Application of weight-height relations for assessing adiposity in a United Kingdom offshore workforce

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ABSTRACT Weight (W), height (H), and skinfold thicknesses at biceps, triceps, subscapular, and suprailliac sites were measured in a United Kingdom offshore workforce. Weight and height were used to calculate W/H relations. The percentage body fat was estimated from skinfold thicknesses and the correlations of adiposity with the various W/H relations were evaluated. The significant increase in percentage body fat (%BF) with increasing age resulted in the development of age group specific regression equations relating %BF to the indices of $W/H^{1.5}$ and W/H^2 (body mass index or Quetelet index). Little difference regarding the qualities of these two indices were detected in terms of poor correlation with height and strong correlation with weight. Thus either may be used with similar levels of confidence. Comparison with other studies, however, would be more easily accomplished if W/H^2 were used. In the absence of skinfold thickness measurements the W/H^2 could readily be implemented during a routine medical and applied for the estimation of %BF in the offshore population provided that the appropriate regression equation were used and that the limitations of the technique are recognised. Percentage values for W, H, W/H relations, and %BF by age group are provided for comparison with other population studies.

The advent of offshore exploration, construction, and subsequent production has resulted in a large number of men and to a lesser degree, some women, being employed in unusual circumstances. Owing to the distance between the worksite and the mainland it is typically necessary for the workforce to become temporary residents of these offshore installations and structures. The employees may therefore spend weeks or multiples of a week on location and often working rotas necessitating 12 hour shifts of alternate work and rest. It has recently been suggested that fishermen and offshore workers may be heavier and possess a higher percentage of body weight as fat.¹ While endowing an enhanced insulation against heat loss and prolongation in survival time against hypothermia in the event of accidental cold water immersion, the possible deleterious effects of increased levels of body fat and obesity must be considered. The inverse relation between percentage body fat and aerobic performance² and hence physical working capacity is well established.³ Furthermore, the health con-

sequences of overweightness and obesity have been extensively reported.⁴

Commercial diving is one occupation that has received considerable interest with regard to body weight and adiposity.⁵⁻⁷ The medical examination of commercial divers for work in the North Sea follows the scheme devised by the Underwater Engineering Group of the Construction Industry Research and Information Association (CIRIA). As reported by McCallum and Petrie,⁶ obesity is one of the factors taken into consideration in deciding whether or not a man is medically fit to drive.⁶ Other studies have shown that a high degree of adiposity may predispose towards decompression sickness.⁸⁻¹⁰ At present numerous techniques may be used in routine medical examinations to help provide more quantitative measures of overweightness and obesity than simply utilising the body weight. Height and weight and, to a lesser extent, skinfold thicknesses are routinely measured during diving medical examinations and usually in the medical examination of non-diving offshore personnel.

The use of weight (W) to height (H) relations has been reported for many populations, particularly

relating to young military² and civilian groups.¹¹ The application of weight/height relations in assessing obesity has received considerable attention.¹² One index that is often used in adult men as a measure of adiposity is the Quetelet (W/H^2) or body mass index. Garrow has established levels of the body mass index commensurate with varying degrees of overweightness and adiposity.¹³ The indices of adiposity are easily calculated, requiring nothing more than the height and weight of an individual. They include W/H itself, W/H^2 , W/H^3 (the Rohr index¹¹), $W^{0.33}/H$ (the Ponderal index¹¹), and $H/W^{0.33}$ (Sheldon's¹⁴ inversion of the Ponderal index).

The usefulness of various W/H relations as measures of obesity has been discussed by Keys *et al* who concluded that the W/H^2 index was the most satisfactory since this index had a significant correlation with body fat and a low correlation with height.¹² Benn has given additional criteria of optimality for a "good" index of obesity¹⁵: (1) it should be highly correlated with measures of relative adiposity and (2) its distribution should be independent of height. Benn also showed that for various values of p for the index of the form W/H^p that there is a zero correlation of $W/H^{1.65}$ with H , but that in the range $1.4 \leq p \leq 2.0$, all indices W/H^p have a low correlation with H .¹⁵ The choice of a weight for height index should be based on the actual group studied with p being chosen from the sample by regression methods if the sample is sufficiently large or an integer form of W/H^p to make computation easy. Nevertheless, for whichever p value is chosen, checks should be made that the index is independent from height.

The percentage overweight is another method that has been used in assessing obesity. This value is calculated from the patient's body weight compared with the equivalent standard weight for individuals of the same sex, height, and age listed in the tables of the Metropolitan Life Insurance Company.¹⁶ These widely used tables have now been superseded by a

revised 1983 version. The values quoted in these tables refer to measurements taken wearing both clothes and shoes. The applicability of such a table in assessing overweightness has been questioned.⁶ There is a requirement to provide appropriate data on height and weight of the offshore population and how these simple measurements may be related to estimates of overweightness and fatness.

The objectives of the present study were to report values of weight and height and to determine a weight/height ratio applicable to the offshore population that satisfies the selection criteria for such an index and that may be readily determined in a routine medical examination.

Methods

The Offshore Survival Centre of Robert Gordon's Institute of Technology provides training in maritime survival for the offshore and oil related industries. In a typical week some 350 trainees attend a variety of courses of varying durations between one and five days. The Offshore Survival Centre is, therefore, ideally placed to undertake population surveys and the subjects reported in the present paper were drawn from a workforce engaged in the British sector of the North Sea in 1984.

Subjects

The subjects were selected from the course registers and every tenth person was asked to participate in the study. A sample of 419 adult male white United Kingdom residents currently engaged in offshore employment were measured.

Procedures

The subjects were assembled in groups and asked to void their bladders and to defecate. A questionnaire was then completed regarding age, current occupation, and years in offshore employment. Height (H) and weight (W) were assessed with the subjects wearing only underpants. (H) was measured barefoot to 0.5 cm with a wall mounted anthropometer and (W) was read to the nearest 0.1 kg using a calibrated Weylux beam balance. Skinfold measurements were taken with the Harpenden caliper (British Indicators Ltd) from biceps, triceps, and subscapular and suprailiac sites as described by Durnin and Womersley.¹⁷ Percentage body weight as fat (%BF) was then calculated from the sum of the skinfold thicknesses using age related coefficients for body density¹⁷ and substituted in the Siri equation.¹⁸

The correlation relation of W/H^p with H was then investigated by choosing values of p in the range 1.0

Fig 1 Benn plot of the correlation coefficient of height versus W/H^p for various values of p .¹⁵ "X" axis intercept gives population specific value of about 1.5.

Table 1 Physical characteristics, indices of adiposity, and skinfold thicknesses of the sample population ($n = 419$)

Variable	Mean	SD	Range
Age (years)	32.5	8.2	18.0 – 57.0
Weight (kg)	76.5	9.9	53.0 – 115.2
Height (m)	1.75	0.07	1.58 – 2.0
Biceps (mm)	6.6	2.8	2.9 – 19.2
Triceps (mm)	13.0	5.0	4.9 – 35.2
Subscapular (mm)	18.8	8.2	7.2 – 51.0
Suprailiac (mm)	31.9	10.5	5.9 – 53.0
Sum of skinfold (mm)	70.3	23.4	22.6 – 133.3

to 3.0 to determine the index which gave zero correlation and by regressing log height on log weight (a linear relation) with p being the gradient. From the correlation $p = 1.47$ and from regression $p = 1.49$ which agrees with Benn's findings¹⁵ (see fig 1). This suggests that the height (H) should be raised to the power of approximately 1.5. The $W/H^{1.5}$ relation was then included for comparison.

Results

Table 1 shows the physical characteristics of the subjects. The mean age of the sample population was 32.5 (SD 8.2) years and the subjects had been engaged in offshore employment in the United Kingdom sector for an average of 4.3 years. Table 2 shows weight, height, and W/H relations including $W/H^{1.5}$. The percentage body fat is shown as percentiles by the age groups 20–29, 30–39, 40–49 (table 3). The percentage BF for the sample population is plotted against age in fig 2. Linear regression analysis showed a highly significant correlation coefficient of 0.65 ($t = 17.7$; $p < 0.0001$). The regression analysis produced a regression equation of the form $\%BF = 0.442(\text{age})$

Table 3 Percentile distributions of percent body fat by age group (subjects below age 20 and above 50 are not included)

Percentile	Age group (years)		
	20–29 ($n = 180$)	30–39 ($n = 144$)	40–49 ($n = 77$)
1	11.3	15.5	18.3
2	12.3	16.7	21.6
5	13.8	18.5	22.1
10	15.1	19.6	23.7
20	17.3	22.2	26.7
25	18.1	22.8	28.1
30	18.5	23.3	28.6
40	19.7	24.6	29.4
50	21.0	25.5	30.6
60	22.3	26.2	31.9
70	23.9	27.0	33.0
75	24.9	27.6	33.5
80	25.7	27.9	34.2
90	27.2	28.8	34.9
95	28.4	29.5	36.2
98	29.7	31.1	38.0
99	30.4	31.4	38.1
Mean	21.2	25.0	30.4
SD	4.6	3.5	4.3

+ 10.225. Further linear regression analysis resulted in the correlation coefficient matrix for height and weight with the selected W/H relations (table 4). The ratio $W/H^{1.5}$ showed the least correlation with height and, with the exception of W/H , the greatest correlation with weight.

Since the relation between the increase in $\%BF$ with age was significant the subjects were divided in the three age groups shown in table 3. The detailed correlation coefficient matrix, obtained by linear regression analysis, relating the $\%BF$ in each group to the height, weight, and W/H relation is recorded in table 5. Regression equations for predicting $\%BF$

Table 2 Percentile distributions of weight/height indices ($n = 419$). W = weight in kilograms; H = height in metres

Percentile	W	H	W/H	$W/H^{1.5}$	W/H^2	W/H^3	$W^{0.33}/H$
1	55.1	1.61	32.94	25.73	19.34	10.52	2.16
2	58.9	1.62	34.55	26.35	19.95	10.88	2.18
5	61.8	1.64	35.73	27.00	20.45	11.45	2.22
10	64.1	1.67	37.18	28.07	20.99	11.87	2.25
20	67.9	1.69	38.88	29.48	22.28	12.62	2.29
25	68.9	1.70	39.87	29.89	22.81	12.83	2.31
30	71.0	1.72	40.46	30.56	23.06	13.03	2.32
40	74.0	1.73	41.86	31.47	23.66	13.53	2.35
50	76.1	1.75	43.33	32.71	24.61	13.91	2.37
60	78.5	1.77	44.67	33.41	25.25	14.40	2.39
70	81.1	1.79	45.92	34.95	26.31	14.90	2.43
75	82.7	1.80	46.84	35.44	26.82	15.20	2.44
80	84.7	1.81	47.87	36.02	27.18	15.76	2.47
90	88.8	1.84	49.94	37.84	28.60	16.78	2.52
95	93.2	1.87	52.20	39.47	30.02	17.62	2.56
98	99.0	1.90	55.55	42.26	32.04	18.67	2.61
99	105.3	1.92	56.90	43.38	32.94	19.04	2.63
Mean	76.5	1.75	43.60	32.90	24.80	14.20	2.38
SD	9.9	0.07	5.20	3.90	2.90	1.90	0.10

Fig 2 Increase in percentage body fat (%BF) shown against age. Regression equation of form $\%BF = 0.442(\text{age}) + 10.225$ was obtained ($t = 17.7$; $p < 0.0001$).

from W/H indices were developed for each age group and shown in table 6. The correlation coefficients relating to $W/H^{1.5}$ and W/H^2 were similar in each respective age group, although the coefficient increased directly with the increase in age.

The r^2 values shown in table 6 show that the percentage of the total variation that may be explained by the regression models is remarkably similar for both $W/H^{1.5}$ and W/H^2 . The standard error of the estimate for the value of %BF predicted from the mean value for each index for the respective age groups (see table 6) indicates the lack of difference in terms of accuracy between the indices.

Discussion

At present, commercial divers are the only group of employees within the North Sea population for whom recommendations regarding degree of overweightness and obesity exists. Since the offshore population is aging and has been shown to be both significantly

Table 5 Correlation coefficients of percent body fat with height (H), weight (W), and indices of adiposity for each age group

	Age group (years)		
	20-29 ($n = 180$)	30-39 ($n = 144$)	40-49 ($n = 77$)
H	-0.07	-0.12	-0.03
W	0.63	0.63	0.69
W/H	0.73	0.74	0.77
$W/H^{1.5}$	0.76	0.77	0.80
W/H^2	0.77	0.78	0.80
W/H^3	0.73	0.73	0.76
$W^{0.33}/H$	0.73	0.74	0.77

fatter and more overweight¹⁹ than to apply a single regression equation would be erroneous.

During routine medical examination, height and weight are normally recorded and perhaps an estimate of overweightness/obesity either from weight for height or by subjective assessment. Rarely are skin-fold thicknesses, underwater weighing, whole body potassium, or other indices of body composition used. Many of these techniques are both complex and time consuming and do not lend themselves to incorporation as part of the routine medical. As height and weight may easily be measured the accuracy of such measurements and their incorporation into an index of adiposity may be useful.

The definite increase in percentage body fat with age suggests that if an index is to be used, it is perhaps better to use a series of regression equations that are age specific. In addition to determining the age specific regression equations regarding which W/H relation is applicable—that is, the power exponent for (H)—each age category should have a specific regression equation.

The log/log plot according to Benn showed that the exponent p for the study population should be 1.5.¹⁵ An interesting value since instead of applying W/H^2 in studies of women a value of 1.5 has also been considered more appropriate. It is well known that women have a higher percentage body weight as fat and the subjects in the present study also showed higher percentage body fat content than their onshore peers.¹⁹

The choice of which W/H index is the most applicable to the reported population may be decided from the correlation coefficients relating the W/H indices to height and weight (table 4). Since any W/H index requires a poor correlation with height and a strong correlation with weight with the exception of W/H itself the smallest height correlation was shown with $W/H^{1.5}$ and W/H^2 . Furthermore, these two indices also showed the strongest correlations with weight. In addition, the strongest positive correlations relating

Table 4 Correlation coefficient of indices of adiposity with height (H) and weight (W)

	H	W
W/H	0.15	0.96
$W/H^{1.5}$	-0.01	0.89
W/H^2	-0.17	0.81
W/H^3	-0.44	0.61
$W^{0.33}/H$	-0.45	0.60
$H/W^{0.33}$	0.46	-0.60

Table 6 Regression equations for the prediction of percentage body fat (%BF) from W/H indices. (Standard error of the estimate (SEE) is calculated for the respective mean index value)

Age group (years)			
20-29		30-39	40-49
W/H ^{1.5} (Kg ^{1.5})	%BF = 0.968 (W/H ^{1.5}) - 9.473	%BF = 0.778 (W/H ^{1.5}) - 0.801	%BF = 0.797 (W/H ^{1.5}) + 2.622
SEE	2.964	2.249	2.612
r ² (% variation)	58.0	60.0	64.0
W/H ² (Kg ²)	%BF = 1.298 (W/H ²) - 9.717	%BF = 1.017 (W/H ²) - 0.570	%BF = 1.058 (W/H ²) + 2.454
SEE	2.914	2.218	2.582
r ² (% variation)	60.0	61.0	64.0

the indices to percentage body fat were detected for W/H^{1.5} and W/H² (table 5).

Since little difference was shown between W/H^{1.5} and W/H² it appears that either relation may be used to describe the offshore workforce. In practical terms W/H² is both easier to calculate and would readily lend itself to comparison with other studies where extensive use has been made of the body mass index.

The index of W/H² would indeed seem to be the most appropriate index of adiposity that should be applied to the offshore workforce. Since height in metres and weight in kilograms is easily obtained without the requirement for either complicated apparatus or sophisticated technique then W/H² may be used as a measure of adiposity for the workforce reported and in the absence of skinfold thickness measurements then the age specific regression equations may be used to predict the percentage body fat. The accuracy of such a technique having being established is shown in table 6.

If such a method of assessment of adiposity were adopted the acknowledged limitations of the application of W/H indices should be appreciated. The well known account of the United States athletes who would not have been passed fit for military service because of an unacceptably high value of adiposity from height and weight measurements should be remembered.²⁰ Weight/height indices have the distinct disadvantages that they do not differentiate the moderately obese from muscular individuals nor do they take into account the changing body composition that occurs with aging. The partitioning of the body mass into lean body mass and percentage body fat would appear valuable. If the limitations and advantages are accepted then W/H² would seem to be the most applicable W/H index for the population measured in the current study.

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