The effect of overfeeding on two fat young women

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As obesity is a common disease and its consequences may be serious, it is surprising how seldom the processes by which it arises have been studied experimentally in man. We know of only five human subjects who have been overfed for a significant length of time while attempts were made to assess the weight gain against measured differences between the calorie intake in the food and the calorie expenditure during daily activity (Gulick, 1922; Wiley & Newburgh, 1931*a*, *b*; Passmore, Meiklejohn, Dewar & Thow, 1955*a*, *b*). All five of these subjects were thin men. Only one of these men, to whom Wiley & Newburgh gave an excess of 1680 kcal/day for 15 days, gained weight easily: he put on 4·4 kg, with a calorie value of 5·7 kcal/g weight gained. Gulick, who studied himself, gained weight easily for the first 16 days, but on a smaller calorie excess. Thereafter his gains were slow and the calorie value of the tissue laid down was always higher than that observed in Wiley & Newburgh's subject. The three thin men to whom Passmore *et al.* (1955*a*, *b*) gave an excess of about 1500 kcal/day for 2 weeks only gained weight slowly and at a cost of over 8 kcal/g. In this paper we record observations on overfeeding two fat women. They gained weight easily for 9 days, putting on 2·86 and 2·58 kg respectively at costs of only 2·5 and 4·0 kcal/g. The paper records a full analysis of their energy balances and the changes in their body composition.

EXPERIMENTAL

Subjects. Two young women, Betty and Pat, agreed to take part in this study. They had been attending an obesity clinic, but were otherwise healthy. There was no obvious endocrine, metabolic or psychological abnormality. Each was earning her living. Their heights, weights, total body water contents and basal metabolic rates (BMR) at the beginning of the experiment are recorded in Table 1. Both had previously been fatter: Betty weighed 118 kg and Pat 112 kg when they first attended the clinic about a year previously. As is frequent with obese people, the BMR of each was high; it was about 15% above the usual standards, based on surface area. Their total body water contents, measured by tritium oxide dilution, corresponded to values for the lean body mass of about 60 and 63 kg and, by difference, a fat content of 32 and

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30 kg, respectively. Thus both Betty and Pat were big women for their height, and muscle as well as adipose tissue contributed to their excess weight.

Regimen. The subjects slept in a hospital ward, but spent the day in a room set aside in the laboratory. Their time was occupied in reading, watching television and doing light handicrafts. They went out for formal exercise consisting of about 1 h walking each day. They were weighed each morning on a beam balance when clad only in a light surgical gown, the balance being accurate to 1 g, and the weight of the gown was subtracted before recording.

Observations were made for 23 days. On the first 9, they were on a diet which met their calorie needs approximately; their weights changed little. For the next 9 days they were overfed, and for the last 5 days they received only a token diet (about 300 kcal/day).

Table 1. *Age, height, weight, basal metabolic rate* (BMR), *and total body water, measured by the tritium oxide dilution method, of the two subjects*

	Age (years)	Height (cm)	Initial weight		O_2 uptake (ml/min)	BMR as % of standard†	Total body water (l.)
			kg	As % of standard*			
Betty	35	167	91·9	146	271	114	42·0
Pat	25	168	92·8	146	271	116	44·5

* Odier & Mach (1949). † Robertson & Reid (1952).

Diets. These were composed of common foods, chosen after discussion with the patients. Three equal portions of all foods were weighed out each day. It was obligatory for the subjects to eat all of their portion and the third portion was homogenized and set aside for analysis. On the last 4 days of overfeeding, when they began to find difficulty in consuming all the food presented, the obligatory diet was reduced slightly. Extra bread, jam and sweetened fruit juices were provided and the subjects were encouraged and persuaded to take as much as possible of them. The amounts consumed were weighed, and each of these extra foods was analysed separately.

The water content of the diet was determined by drying a portion of each homogenate to constant weight. The protein content was calculated by multiplying the nitrogen content (obtained by Kjeldahl analysis) by 6·25. For the extra bread, the N conversion factor of 5·7 was used. The fat content was determined by Soxhlet extraction, and the carbohydrate was determined by the method of Trevelyan & Harrison (1952). All carbohydrate values are expressed in terms of polysaccharides. The gross calorie value of the diet was determined with a bomb calorimeter.

Faeces. Stools were collected and weighed daily. They were then pooled over 4- to 5-day periods and analysed in the same manner as the diet, except that carbohydrate was not measured. At no time did either subject have either diarrhoea or constipation and all samples of stool were soft and well formed.

Urine. This was collected in 24 h periods. The volume and specific gravity were measured and all samples were tested for glucose by the Clinistix (Ames Company (London) Ltd, Nuffield House, London, W. 1) dehydrogenase test and found to be negative. The urinary N was measured by the Kjeldahl method. The calorie value of the urine was calculated by multiplying the N content by 7·9 (Atwater & Bryant, 1900). The amount of urinary water was calculated from the weight of the urine, by subtracting that of the urinary solids. The urinary solids were calculated from the formula:

$$\text{Urinary solids (g/l.)} = (1000 \times \text{sp. gr.} - 1000) \times 2.$$

For a discussion of the use of this formula, see Price, Miller & Hayman (1940).

Energy expenditure. This was calculated from measurements of the respiratory exchanges and records of activity as previously described (Passmore *et al.* 1955*a*; Passmore, Strong & Ritchie, 1958). O_2 consumption and CO_2 output were measured over 10 min periods six times a day on 2 days out of each 3. The measurements were made at irregular intervals throughout the 24 h. Two were always made during the day when the subject was engaged in her usual sitting activities, one was made whilst the subject was walking and two were taken during the night (one before midnight and the other between 2 a.m. and 5 a.m.). The samples for basal metabolism were taken at about 8 a.m.

Records were kept of the time spent in bed, sitting, at exercise and 'up and about'. From these records and the measurements of the respiratory exchanges, estimates were made of the total O_2 uptake and CO_2 output during each 24 h.

Metabolic mixture. The daily utilization of protein, carbohydrate, fat and calories was calculated from the urinary N and from the estimates of daily O_2 utilization and CO_2 output as described in a previous paper (Passmore & Swindells, 1963).

Water balance. This was drawn up daily from analysis of the water in the diet, the fluid intake, the faecal and urinary water, the evaporative water (calculated from the invisible weight loss less the difference between the weight of CO_2 and O_2) and the metabolic water.

RESULTS

Diet. Table 2 shows the analysis of the food consumed by each subject during the control, overfeeding and underfeeding periods. The calorie values of the diets, as determined directly in the bomb calorimeter, are given, as well as the values calculated

Table 2. *Mean values by analysis for the intake of water, solids, protein, fat, carbohydrate (as polysaccharide) and ash (g/day), and of calories (kcal/day)*

	Control period		Overfeeding period		Underfeeding period	
	Betty	Pat	Betty	Pat	Betty	Pat
Water: drunk	2145	816	1987	710	2290	1307
in food	1911	1911	2152	2162	404	404
Solids	615	615	927	981	67	67
Protein	131	131	145	146	14	14
Fat	147	147	91	91	11	11
Carbohydrate	297	297	645	698	35	35
Roughage*	12	12	15	15	5	5
Ash	28	28	31	31	2	2
Calories:						
bomb	3390	3390	4370	4580	350	350
calculated	3390	3390	4380	4600	350	350

* By difference.

from the chemical analysis. The differences between these two independent estimates are negligible. In the control diet the calories were provided by protein 17, fat 44 and carbohydrate 39%. These diets were made up as far as possible according to the subjects' wishes. During overfeeding the calories were provided by protein 16, fat 20 and carbohydrate 64%. This was deliberately made a high-carbohydrate diet; however, as in the control period, the protein intake remained ample. During the underfeeding period the subjects received one or two small snacks a day to reduce the discomforts of hunger. In the control period and during overfeeding Betty drank every day between two and three times as much fluid as Pat.

Faeces. Table 3 shows that even during overfeeding faecal losses were small. During the control period Betty absorbed over 92% of the calories in the diet and Pat over 96%. During overfeeding absorption remained substantially unchanged at these high levels.

Table 3. *Mean values by analysis for the water, solids, protein, fat and ash content of the faeces (g/day) and for calories (kcal/day)*

	Control period		Overfeeding period		Underfeeding period	
	Betty	Pat	Betty	Pat	Betty	Pat
Weight	161	86	192	106	32	63
Water	120	63	141	78	22	48
Solids	41	23	51	28	10	15
Protein	12	7	18	10	4	6
Fat	10	3	11	3	2	2
Roughage*	12	8	15	10	3	5
Ash	7	5	7	5	1	2
Calories:						
bomb	240	110	280	130	60	80
calculation	210	100	270	130	50	70

* By difference.

Table 4. *Weight of urine and its content of water, solids and nitrogen (g/day) and calorie value (kcal/day)*

	Control period		Overfeeding period		Underfeeding period	
	Betty	Pat	Betty	Pat	Betty	Pat
Weight	3004	1784	2988	1788	2817	1664
Water	2949	1723	2940	1736	2794	1639
Solids	55	61	48	52	23	25
Nitrogen	18·7	18·8	17·6	17·4	10·9	12·5
Calories	150	150	140	140	90	100

Urine. Table 4 shows the measured urinary outputs and the calculated calorie value of the urines. The high urinary output of Betty reflects her high fluid intake. None of her samples gave positive reactions for glucose with the Clinistix test.

Weight changes. Fig. 1 shows the daily weight changes and Table 5 shows the mean daily weight balances for the three periods. Both Betty and Pat lost a little weight in the control period. They gained 2·86 and 2·58 kg respectively during the

9 days of overfeeding and lost 6·22 and 5·63 kg respectively during the 5 days of semi-starvation. The significance of the invisible weight losses is discussed later (p. 379).

Energy expenditure. Table 6 shows the distribution of their time throughout the whole experiment. Table 7 gives the mean of all the values for rates of O_2 consumption. The figures for 'sitting' include measurements made when the subjects were watching television, reading and when doing jig-saw puzzles and light handicrafts.

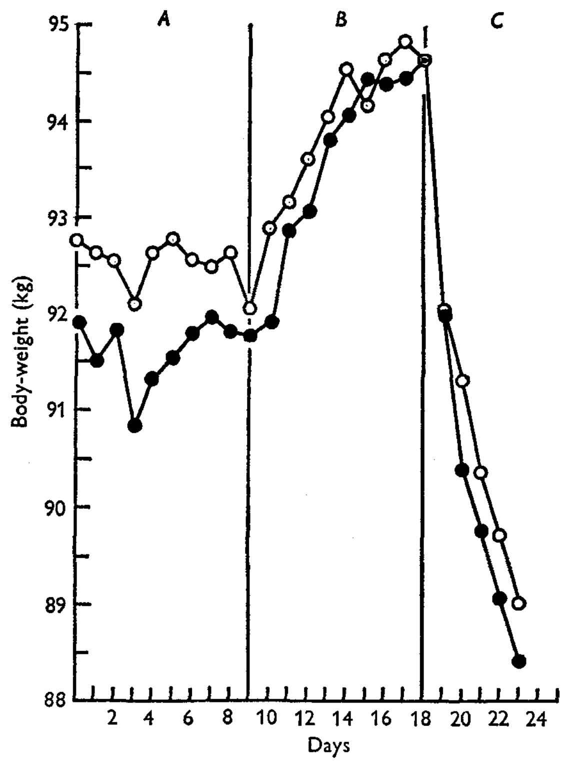

Fig. 1. Daily weight changes of the two subjects: (*A*) when on a balanced diet, (*B*) when overfed, and (*C*) when underfed. o—o, Pat; ●—●, Betty.

Table 5. *Mean values (g/day) for changes in body-weight, intake of fluid and food, output of urine and faeces and invisible weight loss*

	Control period		Overfeeding period		Underfeeding period	
	Betty	Pat	Betty	Pat	Betty	Pat
Body-weight	−16	−78	+318	+287	−1243	−1126
Intake:						
water drunk	2145	816	1987	710	2290	1307
food eaten	2526	2526	3079	3143	471	471
Output:						
urine	3004	1784	2988	1788	2817	1664
faeces	161	86	192	106	32	63
invisible weight loss	1522	1550	1568	1674	1155	1177

During the overfeeding period, rates of O_2 consumption whilst sitting exceeded the rates during the control period by 4% for Betty and 3% for Pat. At night in bed, the excess feeding increased O_2 consumption by 12% for Betty and 5% for Pat. These figures indicate the extent of any possible 'Luxus Konsumption' mechanism for burning off the excess food. As with thin young men (Passmore *et al.* 1955*a*), the increases in O_2 utilization were very small and can probably be attributed to the specific dynamic action of the extra food eaten.

Table 6. *Mean values for the time (min/day) spent in bed, sitting, walking and up and about*

Activity	Control period		Overfeeding period		Underfeeding period	
	Betty	Pat	Betty	Pat	Betty	Pat
In bed	514	512	519	516	605	587
Sitting	611	597	603	609	565	551
Walking	172	170	160	159	165	196
Up and about	143	161	158	156	105	106
Total	1440	1440	1440	1440	1440	1440

Table 7. *Mean values for O_2 consumption (ml/min) determined by analysis of expired air during representative activities at irregular intervals throughout the day and night*

Activity	Control period		Overfeeding period		Underfeeding period	
	Betty	Pat	Betty	Pat	Betty	Pat
In bed	268	281	293	295	281	307
Sitting	320	324	333	335	278	299
Walking	1150	1183	1190	1185	1037	1085
Basal O_2 consumption	271	271	270	278	272	299

Table 8. *Mean values for the* RQ*s during representative activities at irregular intervals throughout the day and night*

Activity	Control period		Overfeeding period		Underfeeding period	
	Betty	Pat	Betty	Pat	Betty	Pat
In bed	0·84	0·86	1·00	0·96	0·80	0·77
Sitting	0·87	0·88	0·95	0·95	0·86	0·84
Walking	0·83	0·81	0·91	0·92	0·79	0·77
Basal RQ	0·84	0·86	0·94	0·93	0·80	0·76

Table 8 gives the mean figures for the RQ, corresponding to O_2 consumption values given in Table 7. These are discussed later (p. 381).

Table 9 gives the rates of energy expenditure calculated from the records of activity (Table 6) and of O_2 consumption (Table 7). The accuracy of these estimates is dependent on how well the values in Tables 6 and 7 represent the overall metabolism for 24 h. Some independent check can be provided by the invisible weight losses set out in Table 5. These weight losses, corrected for losses of CO_2 and for O_2 retention (Table 9), give the evaporative water losses. The evaporative water loss × 0·580 kcal/g (the heat of vaporization of water) gives the evaporative heat loss. Newburgh,

Table 9. (*A*) *Total O_2 utilization and CO_2 output per day determined from the figures given in Tables 6–8 and the output of urinary nitrogen, and* (*B*) *the metabolic mixtures calculated from these totals on the assumptions of Zuntz* (1897)

	Control period		Overfeeding period		Underfeeding period	
	Betty	Pat	Betty	Pat	Betty	Pat
		A				
Total oxygen (l.)	622·6	642·7	648·5	649·0	552·5	621·0
Total carbon dioxide (l.)	527·9	545·6	614·0	611·3	449·7	489·7
Urinary N (g)	18·7	18·8	17·6	17·4	10·9	12·5
		B				
Protein (g)	117	118	110	109	68	78
Fat (g)	124	128	24	30	153	198
Carbohydrate (g)	315	330	598	586	217	179
Water (g)	370	383	430	429	322	351
Calories (kcal)	2970	3080	3160	3170	2630	2940

Johnston, Lashmet & Sheldon (1937) present evidence that the evaporative heat loss is 24–25% of the total metabolic energy, when there is no visible perspiration. The figures for evaporative water losses, calculated from the invisible weight loss as set out in Table 5, represent the following percentages of the estimated energy expenditures recorded in Table 9:

Period	Betty	Pat
Control	26·7	26·1
Overfeeding	23·5	25·4
Underfeeding	23·3	21·6

The very close agreement between these figures and the figure suggested by Newburgh and his colleagues gives confidence in the accuracy of the estimation of energy expenditure.

Metabolic mixture. Table 9 gives estimates of the protein, fat and carbohydrate metabolized and of water formed in the process for each subject for the three periods. The estimates have been calculated from the mean rates of O_2 consumption, CO_2 production and urinary N excretion over 24 h periods. It will be seen that during the overfeeding period a net breakdown of fat continued.

Table 10. *Total changes in body-weight and body composition* (*kg*) *and calorie balance* (*kcal*) *during* 9 *days on a control diet,* 9 *days of overfeeding and* 5 *days of underfeeding*

	Control period		Overfeeding period		Underfeeding period	
	Betty	Pat	Betty	Pat	Betty	Pat
Body-weight	−0·14	−0·70	+2·86	+2·58	−6·22	−5·63
Body composition:						
protein	+0·01	+0·05	+0·14	+0·23	−0·30	−0·36
fat	+0·12	+0·14	+0·50	+0·52	−0·72	−0·95
carbohydrate	−0·16	−0·30	+0·42	+1·01	−0·91	−0·72
water	−0·09	−0·58	+1·87	+0·86	−4·28	−3·61
Calorie balance	+540	+540	+7290	+10440	−12100	−13850

Changes in body composition. From the values presented in Tables 2–5 and 9 balance sheets for protein, fat, carbohydrate, water and calories can be drawn up. The resultant balances are presented in Table 10. In calculating the protein balance a loss of N through the skin, equivalent to 1 g protein/day, has been assumed. In the past

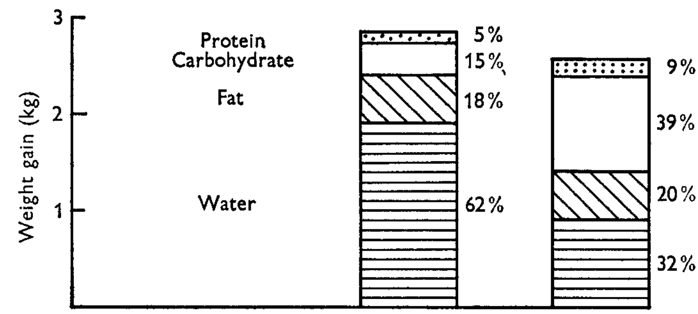

Fig. 2. Chemical composition of the tissue laid down during over-feeding by Betty (left) and Pat (right).

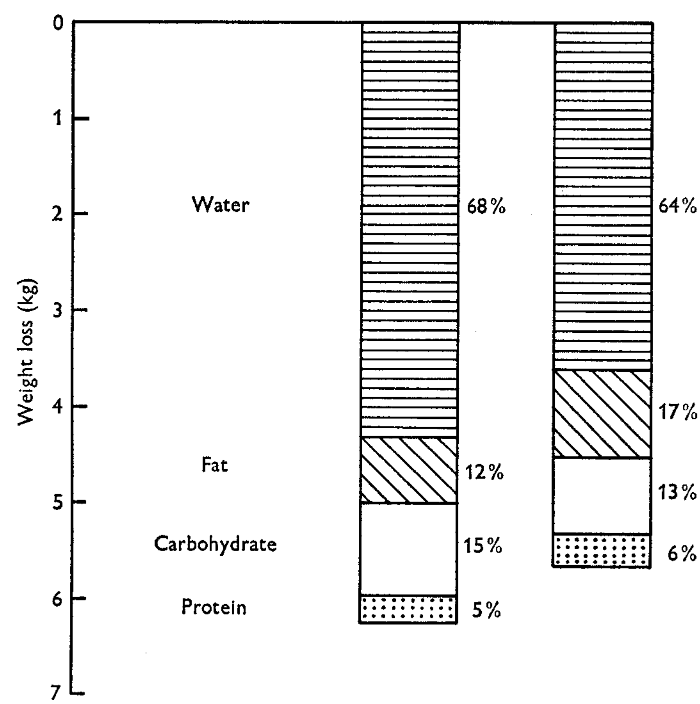

Fig. 3. Chemical composition of the tissue lost during underfeeding by Betty (left) and Pat (right).

in calculating N balances it has been customary to neglect skin losses. This is obviously wrong. Estimations of such loss are very difficult to make, but one of the order which we have assumed is not likely to be seriously wrong (for literature see Darke, 1960).

Figs. 2 and 3 show the composition of the tissue gained and lost by the subjects, calculated from Table 10. The tissue gained by Betty contained 62% water and had a calorie value of 2·5 kcal/g. The tissue gained by Pat contained 32% water and had a calorie value of 4·0. The tissue lost by Betty contained 68% water with a calorie value of 1·9, and that lost by Pat contained 64% water with a calorie value of 2·5. It was calculated that Betty laid down during overfeeding 140 g protein, 500 g fat and 420 g carbohydrate. For Pat the figures were 230 g protein, 520 g fat and 1010 g carbohydrate.

DISCUSSION

The two subjects both gained weight much more readily than the thin young men previously studied (Passmore *et al.* 1955*a*, *b*). Fig. 4, in which weight gain is plotted against excess calories, shows clearly the difference. To put on 2·5 kg Betty required

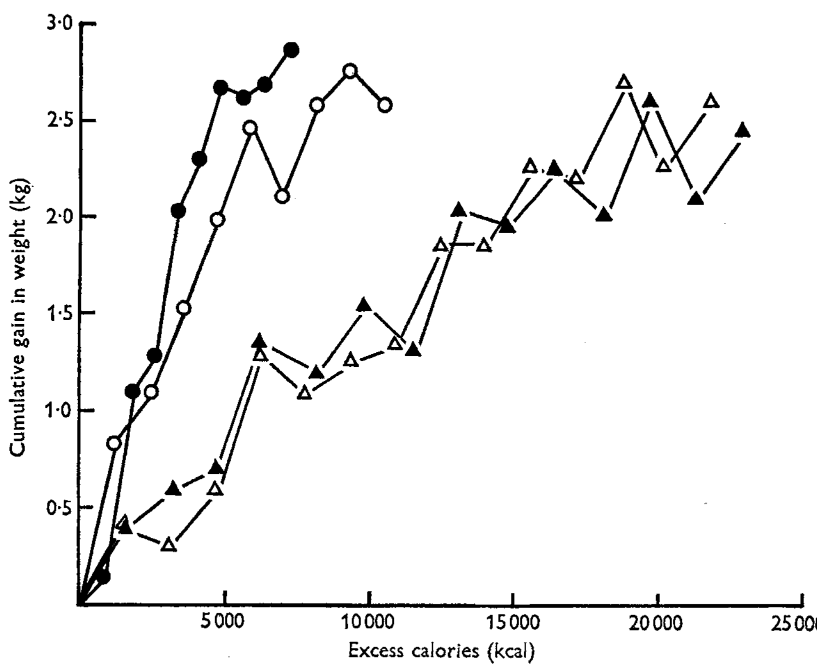

Fig. 4. Gain in weight of two obese women and two thin men plotted against the excess calorie intake during a period of overfeeding. ○—○, Pat; ●—●, Betty; △—△, Sam; ▲—▲, Michael.

an excess of approximately 6000 kcal, Pat required 10000 kcal, whereas Michael and Sam required 20000 kcal. The differences certainly arise from the fact that the thin young men did not retain water corresponding to the extra solids laid down. The obese tissue laid down by Betty contained 62% water and by Pat 32%.

Fig. 5 shows that the RQ of both fat subjects did not rise promptly after the beginning of overfeeding, but climbed fairly steadily: it was not until the 8th day that the mean values reached 1·00. Only on the 9th day did values over 1·00 give unequivocal evidence of the net conversion of carbohydrate into fat. On the 1st morning of starvation Betty had two RQ values, 1·19 and 1·18, and Pat had one value of 1·06. These would indicate that at the end of the experiment there was a steady net conversion of carbohydrate into fat within the body. The validity of the RQ measurements has been discussed already (Passmore & Swindells, 1963). The fact that RQ measurements well above 1·0 were now demonstrated on the 9th day indicates that the technique would have been able to demonstrate them earlier had they been present.

The gradual rise of RQ would seem to be best explained if the excess carbohydrate was first stored as glycogen and if net conversion of carbohydrate into fat only took place when glycogen stores were full. The calculations already given indicate that 420 and 1010 g carbohydrate were stored. This would have to be mostly in the muscle. The lean body mass of the two subjects was estimated to be just over 60 kg. A little over half of it would probably be muscle. If the muscle mass of both subjects was 35 kg, the stored carbohydrate would involve a rise in the mean glycogen content of muscle

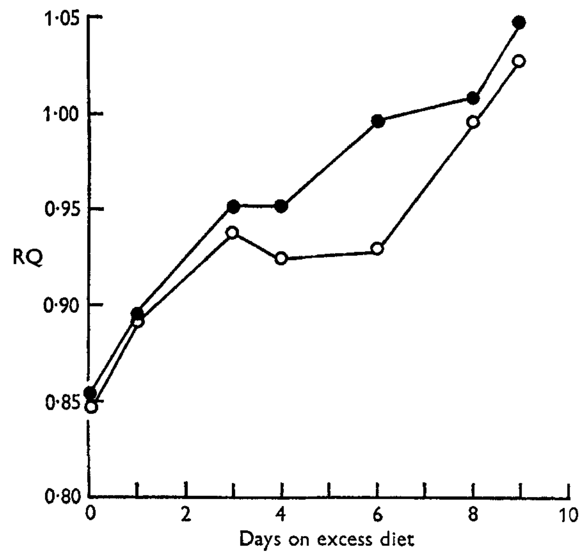

Fig. 5. Mean values for six daily measurements of RQ during overfeeding. ○—○, Pat; ●—●, Betty.

of 1·2 g/100 g for Betty and 2·9 g/100 g for Pat. These figures are not outside the range of muscle glycogen obtained in biopsy samples by Hildes, Sherlock & Walshe (1949). They are, however, higher than those usually given for human muscle glycogen, which are usually based on autopsy material or samples obtained at operation. Such muscle glycogen levels might be expected to be low. Muscle glycogen values of 10 g/100 g or even higher have been obtained with patients suffering from glycogen-storage disease (Illingworth, 1961).

The rapid loss of weight (mostly water) on the reducing regimen is characteristic of the response of obese people and has already been described (Passmore *et al.* 1958).

SUMMARY

1. Two obese young women were overfed to the extent of 7000–10000 kcal in a 9-day period during which they gained 2·86 and 2·58 kg respectively.

2. The RQs did not rise to 1·0 until overfeeding had been in progress for 8 days. It is suggested that excess dietary carbohydrate is first stored in the muscles as glycogen and only when these stores are full is it converted into fat.

3. From measurements of the energy balance and respiratory exchanges, it was calculated that the obese tissue laid down consisted of water 62, fat 18, carbohydrate 15 and protein 5 % for one subject and water 32, fat 20, carbohydrate 39 and protein 9 % for the other subject.

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