Estimation of body composition in Chinese and British men by ultrasonographic assessment of segmental adipose tissue volume

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It has been shown that ultrasonographic measurements can be used to predict body composition in adults. The purpose of this study was to assess the relationship between ultrasonograph and caliper (SKF) measurements of subcutaneous adipose tissue thickness in athletic Caucasian (English, E) and Asian (Chinese, C) men against estimates of body composition determined from hydrodensitometry (HYD). The usefulness of a proposed ultrasonographic method of estimating lean and fat proportions in the upper and lower limbs was also evaluated as a potential method of predicting body composition. Ultrasonography (US) was used to measure adipose and skin thickness at the following sites: biceps, triceps, subscapular, suprailiac, abdominal, pectoral, thigh and calf. Caliper measurements were also made at the above sites. Subcutaneous fat thickness and segmental radius were measured directly from the display screen of the ultrasonic scanner (Aloka 500 SD). By applying the geometry of a cone, the proximal and distal radii of the upper arm and upper leg were used to calculate the proportionate volumes of adipose tissue. The best correlations for US and SKF were obtained at the quadriceps, subscapular and pectoral sites for E ($r = 0.96$, 0.93 and 0.90 , respectively) and at the quadriceps, calf and abdominal sites for C ($r = 0.90$, 0.81 and 0.75 , respectively). The best ultrasonographic predictor of the percentage fat in both groups was the percentage adipose tissue volume in the upper leg ($r = 0.83$ and 0.79 for C and E, respectively). The proportion of adipose tissue in the upper arm segment was not a good predictor in either group ($r = 0.48$ and 0.55 for C and E, respectively). Stepwise multiple regression analysis indicated that the prediction of percentage fat was improved by the addition of the ultrasonographic abdomen measurement in both groups: Chinese sample: $\%fat = \%fat_{leg} (0.491) + US\ abdomen (0.337) + 0.95$ ($R = 0.89$, $s.e.e. = 1.9\%$); English sample: $\%fat = \%fat_{leg} (0.435) + US\ abdomen (0.230) - 0.765$ ($R = 0.80$, $s.e.e. = 3.6\%$). It is concluded that ultrasonographic measurements of subcutaneous adipose tissue and volumetric assessment of percentage adipose tissue in the thigh are useful estimates of body composition in athletic English and Chinese males.

Keywords: Body composition, ultrasound, adipose tissue volume

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The use of ultrasonographic techniques to assess body fat thicknesses has been investigated previously in normal adults¹⁻¹¹. In general, it has been shown that ultrasonographic measurements correlate highly with skinfold thicknesses, although it appears that ultrasonography (US) provides a better estimate of actual subcutaneous fat thickness⁷. It is therefore generally agreed that the two techniques can be used on normal populations with equal accuracy. Ultrasonography has also been used to assess subcutaneous fat thickness in obese individuals. It is reported that the ultrasonographic technique is superior to the caliper technique for measuring fat in obese persons^{12, 13}.

The sites which appear to provide the best ultrasonographic prediction of body density in normal adult males are the quadriceps, subscapular and suprailiac sites⁷. It has also been demonstrated that ultrasonographic measurements of quadriceps combined with biceps provides the best prediction of body density in obese subjects^{12, 13}. To our knowledge, there are no studies which have used US to assess body composition in physically active Chinese and English samples.

The purpose of this study was to assess the relationship between ultrasonograph and caliper measurements in a physically active Caucasian (English) and Asian (Chinese) group of men and to assess the validity of using ultrasonographic measurements for predicting percent body fat in the two ethnic groups. In addition, the validity of ultrasonographic measurements of lean and adipose tissue volumes in the upper and lower limbs was explored as a potential method of predicting body composition in the two ethnic groups.

Methods

Subjects were 25 Chinese and 13 English men. The Chinese subjects were practising physical education teachers in Hong Kong. The English group comprised rugby union players from the Hong Kong first division. Descriptive statistics of both groups are shown in Table 1.

Body density was estimated by the hydrodensitometric technique (Figure 1). Percentage body fat was

Table 1. Physical characteristics of the English and Chinese groups

Physical characteristic	Chinese (n = 25)	English (n = 13)
Age (years)	36.2(3.8)	31.1(5.5)
Height (m)	1.71(0.04)	1.81(0.07)
Mass (kg)	66.3(7.6)	84.7(11.1)
%Fat	16.1(4.0)	14.9(5.6)
Fat-free mass (kg)	56.5(5.5)	72.0(8.4)

Values are mean(s.d.)

estimated by the equations of Brozek *et al.*¹⁴. Residual lung volumes (RV) were predicted by regression equations which were specific to each ethnic group. The equation of Goldman and Becklake¹⁵ was used to predict residual lung volume in the English group, while for the Chinese group the equation of DaCosta¹⁶ was used:

$$RV = 2.7 \text{ stature (m)} + 0.017 \text{ age (years)} - 3.45 \text{ (Goldman and Becklake}^{15})$$
$$RV = 0.0116 \text{ age} + 0.0447 \text{ stature (cm)} - 0.0167 \text{ mass (kg)} - 5.392 \text{ (DaCosta}^{16})$$

Ultrasonographic measurements were carried out using a portable ultrasonic scanning machine (Aloka SSD-500 Scanner, Keymed, Southend-on-Sea, UK) and a curvilinear 5-mHz probe. A stand off gel block was used coupled with transmission gel. Measurements of adipose and skin thicknesses were made on the right side of the body at the following sites: biceps, midpoint of the muscle belly on the anterior aspect of the arm; triceps, midpoint between the acromion and olecranon processes on the posterior aspect of the arm; subscapular, inferior angle of the scapula; suprailiac, midaxillary line immediately superior to the iliac crest; abdominal, 3 cm lateral to the midpoint of the umbilicus; pectoral, mid line

Figure 1. Underwater weighing system showing subject in fully immersed position

between acromion process and nipple; quadriceps, anterior aspect of the thigh midway between inguinal fold and the midpoint of the patella; calf, medial aspect of the calf at the level of maximal girth. All ultrasonographic measurements were taken with the subject in the prone position for posterior measurements and the supine position for anterior measurements. Calipers (Holtain, Crosswell, Crymch, UK) were also used to measure skinfold thickness at each of the ultrasonographic sites. Two measurements were taken at each site and if the difference between the two was greater than 2 mm, a third measurement was taken. The mean of the two measurements was used as the representative value for each site. The specific sites were as recommended by Harrison *et al.*¹⁷.

Subcutaneous fat thickness and segmental radii were measured directly from the transverse cross sectional ultrasonographic images, obtained using the integral measuring calipers with a track ball device (Figures 2 and 3). By applying the geometry of a cone, the proximal and distal radius of a segment of the upper arm (a 10-cm cone taken from the crease of the elbow) and the upper leg (a 20-cm cone from the mid-thigh toward the patella) was used to calculate

Figure 2. The Aloka 500 SD portable ultrasonic scanner

Figure 3. Ultrasonographic image of transverse section of the femoral region; showing quadriceps components (REC F, rectus femoris; VAS I, vastus intermedius; ++, skin and adipose tissue layer; x x, skin, adipose and muscle layer). Caliper markers (x) measure distance from skin surface to bony cortex of femur

the proportionate volume of subcutaneous adipose tissue ($(\text{adipose volume}/\text{total volume}) \times 100$) in these segments. Total volume of each segment was calculated from the formula:

$$0.33 l (P + D + (\sqrt{PD}))$$

where: l is the length of the truncated segment (cm) and P and D are the proximal and distal cross-sectional areas, respectively.

Inner cone volume (muscle + bone) was calculated by subtracting the proximal and distal subcutaneous adipose tissue thickness from the proximal and distal radius of the outer cone. Skin thickness (1 mm) was accounted for in all cases. Circumferences were also measured at the proximal and distal landmarks of the thigh and upper arm with a Gulick anthropometric tape, with the subject in the anatomical zero position. This permitted an additional estimation of outer cone volume. This was used in combination with the ultrasonographic measurement of subcutaneous adipose tissue thickness to calculate a segmental percentage adipose tissue volume. All segmental volumes and percentage adipose tissue calculations were computed by a simple GWBASIC program written by the authors.

Results

The physical characteristics of each group are shown in Table 1. The Chinese sample was slightly older, shorter and lighter than the English group. The small differences in percentage fat between the two groups were not significant.

With the exception of the biceps in the Chinese group, all measurements of fat thickness made by the ultrasonographic technique correlated significantly ($P < 0.01$) with their respective skinfold measurements in both English and Chinese groups (Table 2). The best correlations between ultrasonographic and

Table 2. Results obtained from the ultrasonographic and caliper techniques in the English and Chinese groups

Site	Caliper (mm)*	US (mm)*	Correlation (r)
English Group (n = 13)			
Biceps	6.4†(4.0)	4.2(1.4)	0.88
Triceps	12.4†(4.9)	5.6†(1.9)	0.84
Subscapular	14.5(5.4)	6.9(2.0)	0.93
Suprailiac	16.1(8.5)	8.1(3.7)	0.64‡
Pectoral	8.3(3.3)	6.8(3.1)	0.90
Abdominal	19.0(7.3)	13.1(5.9)	0.82
Thigh	18.3†(8.7)	8.7†(3.4)	0.96
Calf	11.1†(5.9)	6.2†(2.1)	0.69
Chinese Group (n = 25)			
Biceps	4.6(1.4)	3.9(1.4)	0.13§
Triceps	7.9(2.6)	4.2(1.3)	0.74
Subscapular	12.7(4.3)	6.4(1.6)	0.75
Suprailiac	14.1(6.1)	8.6(2.6)	0.71
Pectoral	7.5(3.0)	5.8(1.7)	0.75
Abdominal	16.1(6.7)	10.3(4.3)	0.76
Thigh	10.8(4.0)	6.4(1.9)	0.90
Calf	7.3(2.3)	4.7(1.1)	0.81

*Values are mean(s.d.). †Significantly higher ($P < 0.05$) than Chinese values. All correlations were significant at $P < 0.01$ except ‡ $P < 0.05$ and §n.s.

Table 3. Correlation of measurements made with US, with percentage fat (as determined by hydrodensitometry) in the English and Chinese groups

US measure	Chinese (n = 25)	English (n = 13)
% Adipose tissue volume (Thigh) (US _{rad})	0.79	0.83
% Adipose tissue volume (Thigh) (US _{circ})	0.77	0.68
% Adipose tissue volume (Arm) (US _{rad})	0.55	0.48
% Adipose tissue volume (Arm) (US _{circ})	0.46	0.50
Triceps	0.66	0.52
Biceps	0.65	0.02
Subscapular	0.50	0.64
Pectoral	0.65	0.74
Abdominal	0.73	0.71
Suprailiac	0.74	0.59
Thigh	0.75	0.75
Calf	0.44	0.73

Critical values of r for $n = 13$ at $P < 0.01$ and $P < 0.05 = 0.66$ and 0.53 , respectively. Critical values of r for $n = 25$ at $P < 0.01$ and $P < 0.05 = 0.50$ and 0.39 , respectively. US_{rad} percentage fat volume was determined directly by subcutaneous adipose thickness and radius measurements taken directly from the ultrasonic scanner. US_{circ} percentage fat volume was determined from circumference measurements in combination with subcutaneous adipose thickness measured on the ultrasonic scanner.

skinfold measurements were obtained at the quadriceps, subscapular and pectoral sites for the English group. For the Chinese group, the best correlations were also obtained at the quadriceps, with the next highest correlations being obtained at the calf and abdominal sites. As expected, all ultrasonographic measurements were significantly lower ($P < 0.01$) at each site.

The best ultrasonographic prediction of percentage fat in both groups was the percentage adipose tissue volume obtained at the thigh (Table 3). Specifically, this method involved measurement of cross-sectional radius obtained directly from the ultrasonographic image (US_{rad}; $r = 0.83$ and 0.79 for the Chinese and English groups, respectively). The circumferential-ultrasonographic method (US_{circ}) also correlated significantly, although not as highly in both groups. Fat volume estimations in the upper arm, by both ultrasonographic techniques, were poor predictors in both ethnic groups.

The data were also subjected to stepwise multiple regression analysis. It was revealed that the prediction of percentage fat was improved by the addition of abdominal ultrasonographic measurement in both groups:

Chinese sample: %fat = %fat_{leg} (0.491) + US abdomen (0.337) + 0.95

English sample: %fat = %fat_{leg} (0.435) + US abdomen (0.230) – 0.76

The multiple correlations (R) and standard error of estimates (s.e.) for the above equations were R (s.e.) = 0.89 (1.9%), and 0.80 (3.6%) for the Chinese and English groups, respectively.

Correlations for US_{rad}: US_{circ} were high for both groups (Table 4), although repeated measures t test revealed that all US_{circ} values were significantly lower ($P < 0.01$).

Table 4. Results for segmental percentage adipose tissue volume as determined by two methods: (1) using ultrasonographic cross-sectional radii measurements at proximal and distal sections (US_{rad}); and (2) using segmental circumferences in combination with ultrasonographic measurements to determine fat volumes (US_{circ}) in the English and Chinese groups

	% Fat (US _{rad})*	% Fat (US _{circ})*	Correlations (r)
<i>English Group (n = 13)</i>			
Upper arm	17.8(2.8)	15.7(3.0)	0.92
Upper leg	29.1(7.6)†	18.4(5.5)†	0.97
<i>Chinese Group (n = 25)</i>			
Upper arm	17.0(2.9)	15.8(2.5)	0.93
Upper leg	24.4(4.9)	15.3(3.3)	0.96

*Values are mean(s.d.); †Significantly higher ($P < 0.05$) than Chinese values; all US_{rad} values are significantly higher ($P < 0.01$) than US_{circ} values

Discussion

In general the estimation of fat thickness by US correlated well with the respective skinfold measures. It is notable that the correlations were generally higher (with the exception of calf and suprailiac) in the English group. The correlations tend to agree with previous investigations which have used Caucasian men as subjects^{5,7}. With the exception of the suprailiac and calf, the correlations exceeded 0.70. The small differences in the magnitude of correlations between this study and the above studies may be partly explained by the relatively greater degree of homogeneity in the present sample. Subjects in this study were regular participants in physical activity. For example, the variability of the suprailiac for both ultrasonographic and caliper measurements in the study by Weits *et al.*⁷ was substantially greater than in the English sample in the present study, which may account for the higher correlation obtained at these sites.

There are no studies of ultrasonographic body composition techniques in Chinese subjects. It would appear that the above observation of greater relative homogeneity is particularly prominent in the Chinese sample. It can be seen that this group was characterized by a high level of homogeneity for all caliper and ultrasonographic measurements, particularly when compared to the present English sample and other Caucasian male samples by Weits *et al.*⁷. Despite this, however, significant correlations ($P < 0.01$) (with the exception of biceps – the site with the lowest overall variability) were obtained at each site.

Weits *et al.*⁷ have reported that the best combination of ultrasonographic measurements for predicting body density in young Caucasian men involves the quadriceps, subscapular and suprailiac sites ($R = 0.88$). The quadriceps site was also observed to be the best ultrasonographic predictor of body density in obese women by Fanelli *et al.*¹³. When the ultrasonographic sites were subjected to stepwise multiple regression analysis the quadriceps and subscapular were selected as the best predictors for the English sample (R (s.e.e.) = 0.82 (3.3%)). The combination of quadriceps and calf sites formed the best prediction equation for the Chinese sample (R (s.e.e.) = 0.78

(2.6%)). It is notable that the quadriceps was the best predictor in both groups. This has also been observed in other anthropometric studies, notably the Brussels Cadaver Study. As part of the latter study, Martin *et al.*¹⁸ assessed the value of various caliper sites as predictors of total subcutaneous adipose tissue. They observed that the best predictor of total body adiposity was the quadriceps site. In the present study this site also had the highest correlations between caliper and ultrasonographic measurements in both groups.

The same group of investigators (Clarys *et al.*¹⁸) have since indicated that the selection of predictor sites of total adiposity should be based on a 'commonsense approach of selecting sites from all important storage levels – e.g. segments, and especially the legs . . .'. It is therefore not surprising that the best predictor of percentage fat for both groups was the proportion of subcutaneous adipose tissue in the thigh segment. As previously indicated, this was determined from radii and subcutaneous fat thicknesses obtained directly from the ultrasonographic image (US_{rad}). It appears, however, that the percentage adipose tissue volume estimations are higher when calculated by a combination of anthropometric circumference and subcutaneous adipose tissue measurements obtained by US (US_{circ}) (Table 4). It should be noted, however, that the relationship between the two ultrasonographic techniques, particularly in the thigh segment, was extremely high in both groups. The reason for the difference in estimated fat proportions is most likely attributable to the degree of compression necessary for the ultrasonographic scanning procedure. Nevertheless, despite the difference in values between the two techniques, the US_{rad} technique at the thigh was the best predictor of total percentage body fat in this study.

There are only a few studies which have attempted to assess the volumes of fat and muscle tissue in man by ultrasonographic techniques. Weiss and Clark⁵ used a combination of circumference and ultrasonographic measurements in the calf area and reported high correlations ($R = 0.80$) for the men in their study. More recently, Withers *et al.*¹¹ have reported that an ultrasonographic measurement of muscle thickness in the upper arm is a better predictor of anthropometrically determined lean body mass in men compared with standard measurements of skinfold thickness and mid-arm circumference in healthy men.

It is concluded that ultrasonographic measurements of subcutaneous fat, particularly at the quadriceps, can be used to predict percentage body fat in physically active English and Chinese men. The estimation of percentage adipose tissue volume by US at the quadriceps site can accurately predict percentage body fat in both Caucasian and Chinese men with acceptable levels of error. Further research is recommended in the use of this technique, particularly with normal and obese subjects.

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