useful in producing a proposed predictive equation for this specific population.

CHAPTER 3

RESULTS

RESULTS.

Descriptive Data.

Table 1. **Descriptive data of subjects, including body fat determined by densitometry**

	MALES (n=21)	FEMALES (n=14)	ALL (n=35)
VARIABLE	MEAN (± s.e.m.)	MEAN (± s.e.m.)	MEAN (± s.e.m.)
Age (yrs)	22.7 (0.4)	23.3 (0.8)	22.9 (0.4)
Height (cm)	177.6 (1.3)	167.1 (1.8)	173.4 (1.4)
Weight (kg)	80.5 (2.0)	63.5 (2.9)	73.7 (2.2)
Body Fat (%)	14.1 (1.2)	24.5 (1.1)	18.3 (1.2)
VO_2 Max (ml/kg.min^{-1})[‡]	51.4 (2.1)	44.9 (4.0)	48.8 (2.1)

[‡] Estimated by use of the YMCA protocol (Golding, Myers and Sinning, 1989) - an incremental, submaximal cycle ergometer test

Table 2. **Physical activity level of subjects in current study compared to normative data.**[†]

	Males	Females
This study	67 %	57 %
Normative values	30 %	9 %

[†] Values are percentage of respondents categorised into level 5 - highest level of physical activity. i.e. > 11 20-minute occasions of vigorous activity (> 7.5 kcal / min) in the past 4 weeks (The Sports Council and Health Education Authority, 1992)

Procedural Reliability.

The mean difference observed between measurement occasions was approximately 0 % fat for all methods (0.07, -0.20 and -0.09 % fat for 1st trial minus 2nd trial for densitometry, BIA and skinfolds respectively), allowing the coefficient of repeatability (see Bland and Altman, 1986) to be assessed. This was 2.6 %, 2.7 % and 0.5 % for densitometry, BIA and skinfolds respectively. Thus, 95 % of the differences between testing sessions were within these limits. As the variability of densitometry was as large as the other two methods (also not being noticeably different to that quoted for densitometry by Lohman (1992) of 2.0 - 2.8%), one can be confident that the procedural reliability of this present study was satisfactory.

Agreement Between Methods.

Table 3. **Body fat content determined by each method expressed as a percentage of body weight**

	All (n = 35)	Males (n = 21)	Females (n = 14)
METHOD	MEAN (± s.e.m.) (range)	MEAN (± s.e.m.) (range)	MEAN (± s.e.m.) (range)
Densitometry	18.3 (1.2) (5.8 - 30.9)	14.1 (1.2) (5.8 - 23.6)	24.5 (1.1) (19.0 - 30.9)
Skinfolds	16.0 (1.0) (8.6 - 28.9)	12.2 (0.8) (8.6 - 26.5)	21.8 (0.9) (15.8 - 28.9)
BIA	17.6 (1.0) (5.0 - 29.1)	14.4 (1.0) (5.0 - 24.2)	22.4 (0.9) (15.2 - 29.1)

Table 4. **Comparisons of body composition assessments against densitometry: bias ± 95 % (2 s.d.) limits of agreement; n = 35**

METHOD	BIAS ± 2 s.d.	LOWER LIMIT (95 %)	UPPER LIMIT (95 %)
BIA	0.7 ± 7.4+	- 6.8	8.1
SKINFOLDS	2.2 ± 8.5	- 6.3	10.7

+ The difference between methods is significantly related to the magnitude of measurement (difference becomes more positive with increasing magnitude - see Bland and Altman, 1986)

Estimates of body composition obtained by all three methods are shown in Table 3. In neither comparison with densitometry did the magnitude of the difference between methods become obviously larger or smaller with increasing magnitude of the estimate (Bland and Altman (1986) have identified this as a pre-requisite for assessing agreement between methods without using log transformation of the data). Comparisons of methods (bias and 95% limits of agreement) for estimates of body fat as a percentage of body weight are presented in Table 4. The results show that the predictive methods utilised in this study were found to contain substantial errors in body composition estimation. This is demonstrated by the important large limits of agreement between methods, despite the relatively small bias observed.

Predictive Equations For Body Fat.

The equation utilised by the Bodystat system's manufacturer is unknown, and is not available for direct consideration. However, it is known that the equation initially estimates fat-free mass (FFM) using the independent variables age, sex, weight, height and impedance, with impedance utilised together in one term (Meeuwsen, personal communication, 1995), probably as impedance index : height squared ÷ impedance. Stepwise linear regression analysis of these variables produced the following equation :-

$$\text{FFM by densitometry} = 29.2 + 0.401\,[\text{WEIGHT}] - 9.60\,[\text{SEX}] + 0.238\,[\text{IMPEDANCE INDEX}]$$

where weight is considered in kg, sex is a dummy code of 1 for males and 2 for females, and impedance index is in $m^2 \div$ ohms. This produced an R^2 value of 0.943.

CHAPTER 4

DISCUSSION

DISCUSSION

The main results of the present investigation indicated that the Bodystat apparatus more accurately estimated percent body fat than skinfolds, although the large error of both methods is a cause for concern. The method of statistical analysis used for between-method differences, while correct (Bland and Altman, 1986), does not allow direct comparisons with most previous research carried out - Bland and Altman (1986) and Altman (personal communication, 1995) confirm that this is not possible due to the incorrect nature of the statistical analyses of the previous papers, not of this present one. Nevertheless, the main finding of this present study is in agreement with that of Fuller *et al* (1994) who considered a wider range of anthropometric and BIA prediction methods and equations, although a population of obese women was utilised in their study. Using the correct statistical approach, their work found that the Bodystat system produced a bias ± 95 % limits of agreement of -1.9 ± 7.6 %. However, the work of Maughan (1993) suggested that a 4-site skinfold equation provided a better estimate of percent body fat than the Bodystat apparatus when a mixed-sex population of lean adults was studied. Unfortunately, Maughan's (1993) investigation did not use the appropriate statistical technique. This point is emphasised when one considers that Maughan (1993) concluded that a correlation of 0.830 showed evidence of the ability of the Bodystat system to adequately substitute for densitometry, whereas a correlation of approximately 0.85 (not shown) in this present study is associated with large errors of measurement. (Of course, one must realise that this does not necessarily mean that the agreement between methods in Maughan's study was less good than in this present study, but does give an insight into the questionable interpretations of results that is possible when inappropriate analyses are performed.)

The present study illustrates the practical importance of lack of agreement of either of the two predictive methods with the chosen criterion of densitometry.

Despite a small bias derived from the mean values, the predictive error of approximately ± 7 % for BIA and ± 8 % for skinfold measurements is considered unacceptable for anything other than non-clinical use where a general estimation only is required. Thus, the need identified by Segal, Gutin, Presta, Wang and Van Itallie (1985) for such a system which is suitable for use in clinical settings is still not satisfied. However, some potential may exist for use in epidemiological studies. It is somewhat surprising that the limits of agreement for the Bodystat system in this present study were not significantly less than those reported by Fuller *et al* (1994), given that those investigators utilised a cohort of obese women for whom the predictive equation might have been thought to be less appropriate. From the results of this present study, a similarity with many proposed equations for BIA (Van Loan, 1990) was found in that the Bodystat system tended to overestimate percent body fat for the individuals with the lowest actual values, and underestimate percent body fat for those with the highest.

A redeeming feature of each of the two predictive methods as they are currently available may be found in the good repeatability of the techniques, although this should be investigated further for the Bodystat apparatus with a larger and more diverse subject sample. If substantiated, this quality would allow a confident use of either method in assessing trends over a lengthy period of time such as during a weight-control or physical training programme. Furthermore, although the bias from the true value appears insignificant for a population as in this study, it could be significant and, notably, fairly constant for a particular individual. This subject-specific bias could not be assessed without use of an accepted reference method such as densitometry on one occasion, but could theoretically be incorporated into observed measurements on that same individual to produce a more accurate estimate of true body composition. Thus, the advantage of using a simpler and more practical assessment method on most testing occasions could be maintained.

The Bodystat prediction equation is not released for consideration by the manufacturer. However, Meeuwsen (personal communication, 1995) confirms that FFM is estimated initially via a prediction equation, with percentage body fat subsequently calculated using this information and body mass. The equation for FFM produced from the data of this present study has a good predictive value (R^2 = 0.943) for this population of subjects. It is unlikely that the Bodystat equation is very similar to this as large errors were observed when compared to densitometry. This supports the idea of a need identified by Segal *et al* (1985), supported by Brodie and Eston (1992), for different prediction equations to be used for populations with mean body fat values of below 20 % than for those with greater body fat. This suggests that there may be room for improvement in the Bodystat equation when a population such as that utilised in this study (mean body fat around 18 %) is the concern. The rather low percentage body fat for the sample as a whole is probably related to the high physical activity level reported. A further point to note is that stepwise regression analysis failed to include 'age' as an independent variable in the equation - probably due to the narrow age range of this study's subject population. A greater range would likely produce an important influence of age on body fat. Also of note is the fact that impedance index only improved the predictive equation a small amount, from R^2 = 0.917 to R^2 = 0.943. Thus, body weight and sex account for the vast majority of the observed value of FFM, and hence percent body fat. Relatively speaking, impedance index performs a fine-tuning role only for the population type utilised in this study.

Densitometry was chosen as the criterion method for the purposes of this study, as, indeed, other recent studies have done including Brodie and Eston (1992), Maughan (1993) and Stout *et al* (1994). However, there are undoubtedly certain errors inherent to this method, although the statistical analysis used does account for this to a certain extent. Primarily, large inter-individual variations in the density of FFM have been identified by Martin and Drinkwater (1991), and the conversion of measured body density to body fat by any equation such as that of Siri (1961) is subject to the associated errors. This is perhaps most relevant when a physically active population - such as in this present study - is evaluated, as the possibility of both enhanced bone mass and density will increase the actual density of FFM. Thus, underestimations of percent body fat may occur. Although the mean values were not noticeably different between methods in this present study, admittedly anecdotal evidence contained herein suggests an underestimation of percent body fat for particularly active subjects undergoing strenuous training for the whole body - i.e. providing the greatest stimulus for increased bone mass/density. For example, one subject who reported very heavy fitness training for high-level rugby union was measured at 5.8 % fat by densitometry, but at 9.1 % and 12.4 % by skinfolds and BIA respectively. Similar findings have been reported by Maughan (1993). In addition, Lohman (1981) states that the standard error of estimate in measuring body fat by densitometry is at least 2.7 %. As most predictive equations for any new method of body composition analysis are validated against densitometry, the error of the new methods will be of at least the same magnitude.

One avenue of investigation that does not appear to have been followed by scientific study is the possibility of combining both BIA and skinfold data in a regression equation. This approach may eliminate some of the unexplained variance in actual body composition that each of the two methods suffers from, perhaps from a reduced reliance on the assumptions about fat distribution. Following set theory, as long as some of the variance by one method can be explained by values of the other, the prediction should be improved. Admittedly, the perceived advantage of minimal invasiveness of BIA technology is lost somewhat with the additional necessity of taking skinfold measurements, but the field nature of the analysis would be maintained - including portability and rapid administration - when compared to densitometry, for example. Taking the data of this study as an example only produced a minor improvement in predictive value over BIA data alone

(R^2 = 0.764 compared with 0.744 for percent body fat from densitometry). However, the potential exists for further investigation into this idea for a more heterogeneous population where the prediction may be enhanced due to the diversity of the sample. If favourable results were discovered, the criticism of the skinfold approach by BIA system manufacturers would have to be tempered somewhat, and the path of research may be modified also such that a competitive distinction of each of the two separate methods was not the main focus of future studies.

Innovative work by Organ, Bradham, Gore and Lozier (1994) has developed a particular technique of segmental BIA that does not significantly impair the non-invasive qualities of whole-body BIA, and yet appears to provide enhanced prediction. Furthermore, the possibility exists of assessing patterns of fat distribution by this method. Evidently, there is still the potential for research concerning applications of both existing and modified BIA methodology.

The one major physiological parameter that can influence body composition estimations by BIA, independent of actual body composition, is state of hydration (Thompson *et al*, 1991). This potential source of error was controlled as strictly as possible for the purposes of this present study. However, in settings such as the health and fitness industry, this cannot always be achieved. Nevertheless, emphasis should be placed on users adhering to any manufacturer's instructions as strictly as possible - such as those listed earlier in this paper.

In summary, the results of this study fail to support the widespread use of the Bodystat 1500 for estimating percent body fat in a young, active and physically fit population. This is disappointing given BIA's advantages in terms of cost, portability and reduced intrusion when compared to accepted reference methods. However, the Bodystat 1500 apparatus may be suitable for trend analysis or for general subject categorisation in a non-clinical environment, with the development of population specific equations a potential advance. Also, the possibility exists of use in research work concerning large, heterogeneous populations such as in epidemiological research - as long as users are aware of the current limitations of this technique. On this population of subjects, there was a slightly better agreement between measurements obtained by BIA and densitometry than between skinfold thicknesses and densitometry.

CHAPTER 5

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APPENDICES

APPENDIX A

EXTENDED LITERATURE REVIEW

This section provides a background for this current study by reviewing relevant topics of interest. These topics include the basis and reasoning for body composition assessment, the theory of bioelectrical impedance analysis, and research progress particularly relevant to this study.

EXTENDED LITERATURE REVIEW

Why Study Human Body Composition?

Buskirk (1987) has identified a number of reasons for studying human body composition - and therefore one can extend these notions to become reasons for carrying out methodological investigations. The reasons included viewing body composition analysis as a tool for :-

Characterising populations or specific groups within a population;
Studying ethnic and gender differences;
Describing normal or abnormal growth and development or ageing;
Following body changes during pregnancy or lactation;
Providing bases of reference for physiological variables, as well as for drugs and other therapeutic administrations;
Identifying patterns important in the characterisation of metabolic or other disease, including cancer;
Assessing physical fitness;
Providing information to competitive athletes concerning state of training.

An early review of the importance of the topic of body composition was produced by Brozek and Keys (1951). These authors stated, "Body fat shows the most striking variations in states of nutrition varying along the emaciation-obesity continuum" (p.194). The relationship of body composition to the nutritional status and the nutritional needs of a population were examined. The provision of improved methods of quantitative body composition estimation was identified as a primary task for nutritional scientists of the era.

The use of normative data of body weights alone was criticised by Brozek and Keys (1951) as inappropriate for anything other than very general screening of a population. This was indeed correct, as had been shown expertly by Welham and Behnke (1942) when the body density of professional football (US) players was evaluated. These researchers described the "rugged physique and unusual fitness" (p.498) of these men, and identified the potential errors involved if one assumes body weight alone, even if related to body height, to be a direct measure of obesity.

Since the above-mentioned work was produced, evidence has been accumulating in the scientific literature that there is a clear relationship between obesity and the risk of acquiring cardiovascular disease (Larsson, Bjorntorp and Tibblin, 1981; McArdle, Katch and Katch, 1991). Notably, Segal *et al* (1987) concluded that body composition, rather than body weight per se, is associated with increased prevalence of cardiovascular disease risk factors. Importantly, Segal *et al* (1987) stated that no significant differences in risk factors were observed between normal weight and 'overweight' lean groups of men.

The argument for utilising a measure of body 'size' such as a height/weight relationship is thus seen to be a weakening one. Nevertheless, the Metropolitan Life Insurance Company has periodically produced weight 'standards' for the general population. For instance, almost forty years ago, the Metropolitan Life Insurance Company (1959) updated its tables of desirable weights. Admirable comments were made in the article about the principle of energy balance, with a commendable emphasis placed on the perceived future importance of physical activity during leisure time - due to the envisaged proliferation of labour-saving devices for the home and automation at the workplace. Despite this educated approach to one aspect of the topic, the continued adherence to basic data in the 1980's (Metropolitan Life Insurance Company, 1983) is arguably somewhat flawed.

A study by Gray and Fujioka (1991) assessed the accuracy of height/weight charts and BMI as estimates of body composition. These two indices were found to be almost identical to each other, but proved to be only reasonable estimates of body fatness. The author of this present report agrees with the suggestion of Lohman (1992) that these indices may be of most use in conjunction with a measure of body composition. This would provide a more complete picture of body shape and composition for work of an epidemiological nature.

Garrow and Webster's (1985) suggestion that percent body fat may not be the best measure of obesity did not, however, lead to support by these authors for the widespread use of height/weight indices. They suggested body fat mass divided by the square of height (F/Ht^2) as a preferable measurement scale for obesity. The criticism of percent body fat lay in the theoretical upper limit of this parameter. However, one might suggest that whether one can classify a certain individual as 'very' obese or 'extremely' obese is a point of detail only. Any slight underestimations of degree of obesity at this upper end of the scale will make no practical difference to any treatment diagnosed or other conclusions to be drawn from the analysis. Furthermore, appropriate equipment and procedures are still necessary to determine body composition initially if body fat mass is to be estimated. If a measure is desired that can illustrate advances over time for a certain obese individual for whom body fat percentage is deemed too insensitive, changes in body weight alone can be followed. For extremely obese individuals, trends of change in body weight can satisfactorily indicate changes in body fat (McArdle *et al*, 1991).

Within the health and fitness industry, the measurement of body fat has become routine. Clients of fitness centres associate low body fat with physical fitness and its related benefits - including aesthetic, athletic and medical qualities (Nash, 1985). BIA has perhaps its greatest potential in this area, or maybe that of epidemiological research. Whichever situation, the major advantages of BIA are that it is a quick and easy to perform, non-invasive method of body composition estimation. In addition, the health and fitness industry may perceive advantages in the apparent utilisation of modern technology - a state-of-the-art tool may be viewed approvingly by clients who may also be willing to pay for analysis (Nash, 1985). Thus, BIA methodology provides a possible alternative to other body composition assessments such as BMI or skinfold measurements. It is the role of researchers in physiology to evaluate the accuracy and applicability of these techniques in performing their primary function of analysis. It is for others to ultimately decide, given the evidence, what form of analysis will best suit a specific situation. It is unlikely that any one method could be deemed suitable for body composition assessment in all environments.

One environment where body composition analysis has become commonplace over the last decade or more is that of competitive sport. The likely assumption behind this practice is probably that knowledge gained about an individual during assessment can be used to enhance performance, perhaps through modified training or diet. Also, Barr, McCargar and Crawford (1994) mention how body composition analysis may help to assess an individual's potential for success in a given sport by comparison with data from previously successful competitors. One attempt to achieve this using body composition data and other variables has been reported by Bale, Rowell and Colley (1985).

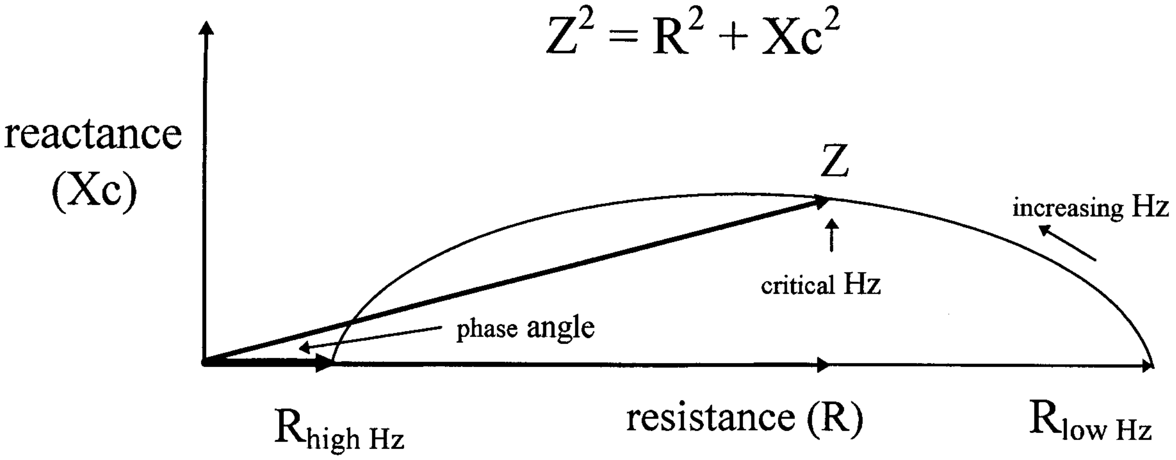
However, Barr *et al* (1994) also state that for elite athletes within a particular sport there is rarely a close relationship between body composition alone and performance. Inter-individual differences in natural body type may also mean that unrealistic targets for body composition may be aimed at by young and enthusiastic competitors. Errors in body composition measurements may only serve to worsen the situation. This is especially concerning when certain disorders are observed in young female athletes. These problems include menstrual dysfunction (possibly amenorrhoea), osteopenia, and eating disorders (Oppliger and Cassady, 1994). The first of these disorders is reviewed by Bale (1994), with reduced calorie intake identified as the major factor in precipitating extremely low body fat levels in some female athletes. Errors in body composition estimation such as overestimation of percent body fat of an individual aspiring athlete, or underestimation of elite competitors, may unfortunately exacerbate such disorders. The possibility of this is a distinct one given the reported lack of validity of both skinfold (Deurenberg, Pieters and Hautvast, 1990; Lohman, Slaughter, Boileau, Burt and Lussier, 1984) and BIA techniques (Malina, 1989; cited in Webster and Barr, 1993) for young or adolescent populations. The potential of errors in the fundamental methodology contributing to such problems should obviously be minimised through research and development. Furthermore, coaches and/or sports science support professionals should be fully aware of the unavoidable errors inherent to any form of body composition analysis.

Theory Of Bioelectrical Impedance

The principle of bioelectrical impedance analysis (BIA) of human and animal tissues was first investigated by workers such as Barnett and Bagno (1936), Barnett (1938), Barnett (1940), Burger and van Milaan (1943), Lofgren (1951) and Schwan and Kay (1956). These preliminary studies explored the relationships among bioelectrical impedance and its parameters to the water content of the body and to various physiological variables. However, much of the resulting information is not directly applicable to today's BIA due to the kind of technology utilised. Hoffer, Meador and Simpson (1969;1970), Nyboer (1970) and Jenin, Lenoir, Roullet, Thomasset and Ducrot (1975) began to develop the idea of BIA as a tool for clinical analysis, particularly its potential to easily determine total body water volume. For example, Hoffer *et al* (1969) demonstrated a good correlation between *in vivo* electrical impedance and total body water volume, and identified that "the impedance method has promise for prediction of total body water volume easily and quickly at the bedside" (p.534). Later work by Lukaski, Johnson, Bolonchuk and Lykken (1985) and Segal, Gutin, Presta, Wang and Van Itallie (1985) began to establish the potential of the first commercially available BIA models to accurately assess body composition.

The impedance value (Z) of a conductor is the frequency-dependent opposition to the flow of an alternating current. Chumlea and Baumgartner (1990) explain how impedance is composed of two vectors, resistance (R) and reactance (Xc), and its magnitude is described by the equation $Z^2 = R^2 + Xc^2$. Figure 1 illustrates the relationships among impedance, frequency, resistance and reactance. The magnitude of the resistance, reactance, and therefore impedance vectors depends upon the frequency of the current - refer to curve in Figure 1. Resistance is the pure opposition of a conductor to an alternating current, while reactance is the additional opposition to flow that results from the presence of capacitance. The critical frequency is the frequency in biological tissue that produces maximum reactance. The phase angle is the angle the impedance vector forms in relation to the resistance vector.

Figure 1. **The relationships between bioelectrical impedance (Z), resistance (R), reactance (Xc) and current frequency (Hz).**



In addition to the above physical relationships, BIA relies upon the greater electrolyte content and conductivity of fat-free mass compared to adipose tissue, and upon the geometrical relationship between impedance and the volume of the conductor. The latter point is explained below in conjunction with Figure 2. According to Ohm's Law, resistance (R) is proportional to the length (L) of a conductor, and inversely proportional to the cross-sectional area (A). Also, the volume of a conductor which has an approximately uniform cross-sectional area is equal to the product of its length and cross-sectional area. Substituting V/L for A in the equation derived from Ohm's Law, we have an equation for resistance (R). Simply rearranging this results in the volume of the conductor being proportional to its length squared divided by its resistance. In the human body, L is normally approximated as body height.

Figure 2. **Formulae explaining the basic principles of bioelectrical impedance.**

$$R = \rho (L / A)$$

$$V = L \times A$$

$$A = V / L$$

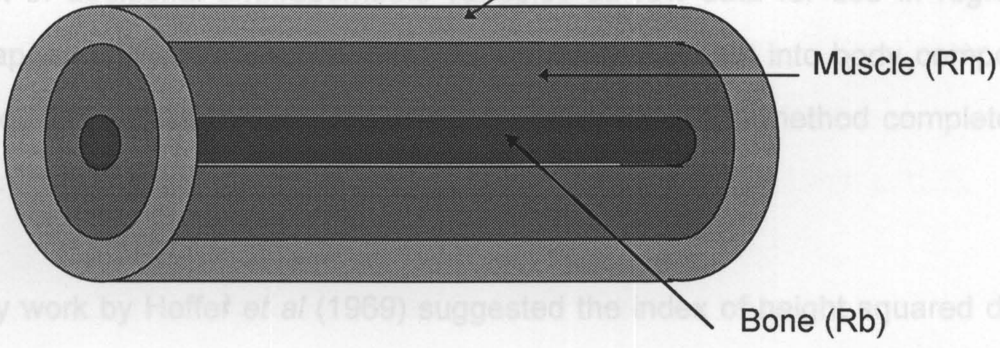
$$R = \rho L (L / V)$$

$$V = \rho L^2 / R$$

The reason for using R in the theoretical calculations above is because only the resistance component of the impedance vector is related to the geometric properties of a conductor. However, R also contributes to about 98% of the value of Z (Lukaski *et al*, 1985; Lukaski, Bolonchuk, Hall and Siders, 1986; Lukaski, 1987). Nevertheless, some investigators such as Baumgartner, Chumlea and Roche (1987) place significant importance on measuring the reactance component of the impedance vector and the resulting phase angle for use in body composition analysis. This is presumably due to the inter-individual differences in capacitance of tissues associated with varying cell size, membrane permeability, intra-cellular composition and fluid distribution amongst body compartments.

The constant in the final equation in Figure 2 represents the 'specific resistivity' of the conductor. Specific resistivity is an electrical property of a conductor, although a heterogeneous conductor has observed 'volume resistivity' representing the sum of all the specific resistivities of its component parts. As biological tissue is heterogeneous in nature, the volume resistivity of the human body is, in reality, subject to intra- and inter-individual variability. Whole-body volume resistivity is a sum of the volume resistivities of the five component parts, excluding the head - that is, two arms, two legs, and the trunk. However, it is assumed to be constant for all individuals (Kushner and Schoeller, 1986). This constant is particularly difficult to estimate when whole-body impedance is measured, as the asymmetrical nature of the internal tissues of the trunk of the body contradicts the otherwise reasonable assumptions involved. These are based on the theory of parallel bioelectric resistance; for example, in a model limb as in Figure 3. For the trunk, the injected current is offset to the right-hand side, and the asymmetrical structure results in a complex electrical field pattern. Nevertheless, a constant is used, although the obvious drawbacks have contributed to the impetus behind the development of a new technique to be referred to later - namely segmental BIA.

***Figure 3.* A simple geometric model of parallel bioelectric resistance in a limb.**



$$\text{Resistance} = \frac{1}{1/Rm + 1/Ra + 1/Rb}$$

Most BIA systems utilise a current frequency of 50 kHz, and this also applies to the Bodystat system. The reasons for this include the assumptions that the total conductive volume of the body is equivalent to that of body water, and that adipose tissue contains minimal body water. A frequency of 50 kHz allows the current applied to pass through both extracellular fluid and body tissues, while the magnitude of the reactance vector is at a maximum. Utilisation of low or high frequencies loses the former and latter of these two qualities, respectively. However, multi-frequency analysis could theoretically allow a distinction to be made between plasma volume, interstitial fluid and intracellular fluid, and thus facilitate a more accurate estimate of body tissue water, and hence body composition. The Bodystat manufacturer has reported that the potential and feasibility of this technique is under investigation (Meeuwsen, 1995).

Certain researchers (Kushner, Schoeller, Fjeld and Danford, 1992) and reviewers (Van Loan, 1990) have questioned the basis of BIA on the grounds of the relatively poor relationship between impedance measurements alone and body fat, and the relatively small contribution that impedance to the regression on fat-free mass. The requirement of additional anthropometric variables as raw data for use in regression equations appears to detract somewhat from the unique insight into body composition that BIA provides. Nevertheless, few investigators dismiss the method completely for this reason.

Early work by Hoffer *et al* (1969) suggested the index of height squared divided by resistance was the single best predictor of total body water. This expression is known as the 'resistive index' or 'impedance index'. As resistance is highly related to total conductor volume, and this, in turn, is related to body weight - given the relatively homogenous density of body tissue at approximately value 1 (between 0.9 and 1.1 g/cm^3) - this finding is not too surprising. This is because substituting body weight for resistance gives an inverse of the expression commonly known as 'body mass index', and this has been put to widespread use as an index of body composition. However, as mentioned previously, the geometrical model which forms the basis of BIA is not accurate for the human body, and the addition of other variables such as age, sex (dummy coded) and weight to the impedance index probably adjusts for differences between individuals and the relative under-representation of the trunk by whole-body impedance (Kushner *et al*, 1992).

Baumgartner, Chumlea and Roche (1989) investigated the possibility of estimating body composition from impedance values obtained from arm or leg segments of the body. As described previously, the geometrical model of BIA fits the structure of human limbs more accurately than either the whole body or the trunk. The potential for body composition analysis of chair- or bed-fast individuals was identified by these authors. They reported a loss in accuracy of prediction of fat-free mass by using the length and resistance of the arm rather than stature and whole-body resistance of about 0.6kg. The idea has not been analysed further by the scientific community, presumably due to the limited application of a technique which is admittedly less accurate than whole-body BIA. Nevertheless, adaptation of the bioelectric impedance approach in this way may still, as the authors suggest, allow an estimation of the "body composition of subjects who have limited mobility and for whom accurate measurements of stature cannot be obtained" (Baumgartner *et al*, 1989, p.226).

An interesting technique has recently been developed and reported by Organ, Bradham, Gore and Lozier (1994). Their innovative work includes an analysis of body composition by segmental bioelectrical impedance theory including trunk impedance analysis, and it does not rely in the same way on the geometrical models outlined earlier in this review. Furthermore, only two additional electrodes - giving a total of six - are necessary, all placed on extremities of the body. Therefore, the ease of application of traditional BIA has been maintained, and possible experimental error from attaching and reattaching electrodes to the body is avoided. The specific arrangement of electrodes after careful theoretical consideration has allowed the researchers to obviate the necessity of attaching electrodes to the proximal ends of the limbs and to the upper and lower trunk.

The complex theory behind the work of Organ *et al* (1994) shares many conceptual similarities with densitometric analysis of body composition. Both assume chemically defined body compartments (fat mass and fat-free mass), and both result in a value that is an aggregate of a measurable parameter of the two compartments. Densitometry utilises body density, while segmental BIA utilises resistivity. This parameter of 'resistivity' is distinct from the theoretical resistance related to the volume of the conductor explained previously. The resistivity model utilised by Organ *et al* (1994) is based on the resistance, cross-sectional area and length of a body segment, where the segment can be visualised as incrementally small, but is one of a number of body segments that contribute to a larger body segment such as a limb. Body weight and height are used as indicators of segmental lengths, and age represents the general change in body structure over time.

This wholly different approach helps to take account of the phenomenon whereby the trunk, a region containing on average 46% of the body's mass (Clarys and Marfell-Jones, 1986), contributes to only approximately 8% of the total body impedance (Organ *et al*, 1994). In contrast, the upper limb contains about 4% of the total body mass, and yet contributes to about 45% of the total impedance. Clearly, it would be advantageous, as achieved by Organ *et al* (1994), to be able to distinguish between trunk impedance and limb impedances.

Organ *et al* (1994) produced predictive equations which included the independent variables of the differing body segment impedances, weight, height and age. About one quarter of the predictive value of the regression equation produced for fat weight in male subjects was accounted for by impedance, and about one-third for female subjects, with body weight accounting for about one half of the predictive value. The relative importance of measured impedance when compared to whole-body BIA was approximately 5% greater using the newly developed technique, and R^2 values for both males and females increased from about 0.91 to about 0.93.

Organ *et al* (1994) also discuss the potential role of segmental BIA in describing body fat distribution. Clearly, an opportunity exists to utilise this technology in assessing the proportion of trunkal fat relative to the fat in the extremities. The importance of body fat distribution in relation to risk status for cardiovascular disease, stroke and diabetes has been identified by researchers such as Seidell, Bakx, De Boer, Deurenberg and Hautvast (1985). Segmental BIA may allow a more comprehensive evaluation than waist-to-hip ratio, as internal adipose tissue stores will be fully accounted for. Further research in this area should correlate data obtained with direct risk factors such plasma levels of triglyceride, cholesterol, etc.

One would hope that manufacturers of commercially available BIA systems see the value of investigating and supporting such new approaches to the traditional BIA method. Although they will obviously wish to market their current models as suitable apparatus, if the predictive validity and the range of uses of their products can be enhanced, all concerned will benefit.

Body Composition Research

The path of research into the methodology of estimating body composition has often focused on the validity of the various regression equations used. This applies to both BIA and skinfold-based methods. Occasional reviews in the literature, such as those by Katch and Katch (1980) and Roche (1984), have referred to the need for further development of regression equations which utilise anthropometric variables. The use of ever more complex mathematical terms such as various power functions (Roche, 1984) has been a major tool in attempting to account for unexplained variance in such predictive methods.

Katch and Katch (1980) correctly focus on the importance of cross-validation of proposed regression equations. The fact that a certain predictive equation has a given validity and error for the sample from which it was derived does not mean that a second random sample from the same wider population will produce similar values. Thus, the need for a number of cross-validation studies for any proposed predictive equation is explained. Of course, this necessary process is independent of the questionable validity of any predictive equation when applied to a sample from a different population altogether than that from which it was derived. This latter phenomenon is known as 'population specificity', and has been previously identified (Katch and McArdle, 1975) as a fact which undermines attempts to produce an 'all-encompassing' regression equation for body composition assessment.

Visual Estimations?

A matter of some considerable interest to all researchers in the field of body composition assessment should be the line of investigation concerning purely visual estimation of percent body fat. If substantiated as a valid method, this would make the vast array of research studies into body composition assessment in the scientific literature appear somewhat elaborate, to say the least (and a somewhat farcical situation, one might then suggest). Original work by Blanchard, Ward, Krzywicki and Canham (1979; cited in Eckerson, Housh and Johnson, 1992a) suggested that visual inspection may give more accurate estimates of body composition than commonly used skinfold equations, irrespective of the experience of the observer. This was presumably a project designed to assess the possibility of rapid field assessment of military personnel. Later work by Sterner and Burke (1986) and Hodgdon, Fitzgerald and Vogel (1989) was also supportive of visual estimations of body composition - each set of authors suggesting that little difference exists between an experienced observer and skinfold measurements. Most recently, Eckerson *et al* (1992a) investigated the same theme, concluding that skinfold methodology was superior to both visual estimations and BIA (model from RJL Systems, Detroit), both of which were found to contain unacceptable errors in assessment. Thus, while the validity of visual estimations of percent body fat remains to be established convincingly, this might also be said of BIA. However, with the greater perceived potential of BIA, in addition to the increasing number of commercial products available, this method obviously receives greater scientific attention.

Validation

Examples of early validation studies include Wilmore and Behnke (1968) and Pollock *et al* (1976). Both these studies utilised anthropometric data for prediction. The two studies assessed the influence of a wide range of anthropometric variables on prediction accuracy. Meanwhile, Sinning *et al* (1985) primarily assessed the ability of existing prediction equations to estimate body density from anthropometric measures. The work of validation can therefore be appreciated as an on-going one, with a constant drive by researchers to discover a more accurate method which retains relative simplicity when compared to criterion methods such as densitometry.

A Criterion

The criterion measure of body composition that the vast majority of reports in the scientific literature use is densitometry. This appears to be the case irrespective of the method of body composition assessment being evaluated. However, this alone is not a sufficient reason for the method's use in this present study - the decision in this case, as, no doubt, in many others, being more related to access and cost. The suitability of densitometry as a true criterion method is dealt with more thoroughly in Appendix B of this report. Examples of investigations into body composition prediction methods other than BIA which have utilised densitometry as the criterion measure include Wilmore and Behnke (1968), Pollock *et al* (1976), Sinning *et al* (1985), Nielsen *et al* (1992) and Ishida *et al* (1995).

BIA Validation

A selection of validation studies concerning BIA methodology will now be examined. Due to the widespread inappropriate use of certain statistical methods such as Pearson correlation coefficients (Bland and Altman, 1986), the precise results will not be listed. However, the conclusions of the respective authors should suffice for consideration here.

Firstly, Lukaski *et al* (1985) assessed an early model from the original BIA system manufacturer RJL Systems (Detroit, USA). As in many research projects concerned with a relatively new topic the population studied was a group of young, healthy men. Densitometry was chosen as the criterion method of body composition assessment, although total body water determination by D_2O dilution and total body potassium whole body counting also allowed an analysis of the theoretical basis for BIA to be undertaken. The authors suggested that the theoretical basis for BIA was substantiated by the results, and concluded that, "The results of the present study have shown that bioelectrical impedance is a reliable and valid method of assessing human body composition and could prove invaluable in the field assessment of nutritional status" (Lukaski *et al*, 1985, p. 816). However, concerns which have yet to be eliminated - such as those about the biological assumptions of the components of fat-free mass, and the method's applicability to abnormal subjects - were mentioned as areas for future work.

Segal *et al* (1985) also investigated the RJL Systems model, utilising both male and female subjects with a relatively wide age and percent body fat range. Densitometry was used as the criterion for body composition analysis, and BIA generally provided what the authors thought of as a good estimation of body composition determined in this way. However, for analysis of obese subjects, BIA tended to give a systematic underestimation of body fat percentage - thus agreeing with the earlier findings of Kushner, Schoeller and Bowman (1984). Nevertheless, BIA was suggested as a possible substitute when the "more cumbersome human body composition techniques" (Segal *et al*, 1985) were not deemed suitable.

A direct comparison of the BIA technique (RJL Systems) and the four-site skinfold method of body composition analysis described by Durnin and Womersley (1974) was undertaken by Lukaski *et al* (1986). Densitometry was again used as criterion. Initially, the reliability of the BIA method was found to be acceptable. Utilising a wide range of percent body fat and age for both male and female subjects, the authors stated that BIA also had a lower predictive error than the anthropometric technique and was suitable for body composition analysis in a variety of settings.

Jackson, Pollock, Graves and Mahar (1988) reported details of another validation study on a heterogeneous population concerning the RJL Systems model. However, a large error of prediction was found after comparison with densitometrically determined body fat percentage, with body weight and stature evidently accounting for most of the variance in the BIA equation. This latter point was emphasised by the authors who stated that body mass index actually provided similar results to the BIA method. Clearly, it is fortunate that the scientific research process requires methods to be cross-validated by investigators. Jackson *et al* (1988) stated the obvious, but correct, in that further research was still necessary.

Given a more limited range of body types and body composition in a sample for analysis, the sensitivity of a technique such as BIA can be evaluated. Such an approach was adopted by Eckerson, Housh and Johnson (1992b) when using mainly young, lean, Caucasian males as subjects. In addition, a range of proposed predictive equations were compared, presumably to enable a more accurate prediction to be achieved than that by the same authors previously (Eckerson *et al*, 1992a) when studying BIA applied to a similar population. Densitometry was again chosen as the criterion method of body composition analysis for the study, and the BIA model investigated was again that of RJL Systems. Although reasonable prediction of fat-free mass was observed when using the equation of Oppliger, Nielsen, Hoegh and Vance (1991), multiple regression analysis showed that utilisation of any variable which included resistance or body height accounted for less than 1 % additional variance over body weight alone. This is perhaps not unexpected given the predominance of fat-free mass in the total body mass of the subjects, in addition to the fact that whole-body resistance is theoretically related directly to fat-free mass. Nevertheless, the results again call into question the whole concept of BIA as a worthwhile method of body composition analysis for a lean population. Visual selection of 'lean' subjects for the study by Eckerson *et al* (1992b), in addition to body weight assessments, seemed to estimate body composition adequately.

Brodie and Eston (1992) took account of the increasing number of commercially available BIA systems in the design of their study. Three models were evaluated, the manufacturers being: RJL Systems, Detroit; Berkeley Medical Research, San Leardro; Spacelabs, Dallas. Inappropriate statistical analysis unfortunately inhibited the clarity of the results - specifically, Pearson correlation coefficients between each BIA system and the criterion densitometry were highly significant, but nonetheless unrevealing due to the fact that "the variance unaccounted for can be as high as 59 % (RJL vs Hydrodensitometry in normal women)" (Brodie and Eston, 1992, p. 321). However, the authors suggested that each of the three BIA systems could prove useful as a reasonably valid alternative to densitometry, especially for epidemiological studies.

A recent study by Stout, Eckerson, Housh, Johnson and Betts (1994) suggests still further that investigations into BIA methodology are not regarded as out-dated or irrelevant. A sample of young adult males was studied using a model from RJL Systems once more, with comparisons against near infra-red interactance and skinfold methods carried out. Densitometry was the criterion method of body composition analysis used. Despite the undoubted interest in the perceived potential of the more technological methods, skinfold (sum of three sites) analysis proved preferable on this occasion for Stout *et al* (1994). Evidently, further research and development is required.

Applicability to a Sports Setting

One population type that might be said to have a significant interest in field methods of body composition assessment is an athletic population. When one considers the potential of BIA for this purpose, the possible drawbacks are related to the need for population-specific equations (outlined earlier) and to the need for normal hydration of subjects on testing occasions. Lukaski, Bolonchuk, Siders and Hall (1990) considered these two factors for both male and female athletes, using densitometry as the criterion method and a BIA model from RJL Systems. These authors claimed that the use of a predictive equation which was originally derived from a heterogeneous population was, in fact, suitable for use with an athletic population. However, the importance of normal hydration of subjects was illustrated by poor the validity observed when conditions prior to testing were not controlled.

Wrestlers have been identified as an athletic population for whom body composition assessment is a most pertinent topic given the accepted practice of attempting to 'make the weight' for competition while maintaining optimum lean body mass (Steen and Brownell, 1990). Oppliger, Nielsen and Vance (1991) performed a study using densitometry as criterion, and comparing three BIA models - Berkeley Medical Research, San Leardro; RJL Systems, Detroit; Valhalla Scientific, San Diego. The authors suggested that a skinfold method (six sites) and the Berkeley Medical Research BIA model were preferable to the other models for this specific subpopulation. Modification of the predictive equation was correctly identified as the logical step to improve validity for body composition assessment of wrestlers. Similar overall conclusions were reached by Clark *et al* (1993) for young wrestlers with a mean age of 15 years, when skinfold methodology (nine sites) previously validated on a similar population was found to be superior to the RJL Systems model.

The validity of BIA methodology in estimating body composition of US football players has also been investigated, again with rather poor results. For instance, Oppliger, Nielsen, Shetler, Crowley and Albright (1992) found that BIA (models were Berkeley Medical Research, RJL Systems, and Valhalla Scientific) significantly overpredicted body fatness when compared to a criterion of densitometry. Certain skinfold equations predicted with less error, and caution was recommended to users of commercially available BIA systems when applying general regression equations (such as those utilised by most manufacturers) to athletic populations. Similar general conclusions were reached by Clark, Kuta and Sullivan (1994), in addition to the identification of ethnicity as a complicating factor.

Research Directions

Certain investigators have focused on particular topics concerning body composition analysis by BIA. Research papers with a narrow but important theme have been the result. Many of these are referred to in Appendix B of this report if they are concerned with procedural techniques, while other assessments of BIA's applicability are now reviewed.

A four-site cross-validation study carried out by Segal, Van Loan, Fitzgerald, Hodgdon and Van Itallie (1988) utilised an interesting experimental design. A total of 1500 adults were studied at four different laboratories. The authors claimed that the small differences in errors when a predictive equation from one site was applied to the subjects from another site indicated a successful cross-validation.

Gray, Bray, Gemayel and Kaplan (1989) considered the errors in body composition assessment by BIA which were apparent when obese subjects were studied. These authors again suggested the development and application of population-specific equation for use with such individuals. A value of > 42 % was identified as a threshold for overestimation of fat-free mass when compared to densitometry. However, one might suggest that any error at this level of obesity is rather insignificant in terms of conclusions to be drawn about the physical state of an individual subject, and in terms of any practical, combative action to be diagnosed.

Some research studies have investigated the ability of BIA to assess changes in body composition during periods of diet and/or exercise. For example, Deurenberg, Westrate and Hautvast (1989) utilised a small group of obese women who volunteered to enter onto a weight reduction programme for the purpose of the study. The findings over an eight-week period of change showed an underestimation of the reduction in fat-free mass when measured by BIA. The authors suggested that losses of water initially bound to glycogen before the dieting period may have caused the discrepancies. A longer period of analysis would have reduced this effect, although - admittedly - the first weeks of such a period may be very important to individuals in a real-life situation. A similar study by Ross, Leger, Martin and Roy (1989) which utilised slightly obese males as subjects supported the applicability of BIA methodology to assessing body composition changes of that population type. However, the errors inherent to all methods of body composition assessment, including densitometry, were correctly identified as uncontrollable factors. In particular, the possibility of changes (during the exercise and dietary programme) in the biological variables assumed to be constants by methods such as densitometry was highlighted as an important theoretical problem. This point might also have been fundamental to the large errors observed by Fulco, Hoyt, Baker-Fulco, Gonzalez and Cymerman (1992) when changes in body composition during an altitude sojourn were assessed. Fulco *et al* (1992) concluded that neither BIA nor skinfold methods were acceptable for this purpose.

Bodystat

Reviews of the scientific literature (Brodie, 1988b; Van Loan, 1990) concerning the accuracy of BIA in assessing body composition have referred to the need for population-specific equations. This has been the main suggestion for future research, while the error of criterion methods such as densitometry has been identified as a major concern in performing true validation studies. A significant matter regarding this present study is that these reviews were published before any research studies concerning the Bodystat BIA system. The three scientific papers to deal directly with this specific apparatus will now be considered.

Smye, Sutcliffe and Pitt (1993) assessed the Bodystat system in comparison with three other commercially available BIA systems - namely RJL, Holtain and EZcomp - although no comparison with a criterion method of body composition assessment was attempted. Two main analyses were carried out, the first being a comparison of results obtained from 21 normal male and female subjects. Three of the BIA systems differed little with each other (e.g. mean difference in impedance value 0.6 % between Bodystat and RJL models), while the Holtain system was notably different from the other three. One might initially suggest from these results that, to a certain extent, many of the previous findings of research studies concerning the RJL system and a similar population type to that used in this study can be said to apply to the Bodystat system. However, only the impedance value obtained was considered, and the differing predictive equations used by the models would have produced more variable estimates of body fat percentage both during that study, and previously. The other main thrust of Smye *et al*'s (1993) study was to compare impedance measurements between BIA systems when a simulation of whole-body impedance was constructed, and this highlighted a potential source of error due to contact impedance. However, the error in the Bodystat measurement was found to be less than that for any of the other systems. A point of note is that Smye *et al* (1993) did not specify which precise Bodystat model was evaluated. Although the two models utilise the same predictive equation (Meeuwsen, personal communication, 1995), the Bodystat 500 requires application of electrolyte gel to the points of electrode attachment, while the Bodystat 1500 requires use of disposable electrodes.

An investigation by Maughan (1993) compared the Bodystat 500, a four-site skinfold equation (Durnin and Rahaman, 1967) and densitometry. A mixed-sex population of healthy volunteers was chosen as subjects. Much of the study appears sound, except for the points concerning the inexperience of the experimenter with the BIA technique, and the admitted lack of control over subjects' hydration levels prior to assessment. The main drawback of the study is the inappropriate method of statistical analysis used. Despite obvious awareness of the work of Bland and Altman (1986), Maughan (1993) proceeds to utilise Pearson correlation coefficients to compare methods of body composition assessment. The correct approach to statistical analysis of two or more methods of clinical measurement is described in full by Bland and Altman (1986), and relatively briefly in Appendix B of this present report. Nevertheless, Maughan (1993) suggested that the results obtained in the published study showed a better relationship between skinfold measurements and densitometry than between the Bodystat 500 model and densitometry, but that either method provided a reasonable estimate of body composition.

The correct statistical approach to evaluation of a new method of body composition assessment was performed recently by Fuller, Sawyer and Elia (1994). A population of obese women were the subjects utilised in their study. A number of BIA models' predictive equations and other proposed predictive equations were directly compared for this population by ingeniously inputting a standard impedance value for each subject. The value for each subject was that obtained via use of the Valhalla model 1990b (Valhalla Scientific, San Diego) BIA system, with the Bodystat 500, E-Z Comp 1500 (Cranlea and Co., Birmingham) and Maltron Model BT-905 (Maltron Ltd., Rayleigh, Essex) manually provided with the same impedance value for use in computations of fat-free mass and percent body fat. (It should be noted that, as mentioned previously, the Bodystat 500 model utilises the same predictive equation as the Bodystat 1500.) Poor results were found for most models and equations, with the specificity of the population identified as the confounding factor. However, the Bodystat equation was found to be most in agreement with the data obtained from densitometry, deuterium dilution, total body potassium, and the three-component model (approximately ± 7 % fat for 95 % limits of agreement) when compared to other manufacturers' predictive equations. No proposed equation from the scientific literature considered by Fuller *et al* (1994) produced a notably better agreement with the reference methods. A similar method of statistical analysis should consistently be carried out by other investigators in this field. It is clear that the results are easy to interpret due to their being maintained in real measurement values, as well as being statistically correct (Bland and Altman, 1986).

APPENDIX B

ADDITIONAL METHODOLOGY

This section contains further details of the methods carried out in this study. Both the reasoning behind the choice of procedures, and detailed descriptions of those procedures are included. Where possible, details have not been repeated if previously mentioned in the body of the dissertation. Therefore, both sections need to be considered for a complete description of methods.

ADDITIONAL METHODOLOGY

Height and weight were measured by use of platform scales. Subjects had bare feet and wore only a bathing suit. Body composition analysis was then carried out by BIA initially, followed by skinfold analysis and finally densitometric analysis.

Bioelectrical Impedance Analysis

A minor potential error was unavoidable for the BIA measurements - namely, ambient temperature was expected to fluctuate between test sessions, and therefore between individual subjects' analyses. Caton, Molé, Adams and Heustis (1988) have identified this factor as a source of error, despite Liang and Norris's (1993) later findings of no significant difference when similar physiological fluctuations were induced by means of an exercise period. Nevertheless, practical applications of the Bodystat system will - until the effect mentioned above is more clearly understood - be undertaken in the same uncontrolled environment as this current study. Another theoretically relevant factor - namely, use of oral contraceptives by female subjects - has been found to have no significant effect on BIA measurements by Chumlea, Roche, Guo and Woynarowska (1987), and therefore was not considered by this current study.

The subject was asked to lie supine on the laboratory floor in a comfortable manner (see Figure 4(a)). Body position prior to this has been eliminated as being an important consideration by Thomas *et al* (1990). The experimenter carefully attached the unused, self-adhesive disposable electrodes supplied with the Bodystat apparatus to the appropriate points of the subject's body (Bodystat Ltd., 1994). All connection tabs of the electrodes were aligned so as to protrude laterally from the body. More specifically, two electrodes were placed on the dorsal aspect of the wrist/hand - one immediately behind the knuckle of the middle finger, the other on the wrist immediately adjacent to the ulnar head. Similarly, two electrodes were placed on the dorsal aspect of the ankle/foot - one immediately behind the second toe next to the big toe, the other on the ankle at the level of and between the medial and lateral malleoli. Considerable care was taken in identifying the electrode sites accurately in order to minimise the potential errors associated with mis-placement (Dunbar, Melahrinides, Michielli and Kalinski (1994).

The subject remained lying for approximately five minutes before assessment was carried out (Thomas *et al* (1990) have suggested a standardisation of this variable will enhance the reliability of the technique) while the experimenter entered the appropriate details (height, weight, etc.) into the Bodystat system. One of the two main leads connected to the BIA system was then taken to the subject's right hand, and the black lead attached via crocodile clips to the connection tab of the more proximal electrode. The red lead was attached to the more distal of the two electrodes. Similarly for the ankle/foot attachments. The experimenter then ensured the subject was relaxed, with the limbs extended in a comfortable position, but not touching either the rest of the body or each other. After one last visual check of electrodes and body position, the analysis was carried out via manual input to the apparatus - the analysis lasting under 3 seconds. The body fat estimation was observed and recorded, and the analysis was then complete.

Skinfolds

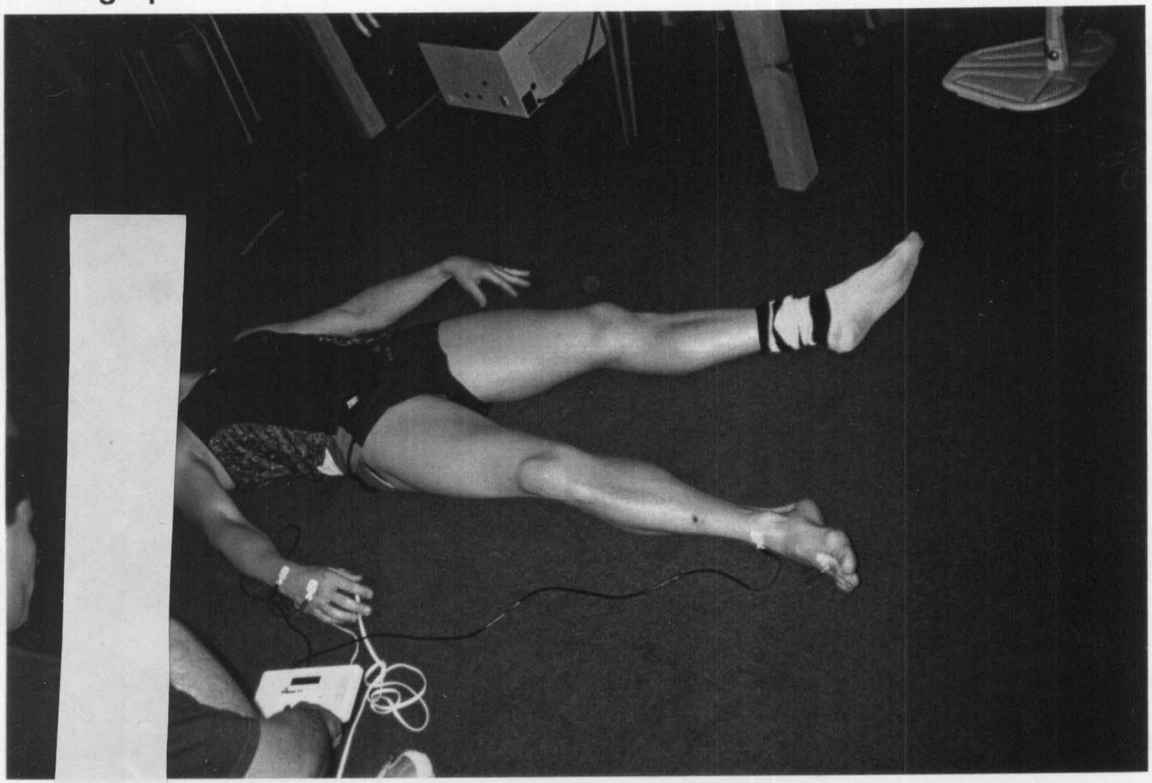
Skinfold thicknesses were measured at four sites (biceps, triceps, supra-iliac, subscapular) on the right-hand side of the body following the method of Durnin and Womersley (1974), and the body fat prediction equation described therein was utilised (1 s.d. error of ± 3.5 % and ± 5 % for males and females respectively, compared to densitometry). Harpenden skinfold calipers were used as this is one of the two caliper types to be used in the development of the Durnin and Womersley (1974) prediction equations - as Gruber, Pollock, Graves, Colvin, and Braith (1990) point out, calipers and prediction equations should be matched to avoid incurring additional error in body fat estimation. This point may also relate to the variable compressibility of skinfolds (Clarys, Martin, Drinkwater and Marfell-Jones, 1987). Gore, Woolford and Carlyon (1995) have recently proposed a method for calibration of skinfold calipers which should be considered for future studies.

There follows a brief description of the skinfold technique described in detail by Harrison *et al* (1988). For a visual example, refer to Figure 4(b).

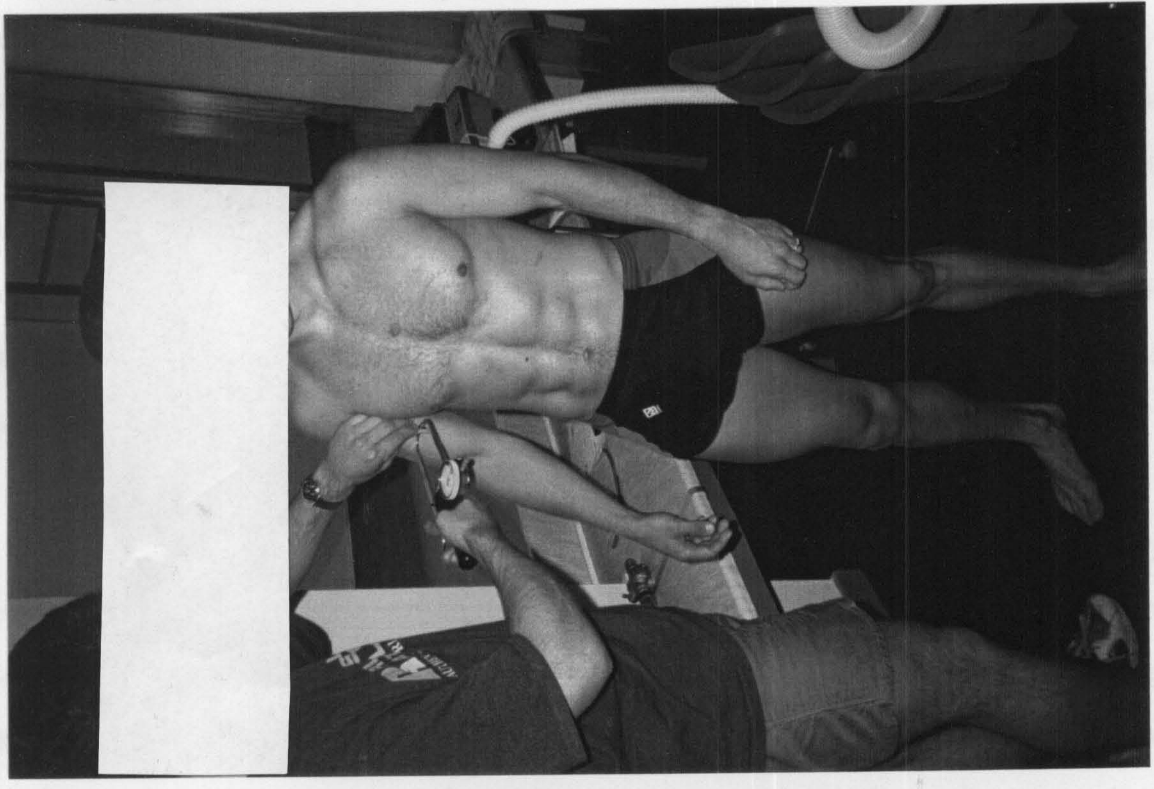
Following identification of each site, the skinfold was elevated with the left hand perpendicular to the surface of the body. The long axis of the fold was aligned parallel to the natural cleavage lines of the skin. The fold was kept elevated until measurement by the caliper held in the right hand was completed. The measurement was made where the sides of the skinfold were approximately parallel, approximately midway between the general surface of the body near the site and the crest of the fold. A reading was taken approximately four seconds after the full pressure of the caliper was applied. Three readings were taken at each site; as long as no obvious outliers (>5mm difference) were suspected (this, in fact, did not occur), the median value calculated was recorded as the thickness of the fold.

Figure 4.

(a) Photograph of BIA.



(b) Photograph of skinfold analysis.



Densitometry.

Densitometry was chosen as the criterion method of determining body composition for this present study. This was partly due to the appropriate facilities being available at Chester College of Higher Education. Also relevant was the comparatively inexpensive nature of the procedure when compared to certain other proposed criterion methods.

Densitometry is generally accepted to provide a criterion value of body density (Behnke, Feen and Welham, 1942), while this value must then be utilised to produce an estimate of body fat percentage. The principles of calculating body density (based on Archimedes's Principle) have been outlined in detail by Siri (1956) and Brozek, Grande, Anderson and Keys (1963) who were some of the original researchers and theorists in this field. Densitometry was originally used to evaluate the accuracy of what is now also considered to be a criterion method of body composition assessment - namely, potassium counting (Myhre and Kessler, 1966). However, certain authors have challenged the accuracy of densitometry on a number of counts related to the assumptions of biological consistency which are fundamental to the method (Barnes, 1987). An example of the method's limitations is clearly illustrated by Schutte *et al* (1984) who studied the body density of black and white individuals, concluding that the former have a denser lean body mass than the latter.

The equation of Siri (1961) for estimating body fat percentage from body density has been put to widespread use, and Lohman (1992) states that for a normal population for whom the assumed biological constants are not suspected of being greatly erroneous (such as in unhealthy conditions) it has yet to be improved upon. Correctly performed procedures should keep the error induced from all sources to a minimum, approximately 2.0 - 2.8 % fat (Lohman, 1992).

The fundamental determination of underwater weight for computation of body volume is discussed by Katch and Katch (1980) who suggest that the mean of the weights recorded on the last few trials of each test should be taken as an individual score. Also, Bonge and Donnelly (1989) investigated and supported the suitability of various choices of trials to be averaged, such as trials 8-10. However, despite these alternate proposals, the method suggested by Adams (1994) of finding the mean of the two heaviest weighings after asymptote is reached was followed.

It is widely accepted that the value used as residual volume for an individual who is being assessed by densitometry is a very important factor in the calculations. Akers and Buskirk (1969) and Morrow, Jackson, Bradley and Hartung (1986) suggested from their work that variation in residual lung volume was by far the most important source of error in determining body composition. It is therefore appropriate to give special consideration to this variable, despite Marks and Katch's (1986) observations that much of the variance over time is biological rather than measurement based.

The most common method of residual volume determination used by investigators of body composition methodology appears to be the closed-circuit oxygen-dilution method developed by Wilmore (1969), based on early work by researchers such as Cournand, Darling, Mansfield and Richards, Jr. (1940). Many also utilise the more simplified method which Wilmore, Vodak, Parr, Girandola and Billing (1980) found to compare well with the other accepted methods. This latter development allowed residual volume determinations to be carried out with use of the more commonly found oxygen and carbon dioxide analysers, without the need for a nitrogen analyser.

If the body is submerged during measurement of residual volume, one might suggest that the effect of hydrostatic pressure on the external chest wall on residual volume during actual underwater weight determination is fully accounted for. Most reports (Jarrett, 1965; Agostini, Gurnter, Torri and Rahn, 1966; Bondi, Young, Bennet and Bradley, 1976; Robertson, Engle and Bradley, 1978; Ostrove and Vaccaro, 1982; Gibbons, Jessup and Bunting, 1985) have suggested a reduction in residual volume when submerged, as one might expect from the above theoretical consideration. However, Brodie (1988a) suggests that the effect is far from consistent between individuals, presumably due to possible lack of subject compliance with the desired procedure, and some other researchers have found contrasting effects (Girandola, Wisewell, Mohler, Romero and Barnes, 1977). The decision was made to follow the recommendations of Gibbons *et al* (1985) who stated, "It is recommended that RV be measured with the subject immersed to the neck in water for research purposes when absolute accuracy is desired." (p. 187).

A possibility that was considered was that of estimating residual lung volume from measurements of either vital capacity or stature, or even assuming a constant value for each sex. However, various investigators (Wilmore and Behnke, 1968; Clark and Mayhew, 1980; Mayhew and Piper, 1982; Withers and Ball, 1988; Withers, Borkent and Ball, 1990) have generally found these methods to be unsatisfactory for research purposes, although there may be a use for them when more rapid assessment is required or equipment is limited. Work such as that of Ross *et al* (1989), Thompson *et al* (1991) and Brodie and Eston (1992) may have suffered from errors related to this theme. Similarly unconvincing results which fail to support use of estimations in research situations have been reported for calculation of body density at total lung capacity (Weltman and Katch, 1981; Timson and Coffman, 1984; Latin and Ruhling, 1986; Lundvall and Thorland, 1987), although there again may be some potential uses of this technique - for instance, for use with older or less water-confident subjects, or when time is limited and true asymptote for the residual volume method cannot be reached. However, the population evaluated in this present study was correctly assumed to have little trouble in performing the standard technique of measuring residual volume.

An original report by Organ, Eklund and Ledbetter (1994) describes a method of densitometry based on automated data acquisition and real-time display of data during underwater weighing, in conjunction with simultaneous lung volume measurements. The authors claim that this technique allows the number of trials necessary per subject to be kept to a minimum, while also providing accurate weighings at known lung volumes approaching - but not necessarily reaching - residual volume. If the technology can easily be replicated, this method seems to have great promise.

Some further procedural details are now described :-

The water in the tank was clean and supplemented with disinfectant. The water temperature was recorded for each individual subject's analysis; 33'C - 38'C appeared to prove comfortable. Further details of the method followed are described in detail by Adams (1994). Briefly, the force transducer (type F256-Z0513) with digital display (type M865) was calibrated for each subject at 0kg with the water - but not the subject - in the tank, and the following procedures then carried out :-

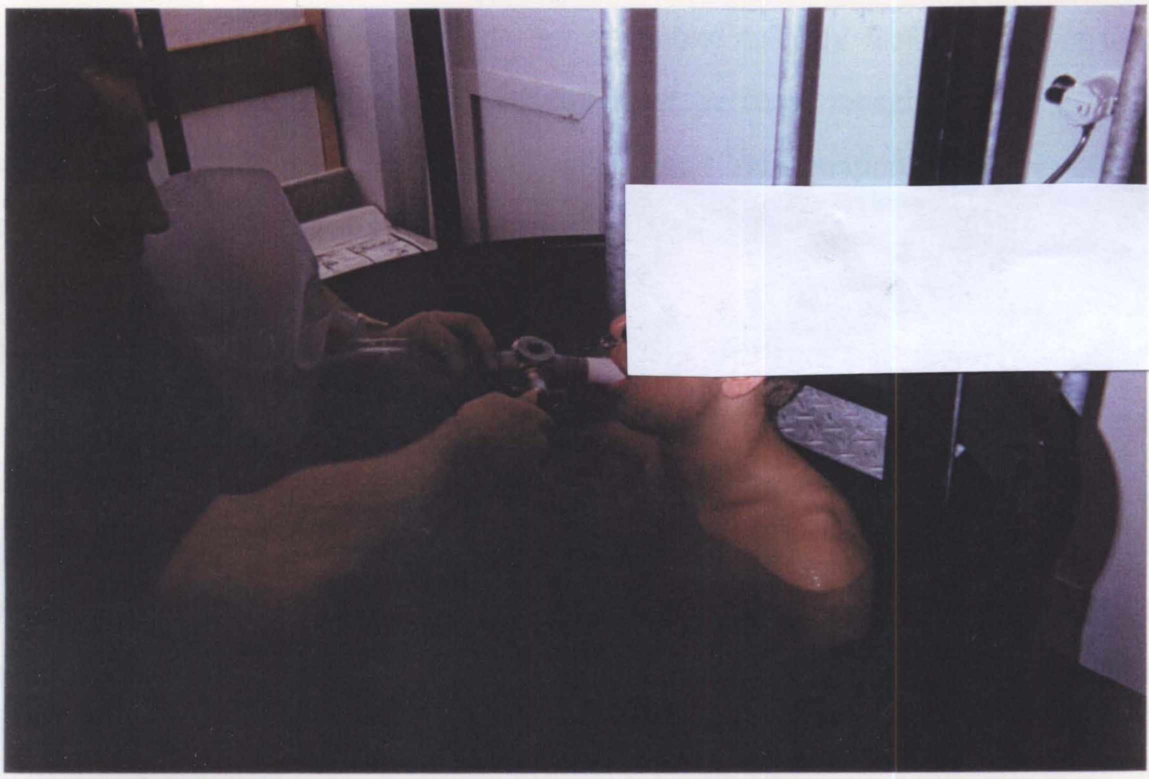
Firstly, subjects were asked to remove any jewellery or metal objects on the body, and to then enter the water tank. Prior to underwater weighing, each subject's residual volume was determined. The effect of external pressure exerted on the subject by the water was accounted for by performing the analysis described by Wilmore *et al* (1980) with the subject immersed to neck level in the water of the tank - refer to Figure 5(a). In brief, gas analysers were calibrated using a 1-litre sample bag prior to each test session, using both room air and a certified gas mixture (96.24 % N_2 and 4.76 % CO_2 - BOC, Guildford, UK). A 5-litre Douglas bag was flushed three times and filled with 3-5 litres of 100% oxygen (BOC, Guildford, UK), approximating to 80-90% of vital capacity determined by use of the Vitalograph. The procedure was then explained to the subject, and he/she was told of the correct body position - i.e. seated in the tank, leaning slightly forward, immersed to the neck. Using a mouthpiece, nose clip and three-way valve, the subject was instructed to perform a maximal expiration when breathing room air, at which point the valve was turned. The subject was then told to take five to seven deep breaths from the bag at a rate of about one breath/two seconds. Wilmore *et al* (1980) emphasised the importance of this rate and depth of breathing in producing a proper mixing of respiratory gases in the bag and the lungs. On the final breath, the subject was again told to perform a maximal expiration, after which the valve was returned to its original position. Oxygen and carbon dioxide analysers were used to calculate the nitrogen percentage of the mixed air, and with the known volume in the bag, used to calculate residual volume. Repeated trials were performed until two readings for the subject were obtained which did not differ by more than 100 ml (requiring at most three trials), with the mean of the two closest values assumed to be the residual volume. Assumptions of this method included: percentage of nitrogen in the original alveolar air (80%); nitrogen impurity of the original pure oxygen (0%); percentage of nitrogen in the alveolar air during the last maximal breath (0.2% higher than the equilibrium percentage).

Non-essential air possibly trapped in hair or clothing was removed by the subject. Instructions for exhalation and positioning on the seat were given to the subject, and clarification of the signal for completion of each trial was achieved - although the subject was assured that he/she may ascend if becoming uncomfortable. Pilot work had suggested that asymptote for recorded underwater weight would be attained more quickly if a subject was encouraged to achieve a maximal expiration by the experimenter's use of the phrase, "the more air you breathe out, the less percent fat you will be seen to have", and this was done so after two preliminary trials for each subject. The subject exhaled while lowering the head and shoulders under the water (refer to Figure 5(b)), with the experimenter taking note of the cessation of this action as suggested by the absence of bubbles rising from the subject's head, while carefully dampening the oscillations of the scale. 5-10 seconds proved sufficient to attain a stable reading - in agreement with the guidelines of Adams (1994).

Body volume was calculated, correcting both for essential air (residual volume plus the assumed constant 100ml in the gastro-intestinal tract (Adams, 1994)) and for water temperature.

Figure 5.

(a) Photograph of residual volume analysis.



[redacted]

(b) Photograph of densitometric analysis.

Aerobic Fitness

The YMCA protocol was used - as described fully by Golding, Myers and Sinning (1989). This predictive assessment of aerobic capacity relies on the assumption of a linear relationship between heart rate response and exercise workload for the range of heart rates 110-150 beats per minute. Also fundamental to the values obtained is the assumed maximal heart rate of subjects, specifically 220 - age.

The assessment was performed with use of a Monark (Stockholm, Sweden) cycle ergometer. A slight modification for the purposes of this study was that exercise heart rate was evaluated by use of a Polar Favor (Kempele, Finland) heart rate monitor. Other apparatus used consisted of a stopclock.

In brief, an initial workload of 25 watts was used for a period of 3 minutes to produce an elevated heart rate response which would determine the first workload for which heart rate would be recorded. This second workload was that designated by the directions of Golding *et al* (1989), and used for at least 3 minutes. Providing that the observed heart rate was above 110 beats per minute, the heart rates at the end of the second and third minutes were recorded and utilised in the analysis. If the heart rate was not above 110 beats per minute, the workload was periodically increased a further 25 watts for at least 2 minutes until such a response was observed. This was occasionally necessary due to the unusually high aerobic fitness level of some of the subjects utilised in this current study. After a workload had been reached which produced a heart rate response greater than 110 beats per minute, and consistent enough to be maintained within 5 beats per minute for two readings one minute apart, the workload was again increased by 25 watts. As previously, steady-state readings of heart rate were required for use in analysis. A cool-down exercise period was then provided as the assessment was complete.

The data was evaluated by using the prediction sheet contained in Appendix D of this report.

Physical Activity Level

It was deemed advantageous to be able to relate the physical activity levels of the subjects in this present study to normative data. The Allied Dunbar National Fitness Survey (The Sports Council and Health Education Authority, 1992) contains data which can be considered as normative, and categorises individuals onto a scale of physical activity of 0-5. Level 5 is the most active - i.e. 12 or more occasions, each of at least 20 minutes vigorous (> 7.5 kcal/min) activity, in the past 4 weeks. It was decided that the proportion of subjects in this present study that could be categorised into level 5 would be contrasted with the equivalent proportion of the general population.

It has been commented by Lamb and Brodie (1991) that leisure-time physical activity is a primary component of physical activity levels due to the sedentary nature of most jobs in many Westernised societies. Furthermore, the subject population of this present study was a student population for whom occupational physical activity was a minimum. Therefore, it was decided that the activity prompt-sheet (Activity and Health Research, 1994) used in the national survey mentioned above which refers to leisure activities would be used for questioning of subjects. The slightly modified version of the activity prompt-sheet used in this current study is found in Appendix D of this report. The modification consists of merely layout and the addition of 'cycling' to the specified list of activities.

Data Analysis

Bland and Altman (1986) have explained a statistical method for assessing agreement between two methods of clinical measurement. Agreement must be considered if the ability of a new method to be used in place of the old is to be assessed. The argument put forward by Bland and Altman (1986) is a strong and convincing one, with a criticism of commonly mis-used approaches a central theme.

The Pearson product-moment correlation coefficient 'r' has unfortunately been thought by many experimenters to show agreement between methods. While this statistical tool is perfectly suited for assessing the strength of a relationship between variables, it does not assess agreement. Bland and Altman (1986) identify five main points to support this statement :-

1 - Plots of two measurement methods will have perfect correlation if the points lie along any straight line, while perfect agreement will only be found if the points lie along the line of equality.

2 - A change in scale of measurement does not affect correlation, but does affect agreement. For instance, multiplication of one set of data by a factor will not affect correlation with another data set, but will obviously impair agreement.

3 - A wide range of values in a pair of data sets will produce a better correlation than a narrow range, irrespective of how well the two data sets actually agree. Thus, a homogenous population of subjects might consistently be expected to produce low correlations between methods purely because of the limited range of the variable in question. As a result, comparisons between scientific studies investigating the same theme is often a very difficult task.

4 - The fact that two methods of measurement are 'significantly' related does not prove a great deal. After all, one is usually considering two methods specifically designed to measure the same parameter, which have been used on the same

subjects. If the correlation was not significant, one would be very surprised. Similarly for tests of differences between methods.

5 - Data which are in poor agreement can produce quite high correlations. This is potentially the case where important clinical measurements are concerned, and small absolute differences between values can represent significant practical impact.

The method described by Bland and Altman (1986) is relatively simple both to do and interpret, as well as being correct. A value is obtained which indicates how far apart measurements by two different methods are likely to be. This value describes the data with a 95 % confidence limit, although one could theoretically account for a chosen confidence limit, depending on the practical impact of a 1 in 20 chance of being wrong, for instance.

An example of a scientific paper can highlight the confusion surrounding the area of statistical analysis between methods - namely that of Khaled *et al* (1988). The main finding of the study is quoted in the abstract as a correlation, while more detailed analyses are, in fact, performed in the results section. Specifically, the slope and intercepts of the line produced when two methods are related graphically are considered. These qualities are actually closely related to the method described by Bland and Altman (1986), although are not so easily understood. Khaled *et al* (1988) state that the slope and intercepts indicate poor agreement - but this finding has reduced impact when the correlation is considered most important. Intuitively, the authors suspected that correlation was misleading, but proceeded to conform to the accepted practice of placing most importance on that incorrect analysis. Bland and Altman (1986) explain that journal referees often do not realise the errors associated with common statistical practices, and actually sometimes complain if no correlation coefficients are provided, even if the reasons for not doing so are given.

It is therefore not surprising that an established, but incorrect method of analysis is apparently reluctant to be replaced.

An example of the precise procedures to be followed during analysis by the method described by Bland and Altman (1986) is contained in Appendix C of this report. The data from this present study is obviously the focus of analysis. According to Altman (personal communication, 1995), the possible complication to the statistical analysis described that Bland and Altman (1995) identify - namely the situation where percentage values are being considered, as in this present study - does not cause concern here due to the limited range of percentage body fat observations in humans.

APPENDIX C

ADDITIONAL RESULTS

This section includes information that was essential to and/or the product of the statistical analyses carried out in this study. However, it was not deemed appropriate to place all the data in the Results section of the Body of the Dissertation. The extra data is contained here, in addition to a brief description of the statistical processes described originally by Bland and Altman (1986).

ADDITIONAL RESULTS

Table 5. Selected Raw Data

SUBJECT	SEX	AGE	HEIGHT	WEIGHT	% FAT BY SKINFOLDS	% FAT BY BIA	% FAT BY DENSIT- OMETRY	VO_2MAX	ACTIVITY LEVEL
1	2	23	158	47.0	20.3	22.1	19.1	62	5
2	1	24	187	97.4	11.5	18.2	23.2	55	5
3	2	23	175	81.1	25.0	29.1	30.9	51	5
4	1	21	167	61.3	11.0	13.1	14.2	34	5
5	1	22	172	72.7	12.5	17.7	19.1	51	2
6	1	22	181	80.0	11.5	10.1	14.4	45	5
7	1	24	183	91.9	12.5	12.4	15.1	55	5
8	2	29	166	51.9	19.9	21.0	23.8	36	3
9	2	25	176	84.2	21.9	21.0	27.7	47	4
10	2	22	162	59.4	19.9	24.3	23.1	41	3
11	1	23	187	88.1	9.1	12.4	5.8	50	5
12	2	22	166	62.0	19.9	20.5	19.4	36	5
13	1	23	178	73.8	11.5	11.8	10.1	49	5
14	1	25	173	77.9	11.0	10.1	8.0	56	5
15	1	25	185	93.4	26.5	24.2	20.1	45	4
16	1	24	183	83.9	10.5	11.6	7.4	66	5
17	1	25	173	73.8	10.1	13.2	7.4	66	5
18	2	19	158	50.2	15.8	15.2	19.0	87	5
19	1	23	180	76.6	9.6	13.0	7.0	72	5
20	1	20	178	80.2	9.6	12.2	14.6	41	5
21	1	24	176	84.1	13.7	12.1	10.7	52	5
22	1	24	180	92.4	15.1	23.2	22.9	50	3
23	1	24	175	80.5	14.1	17.9	15.8	48	2
24	1	18	172	75.6	10.5	11.8	12.9	45	3
25	1	21	183	84.5	13.3	19.0	23.6	49	1
26	2	20	175	69.9	18.0	24.1	25.9	41	2
27	2	21	168	66.3	23.1	19.5	24.3	36	5
28	2	26	167	64.0	23.8	20.9	25.0	42	5
29	1	20	168	73.5	10.5	17.6	16.8	44	5
30	1	22	177	80.5	12.9	15.7	18.2	42	1
31	1	22	172	68.0	8.6	5.0	8.8	65	5
32	2	29	161	60.5	20.7	25.6	20.7	46	5
33	2	21	173	69.1	28.9	23.7	27.8	38	5
34	2	24	174	67.0	24.1	24.2	30.8	24	2
35	2	22	161	56.1	24.4	21.7	25.4	41	2

Descriptive Data

```
SEX

Value Label             Frequency        Percent
male                        21             60.0
female                      14             40.0
                          -------        -------
                            35            100.0


*************************************************************************************


Number of observations =    35  (all)

Variable        Mean    S.E. Mean    Std Dev     Range     Minimum    Maximum    N
% FAT          18.06      1.17         6.95      25.17       5.8        30.9     35
AGE            22.91       .40         2.39      11.00        18          29     35
VO2MAX         48.80      2.06        12.17      63.00        24          87     35
WEIGHT         73.68      2.15        12.74      50.40      47.0        97.4     35
HEIGHT        173.43      1.35         7.99      29.00       158         187     35

**************************************************************************************


 ACTIVITY   (all)
                             Value  Frequency   Percent
                               1          2       5.7
                               2          5      14.3
                               3          4      11.4
                               4          2       5.7
                               5         22      62.9
                                    -------   -------
                            Total        35     100.0
```

```
Number of observations =  21   (males only)

Variable     Mean      S.E. Mean    Std Dev     Range       Minimum    Maximum      N
% FAT         14.10       1.24        5.67      17.84         5.8       23.6       21
AGE           22.67        .41        1.88       7.00         18          25       21
VO2MAX       51.43       2.06       9.45      38.00          34          72       21
WEIGHT        80.48       1.95        8.92      36.10       61.3        97.4       21
HEIGHT       177.62       1.28        5.89      20.00        167         187       21


***************************************************************************************


ACTIVITY   (males only)

            Value      Frequency     Percent
              1            2           9.5
              2            2           9.5
              3            2           9.5
              4            1           4.8
              5           14          66.7
                        -------     -------
            Total         21         100.0

***************************************************************************************


Number of observations = 14   (females only)

Variable     Mean      S.E. Mean    Std Dev     Range       Minimum    Maximum    N
AGE           23.29        .81        3.05      10.00         19          29     14
% FAT         24.01        .97        3.65      11.97       19.0        30.9     14
VO2MAX       44.86       3.98      14.89      63.00          24          87     14
WEIGHT        63.48       2.87       10.73      37.20       47.0        84.2     14
HEIGHT       167.14       1.75        6.54      18.00        158         176     14


***************************************************************************************


ACTIVITY   (females only)

            Value      Frequency      Percent
              2           3             21.4
              3           2             14.3
              4           1              7.1
              5           8             57.1
           -------     -------        -------
            Total         14            100.0
```

Regression Analysis

Stepwise multiple regression of FFM (FFMDEN below) as dependent variable, using age, weight, sex and impedance index (RESINDEX below) as independent variables.

```
   Dependent Variable..   FFMDEN

 Method:  Stepwise     Criteria   PIN  .0500    POUT  .1000

   AGE       WEIGHT   SEX       RESINDEX

Variable(s) Entered on Step Number

   1..    WEIGHT

Multiple R           .90196
R Square             .81354
Adjusted R Square    .80789
Standard Error      5.49436

Analysis of Variance
                    DF      Sum of Squares       Mean Square
Regression           1          4346.46916        4346.46916
Residual            33           996.20466          30.18802
F =     143.97993         Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable               B         SE B       Beta          T  Sig T
WEIGHT           .887487      .073962    .901964     11.999  .0000
(Constant)     -4.972712     5.528118                 -.900  .3749

------------- Variables not in the Equation -------------

Variable      Beta In  Partial  Min Toler         T  Sig T
AGE          -.017293 -.039996    .997431     -.226  .8223
SEX          -.439709 -.761994    .559966    -6.656  .0000
RESINDEX      .427530  .561311    .321413     3.837  .0006


Variable(s) Entered on Step Number

   2..    SEX

Multiple R           .96011
R Square             .92180
Adjusted R Square    .91692
Standard Error      3.61323

Analysis of Variance

                    DF      Sum of Squares       Mean Square
Regression           2          4924.90101        2462.45050
Residual            32           417.77281          13.05540

F =     188.61547         Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable               B         SE B       Beta          T  Sig T
WEIGHT           .600487      .064999    .610282      9.238  .0000
SEX           -11.089335     1.665998   -.439709     -6.656  .0000
(Constant)     31.698506     6.600637                 4.802  .0000

------------- Variables not in the Equation -------------

Variable      Beta In  Partial  Min Toler         T  Sig T
AGE           .056885  .198324    .533594     1.127  .2686
RESINDEX      .293911  .574398    .295845     3.907  .0005
```

```
Variable(s) Entered on Step Number

   3..     RESINDEX

Multiple R           .97345
R Square             .94760
Adjusted R Square    .94253
Standard Error      3.00503

Analysis of Variance

                    DF      Sum of Squares       Mean Square
Regression           3          5062.73784        1687.57928
Residual            31           279.93599           9.03019
F =      186.88186       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable               B          SE B         Beta          T  Sig T
WEIGHT           .400931       .074372      .407471      5.391  .0000
SEX            -9.595113      1.437384     -.380461     -6.675  .0000
RESINDEX         .238434       .061029      .293911      3.907  .0005
(Constant)     29.195892      5.526828                   5.283  .0000

------------- Variables not in the Equation -------------

Variable       Beta In  Partial  Min Toler          T  Sig T
AGE            .033391  .140670    .292206       .778  .4425
```

Final B values above are utilised in the proposed regression equation, for which $R^2 = 0.943$.

Stepwise multiple regression of % fat by densitometry (FATDEN below) as dependent variable, using age, impedance index, sex and weight as independent variables.

```
   Dependent Variable..   FATDEN

 Method:  Stepwise     Criteria   PIN  .0500   POUT  .1000

   AGE      RESINDEX SEX      WEIGHT


Variable(s) Entered on Step Number

   1..    SEX

Multiple R           .71807
R Square             .51563
Adjusted R Square    .50095
Standard Error      5.07790

Analysis of Variance

                    DF      Sum of Squares      Mean Square
Regression           1           905.81538        905.81538
Residual            33           850.90671         25.78505
F =       35.12948       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable                B         SE B       Beta          T  Sig T
SEX             10.384371     1.752041    .718073      5.927  .0000
(Constant)       3.715315     2.598697                 1.430  .1622

------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler         T  Sig T
AGE         -.044243 -.063043    .983470     -.357  .7232
RESINDEX    -.014781 -.015968    .565290     -.090  .9286
WEIGHT       .476372  .512198    .559966     3.374  .0020


Variable(s) Entered on Step Number

   2..    WEIGHT

Multiple R           .80169
R Square             .64270
Adjusted R Square    .62037
Standard Error      4.42886

Analysis of Variance

                    DF      Sum of Squares      Mean Square
Regression           2          1129.04787        564.52394
Residual            32           627.67421         19.61482
F =       28.78048       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable                B         SE B       Beta          T  Sig T
SEX             14.954212     2.042074   1.034074      7.323  .0000
WEIGHT            .268777      .079672    .476372      3.374  .0020
(Constant)     -22.485916     8.090640                -2.779  .0090

------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler         T  Sig T
AGE         -.113927 -.185814    .533594    -1.053  .3005
RESINDEX    -.644302 -.589062    .295845    -4.059  .0003
```

```
Variable(s) Entered on Step Number

   3..    RESINDEX

Multiple R           .87560
R Square             .76668
Adjusted R Square    .74410
Standard Error      3.63618

Analysis of Variance

                    DF       Sum of Squares      Mean Square
Regression           3           1346.84685        448.94895
Residual            31            409.87524         13.22178
F =       33.95525        Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable                 B          SE B        Beta          T  Sig T
RESINDEX         -.299718       .073847   -.644302     -4.059  .0003
SEX             13.075931      1.739279    .904192      7.518  .0000
WEIGHT            .519624       .089993    .920968      5.774  .0000
(Constant)     -19.340058      6.687632                -2.892  .0069

------------- Variables not in the Equation -------------

Variable      Beta In  Partial  Min Toler         T  Sig T
AGE         -.062185 -.124147    .292206      -.685  .4984
```

Final B values above are utilised in a regression equation for which $R^2 = 0.744$.

Stepwise multiple regression of % fat by densitometry as dependent variable, using age, impedance index, sex, sum of 4 skinfold thicknesses (TOTALSK below) and weight as independent variables.

```
  Dependent Variable..   FATDEN

  Method:  Stepwise     Criteria   PIN  .0500   POUT  .1000

   AGE      RESINDEX SEX      TOTALSK  WEIGHT


Variable(s) Entered on Step Number

   1..     TOTALSK

Multiple R           .73431
R Square             .53920
Adjusted R Square    .52524
Standard Error      4.95278

Analysis of Variance

                    DF      Sum of Squares      Mean Square
Regression           1           947.23192        947.23192
Residual            33           809.49017         24.53001
F =       38.61524       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta         T  Sig T
TOTALSK         .658544     .105975    .734305     6.214  .0000
(Constant)    -2.311954    3.413708                -.677  .5030

------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler        T  Sig T
AGE         -.078061 -.113327    .971197     -.645  .5234
RESINDEX    -.274712 -.383352    .897325    -2.348  .0252
SEX          .447192  .545967    .686836     3.686  .0008
WEIGHT      -.141276 -.207184    .991023    -1.198  .2397


Variable(s) Entered on Step Number

   2..     SEX

Multiple R           .82253
R Square             .67656
Adjusted R Square    .65634
Standard Error      4.21381

Analysis of Variance

                    DF      Sum of Squares      Mean Square
Regression           2          1188.52430        594.26215
Residual            32           568.19779         17.75618
F =       33.46790       Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B        SE B       Beta         T  Sig T
SEX            6.467043    1.754320    .447192     3.686  .0008
TOTALSK         .434110     .108794    .484052     3.990  .0004
(Constant)    -4.357068    2.956884               -1.474  .1504

------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler        T  Sig T
AGE         -.093688 -.162208    .677117     -.915  .3671
RESINDEX    -.056685 -.074711    .430063     -.417  .6794
WEIGHT       .296261  .348935    .310960     2.073  .0466
```

```
Variable(s) Entered on Step Number

   3..    WEIGHT

Multiple R           .84613
R Square             .71594
Adjusted R Square    .68845
Standard Error      4.01215

Analysis of Variance

                    DF       Sum of Squares      Mean Square
Regression           3           1257.70545        419.23515
Residual            31            499.01663         16.09731
F =       26.04380        Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B         SE B        Beta          T  Sig T
SEX           10.274171     2.482473     .710452      4.139  .0002
TOTALSK         .327161      .115723     .364798      2.827  .0082
WEIGHT          .167155      .080631     .296261      2.073  .0466
(Constant)   -18.663150     7.453070                 -2.504  .0177

------------- Variables not in the Equation -------------

Variable      Beta In  Partial  Min Toler         T  Sig T
AGE          -.125911 -.230110    .305186    -1.295  .2052
RESINDEX     -.536617 -.515253    .209138    -3.293  .0025


Variable(s) Entered on Step Number

   4..    RESINDEX

Multiple R           .88958
R Square             .79135
Adjusted R Square    .76353
Standard Error      3.49540

Analysis of Variance

                    DF       Sum of Squares      Mean Square
Regression           4           1390.18738        347.54684
Residual            30            366.53471         12.21782
F =       28.44589        Signif F =  .0000

------------------ Variables in the Equation ------------------

Variable              B         SE B        Beta          T  Sig T
RESINDEX       -.249625      .075806    -.536617     -3.293  .0025
SEX           10.489154     2.163728     .725318      4.848  .0000
TOTALSK         .202775      .107663     .226103      1.883  .0694
WEIGHT          .414714      .102890     .735027      4.031  .0004
(Constant)   -17.496479     6.502810                 -2.691  .0115

------------- Variables not in the Equation -------------

Variable      Beta In  Partial  Min Toler         T  Sig T
AGE          -.079520 -.167013    .209000     -.912  .3692
```

Final B values above are utilised in a regression equation for which $R^2 = 0.764$.

Test-Retest Reliability

The method of assessing repeatability described by Bland and Altman (1986) initially required plotting the difference between the two measurement occasions (first reading minus second reading) against the mean of the measurements for each subject. The following graphical representations (Figures 6(a), 6(b) and 6(c)) show this for each method, with the horizontal reference line indicating the mean of the differences.

Figure 6(a).

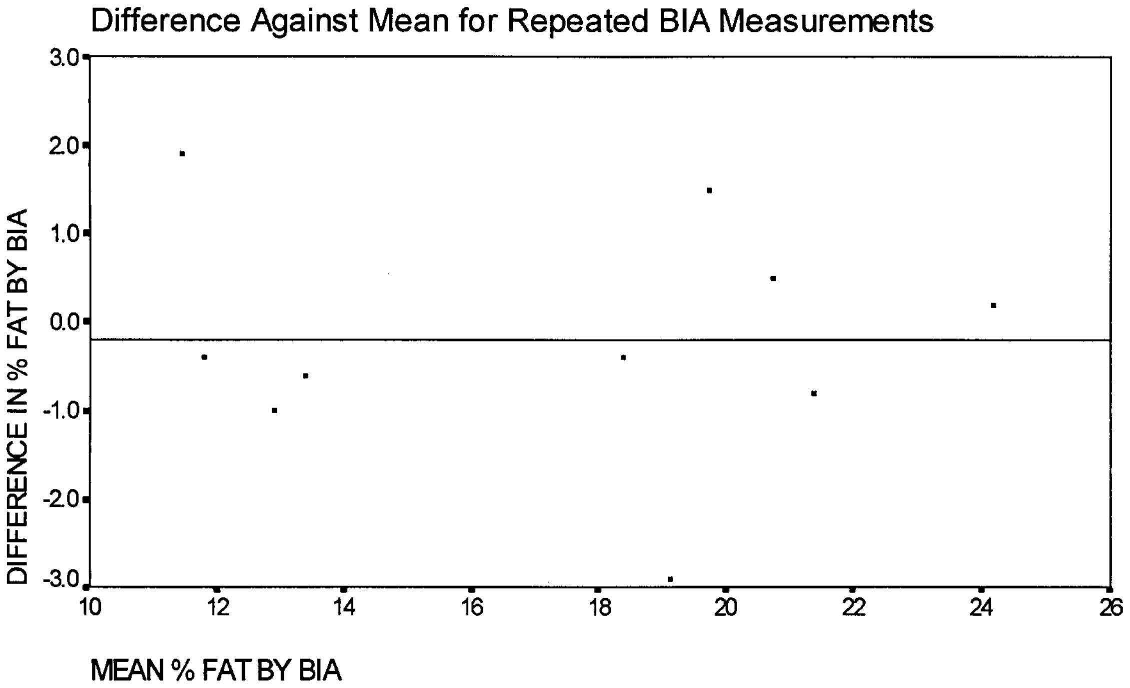


Figure 6(b).

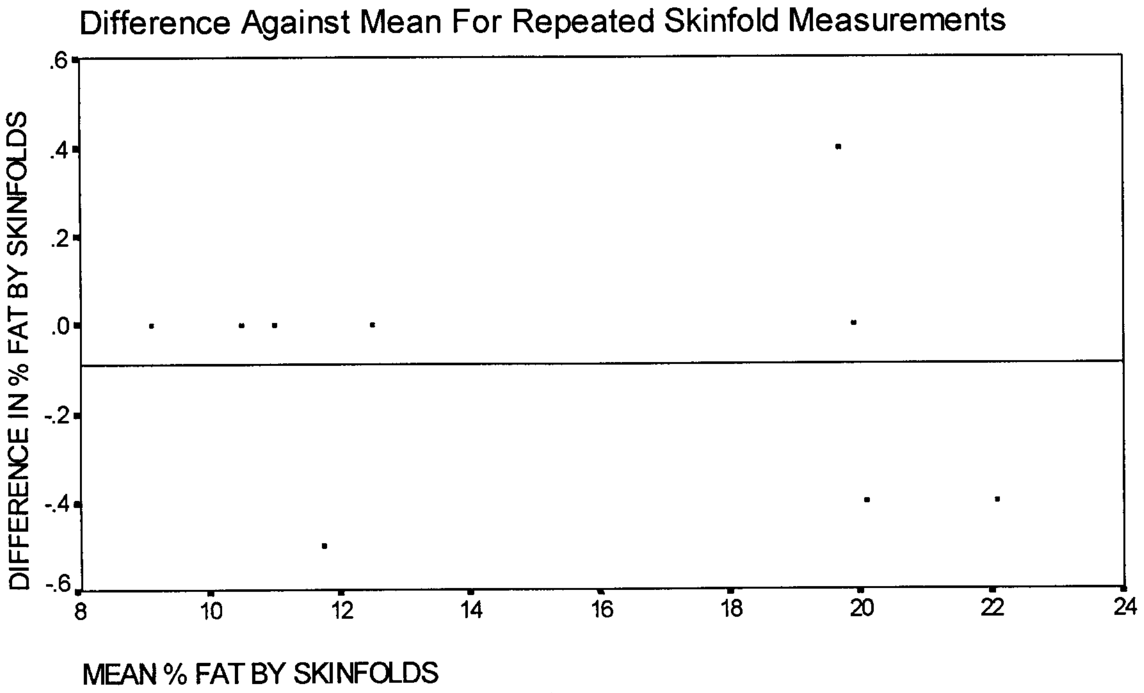
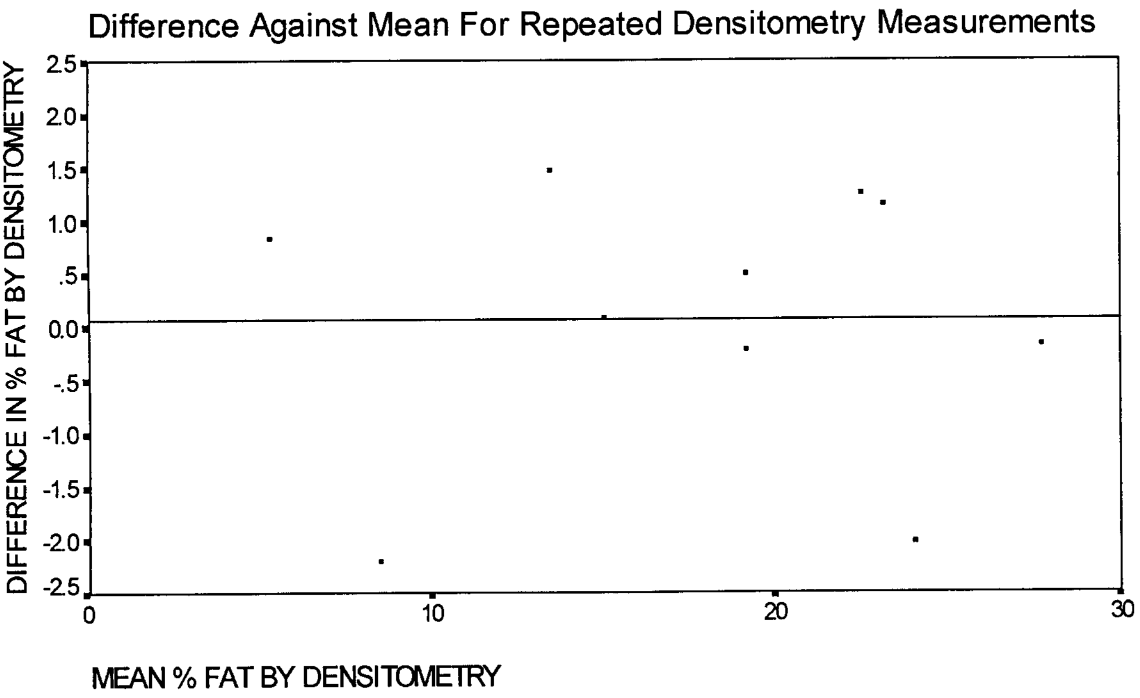


Figure 6(c).



As the magnitude of the differences was not related to the mean for any of the three methods, the use of a logarithmic transformation of the data was not deemed necessary. If there had been such a relationship observed on the graphs, log transformations of the data would have been necessary in order to prevent the limits of repeatability obtained being too small for one end of the data range, and too large for the other end.

The means of the differences between tests for each method were calculated. As these were not significantly different from zero, the simple calculations shown below were carried out.

```
Number of observations  =   10

Variable                  Mean    Std Dev    N

BIA DIFFERENCES           -.20     1.35     10   Coefficient of repeatability = 2 s.d. = 2.7 % fat
SKINFOLD DIFFERENCES      -.09      .27     10   Coefficient of repeatability = 2 s.d. = 0.5 % fat
DENSITOMETRY DIFFERENCES   .07     1.29     10   Coefficient of repeatability = 2 s.d. = 2.6 % fat

N.B. above means are not significantly different from 0, therefore above calculations are valid.
```

Agreement Between Methods

The method of assessing agreement described by Bland and Altman (1986) first required plotting the difference between two methods (densitometry minus predictive method) against the mean of the two methods for each subject. The following graphical representations (Figures 7(a) and 7(b)) show this for BIA and skinfolds respectively, with the solid horizontal reference line indicating the mean of the differences, and the dotted reference lines representing the mean ± 2 standard deviations.

Figure 7(a).

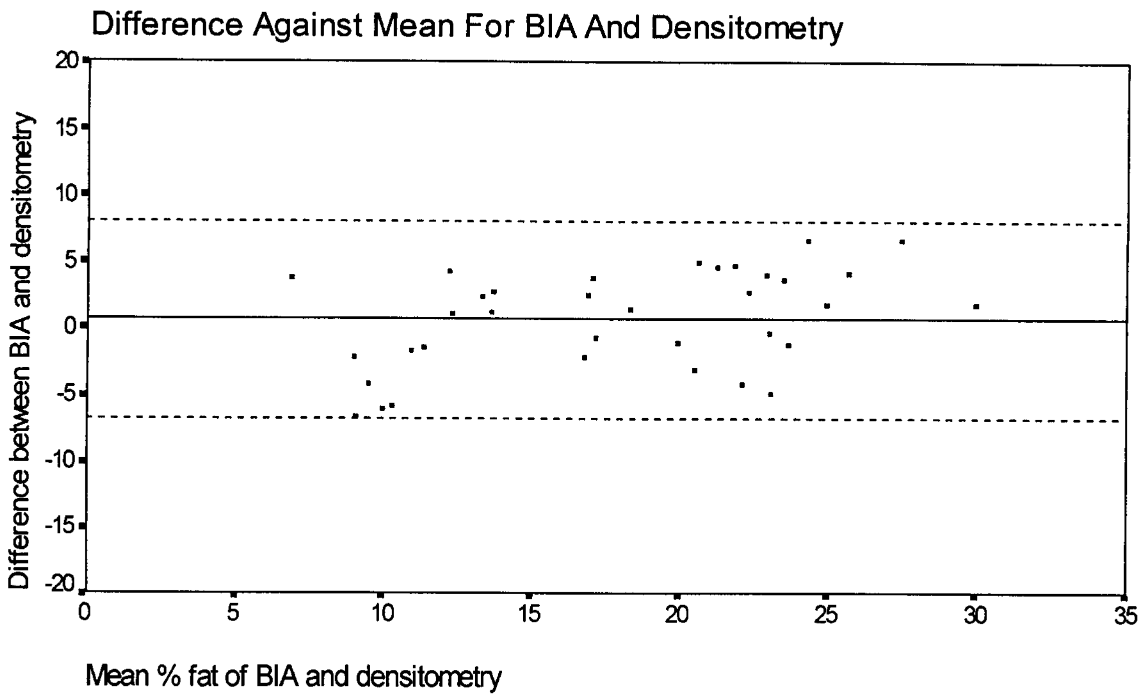
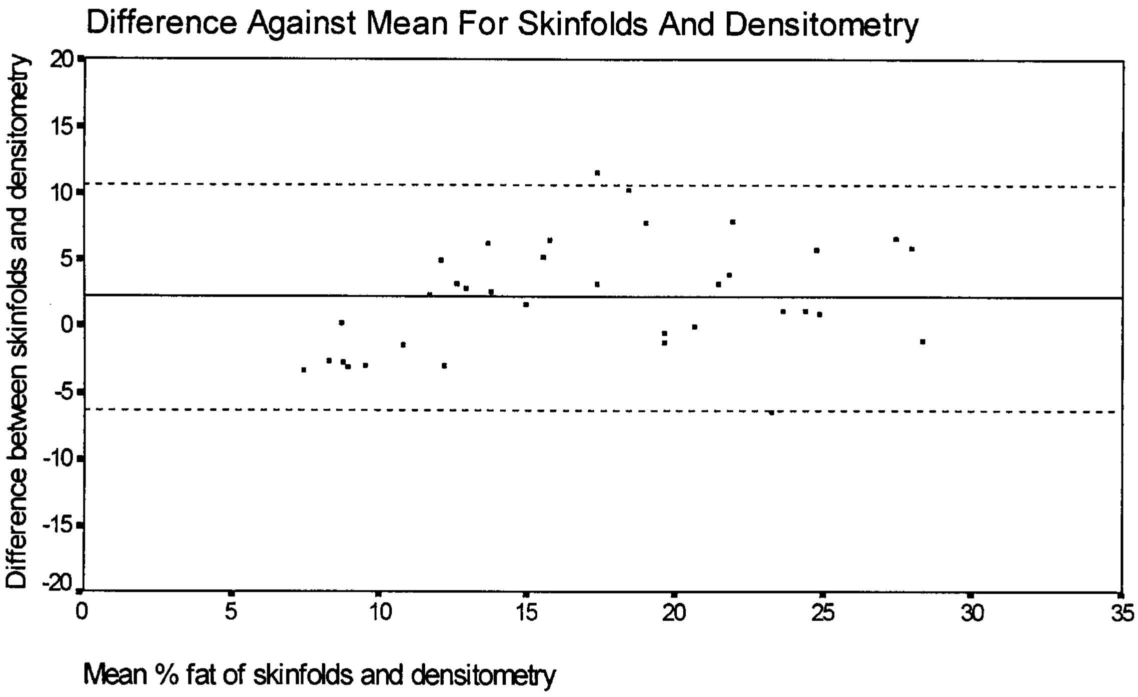


Figure 7(b).



As the magnitude of the differences was not related to the mean for either of the two comparisons, the use of a logarithmic transformation of the data was not deemed necessary. If there had been such a relationship observed on the graphs, log transformations of the data would have been necessary in order to prevent the limits of agreement obtained being too small for one end of the data range, and too large for the other end.

The mean differences between methods were 0.68 and 2.22 % fat for densitometry and BIA, and densitometry and skinfolds, respectively. Theoretically, a large mean difference could be subtracted from observed scores to produce a better agreement. However, the mean differences in this case were not large.

For further analysis to proceed, an assumption of Normality of the differences between methods needed to be substantiated. This was achieved by histogram plots of the differences between densitometry and the two predictive methods (Figures 8(a) and 8(b)). Approximate Normal distributions were observed.

Figure 8(a).

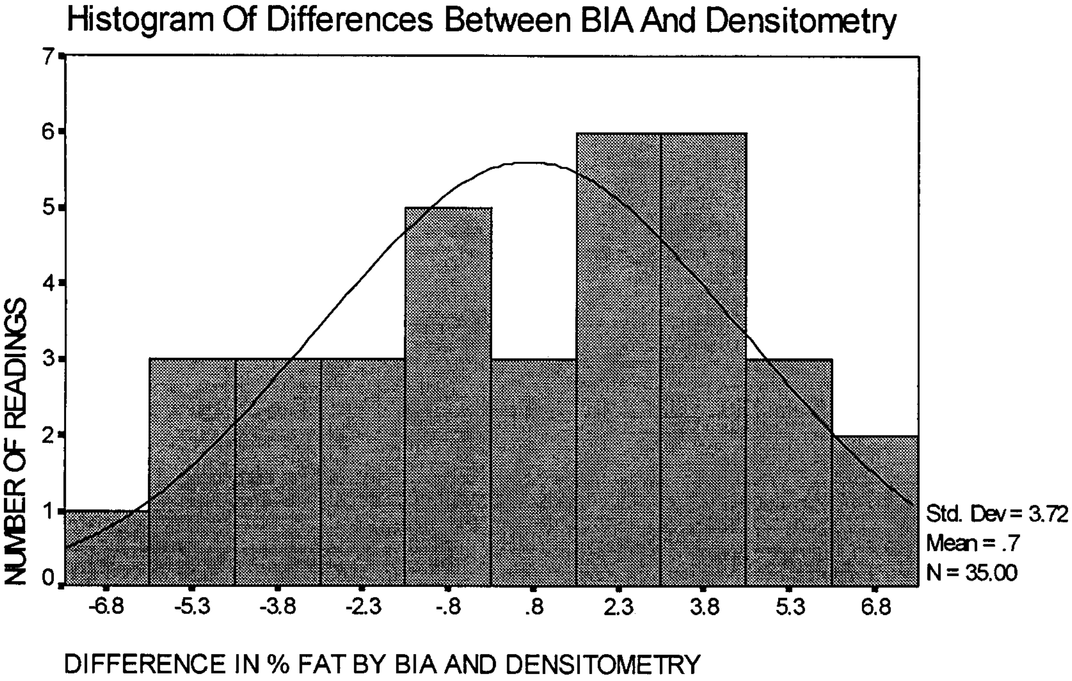
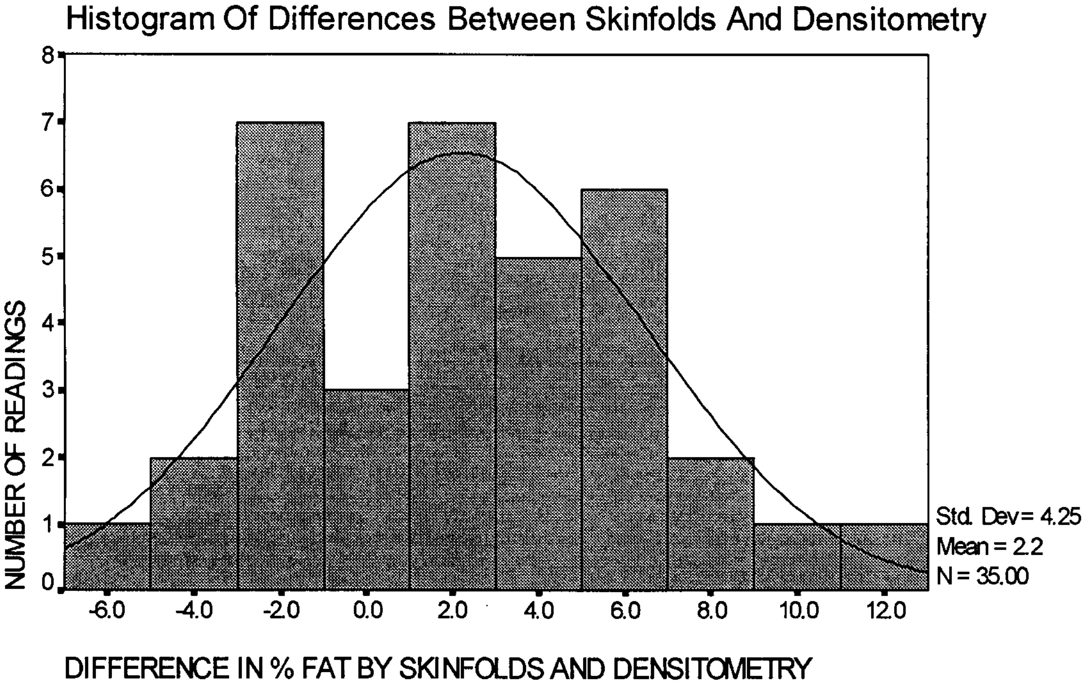


Figure 8(b).



Approximately 95 % of the differences will therefore lie between the limits of the mean difference ± 2 standard deviations of the differences. The following calculations were performed :-

```
Number of observations  =   35

                  Variable                          Mean      Std Dev    N

DIFFERENCE BETWEEN BIA AND DENSITOMETRY              .68        3.72     35
DIFFERENCE BETWEEN SKINFOLDS AND DENSITOMETRY       2.22        4.25     35
```

For BIA, 2 s.d. = 7.4
For skinfolds, 2 s.d. = 8.5

For BIA, mean - 2 std dev = -6.76
For BIA, mean + 2 std dev = 8.12

For skinfolds, mean - 2 std dev = -6.28
For skinfolds, mean + 2 std dev = 10.72

Therefore, bias and 95 % limits of agreement are...

For BIA, 0.7 ± 7.4^{+}
For skinfolds, 2.2 ± 8.5

where superscript $^{+}$ indicates that the difference between the methods is significantly related to the magnitude of measurement (r = 0.43 , p = 0.01).

The above calculations do have confidence intervals which were calculated using t-tables. Thus, the precision of the bias and estimated limits of agreement can be assessed.

For BIA, standard error = 0.63.

Critical t value for n-1 (34) degrees of freedom = 2.03.

Therefore, 95 % confidence interval for the bias is approximately equal to the mean difference between methods ± (2.03 * 0.63)

i.e. interval for bias is -0.60 to 1.96 % fat.

One can see that the bias is not significant.

Using similar calculations, the confidence interval for the lower limit (-6.76) is -4.55 to -8.97 % fat.

For the upper limit (8.12), the interval is 5.91 to 10.33 % fat.

For skinfolds, interval for bias is 0.76 to 3.68 % fat. i.e. a significant, but small bias.
The confidence intervals for the limits of agreement are:
lower limit... -3.76 to -8.80
upper limit... 8.20 to 13.24

Therefore, one can appreciate that even under the most optimistic interpretations of the data, the potential error of the Bodystat system is approximately ± 5 % fat. Also evident is that despite the possibility of accounting for the small bias in skinfold measurements, the remaining error is too large to be of much practical use.

APPENDIX D

ADDITIONAL MATERIALS

This section contains certain additional materials used in the study. It includes an informed consent form, an appointment form, a prompt-sheet for physical activity assessment, and data recording sheets.

(No. .....)

INFORMED CONSENT FORM

VALIDITY OF PERCENT BODY FAT ESTIMATIONS BY A COMMERCIALLY AVAILABLE BIOELECTRICAL IMPEDANCE ANALYSER

Alun Williams BSc (HONS), who is a postgraduate MSc student (Exercise and Nutrition Science), has requested my participation in a research study at Chester College of Higher Education. The title of the research is "Validity of Percent Body Fat Estimations By a Commercially Available Bioelectrical Impedance Analyser".

I have been informed that the purpose of the research is to evaluate the accuracy of the Bodystat^{TM} apparatus in relation to assumed 'true' values obtained by the underwater weighing method.

My participation will involve body fat analysis by three methods on one occasion (unless requested to participate on a second occasion) - time period necessary being less than one hour. The three methods will be bioelectrical impedance analysis, skinfold thicknesses, and underwater weighing. The third method will also require a calculation of my lung residual volume by the closed-circuit oxygen rebreathing technique. On a separate day (but within two weeks of these analyses), I will go to the laboratory to complete a brief activity questionnaire and undertake a submaximal exercise test on a cycle ergometer - time period necessary being less than 45 minutes.

I understand there are foreseeable discomforts to me if I agree to participate in the study. Possible discomforts include an uncomfortable sensation during submersion under water due to the requirement of breathing out maximally before doing so. Also, a moderate degree of exhaustion upon completion of the submaximal exercise test may be encountered.

There are no feasible alternative procedures available for this study.

I understand that the possible benefits of my participation in the research include the satisfactory completion of a scientific study that can provide users (e.g. within the leisure-industry) of the afore-mentioned apparatus with confidence as to its accuracy.

I understand that the results of the research study may be published but that my name or identity will not be revealed. In order to maintain confidentiality of my records, Alun Williams will code my name as a numerical value - only Alun Williams and the MSc examination board will have access to this confidential information.

I have been advised that the research in which I will be participating does not involve more than minimal risk.

I have been informed that I will not be compensated for my participation.

I have been informed that any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by Alun Williams, [redacted]).

I understand that in case of injury, if I have questions about my rights as a subject/participant in this research, or if I feel I have been placed at risk, I can contact the Chair of the Human Subjects Research Review Committee (or its equivalent) at Chester College.

I have read the above information. The nature, demands, risks and benefits of the project have been explained to me. I knowingly assume the risks involved, and understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefit to myself. In signing this consent form, I am not waiving any legal claims, rights, or remedies. A copy of this consent form will be given to me.

Subject's signature..Date....................

I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature. I have also provided the subject/participant a copy of this signed consent document.

Signature of investigator..Date...................

APPOINTMENT FORM

Subject: ....

Please be at the college laboratory / fitness suite at ....

on ....

REQUIREMENTS OF SUBJECT:

No eating or drinking 4-5 hours prior to the test.

No exercise 12 hours prior to the test.

No alcohol or caffeine consumption 24 hours prior to the test.

N.B. THESE CONDITIONS MUST BE STRICTLY ADHERED TO

Thankyou for your co-operation.

Activity Prompt-Sheet

Swimming
Tennis
Table Tennis
Squash
Badminton
Football
Rugby
Cricket
Rounders
Hockey
Netball
Volleyball
Basketball
Golf
Bowls
Boxing
Martial Arts (e.g. Judo, Karate, Kendo, etc.)
Weight-training
Weight-lifting
Yoga
Gymnastics (including Trampolining)
Exercises (e.g. Press-ups, Sit-ups)
Keep Fit
Aerobics
Dancing for Fitness
Jogging / Running
Athletics (Field Events, Track Events, Cross-country)
Rambling
Hiking / Backpacking
Climbing
Social Dancing
Snooker
Darts
Ten-pin Bowling
Skittles
Shooting
Fishing
Horse-riding
Skiing
Motor Sports (Cars and Bikes)
Ice Skating
Roller Skating
Sailing
Rowing
Canoeing
Cycling

Any other sports or exercise activities?

Subject No. ....

DATA RECORDING SHEEET 1

Age............... Height............... Weight............... Sex...............

BIA

% fat =

Impedance =

Skinfolds

				Median
Biceps				
Triceps				
Subscapular				
Suprailiac				

Sum of skinfolds = _______

∴ % fat = _______

Subject No. ....

DATA RECORDING SHEEET 2

Densitometry

Vital Capacity (VC) = ...
80% VC = ...
90% VC = ...

∴ Vol. O_2 in bag = ... + 0.6 l (tubing)

Dead space from mouthpiece to valve = $\pi r^2 h = \pi 3^2 15 = 0.42$ l
Let RV = Observed Residual Volume
Let T_A = Ambient Temperature (°C)

Trial 1 % CO_2 = ... % O_2 = ...

$$\text{Observed RV} = \frac{\ldots\ldots\ (100 - (\ldots\ldots + \ldots\ldots))}{79.8 - (100 - (\ldots\ldots + \ldots\ldots))} - 0.42 = \ldots\ldots\ldots$$

Trial 2 % CO_2 = ... % O_2 = ...

$$\text{Observed RV} = \frac{\ldots\ldots\ (100 - (\ldots\ldots + \ldots\ldots))}{79.8 - (100 - (\ldots\ldots + \ldots\ldots))} - 0.42 = \ldots\ldots\ldots$$

Trial 3 % CO_2 = ... % O_2 = ...

$$\text{Observed RV} = \frac{\ldots\ldots\ (100 - (\ldots\ldots + \ldots\ldots))}{79.8 - (100 - (\ldots\ldots + \ldots\ldots))} - 0.42 = \ldots\ldots\ldots$$

Trial 4 % CO_2 = ... % O_2 = ...

$$\text{Observed RV} = \frac{\ldots\ldots\ (100 - (\ldots\ldots + \ldots\ldots))}{79.8 - (100 - (\ldots\ldots + \ldots\ldots))} - 0.42 = \ldots\ldots\ldots$$

$$\text{Mean RV of 2 trials within 100ml} = \frac{\ldots\ldots + \ldots\ldots}{2} = \ldots\ldots\ldots$$

$$\therefore \text{Assumed RV} = \frac{\ldots\ldots \times 310}{273 = T_A} = \ldots\ldots\ldots$$

Subject No. ....

DATA RECORDING SHEEET 3

Observed body weight in water = ...
....

∴ measured body weight in water (BWt_W) = ... kg

Body weight in air (BWt_A) = ... kg

RV = ... l

Volume of air in gastro-intestinal tract (V_{GI}) = 0.1 l

Temperature of water = ... °C

Volume of body (V_B) = $\frac{BWt_A - BWt_W}{D_W} - RV + V_{GI}$

where D_W = 0.9971 @ 25°C
0.9968 @ 26°C
0.9965 @ 27°C
0.9963 @ 28°C
0.9960 @ 29°C
0.9957 @ 30°C
0.9954 @ 31°C
0.9950 @ 32°C (water density at specific temperature)
0.9947 @ 33°C
0.9944 @ 34°C
0.9941 @ 35°C
0.9937 @ 36°C
0.9934 @ 37°C
0.9930 @ 38°C
0.9926 @ 39°C
0.9922 @ 40°C

∴ $V_B = \frac{\ldots\ldots - \ldots\ldots}{\ldots\ldots} - \ldots\ldots + 0.1$

∴ body density (D_B) = $\frac{BWt_A}{V_B} = \frac{\ldots\ldots}{\ldots\ldots}$ = ...

% fat (Siri) = $\frac{495}{D_B} - 450$

$= \frac{495}{\ldots\ldots} - 450$ = ...

YMCA TEST

MAXIMUM PHYSICAL WORKING CAPACITY PREDICTION

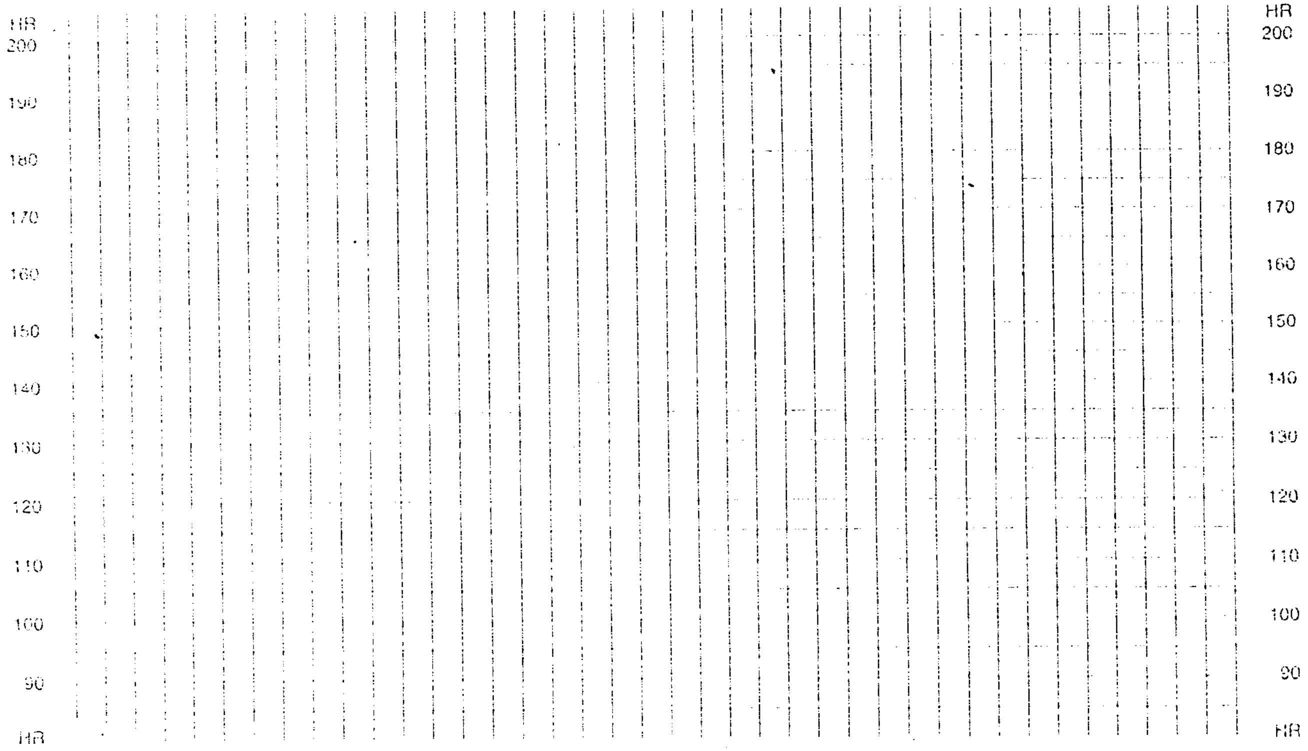
NAME (SUBJECT NO. ....) AGE WEIGHT LB KG SEAT HEIGHT

PREDICTED MAX HR

	DATE	1st WORKLOAD HR USED	2nd WORKLOAD HR USED	MAX WORKLOAD	MAX O_2(L/min)	MAX O_2(mL/kg)
TEST 1						
TEST 2						
TEST 3						

DIRECTIONS

1. Plot the HR of the 2 workloads versus the work (kgm/min).
2. Determine the subject's max HR line by subtracting subject's age from 220 and draw a line across the graph at this value.
3. Draw a line through both points and extend to the max HR line for age.
4. Drop a line from this point to the baseline and read the predicted max workload and O_2 uptake



WORKLOAD (kgm/min)	150	300	450	600	750	900	1050	1200	1350	1500	1650	1800	1950	2100
MAX O_2 UPTAKE (L/m)	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.8	3.2	3.5	3.8	4.2	4.6	5.0
KCAL USED (kcal/m)	3.0	4.5	6.0	7.5	9.0	10.5	12.0	14.0	16.0	17.5	19.0	21.0	23.0	25.0
APPROX MET LEVEL (for 132 lb)	3.3	4.7	6.0	7.3	8.7	10.0	11.3	12.7	14.0	15.3	16.7	18.0	19.3	20.7
APPROX MET LEVEL (for 176 lb)	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0
	0.5Kp	1Kp		2Kp		3Kp		4Kp		5Kp		6Kp		7Kp

Figure 4-24. Form for plotting maximum physical working capacity prediction.

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