The impact of adjustment of a weight–height index (W/H^2) for frame size on the prediction of body fatness

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1. The impact of frame-size categories in weight–height tables was studied by comparing the efficiency of the body-mass index (weight/height^2 (W/H^2)) and weight adjusted for body-height and a body-diameter, W/(H^{2}D^p), in predicting body fatness.

2. Body-weight, body-height, six body-diameters and four skinfold thicknesses were measured in ninety-five men and seventy women, aged between 23 and 35 years. Percentage of body fat was calculated from skinfold thicknesses using regression equations according to Durnin & Womersley (1974).

3. The inclusion of a body-diameter increased the explained variation of body fatness from 57% to 62% (knee) and 63% (shoulder) in men and from 63% to 69% (knee) in women.

4. It can be concluded that in the present population the efficiency of the prediction of percentage of body fat was not improved markedly by the inclusion of a body-diameter in the body-mass index, thus giving no support for the inclusion of frame-size categories in weight–height tables.

The inclusion of frame-size categories in weight–height tables seems to be of disputable value. A criticism of the Metropolitan Life Insurance Company (1959) weight standards in respect of frame-size categories was that no description of the method used to determine these categories was given (Brožek, 1956; Seltzer & Mayer, 1965). In the new Metropolitan Life Insurance Company (1983) height and weight tables, elbow diameter was introduced as a measure of frame size. Recent reviews have emphasized the lack of any measurement of body-diameter in the insurance examination information, resulting in frame-size categories not based on frame-size measurements (Knapp, 1983; Garn & Hawthorne, 1984). Apparently, weight differences at a given height are assumed to be attributable to frame-size differences as assessed from anthropometric measurements.

It is clear that body-weight should be corrected for frame size to obtain a better indication of body fatness. The percentage of body fatness will be lower for a tall than for a short person of the same body-weight and skeleton width and, similarly, lower for a person with a wide skeleton than with a narrow skeleton of the same weight and height. However, it is yet to be established whether adjustment for frame size should take into account body-diameter(s) in addition to body-height. Arguments for the inclusion of both body-height and body-diameter(s) have been put forward by several investigators. Seltzer *et al.* (1970) found differences in elbow and chest diameters in individuals of two relative weight classes of comparable age and height, and Frisancho & Flegel (1983) found larger differences in body-weight among frame-size categories based on elbow diameter than among body-height categories. Several equations have been devised to estimate fat-free mass or body-weight from body-height and body-diameters. These diameters include shoulder, chest, wrist, pelvis, hip, knee and ankle (Brozěk, 1956; Behnke, 1959; Hechter, 1959; Von Döbeln, 1959; De Wijn & Zaat, 1968; Wilmore & Behnke, 1968; Forsyth & Sinning, 1973).

If an estimation of frame size can be improved by using body-diameter(s) in addition to body-height, then the next question is, to what extent can body-diameter(s) improve a weight–height table to make the recommended weight range more appropriate? In other words, as a weight–height table can be considered as a categorized weight–height index, to what extent can the prediction of body fatness from a weight–height index be improved by the inclusion of a body-diameter?

Baecke *et al.* (1982) estimated body-weight from height, knee and wrist diameters and used this weight estimate in an index of relative weight, giving $W/\hat{W}$, where W is body-weight and $\hat{W}$ is estimated body-weight. The improvement of the frame-size correction by the addition of body-diameters was evaluated by comparing $W/\hat{W}$ with weight–height indices in predicting body fatness. No indication was found that frame-size categories based on knee and wrist diameters improved this prediction.

In the present study, additional body-diameters were taken into account, some of which have been suggested recently to be frame-size indicators (Katch & Freedson, 1982; Metropolitan Life Insurance Company, 1983; Frisancho & Flegel, 1983). A further reason is that Behnke (1959) indicated that limb and trunk diameters together give the best estimation of fat-free mass. For evaluation of the diameters used as frame-size indicators in weight–height tables, an analysis procedure somewhat different from that of Baecke *et al.* (1982) was developed. The body-mass index (BMI; W/body-height^2 (H^2)) was selected as the reference index because of its high correlation with measures of body fatness found in several populations (Keys *et al.* 1972; Womersley & Durnin, 1977; Frisancho & Flegel, 1982). Percentage of body fat was estimated by the log sum of four skinfold thicknesses (Durnin & Womersley, 1974). To assess whether an index consisting of weight, height and one body-diameter is more efficient than BMI in predicting percentage of body fat, an alternative index was constructed of the form $W/\hat{W}$, where $\hat{W}$ is an estimation of body-weight from both H^2 and body-diameter to the exponent p (D^p):

$$\hat{W} = c\,D^p H^2, \tag{1}$$

where c is a constant. Then the efficiency of the new index and BMI to predict body fatness was compared. Some anthropometric body-diameters may be biased by the subcutaneous fat layer and give a biased estimate of body-weight, which may well result in overcorrection in the index $W/\hat{W}$ and thus not improve the estimation of body fatness. In other words, an expected improvement in prediction of body fatness by the inclusion of body-diameters in addition to body-height as frame-size indicators in $\hat{W}$, may well be nullified by the fact that some body-diameters and body fatness are correlated. Since the contribution of body-height to BMI (W/H^2) and to $W/\hat{W}$ ($\hat{W} = cD^p H^2$) is identical, a difference in the estimation of body fatness is due entirely to the corresponding body-diameter only.

METHODS

Population and procedure

In November 1983, participants in a project on overweight being conducted in the municipality of Ede, The Netherlands (Baecke *et al.* 1982), were invited to participate in the present study. Complete information was obtained from ninety-five men and seventy women, aged between 23 and 35 years and of various levels of education. Pregnant women were excluded from the study population.

All subjects were invited by mail to visit a mobile research unit, which was stationed in their respective section of the municipality for 7 d. The anthropometric measurements were made at the mobile research unit. For various reasons, eighteen of the men were unable to attend the unit and were thus measured at home.

Measurements

Body-height and body-weight without shoes and in scant clothing only were measured to the nearest 1 mm and 0·1 kg respectively. Body-weight of those visited at home was measured to the nearest 0·5 kg. All measurements were made between 16.00 and 20.00 hours.

The diameters of knee, wrist and elbow were measured on both sides of the body according to Weiner & Lourie (1969). If the difference between the left- and right-side measurement was greater than 5%, then the measurement was repeated. The sum of left and right measurement was used in analyses. The shoulder and pelvic diameters were measured according to Keys *et al.* (1967), and the hip diameter according to Wilmore & Behnke (1969). The chest diameter was not measured because it is subject to a large degree of measurement error (Von Döbeln, 1959; Katch & Freedson, 1982). All diameters were measured to the nearest 1 mm using a GPM spreading caliper.

Duplicate measurements of the biceps, triceps, suprailiac and subscapular skinfold thicknesses were made according to Durnin & Rahaman (1967), on the left side of the body to the nearest 0·2 mm using a Holtain skinfold caliper. Body fat was calculated as a percentage of total body-weight from the average log sum of the four skinfold thicknesses, using linear regression equations for men and women aged from 20 to 29 years according to Durnin & Womersley (1974). All measurements were made by one examiner for each sex. As the values were analysed for men and women separately, it was not necessary to make adjustments for possible observer bias.

Analysis

An alternative index for body fatness, $W/\hat{W}$, was constructed where W is body-weight and $\hat{W}$ is body-weight estimated from body-height squared (H^2) and a body-diameter to the exponent p (D^p). To estimate body-weight, regression coefficients b_k (with corresponding intercept a_k) were estimated from a linear regression of ln BMI *v.* ln body-diameter D_k ($k = 1, \ldots, 6$):

$$\ln(W/H^2) = a_k + b_k \ln D_k + \text{error}, \tag{2}$$

$$\hat{W}_k = \exp(a_k)\, D_k^{b_k} H^2. \tag{3}$$

Subsequently, the efficiency of each index $W/\hat{W}$ in predicting body fatness was compared with the efficiency of BMI to make the same prediction. The relationships were examined visually. The evaluation criterion was the residual variance of body fatness after adjustment for BMI and the respective $W/\hat{W}$ indices. Since these indices were evaluated against the same observations of the external criterion, body fatness, comparison of unexplained variances is equivalent to comparison of correlation coefficients (proportion of variance explained). As these correlation coefficients were not pairwise independent, the difference of the two correlation coefficients was tested according to Olkin & Siotani (1976) with the asymptotically standard normal test statistic z*:

$$z = (r_{13} - r_{12})[\text{var}(r_{13} - r_{12})]^{-\frac{1}{2}}, \tag{4}$$

where

$$\text{var}(r_{13} - r_{12}) = N^{-1}[(1 - r_{12}^2)^2 + (1 - r_{13}^2)^2 - 2r_{23} - (2r_{23}^3 - r_{12}r_{13})(1 - r_{12}^2 - r_{13}^2 - r_{23}^2)], \tag{5}$$

and N is number of subjects, r is correlation coefficient between two X variables, X_1 is percentage of body fat, X_2 is BMI, X_3 is $W/\hat{W}$.

* In the present study ($r_{12} \approx r_{13} \approx 0{\cdot}8$ and $r_{23} \approx 0{\cdot}97$), the statistic defined by eqns (4) and (5) gave similar results as a statistic proposed by Hotelling (1940). This statistic is also defined by eqn (4) but here

$$\text{var}(r_{13} - r_{12}) = (N-3)^{-1}[1 - r_{12}^2 - r_{13}^2 - r_{23}^2 + 2r_{12}r_{13}r_{23}].$$

Table 1. *Anthropometric variables in men and women aged between 23 and 35 years*

(Mean values with their standard errors)

Variable	♂ (*n* 95) Mean	SE	♀ (*n* 70) Mean	SE
Body-wt (kg)	76·0	1·0	61·4	0·9
Body-height (m)	1·792	0·007	1·675	0·007
BMI (kg/m²)	23·6	0·3	21·9	0·3
Body fat (%)*	19·5	0·5	26·1	0·6
Diameter (mm):				
Knee (left and right)	195	1	172	1
Wrist (left and right)	121	1	100	1
Elbow (left and right)	139	1	117	1
Shoulder	394	2	347	2
Pelvis	282	2	281	2
Hip	325	2	314	2

BMI, body-mass index (weight/height²).
* Estimated from skinfold measurements.

RESULTS

The mean with its standard error of each anthropometric variable is given in Table 1, and Table 2 gives the regressions of ln BMI *v*. ln body-diameter (for each diameter). The correlation coefficients show that shoulder and pelvic diameters in men and pelvic and hip diameters in women gave the best estimate of BMI. Thus, these body-diameters together with body-height, gave an estimation of body-weight, $\hat{W}$, that was most closely related to measured body-weight.

The difference of the correlation coefficient between $W/\hat{W}$ and body fatness and the correlation between BMI and body fatness, shows whether $\hat{W}$ is more efficient than H^2 in adjusting body-weight for frame size (Table 3). The limits of the 90% confidence interval of this difference are given (Table 3). Some of the body-diameters, which gave the best estimates of body-weight, were shown to be poor in the new index. Indices based on pelvic and hip diameters did not improve estimation of body fatness from BMI. Knee and shoulder diameters in men and the knee diameter in women improved the estimation of body fatness from BMI significantly (lower limit of the 90% confidence interval > 0).

To illustrate what this improvement means in practice, the regression was carried out of body fatness on $W/\hat{W}$ based on body-diameters that gave the best estimates, i.e. knee and shoulder. By means of the resulting regression coefficients (b_{knee} 35·58 (men), 36·02 (women); b_{shoulder} 37·34 (men)) the effect of a difference in diameter on the prediction of body fatness can be examined. Consider, for example, two men of equal body-weight and height (group means) but of different knee diameter (15th percentile (92 mm) and 85th percentile (103 mm) respectively). On the basis of height and weight only, the percentage of body fat is estimated to be 19·5% and, taking knee diameter into account, it is estimated to be 20·4% for the man of the smaller frame size and 18·8% for the other. Thus, even with this large difference in knee diameter, height and weight being equal, the measurement of an additional criterion results in an estimated difference of only 1·6% in percentage of body fat. In other words, for 70% of the population, frame-size adjustment by including the knee diameter accounts for no more than approximately 0·8% body fatness, where the standard

Table 2. *Regression models with ln body-mass index (weight/height²; kg/m²) as the dependent variable and the respective ln body-diameters* (k = 1, ... 6) *(mm) as the explanatory variable*

Sex	Body-diameter	Intercept (a_k)	Regression coefficient (b_k)	Correlation coefficient
♂(*n* 95)				
	Knee (left and right)	1·96	0·040	0·19
	Wrist (left and right)	3·14	0·001	0·00
	Elbow (left and right)	2·32	0·032	0·17
	Shoulder	0·82	0·064	0·33
	Pelvis	0·85	0·069	0·34
	Hip	1·60	0·045	0·21
♀ (*n* 70)				
	Knee (left and right)	0·95	0·075	0·28
	Wrist (left and right)	3·43	−0·015	0·08
	Elbow (left and right)	2·47	0·025	0·11
	Shoulder	2·53	0·015	0·06
	Pelvis	−0·33	0·102	0·57
	Hip	−0·84	0·114	0·55

Table 3. *Product-moment correlation coefficients* (r) *of the body-mass index (BMI, weight/height², kg/m²) and weight/estimated weight* (W/Ŵ)* *with percentage of body fat*

Sex	Index	r	z†	90% Confidence interval‡	
				Lower limit	Upper limit
♂(*n* 95)					
	BMI	0·758	—	—	—
	W/Ŵ:				
	Knee (left and right)	0·785	2·158	0·006	0·048
	Wrist (left and right)	0·759	0·334	−0·004	0·006
	Elbow (left and right)	0·765	0·630	−0·011	0·025
	Shoulder	0·794	1·648	−0·000	0·072
	Pelvis	0·726	−1·327	−0·072	0·008
	Hip	0·746	−0·866	−0·035	0·011
♀(*n* 70)					
	BMI	0·795	—	—	—
	W/Ŵ:				
	Knee (left and right)	0·828	1·677	0·000	0·066
	Wrist (left and right)	0·787	−1·201	−0·019	0·003
	Elbow (left and right)	0·802	0·817	−0·007	0·021
	Shoulder	0·794	−0·218	−0·009	0·007
	Pelvis	0·729	−1·507	−0·137	0·007
	Hip	0·704	−2·030	−0·165	0·017

* Weight is predicted from

$$\hat{W} = \exp(a_k)\,(\text{diameter}_k)^{b_k}\,\text{height}^2$$

† Standard normally distributed, see p. 337.

‡ Limits of two-sided 90% confidence interval of the difference between the correlation coefficient of body fatness and W/Ŵ (r_{13}) and the correlation coefficient of body fatness and BMI (r_{12}) are $(r_{13}-r_{12}) \pm 1{\cdot}66\,s$, where $s = [\text{var}\,(r_{13}-r_{12})]^{\frac{1}{2}}$.

deviation of body fatness is about 5%. It can be shown that the same difference in predicted body fatness will result from a relative error in the measurement of body-height of 1%, that is, about 18 mm for a subject of medium height.

To assess the potential improvement of prediction of body fatness by taking into account a diameter and also its interaction with body-height (D, D*H), or an additional diameter (D_1, D_2), corresponding analyses were carried out for knee and shoulder diameters in both sexes. The improvement was found not to be greater than that obtained by using the best diameter (knee) alone, in either sex.

As suggested by Katch & Freedson (1982), in subjects of extreme body-height, frame size may be determined by height alone, but this may not be the case for those in normal height ranges. To obtain support for this hypothesis, the analysis was repeated excluding those subjects of body-heights less or greater than the first or ninth decile respectively. In the total group, $W/\hat{W}$ based on the most promising diameters improved the explained variance by 5% (knee: r_{13}^2 0·62, r_{12}^2 0·57) and 6% (shoulder: r_{13}^2 0·63) in men and by 6% (knee: r_{13}^2 0·69, r_{12}^2 0·63) in women, but in the subgroups with reduced range in body-height, this was no more than 6% (knee: r_{13}^2 0·63, r_{12}^2 0·57) in men. The improvement when using shoulder diameter in men or knee diameter in women was no better in the subgroups than in the total group. Thus, by restricting the study population to people with more common values of body-height, the increment of the small beneficial effect of using body-diameters was not striking.

The improvement gained by the inclusion of a body-diameter may be greater for subjects of extreme body-diameters than for the total population. To study this, the analysis was repeated for subjects of a body-diameter less or greater than the first or second tertile respectively, thus excluding subjects with more common values of the body-diameter. This was done for the knee and shoulder diameter separately. The improvement in explained variation was 6% (r_{13}^2 0·65, r_{12}^2 0·59) for the knee diameter in men, but was not significant in the other cases, giving no support for the statement that the prediction of body fatness is better in subjects having relatively small or large body-diameters compared with the total population.

DISCUSSION

In 1980, the ninety-five men and seventy women in the present study did not differ significantly with respect to body-weight, height and BMI from the 1667 men and 1996 women participating in a project on overweight (Baecke *et al.* 1983). Thus, it may be concluded that the present study population was not highly selected.

From the results it can be concluded that indices ($W/\hat{W}$) based on knee and shoulder diameters in men and knee diameter in women, improved the estimation of body fatness from BMI slightly. However, while BMI alone explained 57% of variation in body fatness in men and 63% in women, the inclusion of an additional variable increased the proportion of explained variation to no more than 62% (knee and shoulder in men) and 69% (knee in women). The numerical example shows that a moderate improvement in the measurement of body-height may result in an increment in precision in estimation of body fatness of the same order of magnitude as obtained by the inclusion of an additional measurement.

The question can be asked whether this result depends on the way in which information on body-diameters was used in the analysis. Body-height and various body-diameters were used to estimate body-weight, $\hat{W}$, which was then used to adjust for frame size in the index $W/\hat{W}$. An alternative measure for frame size, for example fat-free mass (FFM) which is more specific than body-weight, may have been more appropriate. However, to estimate FFM ($\hat{FFM}$), another measure for body fatness in addition to the skinfold measurements is necessary to ensure that the index $W/\hat{FFM}$ is not dependent on the criterion, body fatness.

This would introduce new errors in measurement which may weaken the possible effect. Thus, as body-weight is less specific but more accurate to measure, it was decided to estimate it by means of body-height and body-diameters, giving

$$\hat{W} = \exp(a)\, D^b\, H^2 \qquad (6)$$

as reference value for body-weight.

To check whether exponents of the body-diameter in $W/\hat{W}$, other than the regression coefficient b based on weight estimation, yielded higher correlation coefficients with body fatness than found for $W/\hat{W}$, several other exponents were examined. The correlation coefficients, rounded to the second decimal place, were equal to or lower than the correlation coefficient between body fatness and $W/\hat{W}$. Thus, a measure for frame size more specific than $\hat{W}$ would not yield results strikingly different from those found in the present study.

Pelvic and hip diameters were biased by body fatness, as in other studies (Behnke, 1959; Pollock *et al.* 1975, 1976). For other body-diameters also, a fat association may be a reason that inclusion does not really improve the prediction of body fatness from BMI. This fat association may be an artefact of measurement, resulting from the subcutaneous fat layer, but may also be true to some extent. Keys *et al.* (1967) found an association between body fatness and the sum of shoulder and hip diameters divided by body-height. Katch & Freedson (1982) suggested that a causal relationship between fat storage and frame size is present in women. Fat children have been shown to be of greater height (Garn *et al.* 1974; Forbes, 1977) and to have larger body-diameters (Beunen *et al.* 1983) than lean children. Results from longitudinal studies have suggested a cause–effect relationship (Forbes, 1977). These anthropometric studies have been affirmed by a study using radiography (Beunen *et al.* 1982), which suggests that fatness may be a factor accelerating skeletal growth. It is likely that this effect is weakened in adults. Only radiography can show the extent to which an association between body-diameters and body fatness is a true association or whether it is an artefact of measurement. A true association will inevitably produce a bias in the estimation of body-weight from frame size, but an artefact of measurement can be avoided by the use of radiography. Thus measured, body-diameters may be shown to improve a weight–height index more than has been the case in the present study. However, since weight–height tables are used in situations where the measurement of skinfold thicknesses is problematic, difficulties are also likely to be encountered with radiography. Thus, for the use of frame-size categories in weight–height tables, anthropometry seems to be of more practical value.

For epidemiological studies, investigators should decide whether the increment in precision warrants the inclusion of an additional measurement. If possible, measurement of skinfold thicknesses is preferable. As the present study shows that anthropometric diameters used on an interval scale provide only a small improvement in the estimation of body fatness from BMI alone, it is not likely that weight–height tables will be improved by the inclusion of (three) frame-size categories, as indicated by the elbow diameter suggested recently (Metropolitan Life Insurance Company, 1983; Frisancho & Flegel, 1983), or by any of the other five diameters, including indices based on them (Katch & Freedson, 1982). This conclusion is in agreement with other investigators (Baecke *et al.* 1982; McKay *et al.* 1983) and supports the reconstruction of the Metropolitan height and weight tables by Andres *et al.* (1983) and the construction of the weight–height tables of the Fogarty Center Conference on Obesity (Bray, 1973) which were adopted by the Royal College of Physicians (1983).

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REFERENCES

Andres, R., Elahi, D. & Tobin, J. D. A. (1983). *International Congress of Obesity, New York*, Abstr. 228.
Baecke, J. A. H., Burema, J. & Deurenberg, P. (1982). *British Journal of Nutrition* **48**, 1–6.
Baecke, J. A. H., Burema, J., Frijters, J. E. R., Hautvast, J. G. A. J. & Van der Wiel-Wetzels, W. A. M. (1983). *International Journal of Obesity* **7**, 1–12.
Behnke, A. R. (1959). *Human Biology* **31**, 295–315.
Beunen, G., Malina, R. M., Ostyn, M., Renson, R., Simons, J. & Van Gerven, D. (1982). *American Journal of Physiological Anthropometry* **59**, 387–392.
Beunen, G., Malina, R. M., Ostyn, M., Renson, R., Simons, J. & Van Gerven, D. (1983). *Human Biology* **55**, 599–615.
Bray, G. A. (1973). *Obesity in Perspective. PHEW Publication* no. NIH 75-708. Bethesda, MD: National Institute of Health.
Brožek, J. (1956). *Science* **124**, 685.
De Wijn, J. F. & Zaat, J. C. A. (1968). *Voeding* **29**, 208–224.
Durnin, J. V. G. A. & Rahaman, M. M. (1967). *British Journal of Nutrition* **21**, 681–689.
Durnin, J. V. G. A. & Womersley, J. (1974). *British Journal of Nutrition* **32**, 77–97.
Forbes, G. B. (1977). *Journal of Pediatrics* **91**, 40–42.
Forsyth, H. L. & Sinning, W. E. (1973). *Medicine and Science in Sports* **5**, 174–180.
Frisancho, A. R. & Flegel, P. N. (1982). *American Journal of Clinical Nutrition* **36**, 697–699.
Frisancho, A. R. & Flegel, P. N. (1983). *American Journal of Clinical Nutrition* **37**, 311–314.
Garn, S. M., Clark, D. C. & Guire, K. E. (1974). *American Journal of Physiological Anthropometry* **40**, 447–450.
Garn, S. M. & Hawthorne, V. M. (1984). *American Journal of Clinical Nutrition* **39**, 490–499.
Hechter, H. H. (1959). *Human Biology* **31**, 235–243.
Hotelling, H. (1940). *Annals of Mathematical Statistics* **11**, 271–283.
Katch, V. L. & Freedson, P. S. (1982). *American Journal of Clinical Nutrition* **36**, 669–675.
Keys, A., Aravanis, C., Blackburn, H. W., van Buchem, F. S. P., Buzina, R., Djordjevic, B. S., Dontas, A. S., Fidanza, F., Karvonen, M. J., Kimura, N., Lekos, D., Monti, M., Puddu, V. & Taylor, H. L. (1967). *Acta Medica Scandinavica* **460**, Suppl., 289–303.
Keys, A., Fidanza, F., Karvonen, M. J., Kimura, N. & Taylor, H. L. (1972). *Journal of Chronic Diseases* **25**, 329–343.
Knapp, T. R. (1983). *Journal of the American Medical Association* **250**, 506–510.
McKay, F., Webster, C. & Durnin, J. V. G. A. (1983). *Proceedings of the Nutrition Society* **42**, 163A.
Metropolitan Life Insurance Company (1959). *Statistical Bulletin* **40**, 1.
Metropolitan Life Insurance Company (1983). *Statistical Bulletin* **64**, 3.
Olkin, I. & Siotani, M. (1976). In *Essays in Probability and Statistics*, pp. 235–251 [S. Ikeda, T. Hayakawa, H. Hudimoto, M. Okamoto, M. Siotani and S. Yamamoto, editors]. Tokyo: Shinko Tsusho Co. Ltd.
Pollock, M. L., Hickmann, T., Kendrick, Z., Jackson, A., Linnerud, A. C. & Dawson, G. (1976). *Journal of Applied Physiology* **40**, 300–304.
Pollock, M. L., Laughridge, E. E., Coleman, B., Linnerud, A. C. & Jackson, A. (1975). *Journal of Applied Physiology* **38**, 745–749.
Royal College of Physicians (1983). *Journal of the Royal College of Physicians, London* **17**.
Seltzer, C. C. & Mayer, J. (1965). *Postgraduate Medicine* **8**, A101.
Seltzer, C. C., Stoudt, H. W., Bell, B. & Mayer, J. (1970). *American Journal of Epidemiology* **92**, 339–350.
Von Döbeln, W. (1959). *Acta Medica Scandinavica* **165**, 37–41.
Weiner, J. S. & Lourie, J. A. (1969). *Human Biology. A Guide to Field Methods.* Oxford and Edinburgh: Blackwell Scientific Publications.
Wilmore, J. H. & Behnke, A. R. (1968). *Journal of Applied Physiology* **25**, 349–355.
Wilmore, J. H. & Behnke, A. R. (1969). *Journal of Applied Physiology* **27**, 25–31.
Womersley, J. & Durnin, J. V. G. A. (1977). *British Journal of Nutrition* **38**, 271–284.

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