Body Fat Content Influences the Body Composition Response to Nutrition and Exercise

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ABSTRACT: In most situations involving a significant change in body weight, both fat-free body mass (FFM) and body fat participate, but the relative contribution of FFM and fat to the total weight change is influenced by the initial body fat content. Overfeeding: In experiments of at least 3-weeks' duration, the weight gain of thin people comprises 60–70% lean tissues, whereas in the obese it is 30–40%. Underfeeding: In humans, there is an inverse curvilinear relationship between initial body fat content and the proportion of weight loss consisting of lean tissue. The same trend holds for animals and birds, including loss during hibernation. Another factor is the magnitude of the energy deficit: as energy intake is reduced, lean tissue makes up an increasing fraction of the total weight loss. Exercise: If individuals lose much weight with exercise, the result is usually some loss of lean tissue as well as fat, and once again the proportion of lean loss to total weight loss is greater in thin people than in those who have larger body fat burdens. Members of twin pairs often differ in weight. In thin individuals, lean accounts for about half of the intrapair weight difference, whereas in the obese it accounts for only one quarter. Body fat content must be taken into account in evaluating body composition changes induced by nutrition and exercise.

Changes in body weight, whether negative or positive, induced by nutrition usually comprise both lean (fat-free mass or lean body mass) and fat. This is true for many species, including those who lose weight during hibernation. These changes in body composition have been documented by a variety of techniques: nitrogen balance, potassium-40 counting, densitometry, dual-energy X-ray absorptiometry (DXA), total body water, anthropometry, and carcass analysis, and, recently, by computerized axial tomography (CAT scans) and magnetic resonance imaging (MRI).

However, the relative contribution of lean and fat to the change in total weight varies somewhat, and I propose to show that an important factor in determining this variability is the amount of fat in the body. To this end, I present some data of my own, together with observations made by other investigators.

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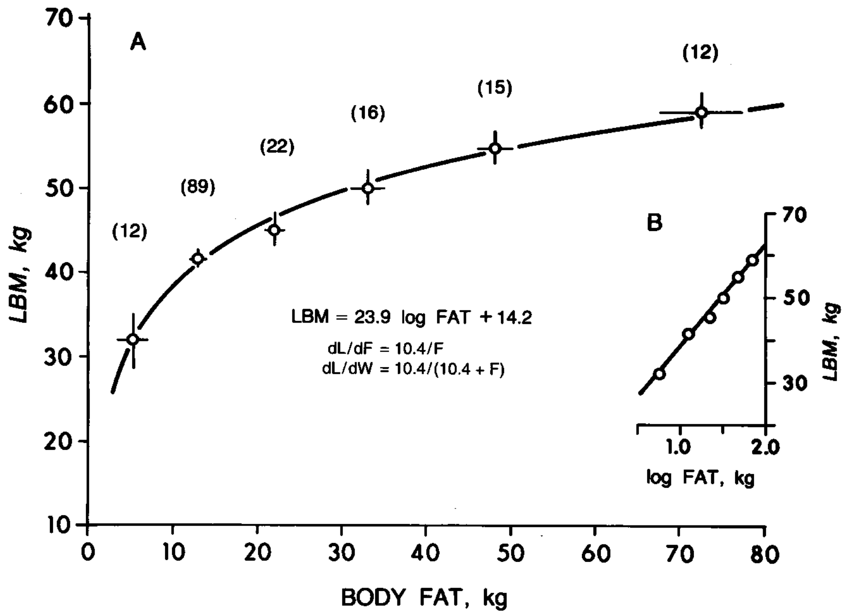

FIGURE 1. **(A)** Plot of lean weight against body fat content in women 156–170 cm tall, grouped according to body fat content; means ± 2 SEM. **(B)** Semi-log plot of same data. Slope of the line ($dL/dF = 10.4$/fat) is hyperbolic; this can be rearranged to yield a relationship between ΔLBM and Δweight. (Adapted from Forbes,[1] Figure 7.2, page 217, with permission.)

This idea about the role of body fat content came from some observations I made on the body composition of women of varying degrees of fatness. When these women were grouped according to body fat content, it was apparent that lean body mass (LBM) was a curvilinear, actually logarithmic, function of body fat (FIG. 1). The slope of the line is determined by differentiating this logarithmic equation, with the result that the slope is a hyperbolic function of body fat, being steep at low values for fat, and then flattening out at higher values.

It is convenient to rearrange the differential equation to relate change in lean mass to change in body weight as shown in FIGURE 1 (L is LBM, F is fat, and W is weight):

$$dL/dW = 10.4/(10.4 + F)^b.$$

One could anticipate, therefore, that a change in weight for a thin person would elicit a larger relative change in LBM than would be the case for an obese person. The data to be presented do show that this is actually the case.

[b] $dL/dF = 10.4/\mathrm{F}$; substitute $dW - dL$ for dF, $F = [10.4\ dW - 10.4\ dL]/(dL)$, hence, $F = 10.4\ dW/dL - 10.4$ and $10.4\ dW/dL = F + 10.4$; inverting, we have the equation.

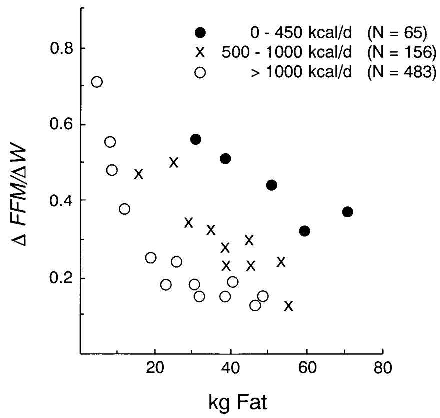

FIGURE 2. Weight loss experiment—human. Change in lean weight as a fraction of total weight loss for adult men and women underfed for at least 3 weeks. Data are arranged in groups according to the recorded energy intake and initial body fat content. Author's data plus data from the literature. Many reports do not provide information on the variability, so only mean values are shown. (From Forbes.[2] Reprinted by permission from Williams and Wilkins.)

FIGURE 2 provides a test of this hypothesis. It includes people who underwent body composition assays at the beginning and at the end of a period of underfeeding, or complete assays of nitrogen balance. Except for those fed very low energy diets, all had an adequate intake of protein. It shows that the proportion of weight lost by LBM is determined by two factors: (a) the initial body fat content, and (b) the magnitude of the energy deficit. For those individuals who consumed at least 1000 kcal daily, the ΔLBM/ΔW values are high for thin individuals and decline in roughly hyperbolic form as body fat increases, thus conforming to the prediction made from the data in FIGURE 1.

However, when the energy intake is much lower, indicating a larger energy deficit, the ΔLBM/ΔW values for a given body fat content are greater. Hence, very low energy diets erode the lean body mass much more than anticipated from the data shown in FIGURE 1.

To those who would suggest that what is being lost is not true lean tissue but merely the stroma and lipocytes of adipose tissue, we can refer to the observation of Ross *et al.*[3] whose MRI data clearly show a loss of muscle tissue. Also, Luke and Schoeller[4] reported that weight loss in the obese is associated with a smaller decline in basal metabolic rate (BMR) than in thin individuals.

The notion that body fat content is a determinant of the relative proportion of lean tissue loss is supported by data from nonhuman species. FIGURE 3 shows that the ΔFFM/ΔW ratio during fasting is inversely related to initial percent body fat, and that this ratio is not altered by hibernation. Hibernating animals lose lean weight as well as fat; the slower rate of weight loss that they enjoy does not protect them from losing lean tissue as well as fat.

There is one exception to this general rule. The bear can hibernate for several months devoid of water and food without an appreciable loss of lean tissue. Bears

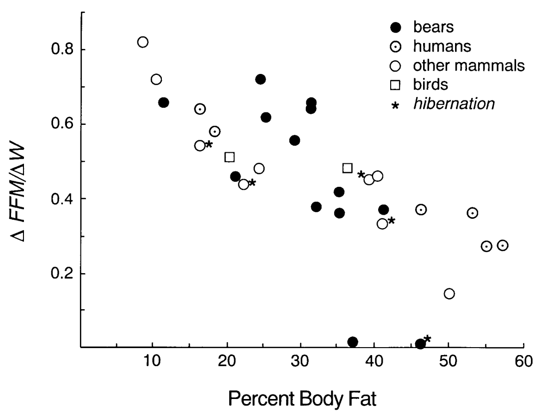

FIGURE 3. Change in body composition with fasting. Relative contribution of lean weight to weight loss during fasting plotted against initial percentage of body fat. Duration of fast 3 weeks or more, except for rat (13–15 days) and petrel (17 days). (From Forbes.[2] Reprinted by permission from Williams and Wilkins.)

TABLE 1. Induced energy deficit

Situation	Subjects	ΔW	ΔFFM/ΔW	Authors
Forced exercise 100 days, constant diet	humans	−7.9 kg	0.16	Bouchard *et al.*[6]
Forced exercise 18 weeks, diet ad lib	rats	−180 gm	0.28	Oscai & Holloszy[7]
Induced hyperthyroidism 63 days	humans	−4.9 kg	0.33	Lovejoy *et al.*[8]
Long-term underfeeding 80% life-span	rats	−250 gm	0.76	Yu *et al.*[9]

apparently reabsorb water, nitrogen, and electrolytes through the wall of the bladder,[5] However, if the bear is fasted in summer, but not thirsted, it loses lean tissue just as do other species.

The above considerations provide reasons for the fact that obese people tolerate famine and starvation much better than those who are thin.

TABLE 1 shows that other types of induced energy deficit also result in loss of lean tissue as well as fat. The data on exercise-induced weight loss and on losses induced by hypermetabolism show that such losses comprise both lean and fat. Hence, it is the energy deficit *per se,* not its cause, that is important. Moreover, the exercise experiments show that physical activity cannot preserve lean weight in the face of significant weight loss. The long-term feeding experiments consisted of feeding rats from an early age at about two thirds the calories taken by *ad libitum* fed controls (normal amounts of protein, minerals, and vitamins). Such rats live longer and have fewer tumors, but this difference in longevity and tumor incidence cannot, as TABLE 1

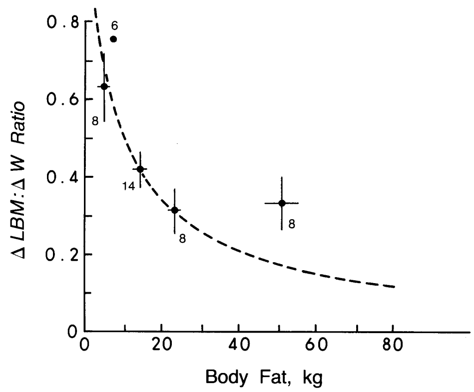

FIGURE 4. Weight gain experiments. Relative contribution of lean weight to gain in total weight in overfed human subjects. Means ± SEM. *Dashed line* based on equation $\Delta LBM/\Delta W = 10.4/(10.4 - fat)$, as shown in FIGURE 1. (From Forbes.[10] Reprinted by permission from *Nutrition Reviews*.)

shows, be ascribed solely to a difference in body fat content, for they also have less lean tissue.

FIGURE 4 shows the situation for humans who are overfed. Once again, both lean and fat participate in the gain in weight, and the relative contribution of lean to the total gain is an inverse function of body fat. It should be pointed out that obese individuals who gain weight "on their own," that is, without dietary advice, put on lean weight as well as fat.[11] Lonn *et al.*[12] showed that the same is true for patients who recover from hyperthyroidism.

A number of body composition studies have been done on individuals who engaged in exercise programs of various sorts. FIGURE 5 shows the results for people who exercised for variable periods and who had had body composition assays at the beginning and end of the exercise period. They were divided into two groups, those with initial body fat content of less than 20 kg, and those with larger body fat burdens. Some individuals had very little change in weight during the exercise period, some lost weight, and there were a few who actually gained weight. (Incidentally, the black dot at the far upper-right section of the graph represents the difference between the body composition of Japanese Sumo wrestlers and that of normal controls.) When the recorded change in lean weight is regressed against the change in body weight, the values tend to fall into two groups, the slope for the thinnest people being twice as steep as that for the heavier ones (0.52 vs. 0.26). The *y*-axis intercept also is higher for the latter group.

It would appear, therefore, that exercisers who maintain their weight can actually gain a bit of lean, and so lose an equal amount of body fat; but, if much weight is lost, lean weight will decline. In those who gain body weight, lean weight will increase along with body fat. Exercise cannot augment, or even preserve, lean weight in the face of significant weight loss.

Finally, it is instructive to look at intrapair differences in body composition in twins. FIGURE 6 represents data from the author's potassium-40 assays on twins.[13]

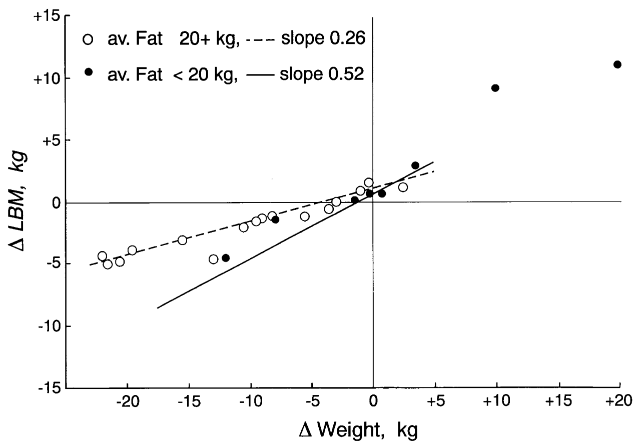

FIGURE 5. Exercise and body composition. Plot of change in lean weight against change in body weight resulting from exercise. Regression lines based on earlier data for 166 people with less than 20 kg body fat (*solid line*), and 248 people with larger burdens of body fat (*dashed line*). More recent data are indicated for 171 thin individuals (*solid circles*) and 301 with larger fat burdens (*open circles*). (From Forbes.[2] Reprinted by permission from Williams and Wilkins.)

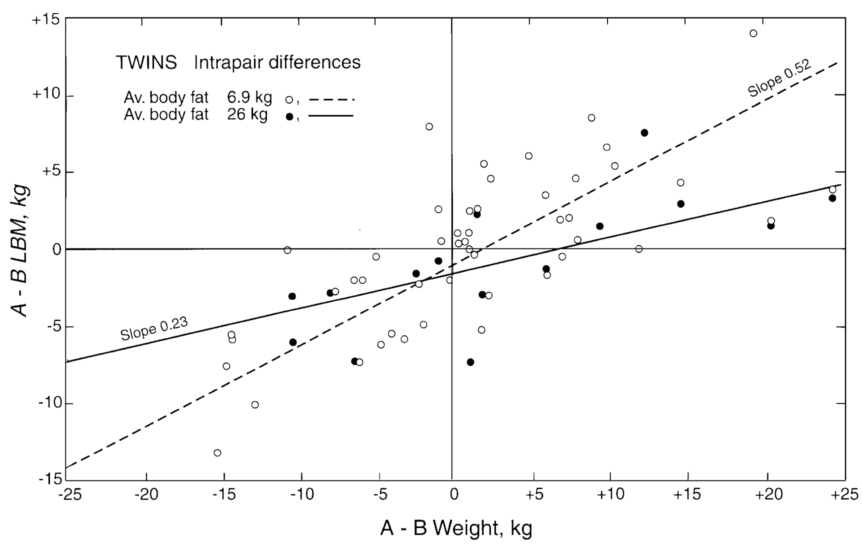

FIGURE 6. Intrapair differences in lean weight plotted against intrapair differences in body weight for twins, identical ($n = 49$), and same sex fraternal ($n = 38$); twin A is the first born. The slope of the regression line for thinner twins is significantly steeper than the one for heavier ones ($p < 0.001$).

Not only did we find that both LBM and body fat, as well as body weight were genetically determined, but that there was a correlation between intrapair differences in LBM and intrapair differences in body weight. Moreover, the regression slope for the thin twins was steeper than that for those who were heavier. Hence, the composition of the intrapair weight difference depends on the amount of body fat. For very thin people LBM accounts, on average, for about half of the intrapair weight difference, whereas, for heavier people, body fat accounts for about three-quarters of the intrapair weight difference.

In summary, observations on several species involving a variety of situations leading to changes in energy balance show that changes in body weight invariably comprise both the lean and fat components of the body and that the relative contribution of lean and fat is, in many situations, a function of initial body fat content. It is no longer correct to consider each component in isolation.

ACKNOWLEDGMENTS

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