

Comparative Effects of Caloric Restriction and Total Starvation on Body Composition in Obesity

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TOTAL STARVATION as a treatment of obesity was introduced by Bloom (1), popularized by Duncan and associates (2, 3), and elaborated upon by Drenick and colleagues (4, 5). An increasing number of reports concerning metabolic effects of this therapeutic approach are appearing (6-10), but only limited data exist concerning the effects of starvation on basic body constituents (11, 12). This study involves the use of densitometric, volume-distribution, and balance techniques to measure change in total body fat and lean body mass during both caloric restriction and total starvation.

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The first study, involving five obese patients, was designed to compare loss of fat and fat-free tissue during both a period of caloric restriction (600 to 800 cal) and a following 16-day period of total caloric deprivation. After starvation the original restricted diet was resumed, and measurements of body compositional changes were continued for an additional 7 days. The second study, of four obese patients, was designed [1] to determine if the rate of fat loss during starvation was affected by previous dietary intake and [2] to compare compositional changes during the first 7 days of refeeding with those occurring later in repletion. Without prior caloric restriction, these subjects were fasted for 16 days, after which they were studied during a similar 16-day interval of caloric restriction (800 cal).

METHODS

The liquid diet used contained 47% of the calories as carbohydrate, 23% as fat, and 30% as protein and was given as four spaced feedings. Daily vitamin and iron supplementation was provided as hexavitamin capsules and ferrous sulfate. Total body water (TBW) was measured from the dilution of an intravenous dose of 200 μ c of tritiated water by the method of Werbin, Chaikoff, and Imada (13). Analysis was performed in duplicate on plasma obtained before and 3 hr after the injection of tritiated water. Nitrogen in diet and excreta was measured by a modified Dumas pyrolysis technique (14). Change in protein was determined from nitrogen balance using the conversion factor of 6.25.

Body volume was measured by a modification of the Siri helium dilution technique (15) and

body density (D), calculated:

$$D = \frac{\text{Mass}}{\text{Volume}}$$

Substitution of values for body density and total body water into the Siri (16) fat prediction equation permitted estimation of body fat and correction for abnormal hydration, a method we have termed "densitometric" (17).

Change in body fat was also obtained as outlined by Edelman, Brooks, and Moore (18) by subtracting the sum of changes of water and protein from change in body weight (Wt), a method we have termed "compartmental" (17).

$$\Delta \text{ Fat} = \Delta \text{ Wt} - (\Delta \text{ TBW} + \Delta \text{ protein})$$

Both techniques were used in the first study. Because there was insignificant difference in compositional change with the two methods, only the compartmental method was used in the second study. The data presented below are derived from the latter method.

Reports of studies on body composition have been beset with semantic difficulties. Development of formulas for estimation of fat content from densitometric measurements requires pre-

cise use of the terms *lean body mass* and *fat-free body*. The difficulty, which one of us has discussed elsewhere (19), stems from the assumption that the more physiologic lean body mass contains a certain amount of essential lipids whereas the fat-free body is totally devoid of fat. In measuring *change* in fat such precision is much less important, and we will use the term fat-free body and lean tissue interchangeably to quantitate changes other than those of body fat. Because of the relative stability of the skeleton and small carbohydrate content of the body, such changes involve predominantly water and protein.

RESULTS

Figure 1 illustrates both the protocol of study and the response noted in a representative patient from the first study (Patient 4—Table 1). This involved an initial period on an 800-cal liquid diet, starvation for the next 16 days, and a third period of 7 days on the original restricted diet. In this individual weight loss averaged 220 g/day during caloric restriction and increased

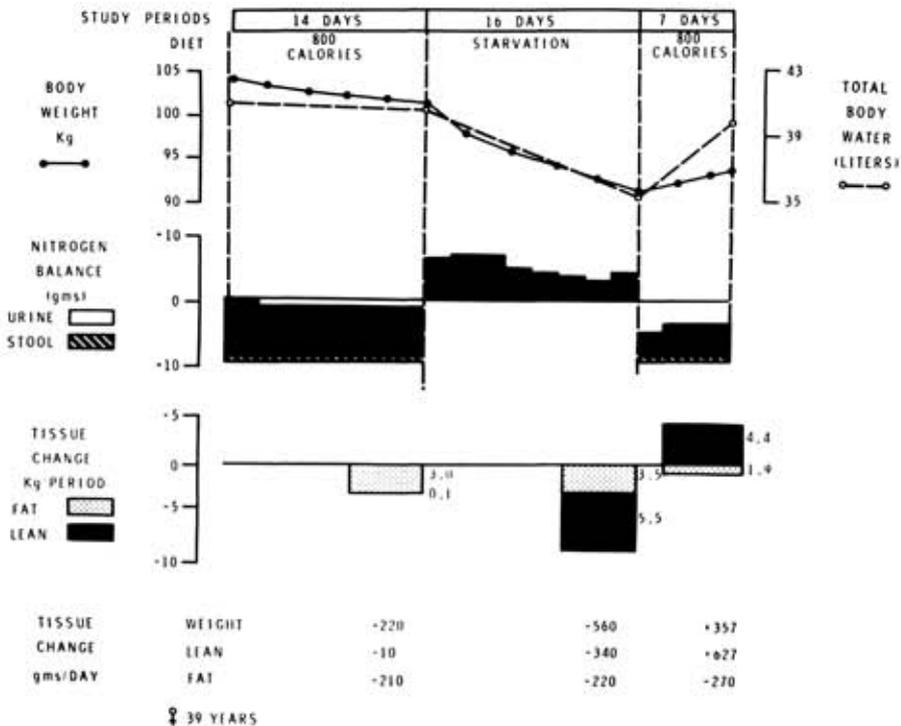


FIGURE 1. Protocol of study and response observed in a representative patient (Patient 4) from the first study.

TABLE 1. Basic Data from Study I in Which Starvation Was Preceded by Caloric Restriction

Patient	Diet Program	Study Days	Body Weight	Total Body Water	Nitrogen Balance	Change in Body Fat
			<i>kg</i>	<i>liters</i>	<i>g</i>	<i>kg</i>
1	Begin study		113.7	48.8		
	End of caloric restriction	12	101.9	40.1	-38	-2.8
	End of starvation	16	93.1	33.6	-95	-1.7
	End of caloric restriction	7	94.8	38.0	+4	-2.7
2	Begin study		183.0	70.7		
	End of caloric restriction	7	173.4	71.4	-46	-10.0
	End of starvation	16	162.5	60.0	-153	+1.4
	End of caloric restriction	7	162.8	62.1	+4	-1.8
3	Begin study		165.3	76.4		
	End of caloric restriction	7	159.7	72.6	-14	-1.7
	End of starvation	16	145.6	63.4	-99	-4.3
	End of caloric restriction	7	147.1	68.8	+25	-4.1
4	Begin study		103.5	40.8		
	End of caloric restriction	14	100.4	40.6	-1	-3.0
	End of starvation	16	91.4	35.6	-81	-3.5
	End of caloric restriction	7	93.9	39.8	+32	-1.9
5	Begin study		101.6	43.6		
	End of caloric restriction	7	98.3	44.7	-23	-4.3
	End of starvation	16	89.0	34.1	-121	+2.1
	End of caloric restriction	7	89.9	38.2	+13	-3.3

to 560 g/day during starvation. Weight gain averaged 357 g/day during poststarvation caloric restriction. During prestarvation caloric restriction most of the tissue lost was fat, whereas during starvation less than 40% of the lost tissue was fat. Poststarvation there was rapid reaccumulation of the previously lost lean tissue associated with continued fat loss. Throughout this study the absolute rate of fat loss was fairly constant.

Table 1 presents the basic data in each of the five patients comprising the first study, and Figure 2 portrays the mean change of body weight, lean tissue, and body fat in these five patients expressed as grams per day. Weight loss averaged 769 g/day during caloric restriction and was slightly less—651 g/day ($P = \text{not significant}$)—during starvation. Poststarvation weight gain averaged 197 g/day. Loss of lean tissue averaged 576 g/day during starvation as compared with variable loss, averaging

224 g/day, during the initial period of caloric restriction. In contrast, the average rate of fat loss was uniform and greater during caloric restriction—553 g/day—than noted during total starvation, wherein fat loss was variable and averaged only 75 g/day. The rate of body fat loss during the poststarvation period also exceeded that observed during starvation (393 g/day as compared with 75 g/day) despite the fact that gain in weight was noted in all patients during this period of repletion.

Figure 3 illustrates both the protocol of study and the response noted in a representative patient from the second study (Case 2—Table 2) in which 16 days of starvation were followed by a 16-day period of dietary restriction (800 cal). Starvation induced significant weight loss (925 g/day), negative nitrogen balance, and loss of water. During a comparable period of study after starvation, when the patient was receiving 800 cal/day, there was gain in

weight (156 g/day), very prominent reaccumulation of water, and retention of nitrogen. Table 2 illustrates the basic measurements of body weight, total body water, nitrogen balance, and change in body fat in each of the four patients studied, and Figure 4 portrays the mean tissue change expressed as grams per day. There was significant loss of lean tissue (563 g/day) during starvation and considerable reaccumulation of lean tissue (418 g/day) during the poststarvation period. The average loss of fat during 16 days of starvation did not exceed that lost during the similar period of repletion but was, in fact, somewhat less (202 g/day versus 359 g/day). The differences between the two groups as concerns changes in weight and lean tissue are significant whether calculated from averages

for the group or as matched pairs, but those for fat loss are not significant.

Comparison of loss of body weight, change in fat-free body, and loss of total body fat in the two studies is shown in Table 3. Although loss of weight and lean tissue was of the same magnitude whether the starvation was begun after an ad lib. diet or after caloric restriction, there appeared to be more substantial loss of fat when starvation immediately followed a free diet (202 g/day) rather than when caloric restriction preceded the total fast (75 g/day). Although this difference has a *P* value of < 0.02 , the subjects in these two studies were different. They were not matched for age, sex, size, degree of obesity, or the preceding dietary pattern, and, as can be seen, there existed considerable vari-

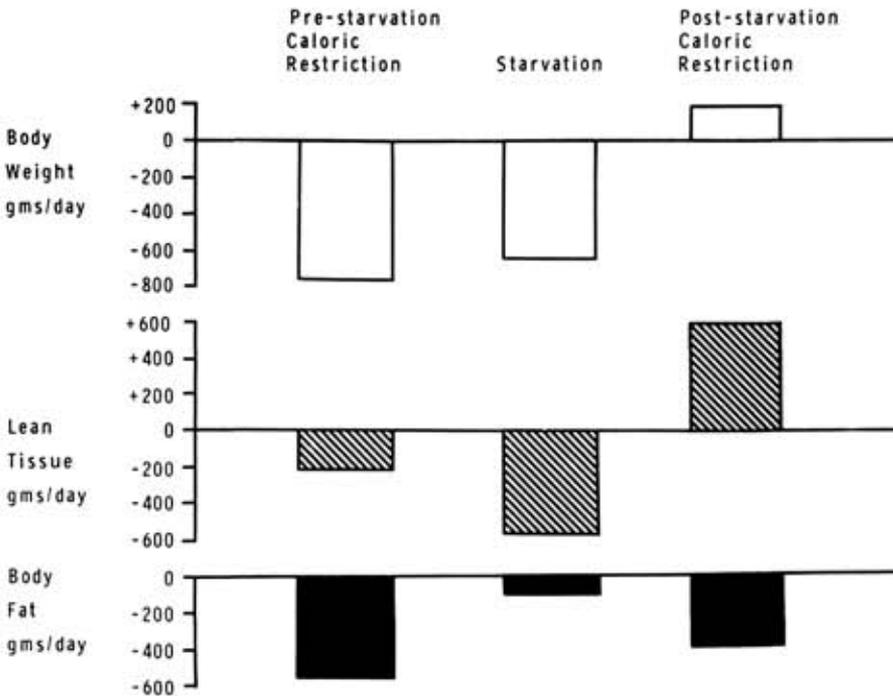


FIGURE 2. Changes in body composition during caloric restriction and starvation. The mean tissue change recorded in five patients comprising the first study is illustrated. Tissue change is expressed in grams per day. Lean tissue is considered as the sum of changes in body water and protein. The statistical significance of the above data when calculated as matched pairs is as follows: differences in [1] weight in prefast versus fast periods, *P* = not significant; in fast versus postfast periods, *P* < 0.001; [2] lean tissue in prefast versus fast periods, *P* = not significant; in fast versus postfast periods, *P* < 0.001; [3] fat tissue in prefast versus fast periods, *P* = not significant; in fast versus postfast periods, *P* < 0.02.

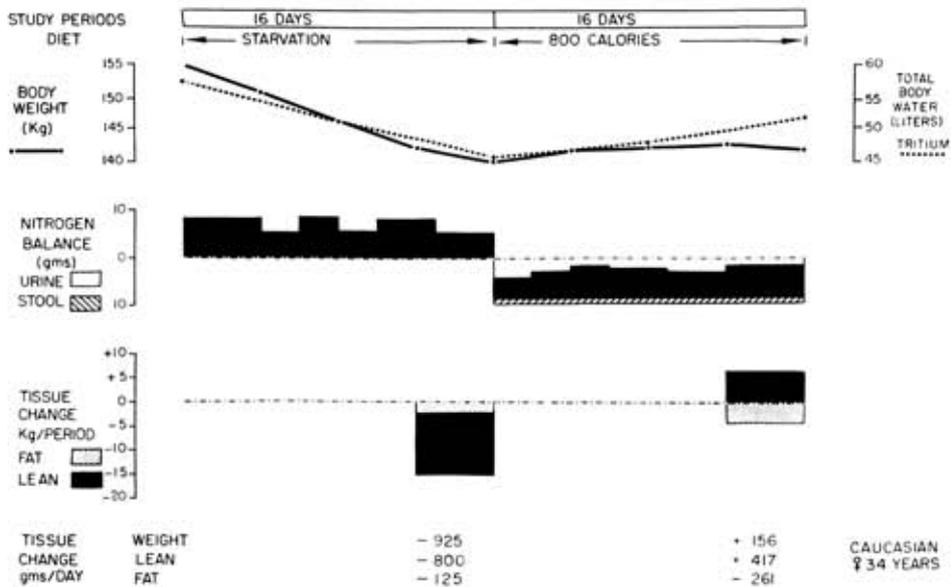


FIGURE 3. Protocol of study and response observed in a representative patient from the second study.

ation in both gain and loss of fat during starvation in both studies.

In Table 4 the compositional changes in three patients in the second study during the first 7 days of repletion are contrasted with those during the following 9 days of poststarvation restricted diet. It appears from these very limited data that restoration of weight and repletion of lean tissue is maximal during the first few days after

termination of starvation. Variability in fat loss in the three patients prohibits definitive conclusions, but the average rate of loss of fat was considerably greater in the immediate poststarvation period.

DISCUSSION

This study does not attempt to define the values or disadvantages of total caloric deprivation in the treatment of obesity.

TABLE 2. Basic Data from Study II in Which Starvation Followed a Free Diet

Patient	Diet Program	Study Days	Body Weight	Total Body Water	Nitrogen Balance	Change in Body Fat
			<i>kg</i>	<i>liters</i>	<i>g</i>	<i>kg</i>
1	Begin study		102.5	45.3		
	End starvation	16	90.7	40.6	-118	-6.3
	End caloric restriction	16	91.1	40.5	+23	+0.3
2	Begin study		154.8	57.5		
	End starvation	16	140.0	45.4	-102	-2.0
	End caloric restriction	16	142.5	51.7	+60	-4.2
3	Begin study		130.3	44.5		
	End starvation	16	118.5	33.6	-107	-0.2
	End caloric restriction	16	121.3	48.0	+38	-11.8
4	Begin study		116.9	46.3		
	End starvation	16	106.3	41.0	-147	-4.4
	End caloric restriction	16	105.2	45.9	+80	-6.5

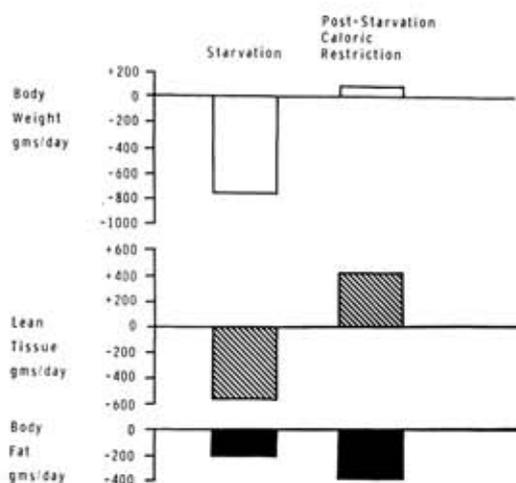


FIGURE 4. Changes in body composition during starvation and poststarvation caloric restriction. The mean tissue change recorded in the four patients comprising the second study is illustrated. Tissue change is expressed in grams per day. The significance of the data when calculated as matched pairs is as follows: differences in [1] weight in fast versus postfast periods, $P < 0.01$; [2] lean tissue in fast versus postfast periods, $P < 0.02$; [3] fat tissue in fast versus postfast periods, $P =$ not significant.

The rapid and substantial loss of weight that occurs during starvation may be of great value in stimulating the enthusiasm of a poorly motivated obese subject whose previous experience with reducing diets has been dispiriting. The data presented do not rule out the possibility that much longer periods of starvation may induce greater loss of fat than can be induced by caloric restriction. Along the same lines, the massive erosion of lean tissue noted during the 16 days of fast would undoubtedly be, at least on a daily basis, much less if the period of starvation were to be lengthened.

This study focuses only on gross compositional changes of lean tissue and fat noted during relatively brief periods of starvation. The apparent greater loss of lean tissue noted during starvation than that seen during caloric deprivation is not surprising. The relatively low mean rate of fat loss noted during 16 days of starvation is, however, much more remarkable. It is

TABLE 3. Comparison of Tissue Change in Patients Who Are Fasted After an Unrestricted Diet with the Tissue Change That Occurs when Starvation Follows a Period of Caloric Restriction

Tissue	Total Fast After Caloric Restriction	Total Fast After an Unrestricted Diet
	<i>g/day</i>	
Body weight	-651 ± 141	-765 ± 116
Lean tissue	-576 ± 187	-563 ± 333
Fat	-75 ± 180	-202 ± 170 ($P < 0.02$)

P was not significant except as noted.

even more impressive that in some patients fat loss accompanying dietary restriction was greater than that noted during total fast whether dietary restriction preceded or followed the period of starvation.

It would appear that starvation does not influence metabolism in the direction of more rapid combustion of adipose tissue. In the five obese patients who underwent caloric restriction before fasting, average fat loss was 553 g/day (Figure 2). In the four subjects whose caloric restriction followed a 16-day period of starvation, the average fat loss during caloric restriction was somewhat less—359 g/day—and obviously not greater as might be expected if starvation induced more marked lipolysis (Figure 4).

Blondheim and Kaufmann (20) have compared weight loss during short-term starvation with that observed during a preceding or following period of moderate caloric restriction (800 to 1,000 cal). During the initial caloric restriction, weight loss was rapid. Total starvation accelerated weight loss, but when the original re-

TABLE 4. Compositional Changes During Early and Late Poststarvation Refeeding

Tissue	Days 1-7	Days 8-16
	<i>g/day</i>	
Body weight	+361 ± 87	- 54 ± 98
Lean tissue	+844 ± 696	+125 ± 425
Fat	-500 ± 666	-182 ± 347

stricted diet was resumed, all patients either gained weight or maintained their weight. With continuation of the restricted diet, after fast, the patients again began to lose weight at approximately the same rate as had been noted before starvation while eating the identical restricted diet. A regression line was constructed through the daily weights recorded during the latter segment of the first 800- to 1,000-cal hypocaloric feeding period, and it was found that the extra weight loss noted during fasting was completely regained postfast. In addition, each patient ended the study with a weight that did not significantly differ from that predicted by the extrapolated regression line of weight loss.

Exact studies on compositional changes during starvation are, as noted above, very limited. Benoit, Martin, and Watten (11) concluded that weight loss during starvation is due predominantly to lean tissue wasting. Drenick (21) has called attention to the fact that Benoit and colleagues have misinterpreted their data. Although our conclusions, based on entirely different experimental techniques, are in accord with those of Benoit and associates, we agree with Drenick's criticisms and add that the changes in body potassium reported by Benoit and associates, when calculated as matched pairs, have no statistical significance. The problems inherent in the utilization of ^{40}K for such measurements under conditions of catabolism have also been delineated by Drenick (21).

Bolinger and coworkers (12), using the theoretical balances of Reifenstein, Albright, and Wells (22), have evaluated tissue change during a prefast restricted caloric mixed diet, total starvation, and a postfast 40-g protein diet. They showed that feeding a mixed diet induced weight loss that was predominantly fat, whereas during starvation, although weight loss increased, fat loss decreased. After starvation the patients were refed with a 40-g protein diet

that slowed the rate of weight loss but did not induce repletion of fat-free tissue.

The rapid and substantial reaccumulation of fat-free tissue that was observed in our patients after starvation is of interest. During the poststarvation period, patients in both studies reaccumulated lean tissue at a rate that was comparable to that at which lean tissue was being lost during starvation. This reaccumulation of fat-free tissue is inconsistent with the concept that the fat-free tissue lost during starvation is "surplus" tissue. In addition, these data emphasize the importance of evaluating not only the tissue changes induced by a proposed treatment program for obesity but also those that occur during the posttreatment period.

SUMMARY

Changes in body weight, lean tissue, and body fat were measured in nine obese subjects during caloric restriction, 16 days of total starvation, and a poststarvation period of dietary restriction. Weight loss was of similar magnitude during the initial caloric restriction and during starvation. However, during the initial caloric restriction over 70% of the weight loss was adipose tissue, whereas during total starvation less than 15% of the lost tissue was composed of fat. Marked loss of weight and lean tissue occurred during starvation that was of the same magnitude whether the starvation was begun after an ad lib. diet or after caloric restriction. During poststarvation caloric restriction, there was gain in weight, considerable reaccumulation of lean tissue, and loss of fat at a rate that was substantially greater than that during starvation.

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