Relationship between skinfold and optical density at upper and lower body measurement sites

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Relationship between Skinfold and Optical Density at upper and lower body measurement sites.

Dissertation submitted in accordance with the requirements of Chester College of Higher Education for the degree of Master of Science.

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Declaration

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

Signed .....

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Abstract

A.C.McLachlan. Relationship between Skinfold and Optical Density measurements at upper and lower body measurement sites.

This study examined the relationship between Skinfold (SKF) and Optical Density (OD) at upper and lower body sites in 20 active (>30 mins per day) male subjects (19-34 years). The use of lower body measurement sites in regression equations developed to predict %BF was also investigated. Percent Body Fat (%BF) was calculated by Hydrostatic Weighing (HW), SKF and Near Infrared Interactance (NIR) using the Futrex 5000. SKF and OD measurements were taken at ten anatomical sites. Estimations of %BF by SKF and NIR were found to be significantly different ($p<0.05$) from %BF by HW. OD1 and OD2 values generated from NIR and SKF thicknesses at each site were found to be poorly correlated in this population. Regression equations developed from SKF and OD data found that upper body sites were generally the best predictors of %BF ($r^2=.63$, SEE +/- 2.15%). A combination of upper and lower body SKF and OD sites showed good predictive accuracy for Fat mass ($r^2=.96$, SEE +/- .97Kg) and Fat Free Mass ($r^2=.98$, SEE +/- .87Kg). In the population studied upper body measurement sites were generally the better predictors of %BF.

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Table of Contents

Section Page

Appendices;

List of Tables

List of Figures

Introduction

The field of body composition has seen the development of many non-invasive, indirect techniques for the prediction of various body components (Cohn, 1987). These methods include Skinfold calipers (SKF), Bioelectrical Impedence (BIA), Ultrasound and Near Infrared Interactance (NIR)(Brodie, 1988). These predictive methods are not without their critics as they all have inherent degrees of error (Lukaski, 1987).

The Skinfold method popularised by Durnin and Womersley (1974) has been criticised due to the number of major assumptions that are made in the skinfold methodology (Clarys, Martin, Drinkwater and Marfell-Jones, 1987). Direct or 'Cadaver' analysis has investigated the assumptions made regarding skinfold compressibility, fat distribution, fat patterning and skin thickness (Clarys et al, 1987). One interesting finding referred to the relationship between measurement sites and percent Body Fat (%BF). Clarys et al (1987) found that lower body skinfold measurement sites were more highly correlated with total subcutaneous adipose tissue than upper body measurement sites. Despite these findings the majority of prediction equations such as that reported by Durnin and Womersley (1974) involve upper body sites either exclusively or as the majority.

One of the predictive techniques which may reduce the number of assumptions burdening the SKF method is Near Infrared Interactance (NIR). This may be due to the fact that NIR produces an objective measurement giving an Optical Density (OD) value as opposed to the SKF method which gives a thickness value of a compressed double fold of skin (Lohman, 1992). This composition method has developed from analysis of foodstuffs (Langa, 1983) based on the principle that the major components of food (and therefore human tissues) have individual absorption spectra of near infrared light (Conway and Norris, 1987). Conway, Norris and Bodwell (1984) used NIR to predict %BF with a standard error of estimate (SEE) of +/- 3.0% compared to larger SEE's for the SKF (+/- 4.4 %BF) an HW (+/- 4.3%BF) methods. Conway and Norris (1987) suggested that the combination of skin thickness and subcutaneous fat thickness at the biceps site allows the NIR beam to penetrate sufficiently, making it the best single site for predicting Total Body Fat (TBF).

The work of Conway et al (1984) has not since been repeated with equivalent accuracy due to the development of a number of NIR devices with questionable prediction validity (Lohman, 1992). The Futrex 5000 model (Futrex Inc, 1988) has attracted criticism suggesting that the predictive accuracy may have been compromised for convenience due to the use of the Mid-Biceps as the measurement site (Brodie & Eston, 1992). It was shown that 58% of the variance in %BF prediction was due to the Biceps OD and that its use significantly underestimated %BF (Israel et al, 1988). Some workers have suggested that NIR is not suitable for %BF and Lean Body Mass (LBM) predictions across differing body composition profiles (Davis, van Loan, Holly, Krstich & Phinney, 1989). At the same time other workers support the use of NIR as a valid predictor of %BF when compared to SKF (Laverty, Poalone, O'Shea & Kendrick, 1989). Much of the error in the NIR method is thought to be due to the Mid-Biceps site with suggestions that other sites or multisite models may yield more valid results

(Israel et al, 1988).

It is clear that the SKF and NIR methods receive much of their criticism due to the choice or combination of measurement sites used. The NIR method in particular is criticised due to its dependence upon regional adiposity for prediction of body composition components (Lukaski, 1987). The findings of Clarys et al (1987) regarding the relationship between measurement sites and %BF may hold applications not only for SKF but also NIR. Other OD sites may correlate more highly with %BF than the Biceps OD site. In contrast a recent multisite study using both SKF and NIR in female subjects found that only Biceps and Pectoral OD values contributed significantly to %BFHW (Quatrochi et al, 1992). The sites used by Quatrochi et al (1992) were biased towards the upper body with two of the nine sites (Thigh and Medial Calf) representing lower body sites.

This study had two aims. To investigate the relationship between SKF measurements and OD values at ten anatomical measurement sites. To investigate the use of OD values using multisite analysis to determine whether other NIR measurement sites may contribute more significantly to NIR prediction of %BF than the current manufacturers recommendation of the mid-biceps site (Futrex Inc, 1988). This study investigated the relationship between OD and SKF measurements in a similar way to Quatrochi et al (1992) but instead male subjects were used. It also involved multisite OD measurements similar to the protocol of Heyward et al (1992) but using an equal number of upper and lower body sites rather than a greater number of upper body sites as in previous studies.

The two hypotheses investigated were :-

1- Lower body SKF and OD values are more highly correlated than upper body SKF and OD values.

2- Lower body sites enable %BF prediction equations which are more accurate than those using upper body sites.

Methodology

Subjects.

The subjects used were 20 healthy male volunteers between 19 and 34 years of age. They were all recruited from Chester College of Higher Education. All subjects gave informed consent and completed a data sheet detailing age, height, weight and physical activity level (See Appendix D). From this it was found that all subjects performed at least 30 minutes of Aerobic type physical activity per day and had done so for at least the last six months.

Body Weight and Height.

A Weylux medical beam scale was used to weigh all subjects barefooted and dressed only in either shorts or trunks. Weight values were taken to the nearest 0.1 Kg.

A stadiometer was utilised to measure height whilst subjects were barefoot and standing upright. Values for height were recorded to the nearest 0.5 cm as subjects were in a mid-inspiratory position.

As height and weight were accurately measured Body Mass Index (BMI) was also calculated (Kg/M^2) (Black et al, 1983)(See Fig 1).

$$\text{BMI} = \frac{\text{Weight (Kg)}}{\text{Height}^2\ (\text{M}^2)}$$

Figure 1: Formula for calculation of BMI (Black et al, 1983)

Skinfold Measurements.

Subject skinfold measurements of double folds of skin were taken on the non- dominant side of the body using Harpenden skinfold calipers using the measurement guidelines of Harrison et al (1988). The measurement sites were determined and lightly marked using a water based marking pen. This was to ensure that the tester measured the same specific site with both the skinfold calipers and NIR light wand.

Upper body sites evaluated were Biceps, Triceps, Subscapula, Suprailiac and Abdominal. Biceps skinfold thickness was measured at the mid-point of the vertical line joining the anterior border of the acromion and the center of the antecubital fossa. Triceps skinfolds were taken at the mid-point between the acromion process of the scapula and the olecranon process of the ulna on the the posterior aspect of the upper arm.

Subscapula measurements were taken directly below the inferior angle of the subscapula and Suprailiac skinfolds were taken superior to the iliac crest. Assessment of abdominal skinfold thickness was achieved by measuring 3cm lateral to and 1cm below the umbilicus. Abdominal measurements were always taken to the right of the umbilicus for all subjects and a horizontal caliper technique was applied as opposed to the normal vertical measurement technique.

Lower body sites were also assessed at the Front Thigh, Medial Thigh, Rear Thigh, Suprapatella and Medial Calf sites. Mid or front thigh measurement was taken midway along the midline between the inguinal crease and the proximal border of the patella. Medial thigh skinfolds were taken at a point lateral to the front thigh site on the medial aspect of the thigh. Rear thigh skinfolds were located by marking a point level to the front and medial thigh sites except on the posterior aspect of the upper leg. Suprapatella skinfolds were taken 2cm above the proximal edge of the patella. Medial calf measures were taken with the leg flexed to 90^0. The site was located at the point of maximum calf girth on the medial aspect of the lower limb.

For each site readings were taken in rotational order (Biceps, Triceps, Subscapula, Suprailiac, Abdominal, Front Thigh, Medial Thigh, Rear Thigh, Suprapatella, Medial Calf). These rotational measurements were repeated three times giving three skinfold readings for each site. Any site readings that were not within 1mm were repeated. Once three skinfold readings were ascertained at each site then the mean skinfold reading at each site was calculated and used in the equation to predict %BF (Durnin & Womersley, 1974) against the criterion method of HW.

%BF using the skinfold measurements was calculated using equations developed by Durnin and Womersley (1974).The Log of the sum of the Mean Bicep, Triceps, Subscapula and Suprailiac measurements were used in the prediction equation to calculate a Body Density value. There were two equations used for the subjects in this study. One equation for the 20-29 years age cohort and a modified equation for the 30-39 years age cohort (See Fig 2 Below).

Figure 2: Age adjusted formulae for calculation of Body Density from Skinfolds (Durnin & Womersley, 1974)

20-29 years.

Body Density = 1.1631 - (0.0632 * Log Sum of Skinfolds).

30-39 years

Body Density = 1.1422 - (0.0544 * Log Sum of Skinfolds).

Body Density values were converted to a %BF value using the equation developed by Siri et al (1961)(See Fig 3 Below).

Figure 3: Formula for calculation of %BF from Body Density (Siri et al, 1961)

$$\%BF = \left(\frac{4.95}{\text{Body Density}} - 4.5 \right) * 100$$

Hydrostatic Weighing.

In order to compare the skinfold and NIR predictions of subcutaneous body fat to a criterion value, Hydrostatic weighing (HW) or Hydrodensitometry was used. The HW method involved calculation of body density based upon Archimedes principle that an object placed in fluid loses an amount of weight relative to the weight of the fluid that is displaced. Either the weight of fluid displaced could be measured or as in this study the weight of the object fully submerged was measured. By calculating the mass of the body underwater, Total Body Volume (TBV) and then Body Density (BD) were calculated. Once BD was calculated then %BF could be ascertained using a %BF formula.

Underwater weighing was carried out at the Department of Movement Science at Liverpool University. Prior to testing the temperature of the water in the tank was taken and the relative density of the water calculated. The predicted Forced Vital Capacity (FVC) of each test subject was obtained prior to testing using a pocket spirometer in order to calculate Residual Volume (RV). RV values were then estimated from FVC by using the following constant developed by Wilmore (1969)(See Figure 4 below).

Figure 4: Formula for estimation of Residual Volume from Forced Vital Capacity (Wilmore et al. 1969).

$$RV(\text{Litres}) = 0.24 * FVC\ (\text{Litres}).$$

Subjects were weighed in the water tank on a weighing cradle attached to a 20 Kg Load cell linked to a calibrated digital voltmeter (Brodie & Eston, 1992). Subjects were required to fully expire the air in their lungs as they became fully submerged in the water tank and the Water Mass (WM) reading was taken. This was repeated five times for each subject and the largest of the WM results used in the further calculations.

Once WM values were obtained it was possible to calculate TBV using the following formula.

$$\text{Total Body Volume} = \frac{\text{Mass in Air - Mass in Water}}{\text{Density of water}}$$

From TBV values BD was calculated using the formula below,

$$\text{Body Density} = \frac{\text{Mass in Air}}{\text{TBV - RV - Gastrointestinal Gas}}$$

A value of 0.1 Litres was given to allow for the effects of gastrointestinal gases (GIG) upon the water mass values. Once these preliminary calculations were carried out it was then possible to calculate %BF using the %BF formula developed by Siri et al (1961)(See Fig 3 previous).

Near Infrared Interactance.

In order to assess the proportions of fat/water/tissue at each measurement site a Near Infrared Interactance Spectrometer was used to predict various body composition components. The Futrex 5000 light wand and microprocessor (Futrex Inc, Gaithersburg MD) was the NIR model used.

Optical Densities (OD1 + OD2) were taken using the Optical Standard provided by the manufacturer (Futrex Inc, Gaithersburg, MD) Measurements were taken using this small metal covering to eliminate any electronic drift in the equipment during measurement. This standardising procedure was carried out at the start of testing and after each rotational measurement of the ten sites.

OD measurements were taken at each of the ten marked skinfold sites in a rotational order (Biceps, Triceps, Subscapula, Suprailiac, Abdominal, Front Thigh, Medial Thigh, Rear Thigh, Suprapatella, Medial Calf). The Futrex 5000 was then standardised as outlined previously and the process repeated two more times. Each repeated rotation was taken to 0.005 unit and a fourth trial carried out if a repeated measurement was more than 0.05 units out. The mean OD1 and OD2 were calculated for each site and used in the equation to predict %BF. In order to predict %BF from the OD values a prediction equation described by the manufacturer (Futrex Inc,1988) was used (See Fig 5 Below).

<u>Figure 5: Manufacturers equation for prediction of %BF (Futrex Inc, 1988)</u>

$$\%BF = 83.62 - 63.5\,(OD2) + 0.209\,(Weight) - 0.3045\,(Height) - 41.5\,(OD1) - 153.5\,(Activity\ Level).$$

Weight = Kg; Height = cm; Activity Level (> 15mins) = 0: (15-30) mins = 0.02: (30-60) mins = 0.05: (>60 mins) = 0.08.

Reliability Study

A subgroup of 8 subjects were tested one week later using identical protocol and tester for the SKF and NIR methods. This was to evaluate the test-retest reliability of both predictive methods in this population.

Statistical Analysis

Unistat 3 statistical software was used to perform the various statistical tests. Test - retest reliability of the SKF and NIR methods was assessed using one way Analysis of Variance (ANOVA) with repeated measures. Pearson product moment correlation was used to examine intraclass reliability between test and retest values.

The relationship between OD and SKF values and between predictive and criterion values for %BF were examined using the Pearson product moment correlation. A Pearson - Spearman -Kendall matrix was used to examine the relationship between OD1 and OD2 at each site, OD1 and SKF at each site and OD2 and SKF at each site.

Stepwise multiple regression analysis was performed on the OD data at each site using %BFHW as the dependent variable and site OD (OD1 and OD2), hieght, weight, age and PAL as independent variables. A second multiple regression analysis was performed on this data with BMI substituted in for height and weight as an independent variable.

Stepwise multiple regression was also used to analyse the best predictors of %BFHW, HWFM and HWFFM (dependent variables) individually. All SKF sites, all OD sites, height, weight, BMI, age and PAL were used as independent variables

Results

Descriptive Analysis

The mean values and standard deviations for age, weight, height, BMI, %BFHW are represented in Table 1.

Table 1: Demographic data for Subjects (n=20)

Age (years)	22.55 +/- 3.36 (19-34)
Weight (Kg)	79.95 +/- 9.21 (67-110)
Height (cm)	178.85 +/- 5.22 (167-185)
BMI	24.89 +/- 2.53 (22.8-34.7)
%BFHW	16.78 +/- 3.55 (12.62-25.08)

Table 2 illustrates the mean and standard deviation values for Fat Mass (FM)(kg), Fat Free Mass (FFM)(Kg) and %BF by HW, SKF and NIR (predicted using each site). HW generated the largest mean value (16.78 +/- 3.55%) and SKF predicted the lowest mean value (14.14 +/- 2.42%) for %BF.

Table 2: Estimation of Fat and Fat Free Mass (FFM) by various methods.

	Fat (Kg)	Fat (%BF)	FFM (Kg)
HW.	13.25 +/- 4.22	16.78 +/- 3.55	66.71 +/- 6.17
SKF.	11.41 +/- 2.92	14.14 +/- 2.42	68.54 +/- 7.07
FX Biceps	12.32 +/- 3.12	15.25 +/- 2.12	68.51 +/- 6.16

%BF estimation using the Triceps as the measurement site yielded mean values closest to those of HW although there was a smaller standard deviation (16.65 +/- 2.89%).

Paired T-Tests showed highly significant differences between %BFHW and %BFSKF ($t(20) = 5.17$, $p<0.001$) and significant difference between %BFHW and %BFFX (Biceps) ($t(20) = 2.13$, $p<0.05$).

Table 3: Skinfold and Optical Density data

	Skinfolds (mm)			OD1			OD2		
	M	SD	r	M	SD	r	M	SD	r
Biceps	5.15	1.07	.97	1.0792	.0814	.96	1.1103	.0734	.91
Triceps	8.40	1.76	.99	1.0131	.1275	.88	1.0408	.1217	.82
Subscapula	10.71	1.75	.99	1.0427	.1178	.93	1.0930	.0984	.89
Suprailiac	8.95	2.98	.94	1.0154	.0834	.77	1.0540	.0805	.84
Abdominal	12.32	1.87	.98	1.0498	.1206	.96	1.0962	.1192	.92
Front thigh	**11.11**	**2.97**	**.96**	**1.0271**	**.0974**	**.89**	**1.0578**	**.0920**	**.80**
Medial thigh	**8.26**	**2.87**	**.94**	**1.0362**	**.0829**	**.91**	**1.0649**	**.0838**	**.87**
Rear thigh	**4.36**	**1.77**	**.91**	**1.0099**	**.1108**	**.68**	**1.0395**	**.0959**	**.71**
Suprapatella	**10.61**	**3.77**	**.91**	**1.0315**	**.0823**	**.96**	**1.0647**	**.0879**	**.84**
Medial calf	**7.21**	**3.09**	**.95**	**1.0605**	**.0880**	**.85**	**1.0880**	**.0842**	**.91**

(Values in **bold - face** type indicate lower body sites.)

Table 3 shows data for Skinfold measurements (mean and SD) and Optical Density data (OD1 and OD2 - means and SD). The Abdominal SKF site yielded the largest mean value (12.32 +/- 1.87). Rear thigh gave the lowest (indicating highest fat) mean OD1 (1.0099 +/- .1108) and OD2 (1.0395 +/- 0.959) values.

Reliability

One way ANOVA with repeated measures performed on a subgroup of 8 subjects showed no significant differences between test - retest mean SKF values. The average reliability coefficients for SKF ranged from $.91<r<.99$.

There were small but significant differences between test - retest mean values for Suprailiac OD1 (f (1,7) = 6.11, $p<0.05$), rear thigh OD1 (f (1,7) = 6.68, $p<0.05$) and rear thigh OD2 (f (1,7) = 7.25, $p<0.05$). Intraclass coefficients for OD values ranged from r=.71(rear thigh OD2) to r=.96 (Abdominal OD1).

Correlational Analysis

Weight ($r = .56$, $p <0.05$) and BMI ($r = .65$, $p<0.05$) were significantly but weakly correlated with %BFHW. Weight ($r = .44$, $p<0.05$), Age ($r = .59$, $p<0.05$) and BMI ($r = .55$, $p<0.05$) correlated with %BFSKF. The strongest significant correlations (See Table 4) were between %BFFX and Weight ($r = .82$, $p<0.05$) and %BFFX and Age ($r = .81$, $p<0.05$) despite age not being a factor in the %BFFX prediction formula (Elia et al, 1990) used in this study.

Table 4: Correlation coefficients for demographic data with %BF by HW, SKF and NIR

	%BFHW	%BFSKF	%BFFX
Height	.0028	.05	.26
Weight	.56*	.44*	.82*
Age	.30	.59*	.81*
BMI	.65*	.55*	.02

* indicates $p <0.05$.

Table 5 overleaf shows the ten measurement sites ranked in order of correlation coefficient with %BF by HW, SKF and NIR. Subscapula ($r = .81$,$p<0.05$) and Suprailiac ($r = .68$, $p< 0.05$) were the most highly correlated with %BFHW. Although these were upper body sites, three of the five sites most highly correlated with %BFHW were lower body sites, rear thigh ($r= .63$, $p=<0.05$), suprapatella ($r= .55$, $p<0.05$) and front thigh ($r= .55$, $p< 0.05$) respectively.

Suprailiac was the most significantly correlated site with %BFSKF ($r= .88$, $p<0.05$). Two of the five sites most significantly correlated with %BFSKF were lower body sites, suprapatella ($r= .71$, $p<0.05$) and front thigh ($r=.70$, $p<0.05$)

respectively.

All five lower body SKF sites showed the most significant relationships with %BF predicted by NIR (See Table 5 overleaf). Medial calf and rear thigh coefficients were the most highly correlated,(r= .72, $p<0.05$) and (r=.71, $p<0.05$) respectively.

Table 5: Correlation coefficients for SKF sites and %BF by HW, SKF and FX.

	%BFHW		%BFSKF		%BFFX
subscapula	.81*	suprailiac	.88*	**medial calf**	**.72***
suprailiac	.68*	subscapula	.77*	**rear thigh**	**.71***
rear thigh	**.63***	**suprapatella**	**.71***	**suprapatella**	**.63***
suprapatella	**.55***	triceps	.71*	**medial thigh**	**.62***
front thigh	**.55***	**front thigh**	**.70***	**front thigh**	**.53***
triceps	.48*	biceps	.62*	abdominal	.47*
abdominal	.43*	abdominal	.54*	suprailiac	.41
medial calf	**.43***	**rear thigh**	**.53***	biceps	.40
biceps	.41*	**medial calf**	**.38***	triceps	.39
medial thigh	**.19**	**medial thigh**	**.28**	subscapula	.24

* indicates $p<0.05$; (values in **bold - face** type indicate lower body sites).

The relationship of SKF caliper readings with Fat Mass (Kg) and Fat Free Mass (Kg) assessed by HW was examined. When correlation coefficients for these relationships were ranked (See Table 6) it was found that lower body SKF sites were significantly correlated. In particular, HWFFM was significantly correlated to all five lower body SKF sites.

Table 6: Correlation coefficients of Caliper reading with HWFM and HWFFM

Site	HWFM (Kg)	Site	HWFFM (Kg)
Subscapula	.75***	**Medial Calf**	__.63**__
Front thigh	__.68***__	**Medial Thigh**	__.54**__
Medial calf	__.66**__	**Rear Thigh**	__.44*__
Suprapatella	__.62**__	**Suprapatella**	__.44*__
Rear thigh	__.59**__	**Front Thigh**	**.32**
Abdominal	.50*	Triceps	.29
Suprailiac	.49*	Subscapula	.27
Biceps	.47*	Abdominal	.25
Medial thigh	__.44*__	Suprailiac	.24
Triceps	.41*	Biceps	.12

*** indicates $p<0.001$; ** indicates $P<0.01$; * indicates $P<0.05$.
(values in **bold - face** type indicate lower body sites)

Of these lower body sites, Front thigh (r= .68, $p<0.001$) showed the most significant correlations with HWFM (Kg) and medial calf (r = .63, $p<0.01$) the most significant correlation with HWFFM (Kg). As shown in Table 5 the subscapula was the most significantly correlated SKF measurement site with %BFHW (r= .81, $p< 0.05$) and subscapula SKF site also had the strongest relationship with HWFM (r = .71, $p<0.001$). The subscapula SKF measurement site was used to develop a regression equation to predict %BF.

OD values were not significantly correlated with HWFM (Kg) but the relationship between HWFFM and OD, although relatively weak, was slightly more significant with Abdominal OD2 (r = .51, $p<0.05$) the most highly correlated site (See Table 7).

Table 7: Correlation coefficients for OD (1 & 2) values and HWFFM

OD1 Site	HWFFM	OD2 Site	HWFFM
Abdominal	.49*	Abdominal	.51*
Front thigh	**.43***	**Front thigh**	**.46***
Rear thigh	**.39***	Suprailiac	.45*
Suprapatella	**.39***	Subscapula	.44*
Suprailiac	.36	**Rear thigh**	**.42***
Subscapula	.34	**Suprapatella**	**.42***
Biceps	.29	**Medial calf**	**.24**
Medial calf	**.22**	**Medial thigh**	**.21**
Medial thigh	**.21**	Biceps	.19
Triceps	.13	Triceps	.11

* indicates $p<0.05$; (values in **bold face** type indicate lower body sites).

The intercorrelations among SKFs at all sites ranged from $.25 < r < .73$ ($p<0.05$) (See Table 8). The intercorrelations between OD sites ranged from $.14 < r < .88$ ($p<0.05$) (See Table 8). Correlations of OD with SKF are shown in Table 9. There were positive significant correlations between OD and SKF at the abdominal ($r=.55$, $p<0.05$) and rear thigh ($r=.42$, $p<0.05$) measurement sites. All other sites were not significantly related.

Table 8: Intercorrelations for SKF and OD data (n=20).

	Triceps	Subscapula	Suprailiac	Abdominal	F.thigh	M.thigh	R.thigh	Suprapatella	Calf
Biceps SKF	**.34**	**.35**	**.37**	**.36**	**.73***	**.44***	**.24**	**.57***	**.32**
Biceps OD1	.59	.56	.55	.29	.63	.52	.35	.46	.55
Triceps SKF		**.32**	**.61***	**.54***	**.66**	**.34**	**.44***	**.50***	**.32**
Triceps OD1		.88	.65	.16	.69	.12	.59	.45	.62
Subscapula SKF			**.64**	**.48***	**.52***	**.17**	**.56***	**.66***	**.59***
Subscapula OD1			.73	.32	.76	.32	.71	.64	.57
Suprailiac SKF				**.25**	**.46***	**.05**	**.43***	**.57***	**.31**
Suprailiac OD1				.49	.49	.57	.54	.66	.32
Abdominal SKF					**.65***	**.46***	**.56***	**.58***	**.43***
Abdominal OD1					.48	.45	.33	.38	.14
Front thigh SKF						**.50***	**.39***	**.62***	**.57***
Front thigh OD1						.41	.80	.45	.72
Medial thigh SKF							**.40***	**.52***	**.52***
Medial thigh OD1							.38	.60	.21
Rear thigh SKF								**.68***	**.57***
Rear thigh OD1								.41	.67
Suprapatella SKF									**.69***
Suprapatella OD1									.45

* indicates $p<0.05$ (values in **bold - face** type indicates SKF intercorrelations).

The strongest intercorrelations for SKF were between the biceps and front thigh measurement sites (r=.73, $p<0.05$). OD intercorrelations were high between the triceps and subscapula (r=.88), front thigh and rear thigh (r=.80), and subscapula and front thigh (r=.76,$p<0.05$). OD values at the subscapula were also correlated to the suprailiac (r=.73) and rear thigh (r-=.71) sites although all OD correlations were not significant at the accepted alpha level of $p<.05$.

Table 9: Correlation coefficients for same site OD and SKF.

Site	r	Site	r
Abdominal	.55*	Rear thigh	.42*
Subscapula	.35	Front thigh	.28
Triceps	.06	Medial calf	.19
Suprailiac	.05	Medial thigh	.17
Biceps	.01	Suprapatella	.09

* indicates $p<0.05$.

Multiple Regression Analysis.

Stepwise regression analysis identified the subscapula SKF measurement as the only predictor variable for %BF in the population studied. %BFHW was used as the dependent variable and no lower body sites were identified as contributors to the prediction equation. A regression equation for the prediction of %BF from subscapula SKF measurement was developed from the stepwise regression analysis ($r2 = .63$, SEE=+/- 2.15%)(See Fig 6 below).

$$\%BF = 1.6332\ (\text{Subscapula SKF}) - 0.6949.$$

Figure 6: Regression equation developed to predict %BF from Subscapula SKF thickness.

Fat mass calculated from HW was used as a dependent variable in the stepwise regression. BMI, Height, abdominal SKF, suprailiac SKF, suprailiac OD2, biceps OD2 and medial calf OD2 were identified as predictor variables. A prediction equation for Fat mass (Kg) was developed using these predictor variables ($r2= .96$, SEE =+/- .87Kg) (See Fig 7 overleaf).

$$
\begin{aligned}
\text{FM} &= -71.298 + 1.124\,(\text{BMI}) + 26.591\,(\text{Suprailiac OD2}) \\
&\quad + 0.1997(\text{Height}) + 0.5299(\text{Abdominal SKF}) - 7.397(\text{Calf OD2}) \\
&\quad + 0.2974(\text{Suprailiac SKF}) - 7.496(\text{Biceps OD2}).
\end{aligned}
$$

Figure 7: Regression equation developed to predict Fat Mass from a combination of SKF and OD values.

Finally, Fat Free Mass determined by HW was used as the dependent variable in a stepwise regression analysis. Weight, subscapula SKF, Front thigh SKF, suprailiac OD2 and biceps OD2 were identified as predictor independent variables. The regression equation developed for prediction of FFM is shown in Figure 8 below (r2 =.98, SEE = +/- .97Kg).

$$
\begin{aligned}
\text{FFM} &= 30.274 + 0.735\,(\text{weight}) - 0.725\,(\text{subscapula SKF}) \\
&\quad - 21.713\,(\text{Suprailiac OD2}) - 0.375\,(\text{Front thigh SKF}) \\
&\quad + 11.56\,(\text{Biceps OD2}).
\end{aligned}
$$

Figure 8: Regression equation developed to predict Fat Free Mass from a combination of SKF and OD values.

Regression analysis was also performed using site OD values (OD1 & OD2), Height, weight, age and PAL as independent variables and %BFHW as the dependent variable. Weight was shown to account for the largest share of variance (27%) in prediction of %BFHW at all sites except suprailiac. Suprailiac OD2 was shown to account for 44% of the variance in %BFFHW prediction. A regression equation was developed using these two variables (r^2=.71, SEE +/- 1.92%BF)(See Fig 9 overleaf).

$$\%BFHW = .255\ (\text{weight}) + 19.491\ (\text{Suprailiac OD2}) - 24.11.$$

Figure 9: Regression equation developed to predict %BF from weight and Suprailiac OD2 values.

BMI was substituted in place of height and weight in the stepwise regresion analysis. It was found that BMI accounted for the largest share in variance (39%) at all sites except suprailiac. Suprailiac OD2 was found to contribute highly (52%) to the variance in %BFHW. The regression equation developed is shown in Figure 10 below (r^2=.91, SEE +/- 1.07%).

$$\%BFHW = .992\ (\text{BMI}) + 17.08\ (\text{Suprailiac OD2}) - 25.95.$$

Figure 10: Regression equation developed to predict %BF from BMI and Suprailiac OD2.

Discussion

SKF measurement test-retest reliability was high for all ten measurement sites. Reliability coefficients ranged from r=.91 (Suprailiac) to r=.99 (Subscapula). The OD Data obtained from the Futrex 5000 had high (r >.80) test - retest reliability for 8 of the 10 measurement sites based on the magnitude of the reliability coefficients (See Table 3). The biceps, abdominal and suprapatella were the most reliable OD1 sites (r=.96). Suprapatella and medial thigh (r=.91) were the only lower body sites with a good reliability coefficient for OD1 retest values. Abdominal (r=.92), biceps and medial calf (r=.91) were the most reliable OD2 sites. Medial calf was the only lower body site with good OD2 test-retest reliability compared to upper body sites. In general, the upper body sites produced more reliable test- retest OD values than lower body sites.

The low reliability coefficients for suprailiac OD1 (r=.77, $p<0.05$), rear thigh OD1 (r=.68, $p<0.05$) and rear thigh OD2 (r=.71, $p<0.05$) may be due in part to the relative thickness of the subcutaneous fat at these sites. The suprailiac site measurements had relatively large mean thickness values (10.71 +/- 1.75mm) and the rear thigh gave the lowest skin thickness values (4.36 +/- 1.77mm) predicted by SKF. The manufacturer suggests that the Futrex 5000 measures upto 4cm depth. If so, then the rear thigh will be more representative of intramuscular fat than other sites and the suprailiac will be more representative of subcutaneous tissues than the other sites. Also the rear thigh OD1 generated the lowest mean OD values (indicating a greater fat content). These two sites were at the extremes of subcutaneous adipose tissue thickness in the population studied and this may account for the measurement variations at the two sites.

The angle of measurement and pressure applied to the light probe may also have contributed to the variation in test-retest measurements at the rear thigh and suprailiac sites. The suprailiac site was the most difficult site to take consistent measurements from at the same angle and pressure for each subject due to the relatively large amount of underlying soft tissue. Although the same investigator was used for all measurements using the Futrex 5000 this may have affected the reliability of the measurements at the suprailiac site.

It was found that the most reliable OD site, abdominal, was also the most highly correlated with HWFM ($r=.49$, $p<0.05$) and HWFFM ($r=.51$, $p<0.05$). However, no abdominal OD values were included in the regression equation to predict HWFM (See Fig 7) although biceps OD2, medial calf OD2 and suprailiac OD2 were used. Similarly, the abdominal OD values were not included as predictor variables in the regression equation to predict HWFFM (See Fig 8).

Investigation of the relationship between SKF and OD at upper and lower measurement sites found a lack of strong relationships (See Table 9). Coefficients of determination (r^2) for upper body sites ranged from 0.01% (biceps) to 30.25% (Abdominal). Lower body site coefficients of determination ranged from .81% (Suprapatella) to 18% (rear thigh).

These results indicate a large amount of unexplained variance which may have been due to the difference in what each technique was measuring. The SKF is accepted as a measure of a double fold of skin and underlying subcutaneous adipose tissue (Harrison et al, 1988) whereas the Futrex 5000 analysed the composition of the underlying tissues within the fatfold site (Lohman, 1992).

However, the underlying tissues at SKF measurement sites were found to be variable in compressibility, fat content and skin thickness (Clarys et al, 1987). A study of SKF measurements of subcutaneous fat thickness in women found SKF significantly underestimated subcutaneous fat thickness when compared to Magnetic Resonance Imaging (MRI) assessment (Hayes, Sowood, Belyavin, Cohen & Smith, 1988). Differences between thickness values along the skinfold itself and between SKF and ultrasound thickness values were also reported (Hayes et al, 1988).

Weight (r=.82, p<0.05) and age (r=.81, p<0.05) showed a strong relationship with %BFFX (See Table 4) despite the fact that age was not a predictor variable in the equation provided by the manufacturer (Futrex Inc, 1988). Inclusion of age into a modified regression equation may have improved the predictive accuracy of the %BFFX equation. Previous workers have developed regression equations including age as a predictor variable and suggest that age should be included in the manufacturers equation for prediction of %BF (Heyward et al, 1992; Quatrochi et al, 1992).

The four SKF sites used in the %BF prediction equation of Durnin and Womersley (1974) were, as would be expected, significantly correlated (r=.62 to r=.88, p<0.05) with %BFSKF (See Table 5). It is interesting to note that front thigh and suprapatella also showed strong relationships, (r=.70, p<0.05) and (r=.71, p<0.05), with %BFSKF despite not being included in the predictive equation.

Two upper body SKF sites, suprailiac and subscapula correlated significantly, (r=.68, p<0.05) and (r=.81, p<0.05) respectively, with the criterion. Of the lower body sites only rear thigh (r=.63, p<0.05) showed a relationship equal to that of the upper body sites.

All five lower body SKF sites were more significantly correlated (r=.53 to r=.72, $p<0.05$) with %BFFX than upper body sites (See Table 5). The abdominal SKF site was the only upper body site (r=.47, $p<0.05$) significantly correlated with %BFFX.

All lower body SKF sites were shown to be more highly correlated (r=.59 to r= .68, $p<0.05$) with Total Fat Mass (Kg) derived from the criterion than all upper body sites except the subscapula (r=.75, $p<0.05$)(See Table 6). To a certain extent these results reflect the findings of Clarys et al (1987) regarding the relationship between measurement site and total subcutaneous adipose tissue mass. Five out of the six sites most highly correlated were lower body sites in the Brussels Cadaver Analysis and four of the five sites most highly correlated with criterion Fat mass in this study were also lower body. It must be noted that these relationships were much weaker than those found by Clarys and coworkers (1987) but a similar site pattern was illustrated.

The relationship between lower body SKF sites and Fat Free Mass assessed by HW, although relatively weak, were found to be better than the relationship between upper body SKF sites and HWFFM (See Table 6). Again these findings illustrate a similar site pattern to the HWFM data and to the findings of Clarys et al (1987).

In this population it was found that lower body SKF values showed better relationships with the criterion body composition factors than upper body SKF sites. These relationships were generally weak and not always significant at the accepted alpha level ($p<0.05$) for this study.

The relationships between OD values and HWFFM (r=.11 to r=.51) were weaker than those for SKF values and HWFFM (r=.12 to r=.63)(See Table 7). The abdominal site was the most highly correlated with HWFFM (r=.51) and lower body sites did not have stronger relationships with HWFFM compared to upper body sites. In general, the OD measurement sites were much more variable in their relationships with HWFFM compared to the SKF measurement sites which showed better lower body site relationships.

Investigation of the relationship between SKF sites yeilded the only significant intercorrelations as the Inter - OD site relationships were not significant (See Table 8). Biceps and front thigh SKF sites were the most strongly related in this population indicating an unusual correlation between upper and lower body measurement sites.

Intercorrelations between ODs highlighted the subscapula OD as being strongly related with tricep OD (r=.88, $p<0.05$), suprailiac OD (r=.73, $P<0.05$), front thigh (r= .76, $p<0.05$) and rear thigh (r=.71, $p<0.05$). This may account for the use of the subscapula site in two of the three regression formulae for prediction of %BF and FFM(Kg) (See Figures 6,9 & 10).

The second aim of this study was to investigate if lower body sites enabled %BF prediction equations to be developed that were more accurate than those using upper body sites. This was not found to be the case when all possible predictor variables were examined. The first equation was developed using all SKF and OD measurement sites, height, weight, age, and PAL as independent variables. Subscapula SKF was found to be the best predictor of %BF in this population (See Fig 6).

The other %BF prediction equations using only OD sites as opposed to SKF sites as predictor variables also selected upper body sites. The suprailiac OD2 in combination with weight (Fig 9) or BMI (Fig 10) was found to be the best predictor OD site for %BF.

When HWFM was used as the dependent variable a number of predictor variables were generated (See Fig 7). Of these predictor variables medial calf OD2 was selected as a contributor to the prediction of Fat mass. Inclusion of the medial calf OD2 improved the shared variance (97%) by 2.4% as opposed to the inclusion of the biceps OD2, the normally used site, which improved the shared variance by only 0.8%. BMI was the most influential variable accounting for 76% of the variance in HWFM and suprailiac OD2 was the most influential site (5.1%) predictor variable.

Prediction of HWFFM also included a lower body site as a predictor variable, front thigh SKF. Weight accounted for 85% of the variance in FFM but the inclusion of front thigh SKF improved the shared variance by 1.5%. Subscapula SKF was the most influential measurement site with an improved variance of 6.4% compared with suprailiac OD2 (3.1%) and biceps OD2 (1.3%).

Of the regression equations developed, the equation using suprailiac OD2 and BMI predicted %BF with the smallest SEE (+/- 1.065) and the largest coefficient of determination ($r^2 = .91$). This was found to be the best predictor of %BF in the adult male population studied. The regression equations developed using the combination of SKF and OD values from various sites to predict FM and FFM were also found to be more accurate than the equations predicting %BF.

The regression models developed in this study did not have an equal contribution from lower body sites as predictor variables compared to upper body sites. Of the ten site prediction factors across the five equations only two lower body values (medial calf OD2 and front thigh SKF) were included. Also, PAL was omitted from regression analysis due to the multicollinearity of the PAL data in this population. This finding suggests that the manufacturers criteria for PAL should be revised to include more specific indications or cohorts of PAL. PAL was not found to influence the predictive accuracy of the regression equations developed in this study and its influence in the manufacturers equation may therefore be questionable (Israel et al, 1989). Perhaps replacement of PAL with Age as a predictor variable may improve the accuracy of the manufacturers equation.

In this study the suprailiac OD2 was found to be a better predictor variable of %BF than the biceps OD. This finding suggests that the commonly used biceps site may affect the accuracy of prediction of %BF in active male adults and suprailiac may be a more appropriate site to use in conjunction with a modified prediction equation.

There were a number of limitations to this study and possible ways in which it may be developed for future research.

The number of subjects used in the study (n=20) may have affected the multiple regression analysis giving correlations that were spuriously high. Thomas and Nelson (1990) suggest that a subject to variable ratio of 10 to 1 is more appropriate as opposed to the 20 subject to 40 variable ratio in this study. A reduction in the number of variables examined may also add validity to the correlations between variables. The test -retest subgroup consisted of only 8 subjects. Again, this number of subjects, although representative of the population studied, is not large enough to provide a truly valid representation of test-retest reliability of the SKF and NIR methodologies in the general population.

The test subjects used were all physically active (>30 mins per day) males between 19 and 34 years of age, with %BF ranging from 12.62 - 25.08%. Although this population could be described mainly as lean, active males the study did not set out to use such a specific test population. Test statistics are biased by the sample and can only be applied to future samples of this type ie/ lean, active males. The regression equations developed in this study will have greater predictive errors if applied to an obese or normal group of subjects. Comparisons with a non-active adult male group would have enabled a more accurate representation of the male campus population. Comparison with an equal number of active adult females would have enabled investigation of the relationship between OD values and SKF thickness at upper and lower body sites between sexes. Presently only within-sex studies on OD and SKF relationships have been carried out (Hicks et al, 1991; Heyward et al, 1992; Quatrochi et al, 1992).

HW provided an adequate criterion method in this study and was used in previous studies particularly for the benchmark assessment of %BF in validity and predictive accuracy studies (Israel et al, 1989; Haddock et al, 1990; Elia et al, 1990). However, this may not be the case in studies of OD-SKF relationships. The findings of these studies suggested that Magnetic Resonance Imaging (MRI) may be a more appropriate criterion method for assessing subcutaneous adipose tissue in comparison to OD values (Heyward et al, 1992; Quatrochi et al, 1992). This facility was not within the resources of this study but may be considered for future research to provide more accurate NIR models for body composition assessment.

The use of a Helium Dilution technique for calculation of residual volume may have improved the accuracy of the Body Density values obtained from HW. This would be as a replacement to the prediction equation (Wilmore et al, 1969) and predictive assessment of Forced Vital Capacity (pocket spirometer) used in this study. Values for %BF once converted from HW body density values (Siri et al, 1961) would therefore have been more accurate. %BF calculated by Siri et al (1961) was used as the dependent variable in this study. HW and SKF values for Body Density were converted to a %BF value for comparison with the %BF values generated by the Futrex 5000. If Body Density had been used as the dependent variable then it may have lessened errors of prediction by enabling equations from multi-component body composition models to be used (Lohman, 1992).

The addition of the Ultrasound methodology as a predictor of subcutaneous fat thickness would have enabled investigation of the predictive accuracy of the SKF measurements. Also, the influence of compressibility on the measurements and the relationship between OD and Ultrasound measurements at upper and lower body sites could have been investigated. Fat thickness (Ultra) and Fat content (OD) at each site could then have been examined and possible protocol developed combining Ultrasound and Infrared methods for estimation of Fat composition in the population studied.

The regression equation reported used in this study to predict %BF from NIR may also be errorsome. Firstly , age was not used as an independent variable in the prediction of %BFFX despite being highly correlated with mean %BFFX values (r=.81, p<0.05). Secondly, Elia et al (1990) report that correcting OD values using the Optical Standard provided by the manufacturer has a negligible effect upon estimated %BFFX of less than 0.2% of body weight. These OD corrections were not made in the methodology of this study using the manufacturers equation but future research or a repeat of this study may yield more accurate data should these corrections be carried out.

In conclusion, this study found poor relationships between OD values and SKF thickness at upper and lower body sites. Lower body site were not better predicton variables of %BF than upper body sites. A combination of upper and lower body OD and SKF sites were found to give the best prediction of %BF in active adult males. Based on the strength of the statistical findings there was insufficient evidence to reject the null hypotheses. In general, lower body SKF and OD sites were not more highly correlated than upper body sites, except when related to HWFFM (See Table 6). The prediction equations developed did not include lower body sites exclusively or as the majority of predictor variables. In terms of predicting %BF the subscapula SKF site and the suprailiac OD2 values were found to be the best site predictor variables for %BF assessed by HW in the active male adults studied.

In terms of future research, this study should be repeated in a larger heterogenous population of active subjects using MRI as the criterion assessment of subcutaneous adipose tissue mass. Investigation of the relationship between OD and SKF thickness with an advanced imaging technique to assess actual thickness may generate stronger relationships between SKF and OD values.

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Appendix A - *Extended Review of Literature*

The field of body composition has witnessed the development of non-invasive techniques for the assessment and estimation of Body Fat (BF), Lean Body Mass (LBM) and other anthropometric components (Cohn, 1987). Many of these methods have developed from the initial work of Behnke in 1942 (Cohn, 1987). The underwater weighing density technique also known as Hydrostatic Weighing (HW) developed by Behnke (1942) assessed body density from which BF and LBM values could be calculated. This method is now used as the criterion method or 'gold standard ' in many body composition studies. Particularly those denied access to more accurate imaging procedures (Brodie, 1988) such as Magnetic Resonance Imaging (MRI) (Lukaski, 1987). Cadaver analysis is the direct method of body composition although its use is obviously limited to researchers with access to and expertise in the analysis of cadavers (Clarys et al, 1987). The HW method is therefore indirect and the use of HW for measuring %BF results in researchers accepting a standard error of estimate (SEE) of +/- 2.0 to +/- 2.8% body fat in the young adult population. This is partly due to variations in the water and mineral content of the Fat Free Mass (FFM) leading to errors in the interpretation of body density of 2% to 4% relative to the population studied (Lohman, 1992). All other indirect predictive protocols are therefore double indirect as they have developed as a result of the work of Behnke (1942) thereby enabling an estimation of %BF common with the value measured by HW (Cohn, 1987). These predictive protocols include such techniques as Ultrasound, Bioelectrical Impedence (BIA), Skinfold measurements (SKF) and Near Infrared

Interactance (NIR) (Lukaski, 1987).

The Ultrasound technique utilises high frequency ultrasonic energy which is transmitted into the body in short pulses. Ultrasound instruments can use imaging techniques to show tissue structure or depth of tissues, however this is an expensive method of estimating adipose tissue thickness in humans. Validity studies comparing ultrasound thickness values with skinfold thickness values at the triceps and subscapula sites have reported correlation coefficients of r=.80 (Lukaski, 1987).

Bioelectrical Impedance (BIA) involves the application of a 50 Khz alternating current to electrodes placed on the hand and foot of a subject. The portable analyser gives a value indicative of the resistance of the body (Gray, Bray, Gemayel & Kaplan, 1989). The use of BIA is accepted as a valid prediction of body composition in the general population (Oppliger, Nielsen, Shetler, Crowley & Allbright, 1992). This is not only due to its portability and relatively low expense but also its reliability (Baumgartner, Chumlea & Roche, 1989).

The Skinfold or 'Fatfold' method is a measure of a double layer of skin and its underlying subcutaneous adipose tissue (Harrison et al, 1988). They provide a relatively simple, non-invasive method of estimating general fatness (Harrison et al, 1988). Skinfold thickness values are used as prediction components in various body composition equation (Durnin & Womersley, 1974; Lohman 1981). These prediction equations use values from different combinations of sites as the predictive value of skinfold sites varies with some sites more related to overall body composition than other sites (Harrison et al, 1988).

Near Infrared Interactance is a relatively new method based upon the principles of light absorption and reflectance and is considered to be in a developmental stage (Lukaski, 1987). It has been suggested that NIR may be advantageous over the SKF method for assessing subcutaneous fat thickness as it does not involve skinfold compression (Lohman, 1992). Research based upon these suggestions has so far proved inconclusive (Houmard, Israel, McCannon, O'Brien, Omer & Zamora, 1991). To assess body composition a spectrometer and fibre optic probe are used to assess the composition of underlying tissues at the measurement site (Lukaski, 1987). This technique has been marketed as a valid predictor of body composition factors using the Biceps as a relative measure of body fat in conjunction with height, weight, age, sex and physical activity (Futrex Inc, 1988).

These indirect techniques predict the %BF content from the difference between total body mass (TBM) and lean body mass (LBM). They all vary in their predictive accuracy and are all dependent upon a number of basic assumptions made (Cohn, 1987).

The skinfold method requires a number of assumptions in the relationship between caliper measurements and prediction of body fat factors .

> "Subcutaneous fat constitutes a constant proportion of total body fat for all weight cohorts."
>
> (Clarys et al, 1987).

> "The sites of measurement are representative of all subcutaneous fat"
>
> (Clarys et al, 1987).

These two major assumptions apply even before any measurement assumptions are made. The validity of these assumptions had not been challenged until Clarys and co-workers (1987) examined the use of skinfold method using Cadaver Analysis as the criterion method.

The first assumption is that the compressibility of a double layer skinfold measurement is constant across all populations. This was not found to be constant by Clarys et al (1987) who showed several examples in their study demonstrating variability in skinfold compression. One such example included two male cadavers with dissected adiposities of 27.1% and 27.8% body fat. Although the difference in total adiposity of each cadaver was negligible (0.7%) the compressibility of caliper readings taken from each subject widely differed. This was assessed by comparing caliper readings with measures of subcutaneous adipose tissue thickness by direct incision (Clarys et al, 1987).

Skin thickness is assumed to be negligible or constant as a fraction of the skinfold thickness (Harrison et al, 1988). The findings of Clarys et al (1987) showed the greatest skin thickness, at the subscapula site, to represent an average of 28.1% of the subscapula skinfold reading . The subscapula is often used as one of the major skinfold sites (Durnin & Womersley, 1974; Lohman ,1981). The findings of Clarys et al (1987) suggest that the subscapula site may be responsible for a large proportion of the variance in prediction of %BF due to skin thickness.

The anatomical distribution of adipose tissue must also be considered when predictive measures at selected sites are taken using skinfolds or other non-invasive site based protocols such as Ultrasound or NIR. The anatomical distribution of subcutaneous adipose tissue is known to be extremely variable between individuals , particularly between sexes (Campaigne, 1990). This highlights the need for the correct number and distribution of measurement sites to obtain an accurate representation of the estimated adiposity. NIR and ultrasound have been criticised due to the dependence of these methods upon regional adiposity distribution to predict body fat (Lukaski, 1987). This dependence limits the use of NIR and Ultrasound in Heterogenous populations (Lukaski, 1987).

Several different protocols are used for body fat predictions by SKF measurements. The majority of these use prediction equations involving upper body sites to predict %BF such as Durnin and Womersley (1974). The question arises as to whether upper body sites, in particular those used in popular prediction protocols are the best predictors of %BF. The findings of Clarys et al (1987)disagree with the upper body measurement bias inherent in many %BF prediction formulae. They compared caliper and incision thicknesses with dissected subcutaneous adipose tissue as the dependent variable.

> 'An unexpected finding is the high correlation for lower limb sites. Of the six best sites all but one were on the lower limb. The triceps, a highly favoured site for fat prediction and sometimes considered the best single indicator of adipose tissue ranked a poor eleventh.'
>
> (Clarys et al, 1987).

Once the assumptions regarding the methodology of the SKF technique have been accepted certain other assumptions still remain. The chemical composition of adipose tissue itself and the relationship between external (subcutaneous) and internal adipose tissue compartments are assumed to be of a fixed proportion.

The chemical composition of adipose tissue itself is assumed to contain a fixed proportion of fat or the 'Ether extractable' component of adipose tissue. This 'ether extractable' component has been shown to increase as a proportion of adipose tissue as the level of adiposity increases, therefore not remaining constant as a proportion of adipose tissue across the general, heterogenous population (Clarys et al, 1987).

Variation in the level of hydration (Contarsy & Girandola, 1990) in the subject population may affect the estimation of the fat component of adipose tissue (Hewitt, Going, Haber, Lohman & Williams, 1990). This is particularly of relevance in subjects with diseases such as cancer as their specific changes in body composition particularly body water and LBM are not well understood (Cohn, 1987).

Although the SKF method is a very popular predictive measurement of %BF, there are a number of inherent assumptions in the methodology which may affect the accuracy of prediction. Despite the assumptions made in the SKF method, many workers have utilised it as a valid predictor of subcutaneous adipose tissue mass (Lohman, 1992). It is also useful for predicting total body density and %BF (Quatrochi et al, 1992) and as an estimation of general adiposity and subcutaneous adiposity patterning (Harrison et al, 1988).

The main use of SKF is as a comparative method with other popular predictive techniques such as NIR (Laverty, Paolone, O'Shea & Kendrick, 1989; Quatrochi et al, 1992). NIR vs SKF studies are common as both protocols involve specific site measurements, in essence different measures of the same factor, subcutaneous body fat (Heyward et al, 1992). This is as opposed to total body impedance (Oppliger, Nielsen, Shetler, Crawley & Allbright, 1992), total body density (Lohman, 1992) or more advanced imaging procedures such as Magnetic Resonance Imaging (MRI) (Lukaski, 1987). These other methods assess body composition factors in totally different ways to SKF or NIR.

NIR is investigated in this paper with regard to the actual Optical Density (OD) values generated and the possible use of measurement sites other than the one , mid-biceps, developed by the manufacturer (Futrex Inc, 1988). These OD values at other sites may provide a more accurate prediction of %BF than the SKF method. This may be because certain of the assumptions that the SKF method is based upon such as the fat content of subcutaneous adipose tissue at the SKF site and the level of hydration (Contarsy & Girandola, 1990) are alleviated. This is because OD values are indicative of the composition of the underlying tissues upto 4cm deep taking into account the relative fat, protein and water components (Futrex Inc, 1988). NIR is an objective measurement giving an OD value representative of the underlying tissues as opposed to the SKF method which gives a value for a compressed double fold of skin (Lohman, 1992).

The NIR method has developed from a technique used since 1965 to analyse the chemical composition of foodstuffs (Conway & Norris, 1987). It is based on the principle that the major components of foodstuffs (Langa, 1983) and therefore human tissues, namely protein, fat and water have specific absorption spectra of near infrared light (Conway & Norris, 1987). Different foodstuffs have different absorption and reflectance spectra and therefore different OD values according to the relative amounts of protein, fat and water they are composed of (Lohman, 1992). The smaller the OD value is then the greater the amount of fat as a proportion of the underlying tissues (Quatrochi et al, 1992).

NIR is not used exclusively as a method for predicting body composition factors, it has also been developed for more elaborate quantitative uses (Hirtz, 1993). For example, NIR has now been developed for the assessment of cerebral haemodynamics (Delpy & Ferrari, 1993). Some studies have examined cerebral blood flow in adults (Roberts et al, 1993) and new born infants (vanBel et al, 1993). As well as measuring fat tissues, NIR is used to examine muscular blood flow (Deblasi et al, 1994) as well as Oxygen saturation and availability in skeletal muscle (Sahlin, 1992). NIR monitoring of Haemoglobin and Cytochrome Oxidase has also proved useful in stroke patients (Hirtz, 1993).

The earliest work on human subjects using the NIR method was performed by Conway, Norris & Bodwell in 1984. They investigated the use of NIR as an estimation of subcutaneous fat thickness. %BF predicted by NIR was compared to a Deuterium Oxide dilution technique ($D^{2}0$), HW and SKF at five measurement sites namely Biceps, Triceps, Subscapula, Suprailiac and Mid-thigh. It was found that the NIR method correlated significantly with $D^{2}O$ ($r=.94, p<0.05$), HW ($r=.85$, $p<0.05$) and SKF ($r=.86$, $p<0.05$). The NIR method predicted %BF with the smallest standard error of estimate (SEE +/- 3.0%BF) compared to HW (SEE +/- 4.3%BF) and the SKF method (SEE +/- 4.4 %BF). The use of NIR was suggested to be a safe, non-invasive, rapid and useful prediction of %BF especially in obese subjects (Conway et al, 1984).

Conway et al (1984) used sophisticated spectrophotometry equipment in their work (Lohman, 1992). This experimental design has not been repeated with the same degree of accuracy since the initial work of Conway et al (1984) (Lohman, 1992). Since then the Futrex corporation (Gaithersburg, MD, USA) have developed two NIR devices, the Futrex 1000 and Futrex 5000, for the measurement of body fat claiming that both devices produce a valid prediction of %BF (Futrex Inc, 1988).

Many studies have investigated the validity of the Futrex 5000 NIR analyser to predict %BF (Haddock, Tan & Berk, 1990). A study by Israel et al (1989) attempted to determine the validity of NIR compared to a three site (SKF3) model and a seven site (SKF7) model (Jackson & Pollock, 1985) for predicting %BF in 80 caucasian males. HW was used as the criterion method of determining %BF from body density (Siri et al, 1961). NIR measurements were made at the mid- biceps SKF site (Futrex Inc, 1988) and correlated significantly with HW (r=.74, p<0.05) and estimated %BF with an SEE of +/- 7.5%BF. The SKF3 and SKF7 predictions were more highly correlated with HW (r=.86, p<0.05) and (r=.84, p<0.05) respectively. Israel et al (1989) concluded that the NIR method significantly underestimated %BF and criticised the manufacturers use of the mid-biceps as a measurement site for the population studied. However, this was contrary to suggestions from the findings of other workers (Dotson, Davis & Manny, 1988). It was suggested that the use of NIR may have been more valid if a multisite model was used (Israel et al, 1989).

Other cross-sections of the population have been tested using NIR. Laverty et al (1989) assessed a heterogenous population (16-61 years) comparing NIR and SKF predictions of %BF to HW evaluation of %BF using the same procedures as Israel et al (1989). It was shown that the relationship between NIR and HW values for %BF was more highly correlated in women ($r=.88$, $p<0.05$) than in men ($r=.78$, $p<0.05$). Compared to NIR, SKF prediction of %BF was more highly correlated to HW in both male ($r=.79$, $p<0.05$) and female subjects ($r=.90$, $p<0.05$). The relationship between %BF predicted by NIR and HW %BF values in women was slightly stronger than the between sexes correlation with HW%BF values ($r=.86$,$p<0.05$) (Laverty et al, 1989).

The use of NIR in female populations was examined across different levels of body fatness (Davis, vanLoan, Holly, Krstich & Phinney, 1989). Predictions of %BF and LBM using NIR were compared to HW values in lean (n=11; 15.9 +/- 2.2%BF; 45.3 +/- 3.2 Kg), normal (n=14; 24.2 +/- 2.9%BF; 46.9 +/- 5.9 Kg) and obese (n=11; 39 +/- 5.9%BF; 56.6 +/- 11.6Kg) female subjects. NIR prediction of %BF and LBM in normal (18.3 +/- 5.1%BF; 51.88 +/- 9.2Kg) and obese (29.1 +/- 4.5%BF; 64.4 +/- 10.4Kg) subjects were found to be significantly different to HW values. NIR predictions of %BF and LBM values in the lean female subjects (16.8 +/- 2.1%BF; 44.4 +/- 3.3Kg) were not significantly different from %BF assessed by HW. It was suggested that the use of NIR to predict %BF and LBM across a wide range of body compostion profiles was not recommended (Davis et al, 1989). These findings supported the suggestions of other workers that the NIR methodology is dependent upon regional adiposity for the prediction of body composition components (Lukaski, 1987). However, these suggestions were also contradictory to the earlier work of Conway et al (1984) inferring that NIR was a useful predictor of %BF, particularly in obese subjects.

In a study by Elia, Parkinson and Diaz (1990) NIR was compared to five other predictive methods of estimating %BF, Fat Mass (FM) and Fat Free Mass (FFM) (See Table 10). These were SKF (Durnin & Womersley, 1974), Impedance (Holtain Analyser UK), Resistance (Valhalla USA), BMI equations (Black et al, 1983) and Height / weight equations (Hume & Weyers, 1971). Criterion values of %BF, FM and FFM were obtained from body density measurements (Siri et al, 1961) using HW. NIR predictions of %BF were significantly different from the criterion ($p<0.001$). NIR had the largest between sexes SEE (+/- 3.88) and a between sexes correlation coefficient of ($r=.85$, $p<0.05$). This relationship was lower compared to impedance ($r=.89$, SEE +/- 3.27, $p<0.05$), SKF ($r=.88$, SEE +/- 3.44, $p<0.05$), resistance ($r=.89$, SEE +/- 3.27, $p<0.05$), BMI equations ($r=.88$, SEE +/- 3.41, $p<0.05$) and Height/weight equations ($r=.88$, SEE +/- 3.48, $p<0.05$). In the population studied, NIR had no advantage over the other contemporary methodologies used to predict body composition factors measured by HW (Elia et al, 1990)

Table 10: Correlation coefficients (r) and standard errors of estimate (SEE) for various predictive methods of %BF studied by Elia et al (1990).

Method	r	SEE (%BF)
Resistance	.92	2.12
Impedance	.91	2.31
BMI	.90	2.38
SKF	.90	2.40
W/H equations	.90	2.44
NIR	.90	2.47

Highly significant correlation coefficients were recently reported between %BFNIR and %BFHW (r=.91, p<0.05) and between %BFNIR and %BFSKF3 (r=.91, p<0.05) in a heterogenous population (n=51) (Haddock et al, 1990). %BF estimation by NIR was also found not to be significantly different from SKF3 or HW measures of %BF. However %BF prediction using NIR was found to be biased depending upon individual %BFHW. NIR predicted lower values for subjects with %BFHW values above the mean value. Conversly, %BF prediction by NIR was found to estimate higher values for subjects with %BFHW values below the mean %BFHW value. It was suggested from these findings that NIR should not be used for clinical purposes until further standardisation with other methods has been carried out (Haddock et al, 1990).

The influence of Physical Activity Level (PAL) determinants upon the Futrex 5000 NIR device using the manufacturers equation (Futrex Inc, 1988) was examined in a heterogenous population (n=125; 32.8 +/- 11.4 yrs)(Crews, Farley & Cobb, 1991). Previous work involving an all male population had found that PAL significantly enhanced the %BF estimation by NIR (Israel et al, 1989). Daily PAL level criteria used were those provided by the manufacturer (Futrex Inc, 1988) which were heavy (>60 mins per day; n=20), moderate (30-60 mins per day; n=48), light (15-30 mins per day; n=30) and other (<15mins per day; n=18). Multiple regression analysis was performed on the data including height, weight, age, PAL and biceps OD as independent variables and %BFHW as the dependent variable. Approximately 78% (r^2= .78, SEE +/- 4.26%BF) of the variance in %BFHW was due to the NIR biceps OD measurement indicating that only 68% of subjects would obtain an NIR prediction of %BFHW within 4.28%BF (Crews et al, 1991). The other variables (including PAL) did not significantly contribute to the variance in %BFHW compared to the biceps OD measurement (Crews et al, 1991). These findings do not add any support to suggestions that PAL should be omitted from NIR prediction equations as it is subjective, difficult to ascertain and extremely variable over time (Israel et al, 1989).

Davis and coworkers (1989) examined the use of NIR for measuring a population with widely different levels of body fatness. It was suggested that this method was not suitable for the prediction of %BF and LBM (Davis et al, 1989). Recent work has been carried out using a subject group of different body fat ranges (Brodie & Eston, 1992). Slightly obese females (n=25, 35.6 +/- 6.85%BF), athletic adults (n= 34, 19.9 +/- 7.2%BF) and normal children (n=22) were tested using NIR, BIA and HW. NIR prediction of %BF showed no mean group difference compared to %BFHW in all three groups tested and produced reasonable correlations with BIA prediction values for slightly obese females (r=.83) and athletic adults (r=.79) (Brodie & Eston, 1992). NIR was suggested to be a valid alternative, allowing for limitations, to HW. It was also suggested to be advantageous in studies involving epidemiological fieldwork were more elaborate and more accurate methodologies may prove impractical (Brodie & Eston, 1992).

Nielsen and coworkers (1992) examined the within-day and between-day reliability of the NIR method in 34 adult male subjects (28-53 years). NIR showed excellent between-day and within-day reliability. No significant mean differences between between %BFNIR and %BFHW, and high intermethod correlation coefficients (r=.83) suggested good measurement agreement. This supported the findings of previous workers (Conway et al, 1984; Dotson et al, 1988; Dotson & Davis, 1992; Brodie & Eston, 1992).

Crews and coworkers (1991) investigated the influence of PAL in the Futrex 5000 prediction equation. Use of another variable, BMI, instead of height and weight data in the Futrex 5000 equation was shown to improve %BF prediction in females from 71% to 83% of the variance in body fat (McClean & Skinner, 1992). Variance due to the substitution of BMI into the prediction equation for males (83%) did not improve the variance when height and weight were used as variables. SKF were more significantly correlated with HW (r=.94, SEE +/- 4.8%BF) than NIR (r=.81, SEE +/- 2.7%BF)(McClean & Skinner, 1992).

A summary of recent validity studies are illustrated in Table 11 showing correlation coefficients with the criterion method and SEE values for each of the studies (See Table 11 below).

Table 11: Summary of recent NIR validity studies (1984-1992).

Authors	r	SEE	Subjects used
Conway et al (1984)	.81-.94	3.0	53 men and women (23-65yrs)
Israel et al (1989)	.74	7.5	80 Caucasian males (26 +/- 10.2 yrs)
Laverty et al (1989)	.86	----	113 males & females (16-61 years)
Elia et al (1990)	.90	2.47	29 males & females (18-45 years)
McClean & Skinner (1992)	.81	4.8	61 males & females (18-45 years)
Nielsen et al (1992)	.83	4.2	34 caucasian males (28-53 years)

A similar study supported the findings of Davis and coworkers (1989) by suggesting that NIR is not suitable for estimations of %BF in obese women

(Heyward et al, 1992). %BF in obese subjects (>30 %BF; n=71) and non-obese subjects (<30 %BF; n=77) was predicted using NIR (Futrex Inc, 1988), BIA (Valhalla) and SKF (Jackson, Pollock & Ward, 1980). In the non-obese female subjects, no significant difference was shown between values of %BFHW compared with %BFSKF (r=.65, SEE +/- 3.4%BF), %BFBIA (r=.61, SEE +/- 3.6%BF) and %BFNIR (r=.58, SEE +/- 3.7%BF). Data for obese female subjects showed significant underestimations by the predictive methods with total errors ranging from 5.6% to 8.0%BF (Heyward et al, 1992). Previous work supports these findings as individual %BF values above mean %BF values were underestimated (Haddock et al, 1990). Heyward and co-workers (1992) concluded that NIR accurately estimated %BF for non-obese females but was not accurate in its estimation of %BF in the obese female population. These conclusions were contrary to earlier work describing the NIR method as particularly useful in the prediction of %BF in obese subjects (Conway et al, 1984). However, the NIR methodologies used in the two studies (Conway et al, 1984; Heyward et al, 1992) were widely different in terms of predictive accuracy as the work of Conway and coworkers (1984) has not since been replicated using the same equipment (Lohman, 1992).

Table 12: Comparison of %BF data in obese subjects taken from Davis et al (1989) and Heyward et al (1992).

Author	Mean %BFNIR	Mean %BFHW
Davies et al (1989)	39.0 +/- 5.9%	29.1 +/-4.5%*^
Heyward et al (1992)	36.9 +/- 4.2%	30.4 +/- 3.7% *

Table 12 shows the data for obese subjects comparing the findings of Davis et al (1989) and Heyward et al (1992). Both studies (Davies et al, 1989; Heyward et al, 1992) clearly show data that suggests the present NIR methodology is not suitable for estimations of %BF in subjects of extreme levels of adiposity.

Despite these suggestions (Davis et al, 1989; Heyward et al, 1992) the body composition of obese subjects has been estimated using NIR (Futrex 5000) in the clinical setting (Kamrath, Plummer, Sadir & Weinstein, 1992). This study utilised the Futrex 5000 to estimate body composition in 11 obese patients (BMI >30) who were placed on a very low calorie diet (VLCD). Patients showed %BF reductions from a mean %BF of 31.3% (+/- .75%BF) to 24.9% (+/- 1.2%BF). %BF prediction using NIR estimated a mean difference in %BF reduction of 6.4% (+/- .5%BF). According to previous authors (Davies et al,1989; Heyward et al, 1992) the use of NIR is not suitable for this population (obese subjects). The data and methodology of Kamrath and coworkers may therefore be questionable.

The use of NIR in another clinical setting involved the estimation of Total body fat (TBF) in full term infants. This involved an investigation of the relationship between skin thickness measured by SKF and ultrasound compared with NIR values (Kabir & Forsum, 1993). NIR values for adipose tissue thickness were only correlated with subcutaneous adipose tissue thickness (SAT) when SAT values were lower. The values obtained by NIR were not shown to be valid estimates of SAT in infants and the NIR device was suggested to require improvements before it could be used to study the body composition of infants more accurately (Kabir & Forsum). This study illustrates clearly that NIR may require further standardisation with currently accepted methods before it should be applied to the clinical setting (Haddock et al, 1990).

However, much of the criticism directed at the use of the Futrex 5000 NIR spectrometer is to do with the use of the mid-biceps as the single predictor of %BF. As mentioned previously it has been suggested that NIR estimations of %BF may be more accurate if multisite models were used (Israel et al, 1989). These suggestions have been followed up by the examination of the validity of using single and multisite models for estimating Body density (BD) (Heyward et al, 1992) and %BF (Hicks et al, 1991; Quatrochi et al, 1992).

The relationship between SKF and OD measurements at nine anatomical sites (pectoral, midaxillary, biceps, triceps, subscapula, abdominal, suprailiac, thigh and medial calf) were examined across age groups (20-72 yrs) and levels of body fatness in female subjects (Hicks et al, 1991). In subjects of low body fat significant positive correlations were found at all sites (r=.41 - r=.70) except thigh (r=.12), triceps (r=.30) and calf (r=.16). Correlations were lower at all sites (r=.14 - r=.57) in subjects with medium body fat and very low, negative relationships were found for six of the nine sites in Obese subjects (Hicks et al, 1991). OD was shown to discriminate between levels of body fatness as average OD values increased across levels of body fatness (Hicks et al, 1991).

Pectoral, biceps and abdominal OD values were found to differ significantly with age. The mean OD value at each of these three sites was found to increase with age indicating lower body fat values for younger (20-29 and 30-39yrs) groups at the three sites (Hicks et al, 1991).

The relatively low correlations between OD and SKF was suggested to be due to the fact that OD values may also be representative of intramuscular fat in addition to subcutaneous adipose tissue composition (Hicks et al, 1991). This suggestion is supported by the manufacturers claims that the Futrex 5000 spectrometer (Futrex Inc, 1988) measures upto 4cm depth but how consistently it measures at 4cm depth may vary. In line with much of the previous work on NIR, the findings of Hicks et al (1991) suggested that OD values should not be used to assess %BF of obese subjects (>30%BF).

Two NIR models, both multisite and single site, for the prediction of BD were investigated by Heyward et al (1992). %BF was later calculated using the %BF equation of Brozek et al (1963). The single site model used the manufacturers equation (Futrex Inc, 1988) including Biceps ODs, height, weight, age, gender and PAL. The multisite model used the sum of two OD measurements (Biceps OD and Pectoral OD), age, height, weight and PAL as potential predictors. Biceps and Pectoral measurement sites were included in the multisite model as they were the only sites to contribute significantly to the variance in BD after analysis of ten anatomical measurement sites (Heyward et al, 1992).

No significant differences were found between HWBD and predicted BD using the various models. It was found that both multisite and single site models were valid to assess female body composition (Heyward et al, 1992). When age was added as a potential predictor in the manufacturers equation the share in variance (83%) was improved (86%) and the SEE (4.1%BF) was reduced (3.1%BF) significantly. Further investigation into the use of multisite models on male subjects and across variations in body composition in male subjects are required for validation in this population.

Similar findings to the work of Hicks et al (1991) were reported by

Quatrochi et al, (1992) also investigating the use of multisite NIR models using female subjects. In line with the work of Hicks et al (1991) they examined the effects of age and level of body fatness. It was found that the relationship between the SKF measurements and OD values generated was stronger in younger, leaner women than in older, fatter women (Hicks et al, 1992; Quatrochi et al, 1992).

A recent study by Guest (1994) involving a multisite NIR model found that the multisite model correlated significantly (r=.86, p<0.05) with the criterion value of %BF when compared with the single site manufacturer (Futrex Inc, 1988) assessment (r=.92, p<0.05). These values were compared to the criterion method of SKF rather than HW, the accepted criterion method. Use of HW in this study would have produced a much more valid reference value.

Due to the criticism directed at the biceps site (Israel et al, 1989; Davis et al, 1989) the actual OD values and their relationship with SKF values was investigated. Israel et al (1989) examined all predictors of %BF used in the manufacturers equation (Weight, height, age, gender, physical activity level). It was found that the biceps OD accounted for the largest share in variance (58%) in the estimation of %BF (Israel et al, 1989). Other studies have found that the Biceps OD accounted for 77% of the variance in %BF prediction (Crews et al, 1991). The lower the OD value is, then the larger the prediction value of subcutaneous fat generated by the Futrex 5000 (Quatrochi et al, 1992). As the Futrex 5000 is claimed to measure upto 4cm deep into subcutaneous tissues it is suggested by the manufacturer to be a good estimation of subcutaneous and intramuscular fat (Futrex Inc, 1988). This suggestion, although feesible in principle, has not been researched and would probably require cadaver analysis for validation.

In this review the main contentious issues concerning the use NIR and SKF have been examined. There are a number of assumptions fundamental to the SKF method which affect its accuracy (Clarys et al, 1987). NIR (Futrex Inc, 1988) is accepted as a valid predictor of %BF in populations of lean and normal %BF ranges (Brodie & Eston, 1992). NIR may overpredict in lean subjects and underpredict in obese subjects (Haddock et al, 1990). NIR is not recommended as a clinical estimation of %BF in obese (Davis et al, 1989) although some workers suggest that it is acceptable (Conway et al, 1984; Dotson et al, 1988; Dotson & Davis, 1992). The OD values generated by Futrex 5000 discriminate between different %BF values (Hicks et al, 1991). The use of multisite NIR models may significantly improve the predictive accuracy and validity of NIR estimations of %BF (Heyward et al, 1992; Quatrochi et al, 1992).

The findings of Clarys et al (1987) showed that lower body SKF sites were more highly correlated to total subcutaneous adipose tissue than upper body sites in cadavers. These findings may possibly be applied to the use of OD and the strength of the relationship they may have with total body fat. Although thigh OD was shown to be poorly correlated to SKF measures (Hicks et al, 1991; Heyward et al, 1992; Quatrochi et al, 1992) the use of OD as a replacement measure to SKF or in combination with SKF has not been investigated. However, the work of investigators using multisite models was biased towards examination of upper body sites rather than equal numbers of upper and lower body sites (See Table 13 overleaf).

Clarys et al (1987)	Quatrochi et al (1992)	Heyward et al (1992)	Present Study (1994)
pectoral	pectoral	pectoral	-------
midaxillary	midaxillary	midaxillary	-------
biceps	biceps	biceps	biceps
triceps	triceps	triceps	triceps
subscapular	subscapular	subscapular	subscapular
abdominal	abdominal	abdominal	abdominal
suprailiac	suprailiac	suprailiac	suprailiac
-------	-------	anterior suprailiac	-----------
thigh	thigh	front thigh	front thigh
--------	---------	medial thigh	medial thigh
---------	---------	rear thigh	rear thigh
---------	----------	suprapatella	suprapatella
medial calf	medial calf	medial calf	medial calf

Table 13: Comparison of Multisite body composition studies

As table 13 (above) shows, the multisite studies were heavily weighted in favour of upper body site investigation.

This study had two aims. Firstly, to investigate OD and SKF relationships at ten anatomical measurement sites. Secondly, multisite analysis using OD to determine if other OD sites may contribute more significantly to NIR prediction of %BF than the current manufacturers recommendation of the mid-biceps. This study investigated the relationship between OD and SKF measurements in a similar way to the work of Quatrochi et al (1992) but instead male subjects were used. It also involved multisite OD measurements similar to the protocol of Heyward et al (1992) but using an equal number of upper and lower body sites rather than a bias towards either upper or lower body sites.

Appendix B - *Additional Methodology*

This study investigated the relationship between OD values and SKF measurements rather than the %BF prediction that the Futrex 5000 calculates as in NIR validity studies (Elia et al, 1990). In order to program the microprocessor to display OD values the microprocessor was switched on at which point the digital display counted down from 15 to 1. By typing 'Clear 881' and pressing 'Enter' the LCD displayed 'OD1'. The light wand was then ready to measure two OD values for each site at 940 nm (OD1) and 950nm (OD2) infrared wavelengths.

A light shield was placed over the light wand to eliminate excess light interference and the light wand was placed upon the marked measurement site with the pressure of a firm handshake. By pressing 'enter' the Futrex 5000 measured OD1 whilst a decimal point flashed on the LCD. The light wand was removed for several seconds and then reapplied with equal pressure ready to measure OD2. By pressing 'enter' a second time, the second OD value (OD2) was taken and again the flashing decimal place indicated this process. Once both measurements were made they then flashed alternately on the LCD for several seconds at a time. 'OD1' was displayed prior to the OD1 value and likewise 'OD2' was displayed prior to the value for OD2. For further information on the Futrex 5000 consult the Futrex 5000 users manual (Futrex Inc, 1988).

Appendix C - *Additional Results.*

Table showing test-retest data for SKF and OD measurements.

	SKF Test		Retest		
	M	SD	M	SD	r
Biceps	5.2	1.07	5.4	1.16	.97
Triceps	8.4	1.76	8.1	1.54	.99
Subscapula	10.7	1.75	10.2	1.81	.99
Suprailiac	9.0	2.98	9.5	2.74	.94
Abdominal	12.3	1.87	12.6	1.66	.98
Front thigh	11.1	2.97	11.2	3.01	.96
Medial thigh	8.3	2.87	8.8	2.46	.94
Rear thigh	4.4	1.77	3.9	1.84	.91
Suprapatella	10.6	3.77	10.9	3.51	.91
Medial Calf	7.2	3.09	7.8	2.89	.95

All r values were significant at the $p<0.05$ alpha level.

Table showing test -retest data for OD values at all sites.

	OD1					OD2				
	Test		Retest		r	Test		Retest		r
	M	SD	M	SD		M	SD	M	SD	
Biceps	1.0792	.014	1.0689	.023	.96	1.1103	.073	1.1001	.069	.91
Triceps	1.0131	.128	1.0165	.127	.88	1.0408	.122	1.0453	.102	.82
Subscapula	1.0427	.118	1.0500	.117	.93	1.0930	.098	1.0889	.090	.89
Suprailiac	1.0154	.083	1.0224	.073	.77	1.0540	.081	1.0407	.073	.84
Abdominal	1.0498	121	1.0608	.111	.96	1.0962	.119	1.0841	.110	.92
Front thigh	1.0271	097	1.0282	092	89	1.0578	.092	1.0593	.088	.80
Medial thigh	1.0362	.083	1.0388	.077	.91	1.0649	.084	1.0601	.079	.87
Rear thigh	1.0099	.111	1.0262	.096	.68	1.0395	.096	1.0516	.089	.71
Suprapatella	1.0315	082	1.0436	.075	96	1.0647	.088	1.0526	.081	.84
Medial calf	1.0605	.088	1.0669	.092	.85	1.0880	.084	1.0857	.076	.91

All r values were significant at the p<0.05 level.

Appendix D - *Additional materials.*

(i) -Data Sheets

(ii) - Sample Consent Form

CHESTER COLLEGE
DEPARTMENT OF PE & SPORTS SCIENCE

INFORMED CONSENT FORM

he following information is provided for all persons taking part n testing carried out by Chester College personnel.

. Chester College Dept of PE & Sports Science carries out testing of human performance for individuals and groups. Its objectives are to enhance performance, aid coaching and training and to add to the body of scientific knowledge of sport.

. The procedures and details of the tests may vary. Subjects may ask questions related to tests and procedures.

. Subjects are free to withdraw consent at any time without prejudice

. Subjects have the right to decline answering questions in questionnaires.

. Data derived from testing will be held by Chester College and no individual data will be submitted to a third party although group data may be imparted.

. Subjects are obliged to inform the tester of any condition that may prevent the subject from taking part in the tests , eg injury or illness.

. The tests may involve some physical activity and therefore subjects take part at their own risk and Chester College can accept no liability for anything that may occur as a result of this activity.

I have read the above and understand the statements contained within this form and freely consent to tests carried out by Chester College Personnel.

FULL NAME(block capitals)........................

SIGNATURE.................... DATE ....

BODY COMPOSITION DATA COLLECTION SHEET.

Date:

Name:

Age:

Height (M):

Weight (KG):

Physical Activity Level:

Sex:

Underwater Weights:						
Residual Volume:			**G.I.G:**			
Body Density:			**% Body Fat:**			

	Skinfolds:	**Futrex:**
Mid-Biceps:		
Mid-Triceps:		
Subscapularis:		
Suprailiac:		
Abdominal:		
Front Thigh:		
Medial Thigh:		
Mid-Rectus Femoris:		
Suprapatellar:		
Medial Calf:		

1.067	1.074	181	75	22.8	22	13.9	9.61	13.91	64.57	10.43
1.069	1.069	180	76	23.4	23	13	11.75	14.04	66.12	9.88
1.07	1.0697	180	81	25	23	12.62	11.76	14.97	70.78	10.23
1.066	1.0647	185	85	24.8	21	14.35	13.917	18.96	72.8	12.2
1.07	1.0655	178	79	24.9	22	12.62	13.48	17.08	69.03	9.97
1.058	1.065	177	75	23.9	19	17.86	13.48	15.34	61.6	13.4
1.061	1.0671	184	80	23.6	20	16.54	11.75	14.66	66.77	13.23
1.056	1.06398	181	80	24.3	19	18.75	14.22	14.25	65	15
1.043	1.0562	178	110	34.7	22	25.08	17.06	21.82	82.5	27.59
1.068	1.0611	180	85	26.2	26	13.48	14.57	15.435	73.54	11.46
1.048	1.0599	185	88	25.73	23	22.32	17.03	17.19	73.02	14.99
1.059	1.0648	167	67	24.1	25	17.4	14.87	13.57	57.04	9.96
1.066	1.0688	170	68	23.18	22	14.27	13.14	13.02	59.15	8.85
1.063	1.0707	181	78	23.81	20	15.66	12.31	14.68	65.79	12.21
1.064	1.0688	176	73	23.56	20	15.22	13.14	14.69	61.56	11.44
1.062	1.068	183	79	23.58	21	16.1	13.48	13.07	66.28	12.72
1.056	1.0647	181	83	25.34	21	18.75	14.92	14.13	67.44	15.56
1.046	1.0532	178	84	26.49	34	23.46	20.39	15.67	64.3	19.71
1.058	1.0647	168	69	24.46	26	17.69	14.92	14.02	56.8	12.21
1.061	1.0599	184	84	24.77	22	16.54	17.02	14.4	70.11	13.89
BDHW	BDSKF	Height	Weight	BMI	Age	%BFHW	%BFSKF	%BFFX	HWFFM	HWFM