A comparison of the skinfold method with extent of 'overweight' and various weight-height relationships in the assessment of obesity

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(*Received* 22 *December* 1976 – *Accepted* 14 *February* 1977)

1. Body-weight, height, skinfold thickness and body density measurements were made on 245 men and 324 women aged between 17 and 72 years. The body fat content of each individual was calculated from his density measurement using equations similar to that of Siri (1956) but appropriate to age, muscular development, and extent of obesity. Regression equations were then derived for separate age-groups for the prediction of body fat from (1) weight–height (W–H) relationships (W:H, W:H^2 W:H^3, $W^{0.33}$:H, H:$W^{0.33}$), (2) 'percentage overweight' (body-weight:mean body-weight; W:$\bar{W}$) and 'percentage desirable weight' body-weight: 'desirable weight' (mean weights for men and women aged 20–24 years); (W:DES), (3) the independent variables weight and height incorporated in a regression equation, (4) skinfold measurements.

2. The correlations between height and indices, W:H, W:H^3, $W^{0.33}$:H and H:$W^{0.33}$: were substantially different from those between height and body fat estimated by densitometry.

3. The method having the highest correlation with body fat estimated by densitometry was the skinfold method, although in the older groups of women other methods sometimes gave equally good correlations. The index H:$W^{0.33}$ had a negative correlation with body fat, and the indices W:H, $W^{0.33}$:H and W:H^3 had a lower correlation with body fat estimated by densitometry than did the other indices. These indices are therefore unsuitable measures of obesity, and this is in agreement with the findings of other workers.

4. The correlations betweeen body fat estimated by densitometry and the indices W:H^2, W:W, W:DES and the equations incorporating the independent variable weight and height are all very similar, although it is not appropriate to use the index W:$\bar{W}$ as a measure of obesity in groups of people of widely different ages.

5. The standard error of prediction of body fat from skinfold measurement may be of the same order of magnitude as the standard error of prediction of body fat by densitometry. It is therefore probably inappropriate to assess the accuracy of the skinfold method by comparison with the density method alone.

6. From the distribution patterns obtained, it was evident that compared with the density method, all methods tended to over-estimate body fat in very lean individuals. The skinfold method however showed this tendency to only a relatively small extent.

The greater the proportion of fat in the body the smaller is the body density. Measurement of body density (for example, by the technique of underwater weighing) thus provides an estimate of body fat content. The relationship between body fat and body density is given by equations such as that of Siri (1956):

$$\text{fat (\% body-weight)} = (4950 \div \text{density} - 4\cdot500) \times 100.$$

We have published equations for the prediction of body density (and therefore of body fat) from measurements of the thickness of the biceps, triceps, subscapular and supra-iliac skinfolds (Durnin & Womersley, 1974). These equations were derived from measurements of body density and of skinfold thickness made on 209 men and 272 women aged between 17 and 72 years.

The purpose of the present study was to derive, for an enlarged group of subjects, equations for the prediction of body fat from the extent of 'overweight' or 'underweight', and from various weight–height (W–H) relationships. The errors associated with the prediction of body fat from skinfold measurements, from the extent of 'overweight' or 'underweight', and from the various W–H relationships were then compared.

Laboratory methods for the assessment of body fat. The fat content of an individual is often estimated from measurements of the total body water, of the total body potassium, or of the whole body density. These methods are based on the assumption that the body can be considered to consist of two distinct compartments: chemical fat and the remainder (fat-free mass, FFM). Chemical fat differs from FFM in having practically no water or K content, and a relatively low density (about 900 kg/m^3). FFM in man has a water content of about 720 g/kg (e.g. Widdowson, 1965) and, depending on age, obesity and muscular development, a K content of approximately 62–69 mmol/kg in men and 55–63 mmol/kg in women, and a density of 1098–1105 kg/m^3 in men and 1087–1100 kg/m^3 in women (Womersley, Durnin, Boddy & Mahaffy, 1976).

Using these values it is possible, by measuring the total body water, or the total body K, or the body density, to estimate the proportion of the body which is fat and the proportion which is FFM. Lean individuals, for example, will have a relatively high content of body water and K, on a per kg body-weight basis, and a relatively high body density.

Fat-soluble indicators such as cyclopropane and radioactive krypton have been used as a completely independent measure of body fat (e.g. Hytten, Taylor & Taggart, 1966), but the errors in this method are probably greater than for the other three methods described.

All these methods are obviously time-consuming and complicated. Therefore various simpler measures, which require information about height and weight only, have been used for the assessment of overweight and obesity. These measures may collectively be called indices of relative weight.

Assessment of obesity from indices of relative weight. These indices are of three types. The first type comprises W–H relationships such as W:H, $W:H^2$ or $W^{0.33}:H$. The second type is the 'percentage overweight' for individuals of the same sex, height and age; the standard weights used are often those listed in the tables of the Metropolitan Life Insurance Company (1959). The third type consists of regression equations, whereby the dependent variable (usually FFM) can be predicted from the independent variables weight (W; kg) and height (H; m); for example, Hume & Weyers (1971):

$$\text{men} \quad 0{\cdot}72\text{FFM} = 0{\cdot}297\text{W} + 19{\cdot}5\text{H} - 14{\cdot}013,$$
$$\text{women} \quad 0{\cdot}72\text{FFM} = 0{\cdot}184\text{W} + 34{\cdot}5 - 35{\cdot}270.$$

Once the FFM has been calculated the predicted fat content of the body can be determined simply by subtraction from this body-weight:

$$\text{body fat (kg)} = \text{body-weight} - \text{FFM}.$$

The usefulness of various W–H relationships and of 'percentage overweight' as measures of obesity has been discussed by Keys, Fidanza, Karvonen, Kimura & Taylor (1972). These workers concluded that the index $W:H^2$ was the most satisfactory measure of obesity, because they found that this index has a comparatively high correlation with body fat (as estimated from body density) but a comparatively low correlation with height. The 'percentage overweight' was also found to have a high correlation with body fat (as estimated from skinfold measurements) and a low correlation with height, but this index is much less easy to compute than the index $W:H^2$ and there is always some doubt about the appropriate value to use for the standard weight.

Several workers have derived regression equations for the prediction of the FFM from measurements of weight and height. However the validity of these equations when used for estimating body fat in individuals outside the groups for which they were originally derived has not usually been assessed.

Estimation of body fat from measurements of skinfold thickness. No index which incorporates measurements of weight and height alone can differentiate between overweight caused by an excess of muscle or bone, and overweight caused by an excess of fat. Individuals of identical weight and height will have identical values for any index which depends only on these two measurements, although there may be considerable differences in their body composition and fat content.

Skinfold thickness has therefore often been used as a simple measure of body fat as distinct from estimates based only on weight and height. The use of the skinfold method depends on the assumption that the subcutaneous fat constitutes a constant, or at least predictable, proportion of the total body fat. Assumptions must also be made concerning the compressibility of the skinfold, the fat content of the subcutaneous tissue, and the thickness of the skin itself. Some of these assumptions have been discussed by Durnin & Womersley (1974). The theoretical basis for estimating body fat from skinfold measurements has been considered in detail by Womersley (1974).

One of the main objectives of the present study was to determine whether measurement of skinfold thickness gives a more accurate indication of body fat content than methods based solely on the measurement of weight and height.

EXPERIMENTAL

Most of the subjects were the 209 men and 272 women who had participated in an earlier study on the estimation of body fat from skinfold measurements (Durnin & Womersley, 1974) in which further details of the selection of subjects and of the methodology are given. Additional groups of subjects have been included to make a total of 245 men and 324 women. There remained a preponderance of moderately sedentary, middle-class men and women although a deliberate selection had been made to represent a variety of body types. The numbers of subjects in each of the age-groups (years): 17–19, 20–29, 30–39, 40–49, $\geqslant$ 50, are given in Table 1, together with the mean values, standard deviations and ranges of their respective weights and heights.

Skinfold measurements were made on both sides of the body and at four sites (over the mid-biceps, mid-triceps, subscapular and supra-iliac areas) in all subjects. The mean of the measurements on the two sides of the body was calculated for each site, and the four values added together to give the 'total skinfold'. The instrument used was either the Harpenden caliper (Holtain Ltd, Bryberian, Crymmych, Dyfed) or the Lange caliper (Cambridge Scientific Industries Inc., Cambridge, Maryland, USA). The influence of differences in type of caliper appears to be relatively unimportant (e.g. Burkinshaw, Jones & Krupowicz, 1973; Womersley & Durnin, 1973).

Skinfolds and height were measured by the standard techniques described by Weiner & Lourie (1969) except that the subscapular skinfold was always taken at an angle of about 45° to the vertical, and the position of the supra-iliac skinfold was just above the iliac crest in the mid-axillary line. Body-weight was measured to the nearest 0·1 kg using a calibrated Avery beam balance (W. & T. Avery Ltd, Avery House, Clerkenwell Green, London EC 1).

The body density of each individual was measured by weighing under water, using the technique described by Durnin & Rahaman (1967); the volume of air in the lungs at the moment of underwater weighing was measured by the three-breath nitrogen-dilution method (Rahn, Fenn & Otis, 1949). At least three measurements were carried out for each subject. The means values, standard deviations and ranges for the 'total skinfold' measurements and the body densities of the subjects are given in Table 1.

Body fat content (expressed as a proportion of body-weight) was calculated from the body density using the general equation:

$$\frac{f}{W} = \frac{1}{D}\left(\frac{d_1 d_2}{d_1 - d_1}\right) - \frac{d_1}{d_2 - d_1},$$

Table 1. *Mean weights and heights and 'total skinfold' thickness and body density of the subjects classified in age-groups*

(Mean values, ranges and standard deviations)

Age (years)	Mean age (years)	No. of subjects	Weight (kg) Mean	Weight (kg) SD	Weight (kg) Range	Height (m) Mean	Height (m) SD	Height (m) Range
Men								
17–19	18·4	28	73·4	17·8	43·7–121·4	1·78	0·087	1·55–1·92
20–29	22·6	112	71·8	13·8	49·8–128·2	1·77	0·070	1·62–1·94
30–39	34·3	38	79·6	11·9	61·6–118·6	1·76	0·054	1·63–1·89
40–49	44·2	37	76·3	9·7	54·8–95·7	1·74	0·075	1·59–1·87
50–76	56·8	30	78·8	12·1	53·9–101·4	1·71	0·072	1·52–1·87
Women								
17–19	18·5	32	57·9	9·6	41·9–77·8	1·63	0·057	1·52–1·73
20–29	23·0	114	62·9	14·6	40·5–113·7	1·63	0·062	1·46–1·80
30–39	34·2	71	70·0	16·5	43·9–108·9	1·62	0·058	1·50–1·80
40–49	43·9	55	69·1	13·4	50·3–116·3	1·63	0·063	1·47–1·77
50–68	55·5	52	71·0	16·2	44·4–121·5	1·62	0·059	1·49–1·75

Age-group (Years)	No. of subjects	'Total skinfold' (mm) Mean	'Total skinfold' (mm) SD	'Total skinfold' (mm) Range	Body density (kg/m³ (× 10⁻³)) Mean	Body density SD	Body density Range
Men							
17–19	28	39	26	16–114	1·067	0·016	1·030–1·084
20–29	112	44	32	16–210	1·064	0·016	1·014–1·087
30–39	38	60	27	19–145	1·048	0·014	1·015–1·084
40–49	37	54	24	23–123	1·043	0·015	1·017–1·077
50–76	30	60	22	26–117	1·035	0·014	1·003–1·056
Women							
17–19	32	56	25	18–125	1·042	0·016	1·004–1·070
20–29	114	64	39	18–173	1·037	0·021	0·983–1·078
30–39	71	90	50	26–215	1·022	0·019	0·985–1·055
40–49	55	79	37	33–215	1·020	0·015	0·984–1·044
50–68	52	88	40	30–202	1·012	0·016	0·986–1·041

where f is the mass of fat in the body, W is the body-weight, D is the measured body density, d_1 is the density of body fat (approximately 900 kg/m^3 at 37°), d_2 is the density of the FFM (which varies with age, muscular development and obesity, see Womersley *et al.* 1976). This general equation may be derived quite simply for any mass (W) of known density (D) which can be subdivided into two compartments of differing density. For young muscular men, for example, the equation reduces to

$$\frac{f}{W} = \frac{5054}{D} - 4{\cdot}615,$$

whereas for the young obese men and young sedentary women the original formula of Siri (1956) applies:

$$\frac{f}{W} = \frac{4950}{D} - 4{\cdot}500.$$

Table 2. *Mean values for various weight–height (W–H) indices*, 'percentage overweight' percentage of 'desirable' weight (DES)† logarithm of skinfold thickness (log Skf) (mm), and body fat (% body-weight) estimated by the equations of Hume & Weyers* (1971) *and by densitometry*

(Mean values and standard deviations)

	Age-group (years)									
	17–19		20–29		30–39		40–49		50	
Index	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
					Men					
W:H	41·2	8·9	40·5	7·6	45·3	7·1	43·8	5·4	45·9	6·6
W:H^2	23·1	4·6	22·9	4·4	25·8	4·4	25·2	3·4	26·8	4·0
W:H^3	13·0	2·5	12·9	2·6	14·7	2·7	14·5	2·3	15·7	2·5
$W^{0\cdot33}$:H	2·31	0·14	2·31	0·14	2·41	0·14	2·40	0·12	2·46	0·13
100H:$W^{0\cdot33}$	43·4	2·4	43·5	2·5	41·7	2·3	41·8	2·1	40·7	2·1
100W:$\bar{W}$	106·6	21·2	99·3	18·9	103·6	17·2	98·9	12·9	104·2	15·4
100W:DES	104·1	20·7	102·7	19·6	115·8	19·4	113·0	15·0	120·1	17·6
Log *Skf*	1·53	0·21	1·58	0·22	1·74	0·19	1·70	0·18	1·75	0·15
Body fat:										
Hume & Weyers (1971)	1·28	6·8	17·9	6·1	22·6	5·1	21·9	4·6	23·8	4·9
Densitometry	15·1	7·0	16·2	7·2	23·3	6·7	25·0	6·8	27·8	6·5
					Women					
W:H	35·4	5·3	38·5	8·6	43·2	10·0	42·3	8·1	44·0	10·0
W:H^2	21·7	3·0	23·6	5·3	26·7	6·2	26·0	5·0	27·2	6·3
W:H^3	13·3	1·8	14·5	3·4	16·5	4·0	16·0	3·3	16·9	4·1
$W^{0\cdot33}$:H	2·33	0·10	2·39	0·17	2·49	0·19	2·47	0·16	2·52	0·19
100H:$W^{0\cdot33}$	42·9	1·8	42·0	2·7	40·3	3·0	40·6	2·4	40·0	2·9
100W:$\bar{W}$	105·4	14·7	110·3	24·2	115·2	26·7	105·8	20·3	107·0	24·6
100W:DES	102·4	14·4	111·4	24·9	125·5	29·2	122·5	23·6	128·2	29·5
Log *Skf*	1·70	0·20	1·73	0·25	1·89	0·25	1·86	0·19	1·90	0·21
Body fat:										
Hume & Weyers (1971)	23·2	6·1	26·3	8·7	31·5	9·3	31·0	7·2	32·6	8·8
Densitometry	24·1	7·7	27·1	9·8	33·6	8·7	34·5	6·7	36·2	7·8

The standards for the average ($\bar{W}$) and 'desirable' weights are those given by the Metropolitan Life Insurance Company (1959) for individuals of the same sex, height and (for the average weights only) age.

* W (kg)–H (m) indices are defined on p. 272.

† For definitions, see below.

RESULTS

Table 2 gives for each age-group the mean values for (1) five W–H indices, (2) 'percentage overweight', (3) the log of the sum of the four skinfold measurements (log *Skf*), (4) the proportion of fat in the body estimated by the equation of Hume & Weyers (1971), (5) the proportion of fat in the body estimated by densitometry. The W–H indices investigated were W:H, W:H^2 (the Quetelet index or body mass index), W:H^3 (the Rohrer index), $W^{0\cdot33}$:H (the ponderal index) and H:$W^{0\cdot33}$ (Sheldon's inversion of the ponderal index). The derivations and use of these indices have been discussed fully by Keys *et al.* (1972).

The 'percentage overweight' was assessed by two criteria: (1) the body-weight (W) divided by the mean weight ($\bar{W}$) for individuals of the same sex, height and age as published by the Metropolitan Life Insurance Company (1959) expressed as a percentage (100W:$\bar{W}$), and (2) the body-weight divided by the so-called 'desirable' weight for individuals of the same sex and height 'desirable' weights used were the mean weights (DES) published by the Metropolitan Life Insurance Company (1959) for men and women in the age-group 20–24 years, also expressed as a percentage (100W ÷ DES).

Table 3. *Correlation coefficients for height (H) v. various measures of relative weight (W)* and (H) v. log skinfold thickness (log Skf)†*

	Age-group (years)				
	17–19	20–29	30–39	40–49	⩾ 50
			Men		
No. of subjects ...	28	112	38	37	30
W:H	0·43	0·06	−0·24	−0·06	0·14
W:H^2	0·23	−0·15	−0·40	−0·36	−0·14
W:H^3	−0·02	−0·33	−0·53	−0·58	−0·39
W$^{0·33}$:H	−0·05	−0·35	−0·55	−0·60	−0·39
H:W$^{0·33}$	−0·06	0·37	0·57	0·60	0·38
W:$\bar{W}$	0·27	−0·07	−0·36	−0·29	−0·10
W:DES	0·26	−0·12	−0·38	−0·33	−0·12
Body fat:					
Hume & Weyers (1971)	0·32	−0·05	−0·36	−0·26	−0·01
Densitometry	0·35	−0·18	−0·15	−0·08	−0·23
Log *Skf*	0·37	−0·06	−0·25	−0·17	−0·22
			Women		
No. of subjects ...	32	114	71	55	52
W:H	0·43	0·19	0·05	0·07	0·01
W:H^2	0·22	−0·06	−0·11	−0·13	−0·14
W:H$_3$	−0·03	−0·22	−0·26	−0·31	−0·28
W$^{0·33}$:H	−0·03	−0·23	−0·26	−0·33	−0·29
H:W$^{0·33}$	0·06	0·24	0·26	0·33	0·29
W:$\bar{W}$	0·22	−0·03	−0·05	−0·06	−0·10
W:DES	0·25	−0·03	−0·09	−0·10	−0·12
Body fat:					
Hume & Weyers (1971)	0·10	−0·17	−0·21	−0·27	−0·25
Densitometry	−0·03	−0·12	−0·15	−0·06	−0·11
Log *Skf*	0·13	−0·03	−0·08	−0·03	−0·06

DES, 'desirable' weight; $\bar{W}$, average weight. * For definitions, see p. 272.
† For definition, see p. 273.

The reason for using log *Skf* was that the relationship between skinfold thickness and body density (and therefore between skinfold thickness and body fat) tends to be logarithmic rather than linear, and because it is preferable to use a combination of skinfold measurements rather than measurements at a single site (Durnin & Womersley, 1974).

Table 2 shows that by the density method the fat contents of the men and of the women increase progressively from the youngest to the oldest age-group. None of the other indices showed this uniform progression, although all but two showed a general tendency to increase in magnitude with increasing age. The two indices which did not tend to increase with increasing age were H:W$^{0·33}$ which showed a tendency to decrease as age increased, and 100W/W ('percentage overweight').

It is often stated that a good index of obesity should give a low correlation with height, since it is assumed that the proportion of fat in the body will be unrelated to height. Table 3 gives for each of the different age-groups the correlation coefficients for height with each of the ten measures listed in Table 2. Significance levels for these correlation coefficients were not calculated because the various measures of relative weight, including body fat estimated by densitometry, did not follow a normal distribution (see p. 281).

Table 3 shows that in both sexes the index W:H^3 and the two indices which incorporate

Table 4. *Spearman rank order correlation coefficients for body fat (% body-weight) estimated by densitometry* v. *various measures of relative weight (W)* and body fat* v. *log skinfold thickness (log Skf)*†

	Age-group (years)				
	17–19	20–29	30–39	40–49	≥50
			Men		
No. of subjects ...	28	112	38	37	30
W:H	0·58	0·50	0·54	0·60	0·51
W:H^2	0·49	0·55	0·56	0·62	0·53
W:H^3	0·32	0·56	0·55	0·57	0·56
W$^{0·33}$:H	0·31	0·56	0·55	0·57	0·55
H:W$^{0·33}$	−0·31	−0·56	−0·55	−0·57	−0·55
W:$\bar{W}$	0·49	0·55	0·57	0·63	0·55
W:DES	0·49	0·55	0·57	0·62	0·53
Body fat: Hume & Weyers (1971)	0·51	0·54	0·57	0·63	0·51
Log *Skf*	0·74	0·76	0·70	0·88	0·81
			Women		
No. of subjects ...	32	114	71	55	52
W:H	0·54	0·68	0·89	0·81	0·86
W:H^2	0·64	0·71	0·91	0·84	0·88
W:H^3	0·66	0·70	0·91	0·83	0·87
W$^{0·33}$:H	0·66	0·70	0·91	0·82	0·87
H:W$^{0·33}$	−0·66	−0·70	−0·91	−0·82	−0·87
W:$\bar{W}$	0·64	0·71	0·91	0·84	0·87
W:DES	0·62	0·71	0·91	0·84	0·88
Body fat: Hume & Weyers (1971)	0·69	0·70	0·91	0·83	0·87
Log *Skf*	0·77	0·83	0·92	0·75	0·85

DES, 'desirable' weight; H, height; $\bar{W}$, average weight.
* For definitions, see p. 272. † For definition, see p. 273.

the term W$^{0·33}$ frequently showed a fairly substantial positive or negative correlation with height (up to 0·60 in the men and 0·33 in the women). In both sexes the correlation coefficients for these indices with height were highest in the 40–49 years age-groups, but they are extremely small (< 0·06 only) in the youngest age-group 17–19 years.

The correlation coefficients for the relationship between height and body fat content estimated by densitometry were of particular interest since the densitometric measure of fat was being used as the standard for comparison of the other indices. In both sexes, and particularly in the men, these correlation coefficients were not negligible. In all groups except the youngest group of men there appeared to be a small negative correlation between height and body fat, so in our sample it seemed that smaller individuals tended to be fatter than taller individuals. If there was a real correlation between height and the proportion of fat in our groups, then it would be reasonable to expect that other indices of fatness should show a similar correlation.

Since the various indices of obesity did not follow a normal distribution it was not possible to normalize the correlation coefficients in order to determine significance levels for the difference between these. However the extent to which other indices of obesity reflected the correlation with height observed for the density method was easily determined from Table 3. The indices which had a correlation with height which differed substantially from that of the density method were W:H, W:H^3, $W^{0\cdot33}$:H and H:$W^{0\cdot33}$ in men, and W:H and H:$W^{0\cdot33}$ in women. The indices W:H^2, W:$\bar{W}$, W:DES, body fat (as calculated from Hume & Weyers' (1971) equation), and skinfold thickness all showed a similar correlation with height as did body fat estimated by densitometry, except that in the men the skinfold method gave much better agreement with densitometry than did the other indices.

Table 4 gives the Spearman rank order correlation coefficients for body fat (estimated by densitometry) with various measures of obesity. It was more appropriate to use these correlation coefficients in the present instance than the product-moment correlations since the relationships between body fat and the various indices may have been non-linear, and neither body fat nor the various indices were distributed normally (see Fig. 1).

In the men skinfold measurement clearly gave the best agreement with the density method in all of the age-groups. In the younger women skinfold measurement again gave the best correlation with the density method, but in the three older groups of women other indices gave as good agreement. Apart from the skinfold method there was very little difference between the various indices in their correlation with body fat.

The real test of these indices however lay in their ability to predict body fat. For example for the 112 women in the age-group 20–29 years, the relationship between body fat estimated by densitometry and log *Skf* is given by the equation:

$$\text{fat (\% body-weight)} = 33\cdot5\ (\log Skf) - 31\cdot1.$$

This regression equation can be used to predict the fat content of a women in the age-group 20–29 years simply from the sum of the skinfold measurements at four sites. For each of the ten age- and sex-groups similar regression equations have been calculated for predicting body fat from different indices of weight and height (Table 5). The indices W:H^2, 100W:DES and skinfold thickness were chosen on the basis of their good correlation with body fat estimated by densitometry, and because they have similar correlations with height to that observed for body fat. The index 'W+H' is a series of regression equations which are of the same form as the equations of Hume & Weyers (1971), but which were derived from measurements of weight and height specifically for each group of our own subjects.

It is obvious from the scatter of points about the regression line that for a given skinfold measurement the value predicted for the fat content is subject to considerable uncertainty. A measure of this scatter is given by the residual variance, or by its square root (the standard deviation of the residual or the standard error of prediction). The method which gives the lowest standard error of prediction is the method which gives the most accurate estimate of fat content. Table 5 shows that in all groups apart from the 40–49 year age-group of women the skinfold method gave the lowest standard error of prediction.

DISCUSSION

The main purpose of this investigation was to compare the skinfold method for assessing body fat with other methods which depend only on the measurement of weight and height. The standard for this comparison was body fat content assessed by densitometry (a laboratory technique which probably gives a more accurate measure of body fat than any of the other techniques at present available).

One requirement for a good index of obesity is that it should have a low correlation with height: *a priori*, there is probably no reason to believe that in the general population smaller individuals tend to be more or less obese than taller individuals.

Table 6 gives correlation coefficients, determined by other workers and by ourselves, for the relationship between height and various measures of obesity. For our own subjects the different age groups were combined for this table. The tendency already noted (see Table 3) for our taller subjects, particularly the men, to be leaner than the smaller individuals was

Table 5. *Linear regression equations for prediction of body fat (as estimated by densitometry) from various weight–height (W–H) indices**

Fat (% body-wt) = *a* (index)+*b* (for W+H, fat (% body-wt)) = *aW*+*bH*+*c*

Men

Index		17–19	20–29	30–39	40–49	50–76	17–76
W:H²	*a*	1·229	1·181	0·887	1·238	0·947	1·340
	b	−13·376	−10·758	+0·438	−6·185	+2·370	−12·469
	SE	4·30	4·98	5·57	5·45	5·42	5·86
100W:W	*a*	0·266	0·267	0·228	0·330	0·247	0·266
	b	−13·271	−10·314	−0·252	−7·579	+2·013	−7·021
	SE	4·23	5·12	5·55	5·41	5·36	6·90
100W:DES	*a*	0·272	0·264	0·201	0·282	0·211	0·300
	b	−13·306	−10·831	+0·051	−6·849	+2·416	−12·620
	SE	4·24	5·00	5·55	5·44	5·44	5·88
W+H		0·356W	0·378W	0·320W	0·448W	0·323W	0·429W
		−13·833H	−38·464H	−15·341H	−23·148H	−43·027H	−43·903H
		+13·466	+57·293	+24·845	+31·156	+76·082	+65·072
	SE	4·18	5·00	5·59	5·52	5·42	5·88
Log *Skf*†	*a*	27·409	27·575	28·581	32·113	31·094	32·362
	b	−26·789	−27·203	−26·325	−29·438	−26·613	−32·951
	SE	3·89	3·94	4·12	3·62	4·37	4·61

Women

Index		17–19	20–29	30–39	40–49	50–68	17-68
W:H²	*a*	1·796	1·469	1·246	1·086	1·033	1·371
	b	−14·918	−7·647	+0·354	+6·270	+8·052	−3·467
	SE	5·50	6·08	3·92	3·95	4·35	5·43
100W:W	*a*	0·370	0·318	0·289	0·271	0·264	0·291
	b	−14·926	−7·990	+0·298	+5·780	+7·912	−0·944
	SE	5·51	6·17	3·98	3·90	4·37	6·65
100W:DES	*a*	0·375	0·311	0·265	0·233	0·221	0·292
	b	−14·298	−7·597	+0·336	+5·992	+7·865	−3·552
	SE	5·56	6·11	3·94	3·92	4·33	5·44
W+H		0·735W	0·552W	0·477W	0·430W	0·407W	0·526W
		−78·230H	−55·249H	−50·979H	−30·438H	−32·936H	−50·135H
		+109·087	+82·449	+82·831	+54·415	+60·459	+77·549
	SE	5·36	6·08	3·82	3·82	4·28	5·35
Log *Skf*†	*a*	30·509	33·539	30·894	27·112	31·674	33·868
	b	−27·899	−31·057	−24·712	−15·815	−23·891	−30·408
	SE	4·70	5·21	3·67	4·40	4·07	4·88

DES, 'desirable' weight; log *Skf*, log skinfold thickness; SE, standard error of prediction.
* For definitions, see p. 272. † For definition, see p. 273.

again apparent. This tendency was not observed in the other investigations summarized in Table 6.

The high correlation of the index $H:W^{0\cdot33}$ with height, and therefore the inappropriateness of this index as an index of obesity, was obvious from Table 6. There was also a marked difference in the correlation with height between index W:H and body fat measured by densitometry, and this difference was apparent for all the investigations given. The measures of obesity which, in their correlations with height, were in best agreement with the assessment

Table 6. *Correlation coefficients between height and some indices of obesity*

Index* ... Source	Subjects	No. of subjects	$H:W^{0.33}$	W:H	$W:H^2$	$W:\overline{W}$	Log *Skf*	Body fat (densitometry)
Allen *et al.* (1956)	Men	55	−0·16	0·41	0·16	—	—	0·03
	Women	26	−0·24	0·27	0·03	—	—	0·05
Brockett *et al.* (1956)	Men	97	−0·40	0·26	0·08	—	—	−0·06
Keys *et al.* (1972)	Students	180	−0·24	0·25	0·02	0·04	0·04	0·04
	Executives	249	−0·30	0·18	0·06	0·10	0·01	0·02
Present investigation	Men	245	−0·43	0·01	−0·22	−0·08	−0·13	−0·22
	Women	324	−0·26	0·06	−0·10	−0·04	−0·06	−0·13

* For definitions, see p. 272.

Table 7. *Correlation coefficients between body fat, estimated by densitometry, and three indices of obesity*

Index* ...	Subjects	No. of subjects	$W^{0.33}:H$	W:H	W/H^2	Log *Skf*
Allen *et al.* (1956)	Men	55	0·68	0·70	0·72	—
	Women	26	0·77	0·74	0·80	—
Brockett *et al.* (1956)	Men	97	0·57	0·57	0·60	—
Keys *et al.* (1972)	Students	180	0·79	0·83	0·85	0·85
	Executives	249	0·66	0·66	0·67	0·82
Present investigation	Men	245	0·72	0·68	0·71	0·84
	Women	324	0·84	0·81	0·82	0·86

For definitions, see p. 272.

of body fat by densitometry were skinfold thickness and the indices $W:H^2$ and $W:\overline{W}$. There was little difference between these three methods.

A second requirement for a good index of obesity is that it should be in good agreement with one of the accepted laboratory measures of obesity, such as body fat estimated by densitometry. Table 7 gives correlation coefficients determined by other workers and by ourselves, for the relationship between body fat estimated by densitometry and by four indices of obesity. These results support our earlier conclusion (see Table 4) that the skinfold method, particularly in the men, gives a higher correlation with body fat than do the other indices. There was again little difference between these other indices in their correlations with body fat.

From consideration of our own results and those of other workers, it seems that the most appropriate simple indices of body fat are skinfold measurements, the indices $W:H^2$, $W:\overline{W}$ and W:DES, and regression equations which incorporate body-weight and height. It is now relevant to try to assess the accuracy with which these different methods provide an estimate of body fat, using densitometry as the standard for comparison. This assessment

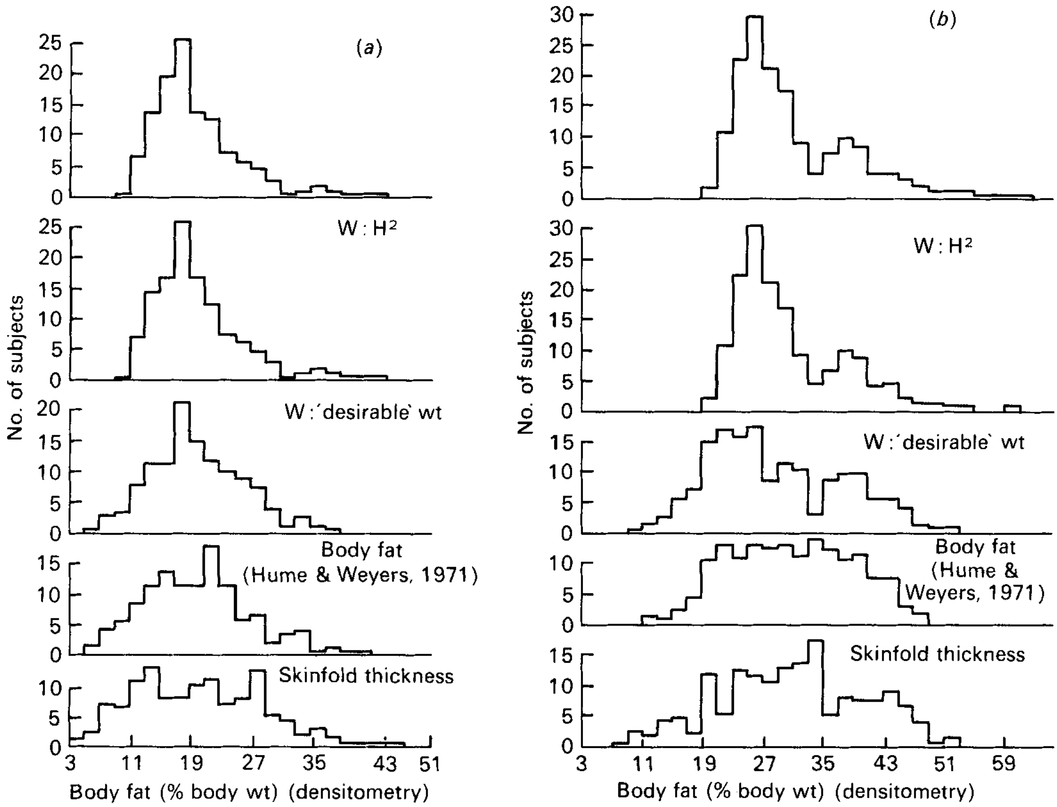

Fig. 1. Distributions of body fat content estimated by different methods: (*a*) men (*n* 245), (*b*) women (*n* 324) aged ⩾ 17 years. For details of methods, see pp. 272–273. W, weight; H, height.

can be carried out by referring to the standard errors of prediction given in Table 5. The skinfold method gives considerably lower standard errors of prediction than the other methods in all the age-groups of men, and gives slightly lower standard errors of prediction in most of the age-groups of women. However in all age-groups, of both sexes, there is little difference between the other four methods in their standard errors of prediction of body fat.

Three other comments about Table 5 should be made. First the index $W:\bar{W}$, although apparently suitable when considered separately for each age-group, provides a relatively poor estimate of body fat when the composite age-groups (⩾ 17 years; Table 5); of men or women are considered. This is presumably because unlike the other indices, the denominator $\bar{W}$ is age dependent: the average weight of men and women increases as they become older. The index $W:\bar{W}$ (in a given individual) will therefore tend to increase less as his age increases than do the other indices.

Secondly, there would appear to be no advantage in using equations of the type: fat (% body-weight) = $aW+bH+c$ (where a, b, c are constants), for the prediction of body fat, in preference to equations of the type: fat (% body-weight) = $a\,(W:H^2)+c$ (where a, c are constants). The great advantage of the latter type of equation is that the independent variables weight and height are incorporated in a single ratio which can readily be compared in different individuals.

Thirdly, if skinfold measurements are not available, then we would agree with Keys *et al.*

(1972) that the most satisfactory index of obesity is the index $W:H^2$ since this index is much more easy to compute than the indices $W:\bar{W}$ and W:DES.

It should perhaps be emphasized that the standard errors of prediction given in Table 5 may not provide a true indication of the accuracy with which the skinfold method and other indices estimate body fat. The difficulty is that the densitometric method, which is the standard for comparison, is itself subject to uncertainty. It is quite possible for example (see Appendix) that the skinfold and densitometric methods are of the same order of accuracy. Therefore it probably is not appropriate to gauge the accuracy of the skinfold method or of other methods only by comparison with the density method. A combination of methods (e.g. body densitometry, total body K measurement and total body water measurement), used in each subject, would provide a more suitable standard for comparison with other measures of obesity. Use of such a combination of methods might also provide some explanation for the very considerable discrepancies which we have occasionally observed between the density and skinfold methods (and between the density method and other simpler methods) in the estimation of body fat in individual subjects.

Finally, we have plotted in Fig. 1 the distributions of body fat, assessed by different methods, for the entire group of men and of women. All the distributions, whatever the method used for estimating body fat, were markedly positively skewed, with a long 'tail' of high values. The χ^2 test for goodness of fit indicated that all of the distributions differ significantly from normal ($P < 0{\cdot}01$). It is evident that in both sexes, compared with the density method, the other four indices all tend to over-estimate body fat in individuals whose fat content is very small. This is particularly true of the indices $W\text{-}H^2$ and W:DES. The equations of Hume & Weyers (1971) and the skinfold method are in much better agreement with the density method in these lean men and women. It is therefore probably inappropriate to use the indices $W:H^2$ and W:DES for assessing body fat in lean individuals. In obese women the converse appears to be true: the indices $W:H^2$ and W:DES tend to over-estimate body fat content.

The authors are very grateful to Mr Robert Murdoch of the Department of Community Medicine, University of Glasgow, for help and advice about statistical and computing aspects of the analysis, and to Mr Robert Campbell for a great deal of technical assistance.

APPENDIX

Possible errors associated with the estimation of body fat by densitometry, skinfold measurement and from indices of weight and height

The equations used for calculating body fat from body density are based on the assumption that the density of the fat-free part of the body (FFM) is constant for individuals of certain defined groups (see p. 272). For the entire population of men and women Siri (1956) estimated that the mean density of FFM was 1100 kg/m^3, with a standard deviation of 10 kg/m^3. Estimation of a separate mean value for each of the defined groups (Womersley *et al.* 1976) will reduce this standard deviation (perhaps to 5 kg/m^3) for each group. In addition, there is a small uncertainty in the true density of body fat and a small experimental error associated with the actual measurement of density. If these three errors are substituted in the equation for calculating body fat from body density, it can be shown that the standard error for the estimate of body fat by densitometry is of the order of 2–3 % body-weight.

There is a considerable scatter about the regression line for body density with skinfold thickness. This scatter is caused by two factors. First, there is variance due to biological differences in the proportion of fat that is situated subcutaneously, in its compressibility and fat content, and in its distribution over the surface of the body. Such differences mean that a given skinfold measurement will not correspond to the same content of body fat in all individuals. Secondly, there is variance due to the error involved in the estimation of body fat by densitometry. Thus:

$$\mathrm{VAR}_{res} = \mathrm{VAR}_{Skf} + \mathrm{VAR}_{d},$$

where VAR_{res} is the residual variance of the observations after accounting for the variance due to the regression of density on skinfold, VAR_{Skf} is the variance due to the skinfold method of estimating body fat, and Var_{d} is the variance due to the densitometric method of estimating body fat.

Now, VAR = $(\mathrm{SD})^2$, and substituting $(\mathrm{SD})^2$ for VAR in the variance equation gives:

$$(\mathrm{SD}_{res})^2 = (\mathrm{SD}_{Skf})^2 + (\mathrm{SD}_{d})^2.$$

We have shown (Table 6) that for men in the age-group 20–29 years, $\mathrm{SD}_{res} = 3{\cdot}94$ % body-weight for the skinfold method. And for the density method, $\mathrm{SD}_{d} = 2$–3 % body-weight. If we take the lower value for SD_{d}:

$$(3{\cdot}94)^2 = (\mathrm{SD}_{Skf})^2 + (2{\cdot}0)^2,$$

$$\therefore\ \mathrm{SD}_{Skf} = \sqrt{(15{\cdot}5-4)} = 3{\cdot}4\ \%\ \text{body-weight}.$$

If we take the higher value for SD_{d}:

$$(3{\cdot}94)^2 = (\mathrm{SD}_{Skf})^2 + (3{\cdot}0)^2,$$

$$\therefore\ \mathrm{SD}_{Skf} = \sqrt{(15{\cdot}5-9)} = 2{\cdot}6\ \%\ \text{body-weight}.$$

It is thus possible from our knowledge of (*a*) SD_{res}, as given in Table 5 and (*b*) the standard error of prediction of body fat from body density (probably 2–3 % body-weight) to determine (*c*) the standard error of prediction of body fat from skinfold measurement. For the 20–29 years age-group of men we have shown that the standard error of prediction of body fat from skinfold measurement (e.g. 2·6–3·4% body-weight) is probably much the same as the standard error of prediction of body fat from densitometry (e.g. 2–3 % body-weight). This means that the skinfold and densitometric methods of estimating body fat are probably of the same order of accuracy, and it is therefore not appropriate to assess the accuracy of one method (skinfolds) by comparison with the other (density) method.

This conclusion holds for both sexes, and each age-group, except that where the standard error of prediction of body fat from skinfold measurement is relatively high (e.g. the age-group 20–29 years of women, Table 6) the calculated standard error of the skinfold method is rather higher (4·2–4·8 % body-weight).

Similar calculations can be made for comparison of other indices of obesity (e.g. the indices $W{:}H^2$ or $W{:}\bar{W}$) with body fat assessed by densitometry. For example, among the different age-groups of men and women, the calculated standard errors for prediction of body fat from the index $W{:}H^2$ range from about 3 to 6 % body-weight.

It should be emphasized that the error associated with the density method for estimating fat can only be estimated very roughly. If the true error in the density method is in fact higher than the estimated 2–3 % body-weight, then the skinfold method may give a more accurate measure of body fat than body density itself.

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Printed in Great Britain