Changes in body composition attendant on force feeding

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COHN, CLARENCE AND DOROTHY JOSEPH. Changes in body composition attendant on force feeding. Am. J. Physiol. 196 (5) : 965--968. 1959.—Normal young adult male rats were either force-fed or allowed to eat ad libitum a moderate carbohydrate diet for 3-4 weeks. The force-fed animals were given either the amount of diet consumed by the animals eating ad libitum (pair-fed) or 80% of this amount (underfed). After a 2-week period of observation, we found that the rats eating ad libitum gained 65 gm of body weight, the pair-fed, force-fed 62 gm and the underfed, force-fed 40 gm. On the basis of the water, fat and protein content of the skin, viscera and carcass of control animals killed at the beginning of the feeding regimen and of similar constituents of the experimental animals after 2 weeks of feeding, the composition of the newly formed tissues of the various groups of animals consisted of the following: a) the rat with free access to food—water = 67.8%, fat = 7.8% and protein = 22.4%; b) the pair-fed, force-fed animal—water = 55.5%, fat = 23.6% and protein = 17.7%; c) the underfed, force-fed animal—water = 64.4%, fat = 7.9% and protein = 20.0%. The ratio of calories retained in newly formed tissue to the calories ingested over the 2-week period was 11.9% for the animals eating ad libitum, 20.6% for the pair-fed, force-fed animals and 23.8% for the underfed, force-fed rats. Force feeding appears to change intermediary metabolic pathways in the direction of increased 'efficiency' with resultant greater fat deposition.

PREVIOUS STUDIES from this laboratory showed that more body fat was accumulated by young adult rats fed by stomach tube than by rats eating the same diet ad libitum and gaining the same amount of body weight (1, 2). Somewhat similar findings had been reported by Levin (3) who found that 67% of the increase in body weight of force-fed rats could be attributed to fat. Although no chemical analyses were performed, Feldman and co-workers (4) have noted that male chickens, tube fed after having been made aphagic with diencephalic lesions, exhibited grossly increased quantities of subcutaneous fat when examined at autopsy. The effect of force feeding on body composition did not appear to be attributable to differences in handling nor to administering the entire daily food intake in two periods of short duration (2).

Heretofore, in our experiments, the criterion for food intake for the force-fed animals had been an amount which would enable them to gain weight at the same rate as animals eating their food ad libitum. Because this basis of comparison does not preclude the possibility of a difference in caloric intake between the two groups, the studies herein reported have been conducted under the conditions of 'pair feeding' force-fed rats against others eating ad libitum, in order to compare body composition under the conditions of identical caloric intakes. Furthermore, the animals were analyzed for their content of water, fat and protein after separation into skin, viscera and carcass. The results of this study form the basis of this report.

METHODS

Male Holtzman rats, weighing between 110-120 gm at the time they were received, were used in the experiment. They were individually housed and had free access to distilled water. The same diet was prepared for all animals and was available in solid form at all times to the rats eating ad libitum but was administered by stomach tube to the force-fed group, after having been homogenized in distilled water, before 9 A.M. and after 4:15 P.M. The composition of the diet, a modification of Ingle's moderate carbohydrate diet (5), was as follows: Cellu flour, 30 gm; salt (Wesson), 20 gm; yeast extract concentrate, 15 gm; methionine, 2 gm; 2-methyl naphthoquinone, 50 mg; casein hydrolysate (enzymatic) 95 gm; lactalbumin hydrolysate (enzymatic), 10 gm; corn starch, 110 gm; sucrose, 110 gm; dextrin, 105 gm; cod liver oil, 5 ml; wheat germ oil, 5 ml; Mazola oil, 100 gm. The dry ingredients and oils were mixed in a Patterson-Kelley twin shell liquids-solids blender.

The animals were placed on their respective diets for approximately a week, to accustom the 14 rats eating ad libitum and to adapt the 21 force-fed rats to the diets. At this time, the animals having reached a weight of
between 150 and 155 gm, six rats of each group were killed for the determination of 'original body composition.' The experimental animals were treated as follows: 
a) the food intake and body weight of the eight animals which ate ad libitum were measured daily for a 14-day period.
b) Eight force-fed rats were given by stomach tube the amounts of diet consumed daily by the group eating ad libitum in feedings of 10 ml twice daily. At the end of the 14-day feeding period, during which they were weighed daily, the animals were killed for analysis.
c) The remaining seven force-fed animals were treated as were the ones in group b, except for the fact that they received only 80% of the calories consumed, i.e. the intact animal less tail, hair and gastrointestinal contents.

At the time of killing, the animals were killed with ether anesthesia, the tail removed and discarded, and the body hair removed by clipping followed by a depilatory (6). The animals were separated into skin, viscera (lungs, heart, liver, spleen and mechanically cleaned gastrointestinal tract) and carcass which were analyzed separately. After the fresh weight of each tissue was obtained, it was frozen until further processed. At that time, each tissue was placed in liquid nitrogen and then pulverized in a liquid nitrogen chilled stainless steel cylinder by a compressed air hammer-driven piston. Further pulverization was achieved in a liquid nitrogen-cooled mortar. The water content of the tissues was determined by the weight difference after heating the tissues to 105°C for 48 hours. Fat was removed by repeated extractions of the water-free tissue with a 1:1 mixture of ethyl ether-petroleum ether; the tissue was considered to be fat-free when colorless extracts were obtained. 'Protein' was estimated on the basis of 6.25 X the nitrogen content of each tissue; it was realized that not all the nitrogen determined was protein nitrogen. The nitrogen analyses were accomplished by the Conway modification of the micro-Kjeldahl method on the fat-free, water-free tissues.

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**TABLE I. Weight Changes and Food Intakes of Pair-Fed, Force-Fed Rats and Rats Eating ad Libitum**

<table>
<thead>
<tr>
<th>Method of Feeding</th>
<th>Force-Fed (Underfed by 20%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ad libitum</td>
</tr>
<tr>
<td></td>
<td>Pair-fed</td>
</tr>
<tr>
<td>Original body weight, gm</td>
<td></td>
</tr>
<tr>
<td>Entire rat</td>
<td>150</td>
</tr>
<tr>
<td>'Analyzed'†</td>
<td>140</td>
</tr>
<tr>
<td>Final body weight, gm</td>
<td>213</td>
</tr>
<tr>
<td>Entire rat</td>
<td>190</td>
</tr>
<tr>
<td>'Analyzed'†</td>
<td>190</td>
</tr>
<tr>
<td>Weight change (14 days)</td>
<td></td>
</tr>
<tr>
<td>Entire rat</td>
<td>65</td>
</tr>
<tr>
<td>'Analyzed'†</td>
<td>58</td>
</tr>
<tr>
<td>Food intake (14 days)</td>
<td></td>
</tr>
<tr>
<td>Grams</td>
<td>172</td>
</tr>
<tr>
<td>Calories</td>
<td>774</td>
</tr>
</tbody>
</table>

* 'Analyzed' refers to portion of animal actually analyzed, i.e. weight of rat minus tail, hair and gastrointestinal contents.
† Based on control animals killed at beginning of feeding period.

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**RESULTS**

The data in table 1 indicate that under the conditions of similar caloric intakes, force fed rats gain essentially the same amount of body weight over a 14-day period as do rats with free access to food. The similarity is evident without regard to whether the gain in weight is based on the intact animal or on the weight of the tissues analyzed, i.e. the intact animal less tail, hair and gastrointestinal contents. On the other hand, as might be expected, the rats force fed only 80% of the calories consumed by the animals eating ad libitum gained only about 64% of the amount of weight gained by the fully force-fed animals.

Although the weight gained by the pair-fed groups was comparable in amount, both the final composition of the animals and the composition of the newly formed tissue were dependent on the manner of feeding. The results given in table 2 show that at the beginning of the pair feeding schedule, the force-fed animals contained less fat but slightly more water and protein than the rats eating ad libitum; after 2 weeks of similar caloric intakes, the tube-fed animals consisted of less water and protein but 35% more fat. It may also be seen that the site of greatest relative fat deposition in the tube-fed animal was in the skin. When the increase in body weight is accounted for in terms of amounts attributable to water, fat and protein, the differences between the groups in composition of the newly acquired tissue is clearly apparent (tables 2 and 3). Fat accounted for almost 24% of the tissue laid down by the force-fed animals and for only 7% of the new tissue of the ones eating ad libitum. The tube-fed rats that received only 80% of the calories eaten or administered to the other two groups deposited less water, fat, and protein. However, both the absolute and relative amount of fat accumulated by the underfed animals was not remarkably different from the quantity gained by the rat eating ad libitum.

The completeness of recovery of both individual tissues during the pulverizing process and the entire animal from its component parts is not evident from the tables. It should be pointed out, therefore, that the pulverizing process employed allowed us to perform our determinations on approximately 97-98% of the tissues removed from the animal. In addition, the sum of the component parts of the animal, taken as water, fat, and protein, accounted for 95% of the body weight (less tail, hair and gastrointestinal contents) exclusive of salts which were not quantitated.

**DISCUSSION**

Our results confirm and extend our earlier observations indicating that the administration of food by stomach tube, in amounts that enable the animals to gain weight at the same rate as other animals eating the
same diet ad libitum, results in markedly different body compositions (1, 2). Two experimental inequities between the tube-fed animals and those eating ad libitum that were present in our earlier experiments were eliminated in the present investigation. A) The diet for both the tube-fed animals and those eating ad libitum was identical, except for the distilled water added to obtain a liquid diet. Formerly we used different bulk formers for the two diets. B) Previously we compared the body composition of the two groups of animals on the basis of equal weight gain, while in the present study, the comparison was made on the basis of equal food intake. Our results indicate that the same amount of food is required to achieve equal weight increases on a "pair-fed" basis. Elimination of these inequities reaffirmed our observations that animals fed by stomach tube have a marked increase in total fat content in comparison to animals eating ad libitum, despite equal gains in body weight.

The data on body composition were extended by dividing the animal into skin, viscera and carcass and by analyzing each tissue for water, fat and protein. The results of our studies reveals nothing of its component parts. True obesity, consisting of water, fat, protein and salts, all capable of varying independently of each other and therefore able to occupy varying amounts of total body mass, body weight itself reveals nothing of its component parts. True obesity, being a disproportionate increase in body fat, may or may not be accompanied by a change in overall body weight, we have previously termed the disproportionate increase in body fat with normal body weight that results from forced feeding as "nonobese obesity."

It is the usual custom, in performing a nutritional experiment and in attempting to evaluate the "efficiency" of a diet or dietary constituent, to compare the weight gained by an animal to the amount of food that the animal has consumed. The assumption is made that the ratio of calories retained/calories consumed, allowing for the carbohydrate content of the animal, the force-fed animals showed a value of 0.206, the animals eating ad libitum a value of 0.095. On this basis, it appears the diet was equally 'efficient' diet. However, if one calculates the efficiency of a diet. On the basis of weight gained per gram of diet consumed, all of our animals consumed an average of 10.2 ± 0.3 cal/gm of fat and 4 cal/gm of protein and disregarding the carbohydrate content of the animal, the force-fed animals showed a value of 0.967, the animals eating ad libitum a value of 0.119 and the underfed force-fed ones a value of 0.095. On this basis, it appears the diet was twice as efficient when fed by stomach tube.

The mechanisms whereby forced feeding results in greater fat accumulation than in the animal consuming
his food appears to be at least partly attributable to the production of hypothyroidism and consequent expenditure of less calories attendant on tube feeding (10). Aside from any contribution of diminished thyroid activity to the deposition of the extra fat, another type of mechanism requires consideration as playing a role in the results that we have observed. Our data suggest that disruption of the normal nocturnal constant feeding habits of rats by a 12-hour shift in the food ingesting cycle and replacement by the forced feeding of the daily ration on two occasions may lead to changes in the metabolic economy. The ingested calories appear to be more efficiently utilized and formerly 'wasted' calories to be deposited as fat. The possibility suggests itself that force feeding adapts the animal to divert its handling of the diet to alternate but more efficient enzymatic pathways of intermediate metabolism. The results with the underfed force fed animal are in accord with this concept since almost as many calories were stored as fat and protein, under these conditions, as by the animal eating 20% more calories ad libitum. This line of reasoning is strengthened by two recent reviews which analyzed possible factors contributing to obesity or leanness. Tepperman (11) summarized evidence for differences in genetic backgrounds of human beings or other animals, with respect to a more or less efficient enzymatic makeup, leading to an economical and efficient utilization (or wasteful squandering) of their ingested calories for their daily activities and maintenance of homeostasis. Kaunitz (12) has reviewed data demonstrating that constituents in the diet may have a similar effect. From our results, it appears that in addition to differences in genetic make-up and to the effect of dietary constituents offered to an animal, the timing of food ingestion may play a role also in the economy of calorie disposition. Findings similar to ours were reported by Van Putten et al. (13) who showed that rats with the hypothalamic-hyperphagic syndrome contained more fat, less water and less nitrogen than pair-fed control animals. Most interesting were his results as influenced by the time period of feeding. When the animals were offered their entire daily ration at one time, the hyperphagic-hypothalamic animals quickly consumed their food while the controls took all day to eat their diet. Under these conditions, the differences in body fat between control and experimental animals were exaggerated. Offering the food in two portions, so as to equalize the time of food consumption, resulted in less marked differences in body fat between the two groups of animals.

REFERENCES