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Reprints and Reflections

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Indices of relative weight and obesity*

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Introduction

THE NEED for an index of relative body weight was recognized from the beginning of anthropometry, that is to say as soon as serious attention was given to the dimensions of the body and their biological and medical implications. Body weight in proportion to height or to some function of height is interesting because it should indicate something about ‘build’ or shape and about obesity or fatness.

Various indices of relative weight have been espoused and applied for many years but as yet there is no agreement on any particular index. In part this reflects confusion-or at least lack of agreement-about what a relative weight index should represent and mean; in part the reason is a lack of “calibrating” data and of systematic examination of wide-ranging samples of data analyzed in parallel. The purpose of this paper is to provide a comparison of various indices of relative weight as applied to data on weight, height and body fatness of men in several countries in Europe, in Japan, men in South Africa, as well as of white men in the United States.

In the present paper guidance in the analysis was provided by two assumptions. First, it is assumed that a major reason for the use of a relative weight index is to remove the dependency of weight on height. Second, it is assumed that in the selection of an index attention should be given to the degree to which the index may indicate relative obesity or body fatness.

Relative body weight-life insurance averages

Superficially, it might seem simplest and most informative to express the weight of the individual as a percentage of the average weight of persons of the same height, age and sex in the population to which he belongs. That was the reasoning that led to publication of “standard height-weight” tables by the life insurance industry, beginning with the Medico-Actuarial Mortality Investigations of 1912.[1]

As originally published, the life insurance industry tables simply provided, for the two sexes, average weights, in pounds, at specified ages and heights, in inches. Those measures were recorded, ‘as customarily dressed in indoor clothing’, in connection with application for life insurance. Roughly, at least for men, it seems that the extra height added by the shoes may be compensated for by the extra weight added by the shoes and the rest of the ‘indoor clothing’, so that similar relationships should hold for barefoot height and nude weight or in light underclothing.

We have published a metric system version of those 1912 tables based on smoothed plots of the discrete values in the original tables.[2] In the present paper, ‘relative body weight’ means the body weight expressed as a percentage

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of those tabular 'averages'. Later tabulations of similar 'average' weights and heights have been published by the life insurance industry, notably in 19592; the differences are not large and their meaning is obscured by such questions as whether 'customarily dressed' in the period 1935 through 1953, covered by the 1959 report, is comparable to the same term in the period 1898–1905 covered by the 1912 report.

It should be noted that for some purposes it is immaterial whether a proposed table of 'standard' weights accurately portrays the average (or median) of the reference population. So long as the standard is accepted and all sets of data on individuals are referred to it, the validity of comparisons between individuals or groups will be independent of the 'quality' of the table.

Weight/height ratios

Populations differ from one another and populations change. Average values for weight and height for given age and sex for a given population do not necessarily apply to other populations or even to the same population at another time. Further, there is no present prospect of obtaining for any population true average values of weight for given height, age and sex. Certainly persons examined in connection with application for life insurance are far from being a random sample of the population.

Apart from such considerations, scientifically minded investigators would much prefer an index of relative weight in purely physical units, unchanging from population to population or from time to time. Obviously we are concerned with weight per unit height but elementary consideration of the ratio, W/H, leads to the question as to why the weight, which is roughly equivalent to a volume, a three-dimensional or cubic unit should be standardized in terms of a single linear dimension. Obviously, if the body had the same form at different heights, weight would tend to be proportional to the third power of the height. That idea was incorporated by Livi in his *indice ponderale,* literally 'ponderal index' in English: the cube root of the body weight divided by the body length or height.[3]

In spite of the fact that it is easy to show that the body form does not remain constant with increasing length, the ponderal index, or the similar Rohrer index, W/H^3, has been rather widely used. Florey[4] suggests this reflects the use of the ponderal index in the popularization of 'somatotypes' by Sheldon[5] and his school.[6] But Sheldon curiously managed to invert the ratio, using the height divided by the cube root of weight which he referred to as 'one variation of the 'ponderal index', or index of bodily mass, which has long been used in attempts at bodily classification'5. Sheldon's inverted version of the ponderal index has the unhappy feature of being inversely proportional to weight at any given height. That bizarre form invented by Sheldon has been used as the 'weight index' in a report on the Los Angeles Heart Study.[7]

Almost a century and a half ago Quetelet, the great pioneer in anthropometry and statistics, explored both W/H^3 and W/H^2 in respect to growth. In recent years the ratio W/H^2, as well as the ratio W/H and the ponderal index or the closely related ratio W/H^3, have been examined with data on population groups in England,[8–9] with data from the Framingham Study in Massachusetts4, and with data on some Polynesians.[10] The ponderal index was included in the description of several population samples by Kemsley et al in the proposal of a 'new height-weight standard' for Britain.[11]

In the choice of an index of relative weight derived from measures of weight and height, apart from the requirement that the index be highly correlated with weight, the prime criterion must be the relative independence of the index from height. In the present paper it will be shown, in confirmation of some recent conclusions of others, that in this respect the ratio W/H^2 is clearly better than the ponderal index. It is proposed that this ratio, W/H^2, be termed the *body mass index*.

Adiposity-body density and subcutaneous fat thickness

In much of the literature, especially in discussions of clinical problems and in reports from the life insurance industry, relative weight is taken as a measure of obesity or fatness in spite of repeated demonstrations and warnings of the serious errors arising from that confusion.[12–18] In the middle range of the various weight indices, say including 90 to 110 per cent of the average weight for given height and age, it is unlikely that any weight index will provide an acceptable indication of adiposity or body fatness, though relationships became more apparent as the relative weight departs further from the population average.

In both medical and popular uses of relative weight data the interest, conscious or unconscious, is on the implication for body fatness. It is of interest, therefore, to examine relationships between the various indices of relative weight and completely independent measures related much more directly to the body fat mass. One of the most widely approved of the latter measures is the body density. Body density measurement with an acceptable degree of accuracy remains a difficult and time- consuming procedure that could not be considered for routine use or for population surveys. In the present study two sets of body density data will be examined in connection with evaluating the several indices of body weight.

In contrast, measurement of the thickness of the subcutaneous fat layer in selected sites of the body, is quick, easy and draws no complaints from the subjects. Measurements of skinfold thickness were available for all men considered in this present study and those data were also used in the analysis of the relative weight indices. Other things being equal, it is agreed, with some other investigators,[4,9,19] that the best relative weight index is the one that shows the least correlation with body height and the highest correlation with independent measures of body fatness.

Methods

Height and weight were measured with the subjects barefoot and clad only in light underwear, the technique following the recommendations of the Committee on Nutritional Anthropometry of the Food and Nutrition Board, National Research Council.[20] Those Committee recommendations were also adhered to in the measurement of the skinfold thickness except in the case of the Minnesota students and businessmen whose data were collected before the Committee on Nutritional Anthropometry was formed. The calipers used for all later skinfold measurements exerted a constant pressure of 10 ± 2 g per mm^2 at all openings to at least 45 mm. Both American- and British-made calipers were used and frequent comparisons of the two makes showed no indication of systematic differences. Except in the case of the Minnesota students, the analyses here concern the sum of two skinfolds, that over the triceps muscle of the upper arm and that on the back just below the tip of the scapula. Because of differences in sites and of method, the skinfold thicknesses of the students are not comparable to the other skinfold data. However, the skinfold values of the students are suitable for analyses of relationships within the student group, if not between the student and other groups.

Body density was measured by weighing the subject completely under water, correcting for the air in the lungs and respiratory passages. At the moment of recording the underwater weight, the mouthpiece valve was switched so as to provide 100 per cent oxygen for inspiration and to collect all expired gas in a counterbalanced Tissot spirometer. Measurement of volume and subsequent gas analysis of the air in the Tissot covered the total nitrogen washout in seven minutes from the moment of underwater weighing.

The skinfold thickness gave some concern in regard to the analysis of the data because the distribution of that measure is far from normal, being skewed far to the right as shown in Fig. 1. Plotted on probability paper, the cumulative distribution fits a straight line for the lower 70 per cent of the skinfold values but deviates progressively to the right thereafter. A transformation of the data to arrive at a more normal distribution would be desirable for statistical analysis concerning correlation and regression in respect to the relative weight indices.

In an effort to arrive at a distribution approximating the normal curve, the late Dr. Jaako K. Kihlberg tried many transformations of the skinfold variable-$X^1 = 1/X$, $X^1 = 1(x - a)$, $X^1 =$ square root of X, $X^1 = a + bX$, etc., with relatively small success. Figure 2 shows the result with the log transformation of the skinfold data used in Fig. 1; the improvement is still not satisfying. A better transformation is indicated by the equation:

$$X^1 = a + bX + c/X \quad (1)$$

Multiple regression solution of equation (1) with several sets of skinfold data yield average 'best' values of the coefficients so that equation (1) becomes:

$$X^1 = 5.529 + 0.0458X - 21.834/X \quad (1a)$$

Applying these coefficients in equation (1a) with the skinfold data used in Figs. 1 and 2 yielded the distribution shown in Fig. 3. The correspondence to the normal curve is excellent. Accordingly, in the analyses in this paper, use is made of both the raw skinfold values and those values transformed with equation (1) and the coefficients given above.

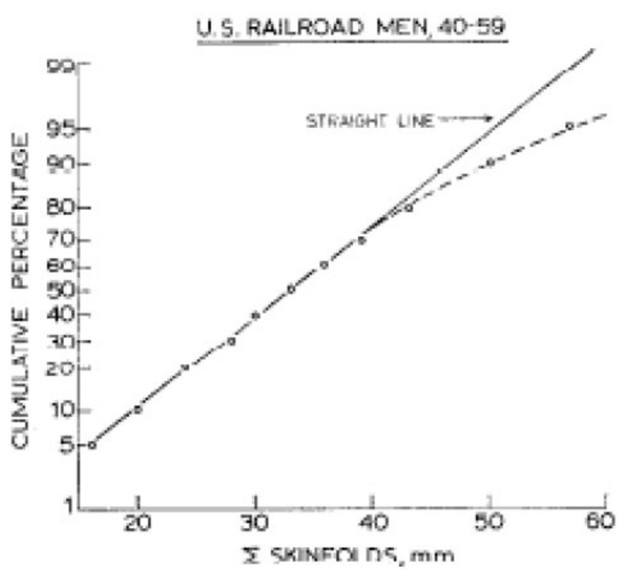

Figure 1. Cumulative percentage distribution (ordinate, probability scale) of the sum of the skinfold thicknesses of 2,404 'healthy' U.S. railroad employees aged 40–59 yr.

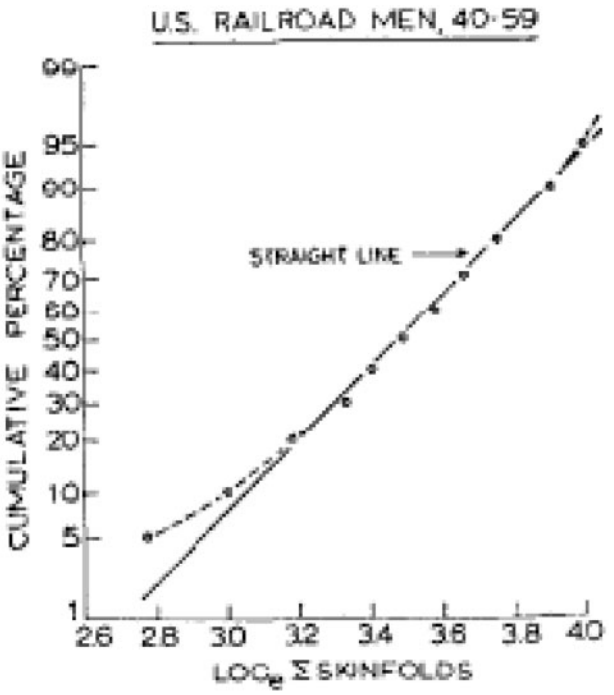

Figure 2. Same as Fig. 1 but using the natural (base e) logarithm of the skinfold thickness.

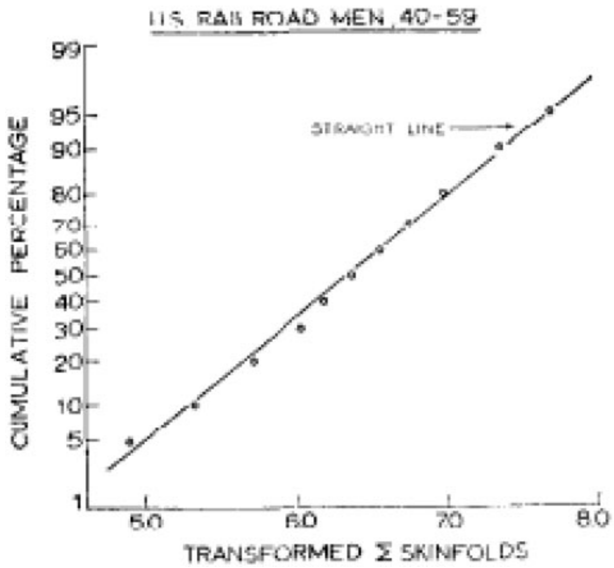

Figure 3. Same as Fig. 1 but using the transformation of the sum of the skinfold thicknesses, *X*, where $X^1 = 5.529 + 0.0458X - 21.834/X$.

In order to facilitate comparison of correlation coefficients, besides reporting the values of *r*, the values of the Z transformation and *SE* of Z are tabulated in the analytical summaries in this paper. Z, which, in contrast *to r*, is normally distributed was calculated:

$$2Z = \log_e(1 + r) - \log_e(1 - r) \qquad (2)$$

The standard error of Z was calculated

$$(SE, Z)^2 = 1/(N - 3) \qquad (3)$$

Subjects

The data analyzed here pertain to men who were being examined in connection with surveys and long-term prospective studies concerned with the incidence of coronary heart disease. Details of the recruiting and sampling procedures have been published elsewhere; here it is enough to provide brief notes together with the corresponding references to the various samples.

In order of chronology, the first two samples were men living in the Twin Cities of Minneapolis-St. Paul or suburbs at the time of the first examination in the years 1947–1949. Men students undergoing physical examination as part of the requirement (at that time) for admission to the University of Minnesota and who were considered ‘healthy’ by the examining physician made up the first group. Those young men studied in respect to the indices of weight and of fatness were not otherwise selected except insofar that no one was forced to undergo the special measurements and a few declined or failed to keep their appointments.

The second sample of men in the Twin Cities area were business and professional men 49–59 yr old and considered to be free of coronary heart disease at the time of the examinations yielding the data used in the present study. Their recruitment and some entry characteristics and disease experience in the next 20 yr have been reported.[21–23] The data used here from that cohort concern 249 men at the fourth of their annual examinations.

The sample of Bantu men studied in South Africa included men working within the city of Cape Town, and judged to be ‘healthy’, could not be suggested to be a representative sample of Bantu men in Cape Province let alone of Bantu men in general; but they were not selected in any way except as being in the employ of the local firms that agreed to cooperate, meaning to tell their Bantu employees to report to the examining room set aside at the place of their work.

The men in all of the other 9 samples of men considered here comprised cohorts in the long-range study on the incidence of heart disease of the International Cooperative Study of Cardiovascular Disease[2,24] and the closely allied study of U.S. railroad employees organized by Taylor.[25,26]

The ‘Rome railroad men’ were a sample of the Rome Division of the Italian State Railroads in selected occupations: clerks and station masters (essentially sedentary on the job), switchmen, electricians (the Italian railroad system is 100 per cent electrified), and the maintenance-of-way men, the men who do the heaviest work in the system.[27,28] The Rome Division extends very far beyond the confines of the metropolitan area of Rome and the 'mix' in the present sample is probably not far different from that of the railroad system in general in central and northern Italy.

The samples of men in east and west Finland,[29,30] in Crevalcore and Montegiorgio in Italy,[31,32] and in Tanushimaru and Ushibuka[33,34] in Japan, comprise 96–100 per cent of all men aged 40–59 who were long-time residents in the defined geographical areas and who were, at the time of their entry examination (the only one from which data are considered here) pronounced to be free from signs or symptoms of coronary heart disease. All six are samples of rural populations. Ushibuka is a fishing village with no other industry; the other areas are agricultural villages and most of the men are simple farmers. The exclusion from the present analyses of the men in nine other cohorts in the International Cooperative Study (in Yugoslavia, the Netherlands, Greece and Hungary) was purely a matter of practical expediency; there was no reason to include all of that material, which essentially tells the same story, and the selection of the cohorts for consideration here was made to include the most contrasting populations.

The findings-distribution of the measures

Table 1 summarizes the 12 samples, a total of 7426 men, considered here, in terms of the means and standard deviations of height, weight, and the four indices of relative weight. The tallest are the U.S. railroad switchmen, the shortest the Japanese farmers.

In terms of mean weight as percentage of average weight of U.S. insurance applicants at given height and age, the relatively heaviest are the Rome railroad men, followed by the University of Minnesota students, U.S. railroad switchmen and Crevalcore, Italy, farmers; the relatively lightest are the Japanese men. No matter what index of relative weight is considered, the present material covers a wide range.

Obviously, the basic requirements for an acceptable relative weight index calculated from weight and height are that it should have the least possible dependency on height; it should not have somewhat different meanings

Table 1. Means, and standard deviations, in parentheses of the several indices of relative weight in the samples of men in the present study. W = weight in kg, H = height in meters, P.I. = H/W⅓, $\%\bar{W}$ = W as % of average weight at given height and age as tabulated in ref. (2). Crev. = Crevalcore; Monte. = Montegiorgio; N = Number of men

Cohort	Age	N	W	H	W/H	W/H^2	P.I.	$\%\bar{W}$
U. Minn. students	18–24	180	74.1	1.77	41.7	23.5	2.358	107.4
			(11.9)	(0.065)	(6.4)	(3.62)	(0.117)	(15.6)
Minn. executives	49–59	249	77.8	1.75	44.3	25.3	2.421	102.1
			(11.9)	(0.062)	(6.3)	(3.55)	(0.123)	(14.5)
Bantu	31–60	116	65.6	1.68	39.1	23.3	2.398	95.2
			(11.3)	(0.068)	(5.7)	(2.98)	(0.098)	(12.5)
Japanese farmers	40–59	499	56.0	1.60	34.9	21.8	2.381	86.9
			(6.9)	(0.054)	(3.8)	(2.30)	(0.085)	(9.7)
Japanese fishermen	40–59	535	56.3	1.60	35.2	22.0	2.392	87.2
			(6.9)	(0.061)	(3.9)	(2.41)	(0.097)	(10.4)
U.S. Ry., sedentary	40–59	926	75.5	1.74	43.2	24.8	2.415	100.7
			(11.0)	(0.070)	(5.7)	(3.16)	(0.111)	(12.9)
U.S. Ry., switchmen	40–59	871	78.2	1.74	44.8	25.7	2.445	104.9
			(11.0)	(0.060)	(5.8)	(3.31)	(0.114)	(13.5)
E. Finland	40–59	797	65.9	1.68	39.2	23.3	2.398	94.8
			(9.9)	(0.061)	(5.3)	(3.05)	(0.104)	(12.3)
W. Finland	40–59	836	70.7	1.71	41.2	24.1	2.404	97.8
			(11.1)	(0.060)	(5.9)	(3.32)	(0.110)	(13.6)
Crev., Italy	40–59	978	72.6	1.68	43.2	25.7	2.457	104.3
			(12.1)	(0.064)	(6.5)	(3.64)	(0.116)	(14.9)
Monte., Italy	40–59	636	67.2	1.65	40.8	24.8	2.457	100.1
			(11.0)	(0.058)	(6.2)	(3.67)	(0.121)	(14.8)
Rome Railroad	40–59	802	73.6	1.66	44.1	26.6	2.513	107.8
			(11.4)	(0.056)	(6.3)	(3.66)	(0.120)	(15.0)

with tall men and with short men. Table 2 shows the results of analyzing, with data from the men considered in Table 1, the correlation of height with the several weight measures. There is, as expected, a substantial correlation of simple body weight with height but in all of the cohorts except the small group of Bantu men there is also a highly significant correlation of the ponderal index with height. In this respect the ponderal index is generally less acceptable than the simple ratio W/H and is much inferior to the body mass index.

Both the percentage of average weight and the body mass index, W/H^2, satisfy the requirement of a very low correlation with height. Except for the Japanese fishermen, less than 1 per cent of the variance in the body mass index is accounted for by regression of body mass index on height; the average, including the Japanese fishermen, is only 0.3 per cent. For the percentage of average weight, height accounts for an average of only about 0.6 per cent so that measure is nearly as good as the body mass index in this respect.

Relative weight and subcutaneous fat

The second question to consider is the degree to which the several indices of weight indicate relative obesity or body fatness. Table 3 summarizes that question using the sum of the skinfolds as a direct measure of fatness. All of the

Table 2. Correlations of the several relative weight indices with height. Headings as in table 1

				Correlation with height of:				
Cohort	Age	N	Item	W	W/H	W/H^2	P.I.	$\%\bar{W}$
U. Minnesota students	18–24	180	*r*	0.456	0.254	0.015	0.241	0.036
			Z	0.492	0.260	0.015	0.246	0.036
			SE, Z	0.075	0.075	0.075	0.075	0.075
Minnesota executives	49–59	249	*r*	0.395	0.181	0.062	0.304	0.102
			Z	0.418	0.183	0.062	0.313	0.102
			SE, Z	0.064	0.064	0.064	0.064	0.064
Bantu	31–60	116	*R*	0.677	0.509	0.249	0.102	0.318
			Z	0.824	0.561	0.254	0.102	0.329
			SE, Z	0.094	0.094	0.094	0.094	0.094
Japanese farmers	40–59	499	*r*	0.514	0.267	0.045	0.356	0.146
			Z	0.568	0.274	0.046	0.372	0.147
			SE, Z	0.045	0.045	0.045	0.045	0.045
Japanese fishermen	40–59	535	*r*	0.463	0.175	0.164	0.474	0,078
			Z	0.501	0.177	0.166	0.515	0.079
			SE, Z	0.044	0.044	0.044	0.044	0.044
U.S. Ry., sedentary	40–59	926	*r*	0.500	0.252	0.058	0.344	0.068
			Z	0.549	0.258	0.058	0.359	0.068
			SE, Z	0.033	0.033	0.033	0.033	0.033
U.S. Ry., switchmen	40–59	871	*r*	0.406	0.171	0.098	0.348	0.119
			Z	0.431	0.172	0.098	0.363	0.120
			SE, Z	0.034	0.034	0.034	0.034	0.034
E. Finland	40–59	797	*r*	0.492	0.273	0.000	0.276	0.064
			Z	0.540	0.280	0.000	0.283	0.064
			SE, Z	0.035	0.035	0.035	0.035	0.035
W. Finland	40–59	836	*r*	0.474	0.278	0.039	0.225	0.054
			Z	0.515	0.286	0.039	0.229	0.054
			SE, Z	0.035	0.035	0.035	0.035	0.035
Crev., Italy	40–59	978	*r*	0.533	0.338	0.087	0.182	0.156
			Z	0.594	0.352	0.087	0.184	0.157
			SE, Z	0.032	0.032	0.032	0.032	0.032
Monte., Italy	40–59	636	*r*	0.423	0.221	0.014	0.249	0.083
			Z	0.451	0.224	0.014	0.255	0.083
			SE, Z	0.040	0.040	0.040	0.040	0.040
Rome Railroad	40–59	802	*r*	0.466	0.270	0.034	0.208	0.105
			Z	0.505	0.276	0.034	0.211	0.105
			SE, Z	0.035	0.035	0.035	0.035	0.035

Table 3. Correlations of the relative weight indices with Σ skinfold thickness. Heading abbreviations as in table 1. in () under 'cohort' are mean Σ skinfolds (mm), mean of the skinfold transform with equation (1′), and the standard deviation of the mean transform

Cohort	Age	N	Item	Correlation with Σ skinfold with:					
				H	W	W/H	W/H^2	P.I.	$\%\bar{W}$
U. Minn. students (27.66, 5.79 ± 1.00)	18–24	134	*r*	0.044	0.777	0.833	0.850	0.790	0.852
			Z	0.044	1.038	1.198	1.256	1.071	1.263
			SE, Z	0.087	0.087	0.087	0.087	0.087	0.087
Minn. executives (33.09, 6.25 ± 0.84)	49–59	248	*r*	0.014	0.723	0.771	0.777	0.736	0.774
			Z	0.014	0.914	1.023	1.038	0.942	1.030
			SE, Z	0.064	0.064	0.064	0.064	0.064	0.064
Bantu (21.09, 5.12 ± 1.10)	31–60	116	*r*	0.335	0.724	0.756	0.732	0.629	0.691
			Z	0.348	0.916	0.987	0.933	0.740	0.850
			SE, Z	0.094	0.094	0.094	0.094	0.094	0.094
Japanese farmers (16.64, 4.74 ± 0.78)	40–59	499	*r*	0.074	0.567	0.613	0.611	0.521	0.559
			Z	0.074	0.643	0.714	0.710	0.577	0.632
			SE, Z	0.045	0.045	0.045	0.045	0.045	0.045
U.S. Ry., sedentary (32.89, 6.23 ± 0.87)	40–59	926	*r*	0.041	0.679	0.747	0.757	0.691	0.748
			Z	0.041	0.827	0.965	0.988	0.850	0.968
			SE, Z	0.033	0.033	0.033	0.033	0.033	0.033
U.S. Ry., switchmen (31.71, 6.13 ± 0.91)	40–59	871	*r*	0.023	0.700	0.761	0.774	0.728	0.766
			Z	0.023	0.867	0.999	1.031	0.925	1.010
			SE, Z	0.034	0.034	0.034	0.034	0.034	0.034
E. Finland (17.36, 4.71 ± 1.03)	40–59	997	*r*	0.053	0.708	0.773	0.791	0.710	0.785
			Z	0.053	0.884	1.028	1.077	0.887	1.059
			SE, Z	0.035	0.035	0.035	0.035	0.035	0.035
W. Finland (19.27, 4.98 ± 0.97)	40–59	836	*r*	0.139	0.769	0.804	0.799	0.718	0.795
			Z	0.140	1.017	1.109	1.095	0.903	1.085
			SE, Z	0.035	0.035	0.035	0.035	0.035	0.035
Crev., Italy (24.05, 5.47 ± 1.01)	40–59	978	*r*	0.130	0.664	0.706	0.711	0.659	0.713
			Z	0.131	0.800	0.879	0.890	0.791	0.894
			SE, Z	0.032	0.032	0.032	0.032	0.032	0.032
Monte., Italy (17.88, 4.78 ± 1.05)	40–59	636	*r*	0.065	0.750	0.793	0.797	0.732	0.796
			Z	0.065	0.973	1.079	1.090	0.934	1.086
			SE, Z	0.040	0.040	0.040	0.040	0.040	0.040
Rome Railroad (27.47, 5.79 ± 0.94)	40–59	802	*r*	0.141	0.736	0.768	0.762	0.705	0.767
			Z	0.142	0.942	1.015	1.000	0.877	1.012
			SE, Z	0.035	0.035	0.035	0.035	0.035	0.035

indices of relative weight are fairly highly correlated with the thickness of the subcutaneous fat layer and the differences in this respect between the various indices are small. Still, it should be noted that, among the four indices, in every cohort the ponderal index has the lowest correlation with the direct measure of fatness. Further, it may be noted that the highest correlation shown in Table 3, namely r = 0.8, means that only some two-thirds of the variance of the sum of the skinfolds is accounted for by the variance of that measure on the most closely correlated index of relative weight.

In Table 3, the tabulated correlation coefficients were calculated from the simple, untransformed sums of skinfold thicknesses. The question may be asked why, in view of the markedly non-normal distribution of the skinfold thickness, calculations were not made with the skinfolds transformed with equation (1'). The answer is that all of the correlations considered in Table 3 were calculated both with the transformed as well as with the raw variable and the differences in the results were unimportant. In all cases the correlations obtained with the transformed sum of skinfolds were only slightly different from those obtained with the plain sum of skinfolds. Table 4, confined to examples from three of the largest cohorts in this study, illustrates the trivial change resulting from using the transformed variable.

Table 4. Comparison of correlations of H and of W//H^2 with: Σ skinfolds and with the normally distributed transformation of Σ skinfolds

Cohort	Variables correlated	*r*	*z*	*SE, Z*
U.S. Ry., sedentry seden tary	H and Σ skinfolds	0.041	0.041	0.033
	H and Σ skinfolds transformed	0.041	0.041	0.033
Crevalcore	H and Σ skinfolds	0.130	0.131	0.032
	H and Σ skinfolds transformed	0.146	0.147	0.032
West Finland	H and Σ skinfolds	0.139	0.140	0.035
	H and Σ skinfolds transformed	0.146	0.147	0.035
U.S. Ry., sedentry	W/H^2 and Σ skinfolds	0.757	0.988	0.033
	W/H^2 and Σ skinfolds transformed	0.758	0.992	0.033
Crevalcore	W/H^2 and Σ skinfolds	0.711	0.890	0.032
	W/H^2 and Σ skinfolds transformed	0.706	0.879	0.032
West Finland	W/H^2 and Σ skinfolds	0.799	1.095	0.035
	W/H^2 and Σ skinfolds transformed	0.808	1.121	0.035

Table 5. Correlations of various measures with body density and with the sum of the skinfolds transformed to make a normal distribution. '95% Lo' and '95% Hi' are the 95% confidence limits of the correlation coefficient, *r*. *Z* is the normally distributed transform of *r*. Values in () are the cutting points for the 20th, 50th and 80th centiles of the body density and the sum of skinfolds (in mm). N = 180 for University of Minnesota Students (aged 18–24); N = 249 for the Minnesota Executives (aged 49–59). 'P.I.' = ponderal index

Cohort	Correlate	Item	Density	Sum of skinfold	H	W	W/H	W/H^2	P.I.
Students (1.056, 1.067, 1.079)	Density	*R*	1.000	−0.854	0.044	−0.777	−0.833	−0.850	−0.791
		95% Lo	–	−0.801	−1.103	−0.712	−0.782	−0.804	−0.729
		95% Hi	–	−0.893	0.189	−0.829	−0.873	0.886	−0.840
		Z	–	−1.272	0.044	−1.038	−1.198	−1.256	−1.074
		SE, Z	–	0.075	0.075	0.075	0.075	0.075	0.075
Students (17, 25, 37)	Σ Skinfold	*R*	−0.854	1.000	0.060	0.779	0.834	0.847	0.810
		95% Lo	−0.801	–	−0.110	0.702	0.751	0.770	0.743
		95% Hi	−0.893	–	0.278	0.838	0.891	0.900	0.861
		Z	−1.272	–	0.060	1.042	1.200	1.246	1.127
		SE, Z	0.087	–	0.075	0.075	0.075	0.075	0.075
Executives (1.041, 1.050, 1.060)	Density	*R*	1.000	−0.818	0.020	−0.618	−0.658	0.666	0.657
		95% Lo	–	−0.771	−0.105	−0.534	−0.581	−0.591	−0.581
		95% Hi	–	−0.855	0.144	−0.689	−0.724	−0.730	−0.723
		Z	–	−1.149	0.020	−0.721	−0.790	−0.804	−0.788
		SE, Z	–	0.064	0.064	0.064	0.064	0.064	0.064
Executives (15, 24, 32)	Σ Skinfold	*R*	−0.818	1.000	0.000	0.718	0.768	0.779	0.744
		95% Lo	−0.771	–	−0.124	0.651	0.712	0.724	0.683
		95% Hi	−0.855	–	0.125	0.773	0.815	0.823	0.795
		Z	−1.149	–	0.000	0.902	1.016	1.042	0.960
		SE, Z	0.064	–	0.064	0.064	0.064	0.064	0.064

Relative weight and body density

On the average something like half of the total body fat is subcutaneous so the skinfold thickness should fairly well indicate the total body fat, and therefore the true obesity, if the pattern of distribution of fat in the body were uniform, both as to proportion of total fat in the subcutaneous layer and in the representation of the subcutaneous fat at different sites on the body. But such uniformity does not, in fact, exist. The pattern not only differs with age and sex; within the same age and sex there is obviously much individual variation.

It is widely held that a much better indication of the proportion of the body mass made up of fat is provided by the body density.[12,13,34,35] The validity of skinfold thickness as an indication of body fatness is often judged by its correlation with body density.[36,37] Unfortunately, the measurement of the density of the living human body by any method so far suggested is a difficult and laborious procedure, totally unsuitable for surveys or any application other than in relatively small-scale, highly specialized research programs. Moreover, even estimated total body fat from the best measurement of body density depends on assumptions about body water and mineral content. Still, the body density should be more closely related (inversely) to body fatness than is skinfold thickness, so Table *5* is of interest.

In young men and in business and professional men in Minnesota, at least, body density, and therefore presumably body fatness, is not significantly related to height but it is significantly related (inversely) to each of the suggested indices of relative weight. It is interesting that the correlation with the simple gross body weight is not significantly lower than with any of the indices that take height into account. But body fatness as indicated by density or skinfold thickness is less well correlated with the ponderal index than with any other suggested index of relative weight.

Again the body mass index, W/H^2, proves to be, if not fully satisfactory, at least as good as any other relative weight index as an indicator of relative obesity. Still, if density is truly and closely (inversely) proportional to body fatness, not more than half of the total variance of body fatness is accounted for by the regression of fatness on the body mass index.

Discussion

It is reasonable and, indeed, necessary to search for means to get some kind of estimate for variables such as obesity or body type that are biologically or medically important but involve arbitrary definitions or are exceedingly difficult to measure directly.

However, in all such efforts it is essential to examine carefully the premises, to subject the proposed method or indicator to critical analysis with relevant data, and to compare the results when the same data are tested with alternative and competing methods.

Until recently, critical consideration of the simple concept of relative body weight has been relatively neglected. But there has been no lack of indices and formulas, usually bearing the names of their proponents accompanied by arbitrary proclamations about 'normality'. Much of the earlier literature was summarized by Rudolf Martin[38] and the period 1926–1938 was reviewed by Krogman.[39] Besides Livi,[3] many other investigators were attracted by the idea that a weight measure should be related to the cube of a length measure. Pirquet, focusing on linear growth in childhood, called the ratio, H^3/W, the 'height-weight index'; perhaps that was the origin of the inverted ratio used by Sheldon and his somatotyping school and in some other applications in the United States.[40,41] But Pirquet later stressed his 'Pelidisi', or index of body build, which is the ratio of the cube root of the weight divided by the *sitting* height (see ref[39]). Pirquet's index was rather widely used by other anthropometrists but its meaning and relationships have not been analyzed in any depth.

What we here call the body mass index, W/H^2, has a long history. Because Quetelet was the first to calculate that ratio, W/H^2 has sometimes been called Quetelet's index. But Quetelet himself did not actually advocate that ratio as the general measure of 'build' or of adiposity; he merely noted that in young adults W/H^2 was more stable than W/H^3 or W/H with increasing height. Krogman, in his extensive list of 'indices of nutritional status, proportion and body type', noted[39] the advocacy in the period 1919–1936 of W/H^2 by Bardeen who called it 'index of weight relative to stature', by Davenport who termed it the 'index of build', by Kaup, Kruse, van der Loo and others who referred to it as 'weight-height index'. But none of those proponents offered a convincing objective analysis in favor of the index. Further, it should be observed that the greatest emphasis in almost all of the index making of the anthropometrists was on growth with relatively little consideration of the evaluation of body composition, nutritional status or adiposity.

We have noted that recent examinations of weight-height indices concur in condemning the ponderal index and in favoring the ratio W/H^2. But in one of the major studies arriving at those conclusions[8] the ratio W/H^3 was used as a substitute for the ponderal index. Actually, $W/H^3 = P^3$ where P is the ponderal index, i.e. the cube root of the weight divided by the height.

The important difference between the properties of the ponderal index and those of the ratios W/H, W/H^2 and W/H^3 is apparent when calculations are made with increasing weights at constant height. A given increase in weight with constant height will produce exactly the same percentage increase in the values of all of the ratios, W/H, W/H^2, W/H^3 but a much smaller relative increase in the ponderal index. Consider a man 1.70 m tall who weighs 60 kg and then gains 15 kg. He gains 25 per cent in weight; his value of W/H changes in the same proportion, his body mass index W/H^2 changes from 20.76 to 25.95, i.e. it increases by 25 per cent also. But his ponderal index changes only from 2.3029 to 2.4807, an increase of only 7.7 per cent.

Now consider two persons of the same weight of 60 kg, one 1.70 m tall, the other 1.45 m in height. The ponderal index of the shorter person is (2.700)/(2.303) = 117.2 per cent that of the taller person, while the percentage comparisons using W/H, W/H^2 and W/H^3 are 117.2, 137.4 and 161.1, respectively. Of the various indices considered, the ponderal index is the least sensitive to differences in weight.

In recent medical literature the so-called 'ideal' or 'desirable' body weight is often used as a basis of reference, the relative body weight then being expressed as percentages of values in the tables published by the Metropolitan Life Insurance Company.[42] Those tables take no account of age; in effect they simply list the average weights of insurance applicants of given sex and height at age about 25.[13–16] As noted elsewhere,[43] the use of ideal or recommended weight confounds age and weight because on the average weight increases with age until the fifties while increase in height is over by the early twenties at the latest. The general trend to continue growth in weight may be undesirable but it has no relevance to the question of providing an objective description of relative body mass; it is scientifically indefensible to include a value judgement in that description. The characterization of persons in terms of desirable weight percentage has resulted in attributing to 'overweight' some tendencies to ill health and death that are actually only related to age.[43]

Summary

Analyses are reported on the correlation with height and with subcutaneous fat thickness of relative weight expressed as per cent of average weight at given height, and of the ratios weight/height, weight/height squared, and the ponderal index (cube root of weight divided by height) in 7424 'healthy' men in 12 cohorts in five countries. Analyses are also reported on the relationship of those indicators of relative weight to body density in 180 young men and in 248 men aged 49–59.

Judged by the criteria of correlation with height (lowest is best) and to measures of body fatness (highest is best), the ponderal index is the poorest of the relative weight indices studied. The ratio of weight to height squared, here termed the body mass index, is slightly better in these respects than the simple ratio of weight to height. The body mass index seems preferable over other indices of relative weight on these grounds as well as on the simplicity of the calculation and, in contrast to percentage of average weight, the applicability to all populations at all times.

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Commentary: Origins and evolution of body mass index (BMI): continuing saga

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We reflect upon Ancel Keys' classic article, reprinted here, which dealt with a leitmotif of his long career: body mass, its composition, measurement, function and meaning for health, disease and survival.[1] This preoccupation was

