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A PHYSICAL MODEL FOR ESTIMATING BODY FAT

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This report describes a set of measurements of lengths, circumferences, and skin-fold thickness by which to estimate the volume of fat in human subjects. The fat mass of seven body compartments is estimated and summed to obtain an estimate of the total body fat. Measurements were made on 61 young men. Body compositions computed from these measurements were compared with estimates made at about the same times using a body volumeter. Correlation coefficients for lean mass, fat mass, and percent body fat were 0.926, 0.845, and 0.756, respectively. Changes in fat mass estimated by the two methods were compared with the

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corresponding changes in body weight. Results from the anthropometric model were apparently as dependable as those obtained with the body volumeter. The anthropometric model is therefore considered acceptable for monitoring body composition when the composition can be checked occasionally with a body volumeter. Such a check is required to calibrate the anthropometric model, which tends to overestimate fat in lean men and underestimate it in fat men.

A PHYSICAL MODEL FOR ESTIMATING BODY FAT

A planned study of the impact of specific environments on the development of cardiovascular disease risk factors required measuring body composition of 150 subjects three times per year for 4 years. Facilities for estimating body composition by densitometric methods, whole body counting, or body water dilution were not available at the study site; therefore, a group of anthropometric measurements were taken to compute an estimate of body fat. These estimates were compared on three occasions with estimates of body composition made with a body volumeter. The purpose of this report is to describe the anthropometric model by which the estimate of fat mass was computed and to present data by which the model was validated.

THE ANTHROPOMETRIC MODEL

The purpose of estimating body composition in the parent study was to provide information by which to relate changes in levels of selected serum components to changes in body weight and/or the apparent degree of leanness or fatness of the individual. It was desirable, therefore, to have an anthropometric model that would estimate the fat or muscle mass associated with discrete parts of the body. For this purpose, the various formulas (5) that relate some measurement to overall body composition by a correlation coefficient were less attractive than a model such as Behnke's (3), which fractionates body weight into various physical compartments.

During the development of that model, Behnke and associates (4) used a cylinder as a geometrical analog of the body and applied the formula $W=\pi R^2 h$, where R = the "body radius," W = weight, and h = height. This "body radius" represented a parameter linking height and weight in quantitative assessment of body build. Behnke (2) subsequently modified the formula into the form $W = D^2 h$, and applied it to both the whole body and various component parts. Using a set of 11 measurements, he fractionated the body weight into 11 physical compartments. Subsequently this quantitative assessment of body build was modified to use 11 circumferences and 8 diameters (3).

The fact that the cylinder can be a useful model for the irregularly shaped human body encouraged the author to pursue a model predicted on the assumption that the human body can be represented by a group of conical or cylindrical segments (Fig. 1). For those two geometric forms if the length and the circumference halfway between the ends are measured, the surface can be computed. If an appropriate skinfold is also measured, the volume of surface fat attributed to that body compartment can be estimated. Multiplication of the fat volume by 0.9007, the density of fat (6), provides an estimate of the weight of fat attributed to that compartment. Summation of those weights yields an estimate of the total body fat. The formulas used are listed in Table 1.

Certain factors in the formulas deserve comment. Since a skinfold was measured as two thicknesses of skin, the measured skinfold was divided by 2. Because approximately half the body fat is located internally or within the tissues (6), the subcutaneous fat computed for chest, waist, and hips was multiplied by 2 for inclusion in the estimated total body fat. The girth of the flexed biceps was used as the girth of the upper arm. The triceps skinfold was used in estimating the fat associated with both the upper arm and the forearm. The chest length was taken as the upper half of the acromion-iliac distance; the lower half of that distance was attributed to the abdominal compartment (waist). The next 20 cm below the iliac crest was assigned to the hips, and the remaining distance to the top of the patella was assigned to the upper legs (thigh). The thigh circumference was measured halfway between the iliac crest and the patella. The calf skinfold was used in estimating the fat associated with both the thighs and the lower legs. The maximum girth of the calf was used in computing the fat associated with the lower leg. Other circumferences and lengths were measured as described by Hertzberg et al. (7); skinfolds were measured as described by Wilmore and Behnke (8), using Harpenden calipers.

EVALUATION OF THE MODEL

In evaluating the anthropometric model, measurments were made at the USAF School of Aerospace Medicine on three groups of subjects whose body composition was also measured by body volumetry (1).

In group I, 34 subjects, anthropometric measurements were made on men whose body volume had been measured 2 to 3 weeks earlier.

In group II, 12 subjects, body composition was initially estimated with both the body volumeter and anthropometric measurements and repeated by both techniques 2 months later. For the initial measurements, the elapsed time between body volume and anthropometric measurements was up to 1 week. The final measurements by both techniques were accomplished during 1 workday.

In group III, 15 subjects (8 control and 7 bedrest), body composition was measured by both techniques, repeated 1 month later and again after another month. For the first and second sets of measurements, up to 4 days elapsed between measurements by the two methods; for the third set, measurements by both techniques were accomplished within one 8-hour day.

Table 2 summarizes the evaluation of the accuracy of the anthropometric method. The body compositions estimated by the body volumeter (BV) technique are assumed to be the best values. The extent to which the estimates by the anthropometric model (AM) agree with the BV estimates is therefore accepted as a measure of the accuracy of the AM method. The results tabulated show that the actual values obtained by the AM method are not statistically different for percent fat, fat mass, or lean body mass than values obtained by the BV method. The fact that the differences are just below the level of significance suggests that in other populations or in larger groups, the results by the AM model might well be slightly higher for fat mass and lower for lean mass than by the BV method.

This possibility is examined in Figure 2 in which, for each of the 61 subjects, the percent body fat (B.F.) estimated by the AM method is plotted against the percent body fat estimated by the BV method. Statistical analysis of the data, fitted by the method of least squares, gave the equation $\%B.F._{AM} = 0.6796(\%B.F._{BV}) + 5.48$. By this equation 10% $B.F._{BV}$ calculates as 12.3% $B.F._{AM}$, but 30% $B.F._{BV}$ calculates as 25.9% $B.F._{AM}$. The AM model, therefore, tends to overestimate fat in lean men and to underestimate it in fat men, the crossover point being 17.1% B.F. The nearly significant differences noted above could be partially explained by the fact that the mean $\%B.F._{BV}$ in both groups is near 14.7.

The variability of the AM method was examined by repeated measurements in groups II and III. The data are summarized in Table 3. (A significant fact is that the reproducibility in repeat measurements may be better with the AM than with the BV technique.) The data were examined further by statistical analysis of the differences between final and initial estimates of body composition. These results are summarized in Table 4. The mean differences (final estimate minus initial estimate) were not significantly different by the two methods; i.e., the method of making the estimate (BV or AM) did not significantly affect the mean differences between the final and initial estimates.

The lower variability among repeated measurements with the AM method seems to indicate that this method is at least as reproducible as the BV, if not more reproducible. However, other interpretations are possible since changes in body weight of the subjects occurred during the 2-month span of the observations. During that time, mean body weights increased 1.88 kg, a statistically significant increase ($p<.005$). These weight changes indicate possible changes in body composition. Observations of the activity level of these men supported the prediction that, in general, any changes of weight were apt to be an increase associated with an increase in the mass of body fat. However, a few individuals maintained high activity levels that might have decreased both body fat and body weight.

To evaluate this relationship, correlations between observed changes in body weight and fat mass, required by the changes in body composition estimated by both the AM and BV methods, were computed. The results are plotted in Figure 3. The regression lines for the two methods are quite similar, but the correlation coefficient is higher for the AM than for the BV. This fact reflects the wider scatter of the BV data and supports the interpretation that the lower variability of repeat measurements by the AM method (Table 4) is not due to lack of sensitivity, but reflects a degree of reproducibility that equaled or exceeded the reproducibility of the BV method.

DISCUSSION

The described anthropometric model provides a direct estimate of body fat associated with each of seven body compartments (Table 1). This model ignores the head, hands, and feet, and therefore should underestimate the total body fat. However, the tendency to include some nonfat tissues in the skinfold thicknesses should overestimate the fat content. In some individuals this is a severe problem, especially for the triceps and suprailiac skinfolds. To the extent that skinfold measurements are erroneously high, the resulting estimate of fat will be erroneously high. This source of error underlies the fact that in Tables 2 and 3 the estimates of fat mass and percent body fat by the AM method appear larger than by the BV technique. The tendency of the AM model to overestimate fat in lean men suggests that inclusion of nonfat tissue in the skinfolds is a greater source of overestimation in lean than in fat men. The underestimation of fat in obese men suggests that fat associated with body compartments (e.g., the neck) not included in the model becomes a significant oversight. Fat in the arms and legs but not measured in skinfolds is also excluded in the model. The exclusion is more apt to be a significant underestimation in obese than in lean men. These three sources of error--inclusion of nonfat tissue in some skinfolds, exclusion of fat in extremities and neck, and exclusion of nonsubcutaneous fat in arms and legs--probably account for the tendency of the model to overestimate fat mass in lean men and underestimate it in fat men.

The combined weight of fat in the seven body compartments is subtracted from the body weight to provide an estimate of the lean body mass. It is gratifying to note that the lean mass estimates from the anthropometric model agree quite well with estimates made with the body volumeter and that the correlation coefficient for estimates by the two methods is 0.926.

The net effect of the over- and underestimations of body fat by the AM model doubtless varies from person-to-person, but it is reasonable to assume that this net effect would tend to be constant for each individual if body composition were relatively constant. This net effect can be computed for each person as the ratio of the estimates of fat content by the two methods (Fat_{BV}/Fat_{AM}). Multiplication of this factor by the fat content estimated from subsequent anthropometric measurements would permit calculation of a reasonably accurate estimate of body fat. This is precisely the use planned for the AM model.

For that use to be valid, results of repeated measurements must show reasonable consistency. In addition to the data in Tables 3 and 4, Figure 3 suggests that the AM method is as consistent as the BV method. In Figure 3, the upper left and lower right quadrants of the plots are doubtful areas. A point in the upper left would represent a weight loss with concomitant gain of fat. A point in the lower right quadrant would represent a weight gain with a concomitant loss of fat. For normal young men performing routine military duties, these combinations are unlikely.

Points in these quadrants are probably artifacts caused by errors that are within the "noise level" of measurements by the technique. Several errors of these sorts are apparent with both the BV and AM techniques, but the absence of large errors in the AM data increases confidence in the validity of that technique by suggesting that the noise level is no greater than with the BV methods.

The range of body compositions studied was from 3.5% to 25.5% body fat, with variation in the ponderal index from 11.64 to 14.44. Within these ranges and within the age range (18-28) of the subjects who were tested, the AM method appears to be at least as reproducible as the BV technique.

CONCLUSIONS

From the data presented, it is concluded that: (a) the anthropometric model, using repeat measurements on subjects, gives results that are at least as reproducible as (i.e., no more variable than) results obtained with the body volumeter; (b) estimates of body fat by the anthropometric model tend to overestimate the percent body fat in lean individuals and underestimate it in obese individuals; and (c) the anthropometric model is acceptable for repeated use with an individual when the estimates of body fat can be evaluated by occasional measurements in that individual by a standard method such as body volumetry.

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TABLE 1. FORMULAS USE FOR ESTIMATING FAT ASSOCIATED WITH THE VARIOUS BODY COMPARTMENTS

FAT COMPARTMENT	=	LENGTH[a]	x	CIRCUMFERENCE[a]	x	SKINFOLD[a]	x	FACTOR[b]
Upper arms	=	humerus	x	flexed biceps	x	$\frac{\text{triceps}}{2}$	x	1.8014×10^{-3}
Forearms	=	radius	x	forearm	x	$\frac{\text{triceps}}{2}$	x	1.8014×10^{-3}
Chest	=	$\frac{\text{acr-il}^{c}}{2}$	x	chest	x	$\frac{\text{scapula}}{2}$	x	1.8014×10^{-3}
Waist	=	$\frac{\text{acr-il}}{2}$	x	waist	x	$\frac{\text{suprailiac}}{2}$	x	1.8014×10^{-3}
Hips	=	20 cm	x	buttocks	x	$\frac{\text{suprailiac}}{2}$	x	1.8014×10^{-3}
Thighs	=	(il-pat[c] - 20)	x	thigh	x	$\frac{\text{calf}}{2}$	x	1.8014×10^{-3}
Lower legs	=	tibia	x	calf	x	$\frac{\text{calf}}{2}$	x	1.8014×10^{-3}

SUM = Total body fat

[a] Measured in cm

[b] Factor multiplies by density of fat (0.9007) and by number of limbs or by fat correction described in text and converts product to kg fat

[c] acr = acromion; il = iliac crest; pat = patella

TABLE 2. **COMPARISON OF BODY FAT ESTIMATES BY BODY VOLUMETER (BV) AND ANTHROPOMETRIC MODEL (AM), USING THE INITIAL ESTIMATE OF BODY COMPOSITION IN ALL 61 SUBJECTS**

	Lean mass kg	Fat mass kg	% Body fat
Body volumeter			
Mean	59.399	10.469	14 66
S.D.	6.140	4.450	5.04
Anthropometric model			
Mean	58.893	10.975	15.43
S.D.	6.322	4.123	4.53
Correlation coefficient	0.926	0.845	0.756
Difference between estimates (BV minus AM)			
Mean	+0.506	-0.506	-0.77
S.D.	2.405	2.405	3.37
P	NS	NS	0.1>P>.05

NS = not significant   P = P value, paired t test
Mean body weight of subjects = 69.87 ± 8.62 kg
Mean ponderal index of subjects = 12.96 ± 0.53

Ponderal index: $\text{Height}_{in} \div \sqrt[3]{\text{Weight}_{lb}} = \frac{\text{Height}_{cm}}{2.54} \div \sqrt[3]{\text{Weight}_{kg} \times 2.2}$

TABLE 3. VARIABILITY OF ESTIMATES OF BODY-COMPOSITION BY THE BODY VOLUMETER AND THE ANTHROPOMETRIC MODEL, USING POOLED DATA FROM THREE ESTIMATES ON EACH OF 8 CONTROL SUBJECTS IN GROUP III AND TWO ESTIMATES ON EACH OF 12 SUBJECTS IN GROUP II

Parameter estimated	Within-subject S.D. of estimates: Body volumeter	Anthropometric model
Lean mass (kg)	1.74	1.27
Fat mass (kg)	1.32	1.02
% Body fat	1.71	1.23

TABLE 4. CHANGES IN BODY COMPOSITION ESTIMATED BY BODY VOLUMETER AND ANTHROPOMETRIC MODEL, USING POOLED DATA (12 SUBJECTS, GROUP II; 8 CONTROL SUBJECTS, GROUP III) OF DIFFERENCES BETWEEN LAST AND FIRST ESTIMATES

Parameter changed	Body volumeter Mean	S.D.	Anthropometric model Mean	S.D.	Correlation coefficient
Lean mass (kg)	+ 1.609	± 2.090	1.168	± 1.677	0.758
Fat mass (kg)	+ 0.274	± 2.032	0.715	± 1.464	0.740
% Body mass	+ 0.050	± 2.616	0.636	± 1.858	0.700

Mean change in body weight = 1.88 ± 1.69 kg

Mean initial ponderal index = 13.05 ± 0.53

Mean initial body weight = 68.42 ± 8.15 kg

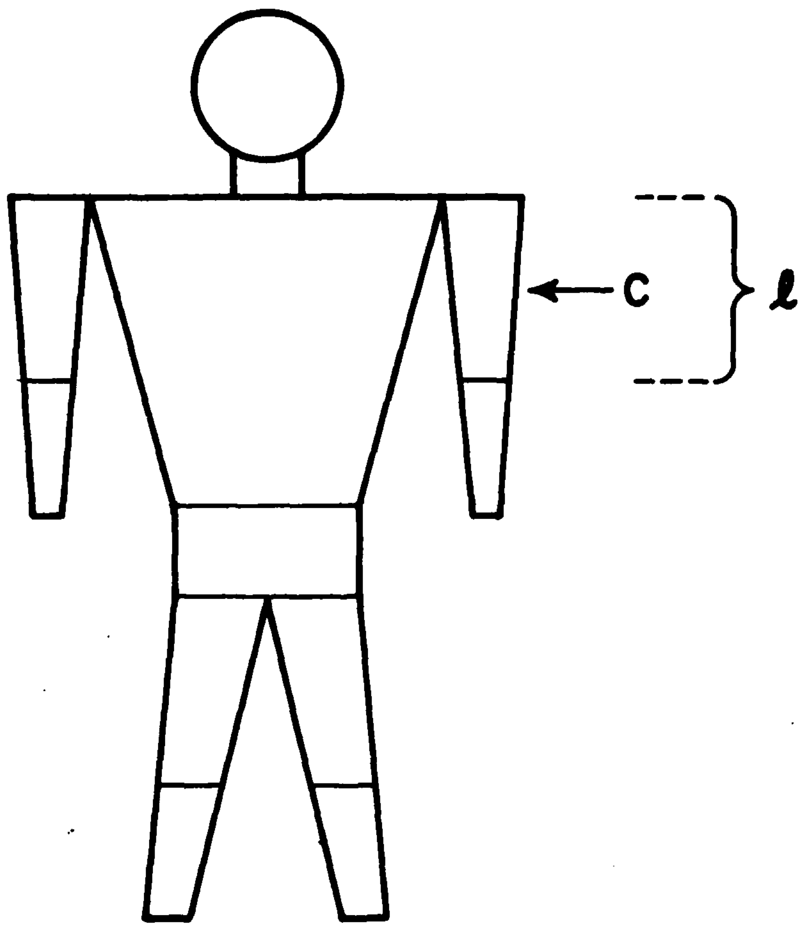

Figure 1. Representation of the human body as a group of conical or cylindrical segments, excepting head, neck, hands, and feet. The ℓ indicates the length of a conical segment, and c denotes the circumference measured halfway between the ends of the conical segment.

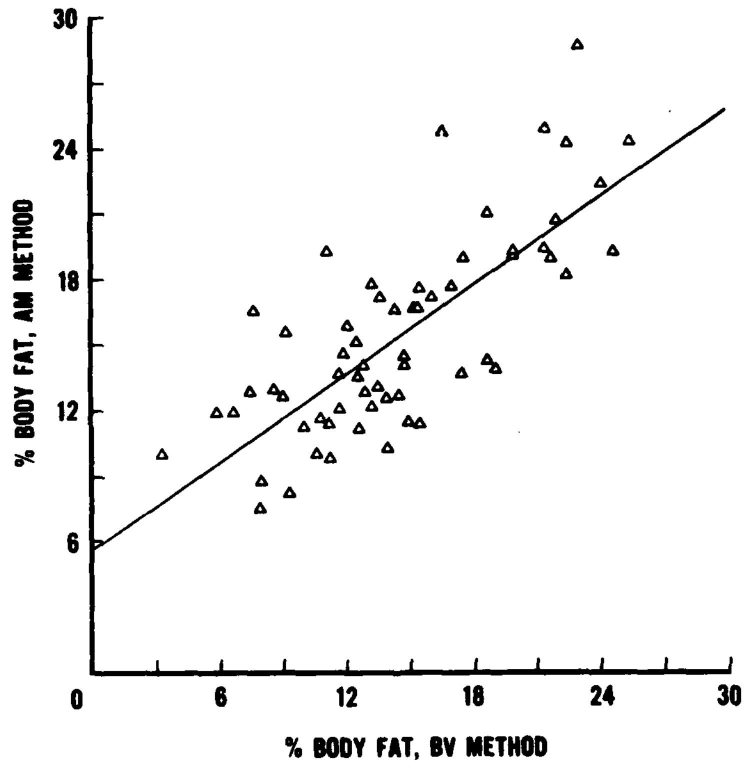

Figure 2. Comparison of estimates of percent body fat by the BV (x axis) and AM (y axis) methods. The dotted regression line, computed by the method of least squares, has the formula y = .6796x + 5.48. The correlation coefficient is .757; N=61.

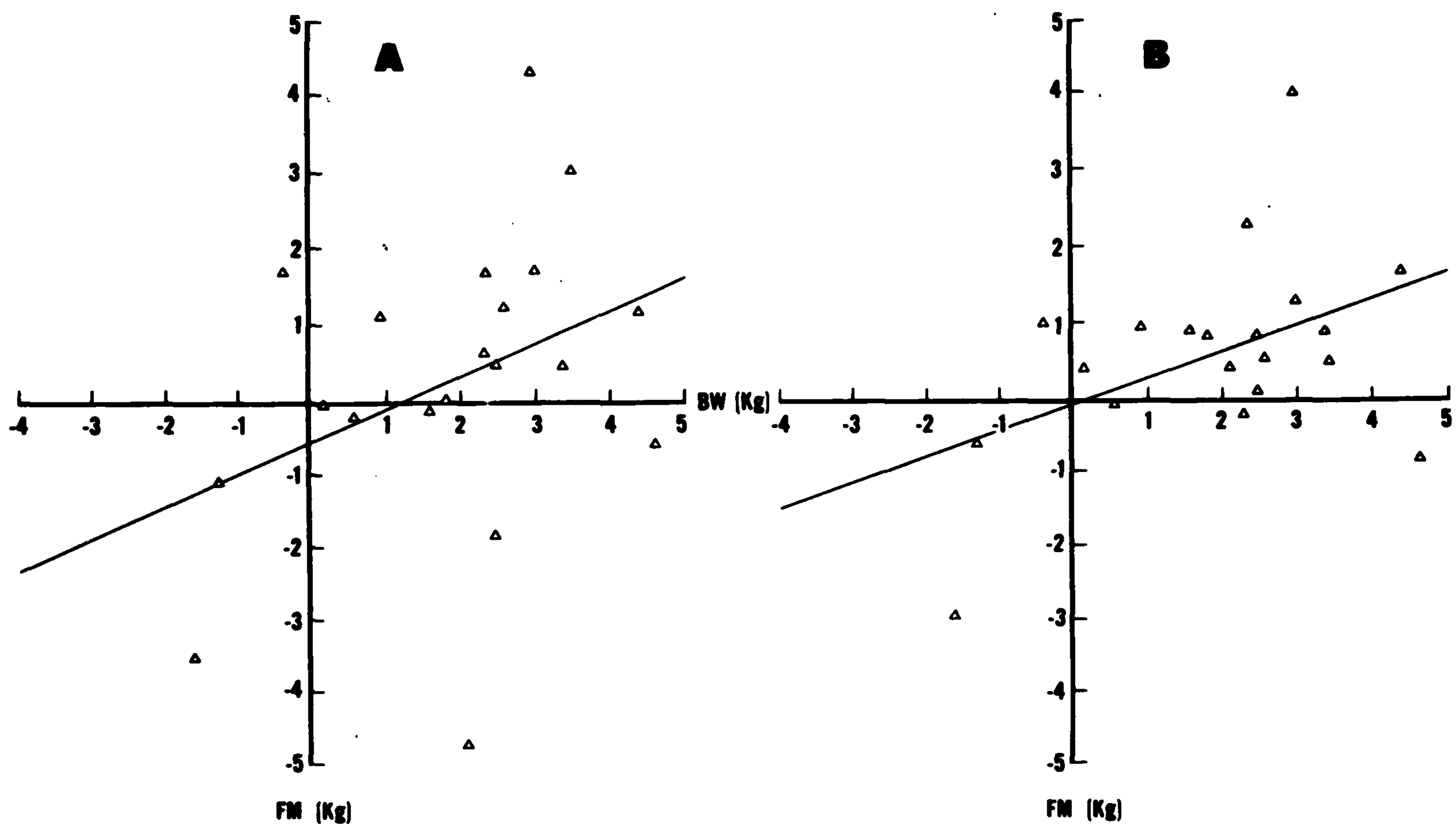

Figure 3. Comparison of changes in body weight (x axis) with changes in body fat (y axis) required to account for the differences between initial and final % body fat estimated in the same men by the BV (graph A) and AM (graph B) methods. N=20. Correlation coefficients are .364 and .449 for graphs A and B, respectively.