Overfeeding in Identical Twins: 5-Year Postoverfeeding Results

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From a total of 12 pairs of young male identical twins who were overfed by an estimated 84,000 kcal over a period of 100 days, several pairs (eight to 11, depending on variables) were remeasured for body weight, body composition with the underwater weighing technique, regional fat distribution from skinfolds, girths, computed tomography (CT) fat areas in the abdominal region, and fasting plasma glucose, insulin, total cholesterol, high-density lipoprotein (HDL) cholesterol, and triglycerides 4 months and 5 years after completion of the overfeeding protocol. At 4 months, the twins had lost approximately 7 of 8 kg that they had gained with overfeeding. However, 5 years later, body weight had increased by 5 kg over the preoverfeeding level. Fluctuations in fat mass were greater than those in fat-free mass. The younger twins gained approximately twice as much as the older twins in the late recovery period, a difference attributed to the late phase of growth in body mass in the former. Upper-body fat was reduced at 4 months of follow-up study, but was increased in the late recovery phase. All blood values were normalized in the postoverfeeding periods. A within-pair resemblance was generally observed for the changes noted in the recovery periods, but it was more striking when variations between preoverfeeding and 4-month or 5-year values were considered. We conclude from these observations that there were no persistent effects of exposure to the overfeeding protocol over the expected age-associated increases in body mass, body fat, upper-body fat, abdominal visceral fat (AVF), and metabolic variables predictive of risk for common diseases in individuals of normal body weight and with no family history of obesity. The intrapair resemblance suggests that the genotype contributes to the alterations observed in the recovery from overfeeding and in the age-associated changes.

OVER THE PAST three decades, several overfeeding studies have been performed to address a variety of issues pertaining to the acute and chronic response to a level of caloric intake above the energy cost of weight maintenance. These studies have generally been undertaken in young adult men and the overfeeding periods have lasted for a few days in most cases, but up to approximately 6 months in the Vermont overfeeding studies.[1] Our own group has conducted two of these studies, both with young adult male identical twins, the first with a caloric surplus of 22,000 kcal over 22 days[2] and the second with a 84,000-kcal surplus over 100 days.[3]

One recent report has concluded that subjects who gained, on average, 19 kg body mass after a traditional massive fattening regimen lasting 4 to 6 months recovered their initial body mass 2.5 years after cessation of the fattening ritual.[4] However, few studies have dealt with the recovery from the overfeeding protocol and the long-term changes following exposure to a standardized period of overfeeding. This report addresses these two issues. From the 12 pairs of identical twins who were overfed by 84,000 kcal over a period of 100 days, eight to 11 pairs, depending on variables, were remeasured for body mass, body composition, and fat distribution indicators, as well as metabolic variables predictive of diabetes and cardiovascular disease risk, 4 months and 5 years after completion of the initial overfeeding protocol.

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SUBJECTS AND METHODS

Subjects

Twenty-four sedentary young males (aged 21 ± 2 years, mean ± SD) gave written consent to participate in an overfeeding study approved by the Laval University Medical Ethics Committee and the Office for Protection from Research Risks of the National Institutes of Health, Bethesda, MD. These subjects constituted 12 pairs of identical twins who had been reared together and living together before this study. A maximum of 11 pairs were able to return to the laboratory for postoverfeeding measurements on two occasions, and the present study is based on measurements performed on these subjects.

The monozygosity of the twins was established on the basis of a questionnaire, their physical appearance, and the similarity of 12 polymorphic red blood cell antigens and enzymes, the A, B, and C loci of the HLA-antigen system, and 10 polymorphic adipose tissue proteins visualized by two-dimensional gel electrophoresis. The monozygosity has been subsequently confirmed by a large number of DNA markers since the study began. None of the subjects had a history of recent illness, obesity, diabetes, hyperlipidemia, hypertension, or endocrinopathy, and each had a normal physical examination. Eight subjects were light smokers. Additional details about the study can be found in the first report of the series[1] and in other reports dealing with the response to the overfeeding protocol.[5-10]

Overfeeding Protocol

Eight subjects at a time were tested with exactly the same experimental protocol over a period of 18 months: the first subgroup started in August 1986, the second in February 1987, and the third the following August. Subjects were housed in a closed section of a dormitory on the campus of Laval University under 24-hour supervision. Each subject stayed in the unit for 120 consecutive days. The first 14 days constituted the baseline observa-

tion period. The subjects were then submitted to 3 days of testing. The test battery was repeated at 25, 50, and 100 days. Following the initial testing period, subjects were submitted to a standardized overfeeding protocol for 100 days.

The energy cost of weight maintenance was estimated during the 14-day baseline period. Subjects were instructed to eat freely from foods prepared for them and monitored for energy and macronutrient content by dieticians using a computerized version of the Canadian food composition tables.[11] Body weight was measured daily, and body density measurements were performed three times. The macronutrient composition of food eaten during the baseline period was 52% ± 6% carbohydrate, 34% ± 6% lipid, and 14% ± 6% protein (mean ± SD).

During the overfeeding period, subjects were fed a diet containing 4.2 MJ (1,000 kcal)/d over their established baseline energy intake 6 days per week for 100 days. On the remaining day of each week, energy intake corresponded to baseline energy needs. Subjects were thus overfed during 84 of 100 days, with the total excess energy intake being 353 MJ (84,000 kcal). The macronutrient composition of the food consumed each day was 50% carbohydrate, 35% lipid, and 15% protein. The subjects were instructed to remain sedentary throughout the 4 months of the study. Their schedule included activities such as playing videogames, reading, playing cards, watching television, and walking 30 minutes per day. The staff involved in the study constantly supervised the subjects. Therefore, we believe that the compliance with a sedentary mode of life was perfect. Because subjects were sedentary under free-living conditions, we believe that the activity program maintained during the experimental period did not impose a significant change in activity habits.

Postoverfeeding Testing at 4 Months

Subjects were recalled for a postoverfeeding evaluation session 4 months after completion of the overfeeding protocol. At that time, body composition, fat distribution, and blood assessments (described below) were repeated, with the exception of the computed tomographic (CT) scan examination.

Postoverfeeding Testing at 5 Years

Finally, subjects were asked to return to the laboratory for a final examination 5 years after completion of the overfeeding protocol. All measurements described in the following sections were obtained on a minimum of 16 and a maximum of 22 overfed twins.

Body Composition

Body weight was measured with the subjects wearing light exercise shorts. Body density was determined by the hydrostatic weighing technique.[12] Percent body fat was estimated from body density with the equation of Siri.[13] Fat mass and fat-free mass were obtained from percent body fat and body weight. Pulmonary residual volume was measured before immersion in the water tank by the helium dilution technique.[14]

Fat Distribution and Visceral Fat

Skinfold thickness was measured at eight sites, as were waist and hip circumferences, according to the procedures recommended at the Airlie Conference.[15] The ratio of the sum of skinfold thicknesses for the trunk (subscapular, suprailiac, abdominal, and midaxillary) to the sum of the values for the limbs (biceps, triceps, front midthigh, and medial calf) was used as one estimate of the regional subcutaneous fat distribution (referred to as TER).[16] The waist to hip ratio (WHR) was used as another estimate of regional fat distribution.[15] Two measurements were performed for all anthropometric variables, and the mean was used when the difference between the two measurements was less than 5%. If the difference was 5% or greater, further measurements were made until the criterion of 5% was met.

CT measurements were performed with a Siemens Somatom DRH scanner (Erlanger, Germany). Subjects were examined in the supine position with their arms stretched above their head.[17] The scan was performed between the fourth and fifth lumbar vertebrae. The attenuation interval used in the quantification of the areas of adipose tissue was −30 to −190 Hounsfield units. The total areas of abdominal fat and abdominal visceral fat (AVF) were calculated by delineating their surfaces with a computerized pen.[18] The AVF area was defined by drawing a line on the inside of the muscle wall surrounding the abdominal cavity. The area of subcutaneous abdominal fat was computed as the total abdominal fat area minus the AVF.

Blood Assays

A fasting blood sample was then obtained for assay of plasma glucose, insulin, triglycerides, and total cholesterol. Plasma glucose level was measured enzymatically,[19] and plasma insulin level was measured by radioimmunoassay with polyethylene glycol separation.[20] Total plasma cholesterol was determined using the enzymatic kit CHOD-PAP from Boehringer (Mannheim, Germany). High-density lipoprotein (HDL) cholesterol was assayed with the same method after separation of HDL from low- and very–low-density lipoprotein. Plasma triglycerides were determined enzymatically with the A-Gent kit (Abbott Laboratories, South Pasadena, CA).

Statistical Analysis

For each variable across the four time points (ie, before overfeeding time, 0; postoverfeeding, 100 days; 4 months after the overfeeding protocol; and 5 years after the overfeeding protocol), a two-way ANOVA for repeated measures on the time factor with twins nested in pairs was used to assess statistical significance and to evaluate the twin resemblance for the changes across the time points.[3] The intraclass coefficient derived from the within-pair and between-pair means of squares was computed.[21]

The following periods were considered: 0 to 100 days, 100 days to 4 months, 4 months to 5 years, 0 to 4 months, and 0 to 5 years. The P level for statistical significance was set at .05.

RESULTS

The elapsed time between the end of the overfeeding protocol and the 5-year postoverfeeding laboratory visit ranged from 4.6 to 5.7 years (mean ± SD, 5.2 ± 0.4). Body weight increased from 60.4 to 68.6 kg ($P < .0001$) with the overfeeding protocol. Four months after cessation of the overfeeding treatment, mean body weight had decreased to 61.7 kg, a value not significantly different from the preoverfeeding mean. From 4 months to 5 years, body weight increased to 65.3 kg, an increase that was significant ($P < .01$) compared with the preoverfeeding value but not with the 4-month body weight. Preoverfeeding body mass index was 19.7, on average, but it was 22.3 ($P < .0001$) after overfeeding. It was reduced to 20.1 after 4 months, a significant decrease from 100 days ($P < .01$), but it increased to a mean of 21.3 after 5 years ($P < .001$). Fat-free mass fluctuated only by approximately 2.5 kg across the four time points. At 5 years, it was 55.5 kg, a mean value not significantly different from the mean of 54.2 kg observed at 0 days. Percent body fat was highest after 100 days at 17.7%

($P < .0001$); it decreased to 12.6% at 4 months ($P < .01$), but increased to 15.3% at 5 years ($P < .001$). The values for percent body fat at 4 months and 5 years were significantly different from the preoverfeeding level. These changes in body mass and body composition are depicted in Fig 1.

Data on subcutaneous fat distribution and CT abdominal fat are presented in Table 1. Subcutaneous fat fully returned to preoverfeeding values by 4 months, as shown by the comparison of values for the sum of eight skinfolds, trunk skinfolds and extremity skinfolds. Five years later, the amount of subcutaneous fat was significantly increased ($P < .05$). Waist girth was also decreased to the pretreatment level by 4 months, but it was increased again at 5 years ($P < .001$). This pattern was also observed for the TER and WHR. CT-assessed abdominal subcutaneous fat area increased from 68 to 136 cm^2 ($P < .0001$) with the overfeeding treatment, but decreased to 104 cm^2 at 5 years, a value that remained significantly higher than the preoverfeeding mean ($P < .001$). Finally, CT AVF area increased from 32 to 56 cm^2 ($P < .0001$) with overfeeding, and remained essentially unchanged by 5 years, at 52 cm^2 ($P < .001$). The pattern of fluctuation over time for waist girth, TER, and CT total abdominal fat and AVF area is illustrated in Fig 2.

Changes in plasma glucose, insulin, total cholesterol, HDL cholesterol, and triglycerides across the four time points are listed in Table 2 and depicted in Fig 3. Plasma glucose was decreased significantly by 4 months and remained comparable to the preoverfeeding level by 5 years. The same pattern was observed for plasma insulin. The insulin to glucose ratio increased significantly with overfeeding ($P < .01$) but the 4-month and 5-year ratios were indistinguishable from the value for 0 days. Total cholesterol levels remained constant across the four time points. HDL cholesterol decreased with overfeeding ($P < .05$) but recovered by 4 months, and remained stable at 5 years. A similar pattern was observed for plasma triglycerides, with the exception that it increased with overfeeding but decreased at 4 months and 5 years.

The intrapair resemblance for changes in body weight in nine pairs of monozygotic twins with complete data from 0 to 100 days (overfeeding), 100 days to 4 months (early recovery), and 4 months to 5 years (later recovery) is depicted in Fig 4. There was three times more variance between pairs of twins than within pairs for the changes in weight during overfeeding and in the late recovery period, but a F ratio of approximately 8 ($P < .001$) was observed for the period 100 days to 4 months. The latter period was thus characterized by a highly significant within-pair resemblance in weight loss ($P < .001$).

The pattern of intrapair resemblance for percent body fat changes is illustrated in Fig 5. A consistent picture emerged for the three periods, with F ratios of approximately 3 to 4 and intraclass coefficients of .5 to .6 ($P < .05$). Similar trends were observed for changes in fat mass, but the intrapair resemblance was consistently lower for changes in fat-free mass, with F ratios clustering around 2 (data not shown).

Intrapair resemblance for the changes in TER and waist girth is depicted in Figs 6 and 7 based on nine pairs of monozygotic twins. Changes in this indicator of relative upper- to lower-body subcutaneous fat distribution are characterized by a moderate degree of intrapair resemblance, with F ratios ranging from approximately 3 to 5 across the three periods (Fig 6). On the other hand, within-pair resemblance for the changes in waist circumference was observed from 0 to 100 days ($P < .01$) and from 100 days to 4 months ($P < .001$), but not from 4 months to 5 years (Fig 7). Similar trends were seen for WHR (data not shown). The twin pair resemblance in CT fat area changes was more evident for AVF than for subcutaneous fat. The F ratio reached 3.6 ($P < .05$) for eight pairs measured before and after overfeeding (intraclass coefficient, .56), and it remained the same from 100 days to 5 years (F ratio = 3.7, $P < .05$, intraclass coefficient = .57). In contrast, the twin resemblance for CT abdominal subcutaneous fat area fluctuations was not significant at either of the two periods.

Intrapair resemblance for the changes in plasma glucose ($P < .05$), insulin ($P < .05$), total cholesterol ($P < .01$), HDL cholesterol ($P < .05$), and triglycerides ($P < .001$) was generally significant under the influence of the overfeed-

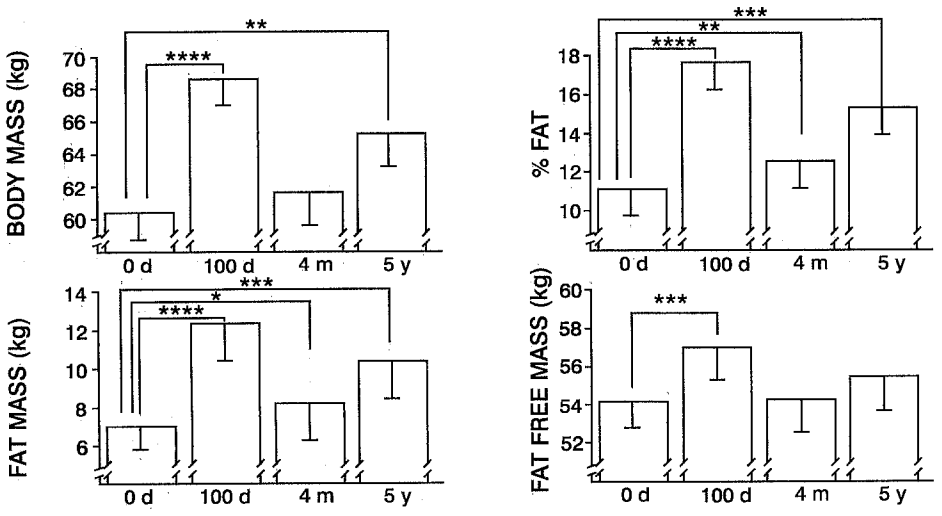

Fig 1. Changes in body mass and body composition during the overfeeding protocol and the postoverfeeding periods. Statistical significance was assessed with a 2-way ANOVA for repeated measures on the time factor with the twins nested within pairs. *$P < .05$, **$P < .01$, ***$P < .001$, ****$P < .0001$.

Table 1. Subcutaneous and Visceral Fat During the Overfeeding Protocol and the Postoverfeeding Periods

Variable	No.	Overfeeding		Postoverfeeding		F Ratio		
		0 d	100 d	4 mo	5 yr	100 d-4 mo	100 d-5 yr	4 mo-5 yr
Trunk skinfolds (mm)	18	37.7 ± 3.8	70.3 ± 6.4§	41.3 ± 5.4	59.1 ± 7.7†	74.87**	10.41¶	16.92¶
Extremity skinfolds (mm)	18	26.0 ± 1.7	39.2 ± 2.3§	27.5 ± 2.5	30.2 ± 2.8*	49.56#	16.85¶	6.46‖
Trunk/extremity ratio	18	1.44 ± 0.09	1.79 ± 0.12‡	1.46 ± 0.09	1.90 ± 0.13†	23.19#	0.90	19.37¶
Sum of 8 skinfolds (mm)	18	63.6 ± 5.2	109.5 ± 8.0§	68.8 ± 7.6	89.4 ± 10.1†	81.84**	15.29¶	16.36¶
Waist circumference (cm)	18	75.5 ± 1.3	83.3 ± 1.3§	76.9 ± 1.8	81.1 ± 1.7‡	31.92#	6.17‖	34.05#
Hip circumference (cm)	16	87.9 ± 1.4	93.9 ± 1.6‡	89.5 ± 1.8*	92.4 ± 1.8†	26.38¶	6.67‖	31.06#
WHR	16	0.87 ± 0.01	0.90 ± 0.01‡	0.88 ± 0.01	0.89 ± 0.01†	17.81¶	0.05	8.17‖
CT AVF (cm^2)	18	32.3 ± 2.1	55.6 ± 2.8‡	NA	52.1 ± 5.0‡	NA	0.45	NA
CT total abdominal fat (cm^2)	18	100.8 ± 12.4	191.2 ± 12.8§	NA	156.7 ± 17.3‡	NA	10.66¶	NA
CT subcutaneous abdominal fat (cm^2)	18	68.5 ± 10.8	135.6 ± 12.2§	NA	104.5 ± 13.6‡	NA	25.44#	NA

NOTE. Values are the mean ± SEM. Statistical significance was established from a two-way ANOVA for repeated measures on the time factor with the twins nested within pairs.

Abbreviation: NA, not available.

*$P < .05$, †$P < .01$, ‡$P < .001$, §$P < .0001$: *v* day 0.

‖$P < .05$, ¶$P < .01$, #$P < .001$, **$P < .0001$: for the statistical comparisons defined in the heading.

ing protocol. However, no consistent within-pair resemblance could be detected for the recovery periods of 100 days to 4 months and 4 months to 5 years, with the exception of the changes in plasma glucose ($.01 < P < .001$) and plasma triglycerides for 100 days to 4 months ($P < .02$) (data not shown).

The intrapair resemblance for the pattern of changes from the preoverfeeding level to the two recovery time points was also considered. The most significant results are displayed in Figs 8 and 9. Fluctuations in body weight and fat-free mass from 0 days to 4 months or 5 years were characterized by significant within-pair resemblance, as shown by F ratios for the between-pair to within-pair variance in response ranging from approximately 4 to 7 and intraclass coefficients from approximately .6 to .75 (Fig 8). Intraclass coefficients for such fluctuations reached .63 and higher. Figure 9 illustrates the twin resemblance for the variation in amount of upper-body subcutaneous fat (trunk skinfolds) and TER. F ratios ranged from approximately 3 to 10 and were all significant ($P \leq .05$). Similar results were obtained for the fluctuations in the sum of eight skinfolds and waist and hip circumferences, with F ratios ranging from approximately 2.5 to 6.5 (data not shown).

In contrast, no clear intrapair resemblance pattern could be observed for the variations in plasma glucose, insulin, insulin to glucose ratio, total cholesterol, HDL cholesterol, and triglycerides between the preoverfeeding period and 4 months and 5 years (data not shown).

DISCUSSION

Four months after the end of the overfeeding protocol, the twins had lost about 7 of 8 kg gained with the caloric surplus. Fat mass and fat-free mass had also reversed almost completely to the preoverfeeding values. This weight loss and the concomitant body composition changes that occurred over the 4-month recovery period can be defined as being mainly spontaneous, since the subjects were not under supervision during that period. Recovery is com-

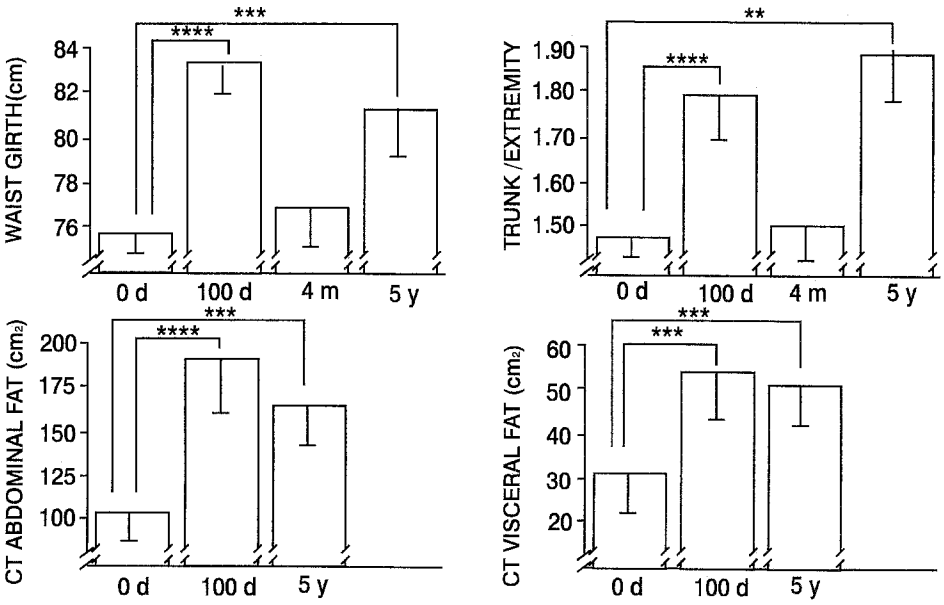

Fig 2. Changes in upper-body fat and CT total abdominal fat and AVF across the overfeeding protocol and the postoverfeeding periods. Statistical significance was assessed with a 2-way ANOVA for repeated measures on the time factor with the twins nested within pairs. **$P < .01$, ***$P < .001$, ****$P < .0001$.

Table 2. Fasting Plasma Glucose, Insulin, Cholesterol, and Triglycerides During the Overfeeding Protocol and the Postoverfeeding Periods

Variable	No.	Overfeeding		Postoverfeeding		F Ratio		
		0 d	100 d	4 mo	5 yr	100 d-4 mo	100 d-5 yr	4 mo-5 yr
Glucose (mmol/L)	22	4.53 ± 0.08	4.93 ± 0.06‡	4.49 ± 0.11	4.84 ± 0.13	8.00§	0.41	2.05
Insulin (pmol/L)	20	36.5 ± 2.9	71.0 ± 6.6‡	47.1 ± 5.7	50.8 ± 6.7	44.87¶	9.05‖	0.23
Insulin/glucose ratio	20	8.1 ± 0.6	14.3 ± 1.3†	10.9 ± 1.4	10.9 ± 1.9	15.50‖	6.26§	0.00
Cholesterol (mmol/L)	22	4.55 ± 0.18	5.02 ± 0.25	4.52 ± 0.21	4.83 ± 0.17	6.16§	0.63	3.69
HDL cholesterol (mmol/L)	22	1.19 ± 0.04	1.09 ± 0.04†	1.18 ± 0.04	1.22 ± 0.07	7.09§	8.91‖	0.85
Triglycerides (mmol/L)	22	1.15 ± 0.11	1.83 ± 0.29*	1.26 ± 0.19	1.33 ± 0.15	2.89	3.08	0.15

NOTE. Values are the mean ± SEM. Statistical significance was established from a two-way ANOVA for repeated measures on the time factor with the twins nested within pairs.

*$P < .05$, †$P < .01$, ‡$P < .001$: *v* day 0.

§$P < .05$, ‖$P < .01$, ¶$P < .0001$: for the statistical comparisons defined in the heading.

monly observed after a period of overfeeding, although subjects in the Vermont studies were encouraged by a stipend to return to their initial weight.[1,22] The recovery was particularly striking in the recent follow-up study following a 4- to 6-month Guru fattening session.[4]

However, over the next 5 years, the subjects regained some of the weight and fat mass lost in the early recovery phase. Thus, over the whole study period, body weight increased from 60.4 to 65.3 kg, approximately 5 kg. Prospective and longitudinal studies have clearly demonstrated that free-living individuals, on average, gain weight during their twenties. For instance, three studies with follow-up periods ranging from 12 to 20 years and with subjects entering the study at age 18 to 20 years reported a mean weight gain of about 0.7 kg per year over the follow-up period.[23-25] In the present study, the younger twins at entry, ie, five pairs who were less than 20 years of age (range, 18.7 to 19.8), had gained, on average, 6.8 kg at the 5-year postoverfeeding period. The older twins (20.6 to 21.9 years), on the other hand, gained an average of only 3.5 kg. This difference suggests that some of the body mass increase may have resulted from the residual growth in mass that often occurs in the late teens and early twenties. Indeed, growth in body mass has not reached its maximum by 18 or 19 years of age, particularly in boys, and the late increase in body mass is more important in late maturers.[26] This phenomenon is also observed in a cross-sectional but representative sample of the US population from 2 to 25 years of age.[27] Thus, over a 5-year span from 19 to 24 years, as in the younger twins of the present study, the increase in body mass at the 50th percentile of the distribution was 9.49 kg, or 1.89 kg/y. In this context, the weight gain in the late recovery phase does not appear to be unusual for free-living individuals of this age group.

At 4 months of the recovery phase, the indicators of upper-body fat were decreased to the preoverfeeding levels (trunk skinfolds, TER, waist circumference, and WHR). However, they were elevated again at the 5-year measurement, indicating that these young males were gaining more fat on the trunk by that time. This is not an unexpected finding, since young males tend to gain progressively more upper-body fat after puberty. At the 5-year measurement, total abdominal fat and AVF areas from CT were also higher than at the preoverfeeding period. It is not possible to establish if these increases were influenced by exposure to the overfeeding protocol or were simply the age-

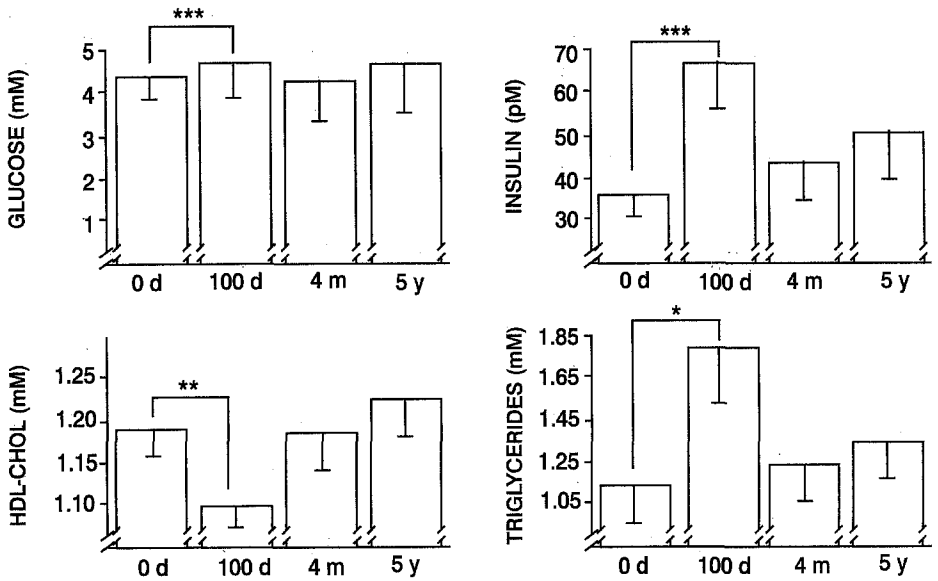

Fig 3. Changes in fasting plasma values across the overfeeding protocol and the postoverfeeding periods. Statistical significance was assessed with a 2-way ANOVA for repeated measures on the time factor with the twins nested within pairs. *$P < .05$, **$P < .01$, ***$P < .001$.

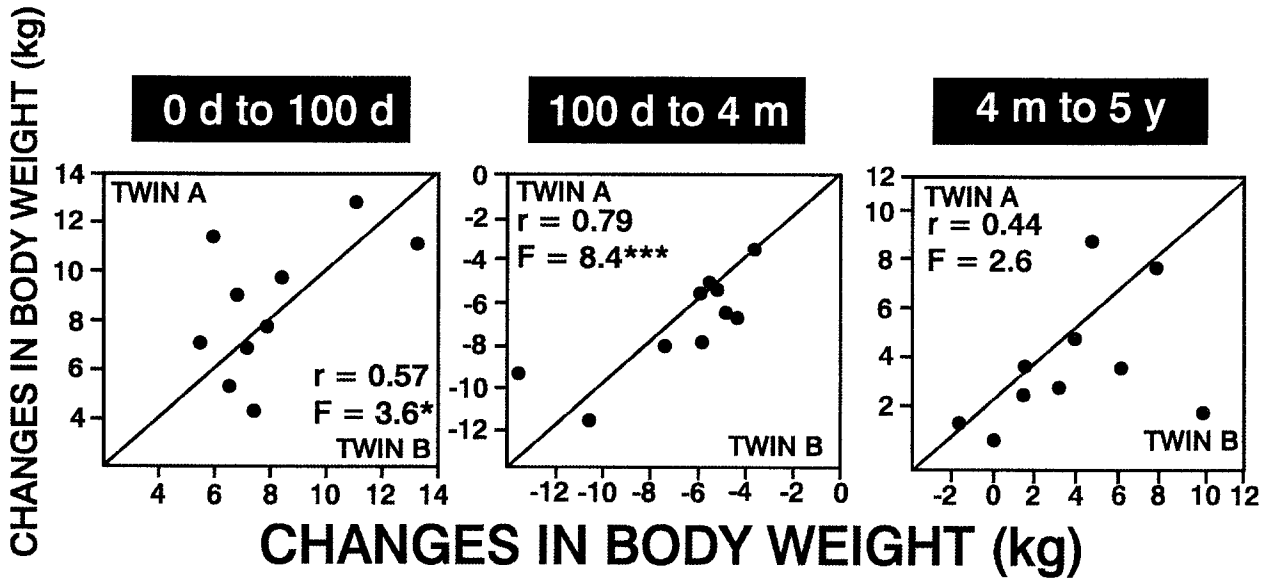

Fig 4. Twin resemblance with respect to changes in body weight for 3 time intervals. Each point represents the changes for 2 brothers of a pair of twins. *r*, intraclass coefficient. F ratio was computed with the between-pair and within-pair means of squares. *$P < .05$, ***$P < .001$.

associated increases to be expected in these age ranges. However, the mean CT abdominal fat areas attained at the 5-year postoverfeeding time point were well within the range of values commonly observed in young men and were even less than the fat areas commonly reported with the same technique.[28,29] This is particularly obvious for the AVF area, which remains strikingly low despite exposure to the overfeeding protocol. Globally, these observations strongly suggest that there were no persistent effects of exposure to the overfeeding protocol on AVF and fat topography.

Despite the increases in body mass, upper-body fat, and AVF, there were no indications that fasting plasma glucose, insulin, total cholesterol, HDL cholesterol, and triglycerides were adversely affected. By 4 months of recovery, the blood levels had all reverted to preoverfeeding values and remained essentially unchanged over the next 5 years. Systolic and diastolic blood pressures were measured at 4 months and both remained low (117 ± 4 and 62 ± 4 mm Hg) and not different from the preoverfeeding values (results not shown). This provides additional support for the notion that much of the body fat and fat topography observed in the latter recovery phase was probably age-related and had little to do with the previous exposure to the overfeeding protocol.

One interesting aspect of this follow-up study is that the twin resemblance in weight and body composition fluctuations is generally significant and not markedly different

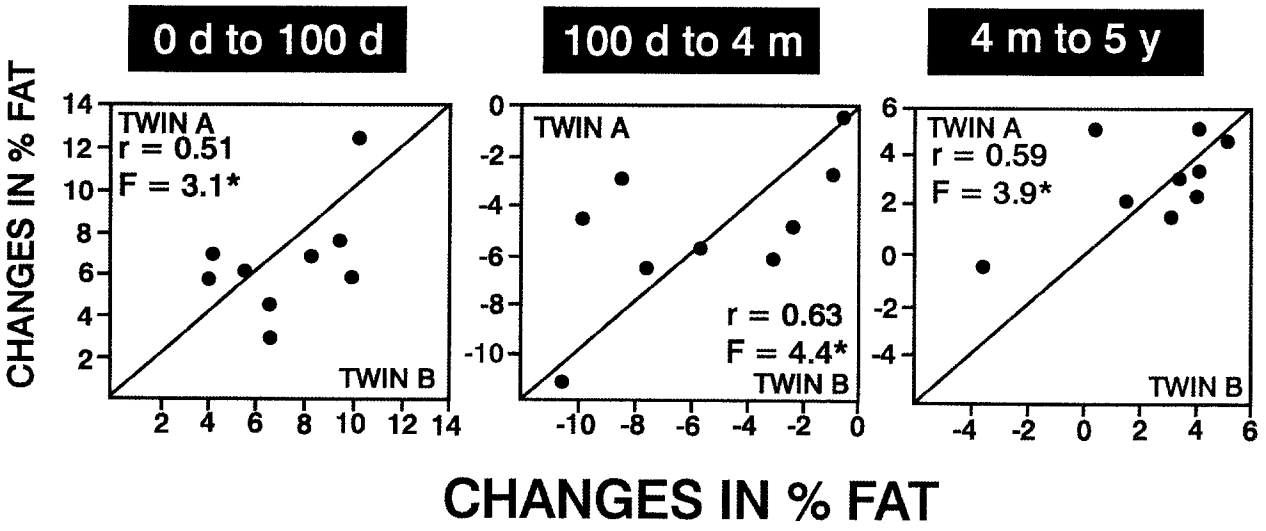

Fig 5. Twin resemblance with respect to changes in percent fat for 3 time intervals. Each point represents the changes for 2 brothers of a pair of twins. *r*, intraclass coefficient. F ratio was computed with the between-pair and within-pair means of squares. *$P < .05$.

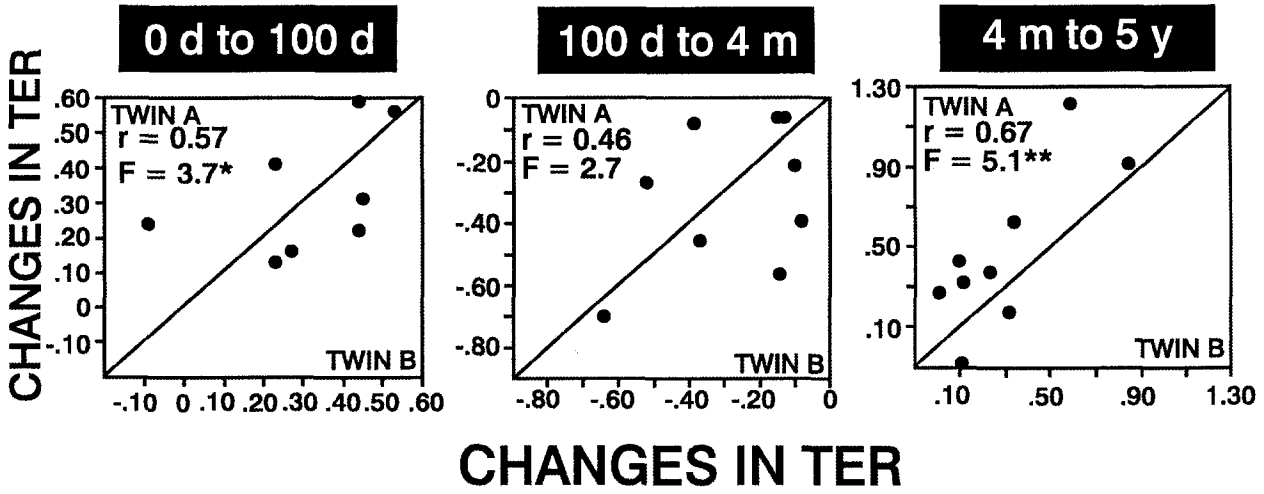

Fig 6. Twin resemblance with respect to changes in the trunk to extremity ratio for 3 time intervals. Each point represents the changes for 2 brothers of a pair of twins. *r*, intraclass coefficient. F ratio was computed with the between-pair and within-pair means of squares. *$P < .05$, **$P < .01$.

from the within-pair resemblance reported previously with this chronic exposure to overfeeding.[3] There was also a clear trend for the changes in recovery periods for fat distribution measurements to be more similar within pairs of twins than between pairs, although there were fluctuations in the variance ratios (Figs 6 and 7).

A clearer picture emerged when the changes between preoverfeeding levels and those observed at 4 months or 5 years of recovery were considered. Here, the twin resemblance results from the response to the overfeeding protocol and the subsequent return to normal daily activities. In this case, the intrapair resemblance from 0 days to 4 months and 0 days to 5 years is remarkable for body weight and body composition components, but only fat-free mass is illustrated in Fig 8. A similar pattern of intrapair resemblance in changes was also observed for indicators of subcutaneous fat and fat topography. As for the CT fat areas between 100 days and 5 years, the significant differences reported herein for AVF but not for subcutaneous area were characterized by within-pair similarity. For instance, a F ratio of 3.7 ($P < .05$) was observed for the changes in AVF over that period. These results are concordant with results we obtained for the response of AVF to positive energy balance or negative energy balance when the alterations induced in AVF were more substantial.[3,30]

Currently, there are no data reported with which the present observations can be compared. Hence, the interpretation of these results may be enriched when more material on age-associated changes becomes available. However, in our view, the study suggests that there were no persistent effects of exposure to the long-term overfeeding protocol in terms of recovery of body weight, body composition, fat topography, and conventional metabolic markers predictive of risks for cardiovascular disease and type II diabetes

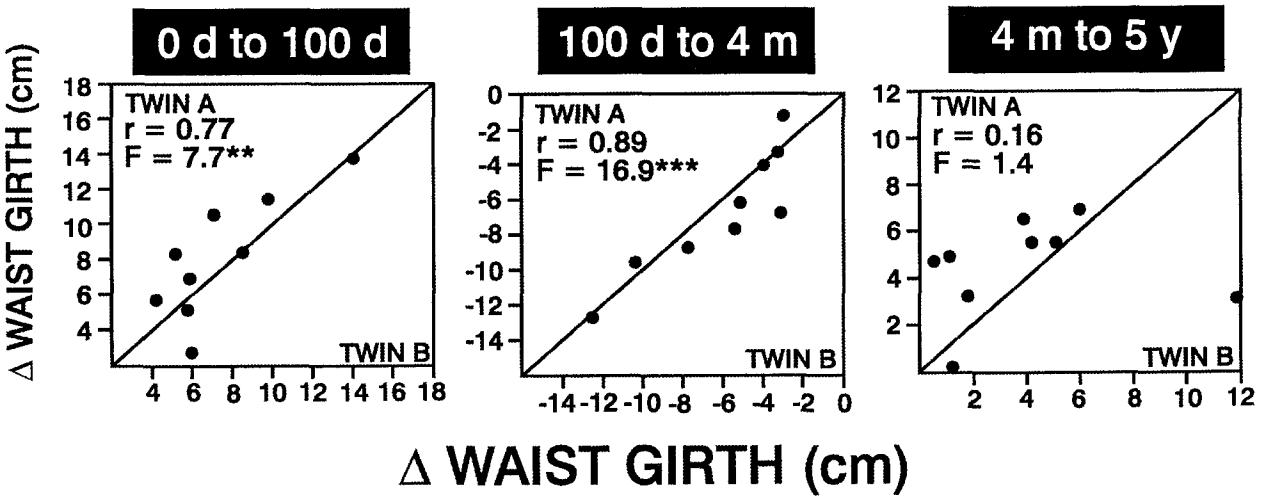

Fig 7. Twin resemblance with respect to changes in waist girth for 3 time intervals. Each point represents the changes for 2 brothers of a pair of twins. *r*, intraclass coefficient. F ratio was computed with the between-pair and within-pair means of squares. **$P < .01$, ***$P < .001$.

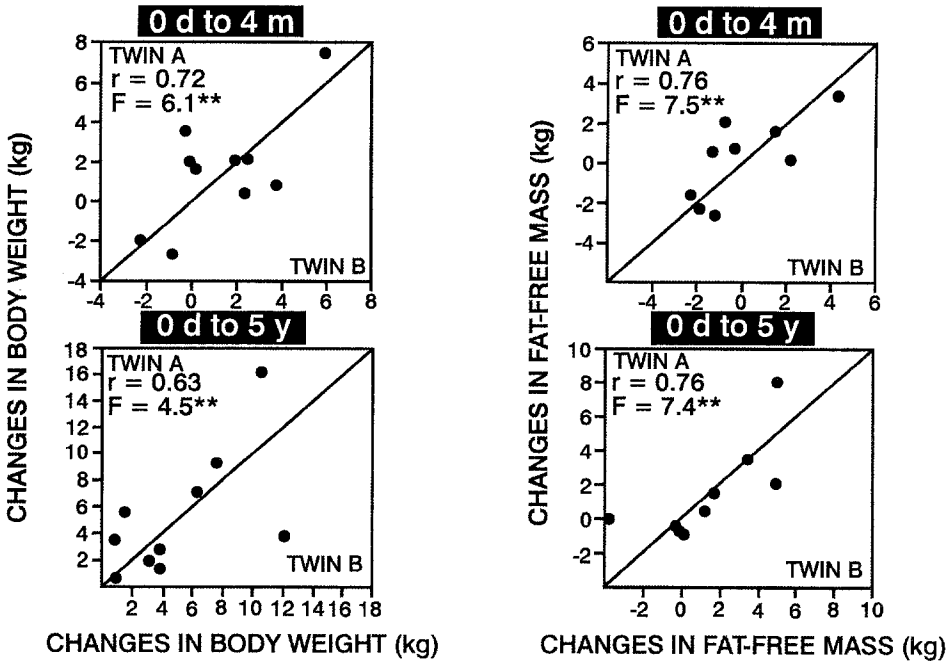

Fig 8. Twin resemblance with respect to changes in body weight and fat-free mass from the preoverfeeding to recovery periods. Statistical significance was assessed with a 2-way ANOVA for repeated measures on the time factor with the twins nested within pairs. **$P < .01$.

mellitus in subjects of normal body weight and with no family history of obesity. The contribution of genetic similarity versus genetic difference in the response pattern reported previously following exposure to the overfeeding protocol itself[3] appears to be present also in the changes that took place early and late in the recovery phase. Since the twins were free-living and in their original environment during the postoverfeeding phase, it is not possible to identify whether the changes observed were caused by the dietary restriction, or increase in the level of physical activity, or other factors.

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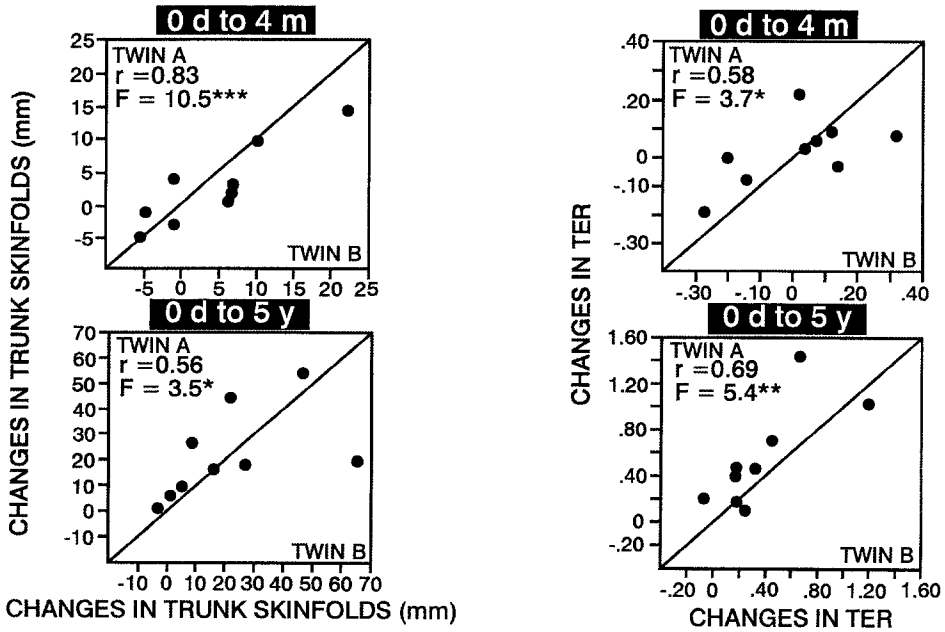

Fig 9. Twin resemblance with respect to changes in trunk skinfolds and TER from the preoverfeeding to recovery periods. Statistical significance was assessed with a 2-way ANOVA for repeated measures on the time factor with the twins nested within pairs. *$P < .05$, **$P < .01$, ***$P < .001$.

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