Loss of Weight, Sodium and Water in Obese Persons Consuming a High- or Low-Carbohydrate Diet

U. Rabast, K.H. Vornberger, M. Ehl
St. Elisabeth Hospital, Hattingen and Medical University Clinic, Würzburg

Key Words: Obesity • Weight reduction • High- or low-carbohydrate diet • Loss of sodium and water

Abstract. Isocaloric 5.61 kcal (1,340 kcal) formula diets involving the isocaloric exchange of fat and carbohydrate were fed to 21 obese persons selected for sex, height, and weight before the start of the treatment and distributed over three groups. The weight loss observed during the carbohydrate-restricted diets was significantly greater than during the high-carbohydrate diet. After 28 days of treatment the weight loss recorded on the high-carbohydrate diet was 9.5 ± 0.7 kg as compared to 11.4 ± 0.7 kg (p < 0.05) on the corn oil-containing diet and 12.5 ± 8.9 kg (p < 0.01) on the butter-fat-containing diet. The weight loss achieved was not dependent on the type of fat administered (saturated vs. polyunsaturated). When calculated cumulatively, sodium excretion during the first 7 days was significantly greater on the low-carbohydrate diet, whereas after 28 days the total amount of sodium excreted was highest on the high-carbohydrate diet. Potassium excretion during the low-carbohydrate diets was significantly greater for as long as 14 days, but at the end of the experimental period the observed differences no longer attained statistical significance. At no time did the intake and loss of fluid and the balances calculated therefore show significant differences. From the findings obtained it appears that the alterations in the water and electrolyte balance observed during the low-carbohydrate diets are reversible phenomena and should thus not be regarded as usual agents of the different weight reduction.

Introduction.

The weight loss achieved on a low-carbohydrate, relatively high-fat diet has repeatedly been found to be more pronounced than on an isocaloric high-carbohydrate diet [10, 12, 13, 22–24]. Changes in the water and electrolyte balance have been suggested as the most likely causes of this weight reduction [2–5, 20, 21, 32, 34]. However, in the majority of cases previous investigations were restricted to small and heterogeneous groups and short experimental periods (for references, Rabast et al., 25).

The present studies were, therefore, designed to clarify this question using groups of equal size selected for sex, height, and body
weight and treated over a sufficiently long period of time with isocaloric diets. It was further attempted to determine whether the type of fat administered (saturated or polyunsaturated) influences weight reduction.

Methods

Obese Persons

Before starting the dietary experiments, three groups of 7 obese persons (4 male, 3 female) each were formed to include in each group 1 person of the same sex who in terms of height (2.09 ± 0.55 m) and weight (42.1 ± 0.15 kg) did not vary significantly from the test persons of the two other groups.

The mean age of the total group was 32.9 ± 2.6 years (35-54 yrs), the mean height 167.7 ± 1.3 cm (159-183 cm), and the mean weight 107.2 ± 2.3 kg (93.3-126 kg). The mean weight excess being 62.3 ± 4.7 kg, the mean weight excess being 62.3 ± 4.7 kg. Broca's index (Broca) as the basis, the following distribution was obtained within the three groups:

Dietary Regimens

Groups of 7 obese patients received one of the following 3.61 ml (1,340 kcal) diets: diet 1, high-carbohydrate diet (consisting of 223 g carbohydrate, 18 g fat, 69 g protein); diet 2, low-carbohydrate diet (consisting of 40 g carbohydrate, 10 g fat, 60 g protein). The carbohydrate given in diet 1 consisted of monosaccharides (25%), oligosaccharides (35%) and polysaccharides (45%). The fat in diets 2 and 3 was supplied as corn oil and butter fat, respectively. Protein was administered in the form of milk protein. The sodium and potassium content was the same for all diets (table 3). In outward appearance, the three diets were virtually identical. Noncaloric juices (tea, coffee, mo-

Table 1. Characterization of groups and results of dietary treatment (E ± SEM)

<table>
<thead>
<tr>
<th>Sex distribution</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Excess weight (kg)</th>
<th>Excess weight % (Broca)</th>
<th>Total weight loss (kg)</th>
<th>Dietary period (days)</th>
<th>Weight loss (g/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diet 1 4/79</td>
<td>33.2 ± 2.6</td>
<td>108.8 ± 4.2</td>
<td>167.7 ± 5.8</td>
<td>42.8 ± 7.6</td>
<td>66.9 ± 10.3</td>
<td>9.5 ± 1.2</td>
<td>28.0 ± 1.0</td>
<td>33.6 ± 2.3</td>
</tr>
<tr>
<td>Diet 2 4/79</td>
<td>30.7 ± 2.6</td>
<td>109.3 ± 4.2</td>
<td>170.1 ± 5.8</td>
<td>41.9 ± 7.6</td>
<td>65.4 ± 10.3</td>
<td>11.4 ± 1.2</td>
<td>28.0 ± 1.0</td>
<td>42.8 ± 2.3</td>
</tr>
<tr>
<td>Diet 3 4/79</td>
<td>34.1 ± 2.6</td>
<td>109.3 ± 4.2</td>
<td>170.1 ± 5.8</td>
<td>41.9 ± 7.6</td>
<td>63.7 ± 10.3</td>
<td>12.5 ± 1.2</td>
<td>28.0 ± 1.0</td>
<td>44.8 ± 2.3</td>
</tr>
</tbody>
</table>

Diet 1: 1,340 kcal (1.61 ml) high carbohydrate. Diet 2: 1,340 kcal (1.61 ml) low carbohydrate (corn oil). Diet 3: 1,340 kcal (0.61 ml) low carbohydrate (butter fat).

* p < 0.05 (diet 1/diet 2); ** p < 0.05 (diet 1/diet 3).
Experimental Design

Before the start of the experiments, a diet and exercise plan was agreed upon by the patients. A dietitian advised the patients on the dietary intake and monitored their weight. The patients then followed the diet plan for 6 months. The weight loss was calculated using the following formula:

\[ \text{Weight Loss} = \text{Initial Weight} - \text{Final Weight} \]

Laboratory Studies

Intake and loss of fluid, and the urinary sodium and potassium levels were determined daily and calculated cumulatively over the total 28-day treatment period. The urine was analyzed for ketones (semi-quantitative assay using Acentest test strips). In addition, the following laboratory parameters in the serum were measured twice before the start of the treatment, and at 1-day intervals thereafter: sodium, potassium, blood sugar, urea, creatinine, triglycerides, and transaminases. The blood pressure was measured daily.

Results

Body Weight

Although the patients were encouraged to keep their body weights constant, weight losses of 2.0 ± 1.5 kg (0.2-6.5 kg) were registered during the preliminary period. During the dietary period, the weight reduction achieved during the diet 1 (0.9 ± 0.7 kg) was significantly less than during diet 2 (1.1 ± 0.7 kg; p < 0.05) and diet 3 (1.25 ± 0.5 kg; p < 0.01). Table 2 (fig 1). Differences in weight loss were found as early as 7 days after starting treatment without, however, attaining statistical significance (p < 0.1). During the dietary period, the body weight measured in the persons on diet 1 declined from 107.6 ± 4.6 to 98.1 ± 4.4 kg; the corresponding decline during diet 2 was from 106.9 ± 5.1 to 95.5 ± 2.7 kg, and during diet 3 from 107.0 ± 4.6 to 94.5 ± 4.0 kg. The mean daily weight loss recorded during diet 1 (338.3 ± 25.9 g) was significantly less than on diet 2 (407.1 ± 25.1 g; p < 0.05) and diet 3 (444.0 ± 32.2 g; p < 0.01). The differences between diets 2 and 3 in terms of weight behavior were not statistically significant (table III).

Table II: Composition of isocaloric diets

<table>
<thead>
<tr>
<th>Diet 1</th>
<th>Diet 2</th>
<th>Diet 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(corn)</td>
<td>(butter)</td>
<td>(oil)</td>
</tr>
<tr>
<td>g</td>
<td>g</td>
<td>g</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>225</td>
<td>40</td>
</tr>
<tr>
<td>kcal (MJ)</td>
<td>923</td>
<td>164</td>
</tr>
<tr>
<td>(1.05)</td>
<td>(0.66)</td>
<td>(0.69)</td>
</tr>
<tr>
<td>Fat</td>
<td>18</td>
<td>100</td>
</tr>
<tr>
<td>kcal (MJ)</td>
<td>167</td>
<td>930</td>
</tr>
<tr>
<td>(0.70)</td>
<td>(3.89)</td>
<td>(3.89)</td>
</tr>
<tr>
<td>Protein</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>kcal (MJ)</td>
<td>246</td>
<td>246</td>
</tr>
<tr>
<td>(1.03)</td>
<td>(1.03)</td>
<td>(1.03)</td>
</tr>
<tr>
<td>Sodium, mEq/day</td>
<td>5.46</td>
<td>1.43</td>
</tr>
<tr>
<td>Potassium, mEq/day</td>
<td>8.55</td>
<td>8.29</td>
</tr>
</tbody>
</table>
Fig. 1. Weight loss ($T \pm$ SEM) during treatment with diet 1, 2 and 3.* $p < 0.05$ (diet 1/diet 2); ** $p < 0.025$ (diet 1/diet 3).

Fig. 2. Cumulative fluid balance. a Fluid intake. b Urinary excretion. c Differences between intake and excretion.

Table III. Weight loss during treatment with diets 1, 2 and 3 ($T \pm$ SEM)

<table>
<thead>
<tr>
<th>Diet</th>
<th>1-7</th>
<th>1-14</th>
<th>1-21</th>
<th>1-28</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$W_{-}$, kg, on days</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet 1</td>
<td>7</td>
<td>3.9 ± 0.5</td>
<td>3.4 ± 0.6</td>
<td>7.4 ± 0.7</td>
</tr>
<tr>
<td>Significance</td>
<td>p &lt; 0.1</td>
<td>p &lt; 0.05</td>
<td>p &lt; 0.01</td>
<td>p &lt; 0.01</td>
</tr>
<tr>
<td>Diet 2</td>
<td>7</td>
<td>5.0 ± 0.3</td>
<td>7.4 ± 0.7</td>
<td>9.6 ± 0.6</td>
</tr>
<tr>
<td>Diet 3</td>
<td>7</td>
<td>5.3 ± 0.5</td>
<td>7.7 ± 0.6</td>
<td>10.0 ± 0.7</td>
</tr>
<tr>
<td>Significance</td>
<td>p &lt; 0.1</td>
<td>p &lt; 0.025</td>
<td>p &lt; 0.01</td>
<td>p &lt; 0.01</td>
</tr>
</tbody>
</table>
Fluid and Electrolyte Balances

After days 7–28, cumulative calculation of the water intake and excretion and of the balances calculated therefrom failed to reveal significant differences at any time between the individual diets (fig. 2).

A cumulative plot of the urinary sodium excretion showed that up to day 7, values obtained on the high-carbohydrate diet 1 (114.0 ± 10.6 mEq) were significantly lower than on diet 2 (223.5 ± 30.5 mEq; p < 0.05) and diet 3 (198.8 ± 38.1 mEq; p < 0.05). After 2 weeks, sodium excretion showed no significant difference, whereas after 28 days, the total sodium excreted on diet 1 (548.3 ± 47.4 mEq) was higher than on diet 2 (480.2 ± 63.5 mEq; not significant) and diet 3 (407.8 ± 39.3 mEq; p < 0.05; fig. 3).

A cumulative plot of the potassium excreted revealed that compared to diet 1 the potassium excretion on diets 2 and 3 was significantly greater up to day 21 and day 14, respectively (p < 0.05). During the two low-carbohydrate diets, the tendency, towards a higher potassium excretion persisted even after 28 days, but the differences failed to attain significance (diet 1: 301.9 ± 43.0 mEq; diet 2: 342.9 ± 98.9 mEq; diet 3: 560.6 ± 33.5 mEq).

Irrespective of the dietary regimen given, the serum sodium and potassium concentrations did not change significantly throughout the experimental period.

Laboratory Parameters

Ketones appeared within 24–36 h during diets 2 and 3, but was absent on diet 1. During the first week of dietary treatment, the serum uric acid rose consistently to more than 9 mg/dL on diets 2 and 3, whereas in diet 1 serum uric acid concentrations above 9 mg/dL were measured in not more than 3 persons throughout the experimental period. Blood glucose fell significantly during diet 2 (from 124.0 ± 22.1 to 94.9 ± 4.4 mg/dL after 1 week, and to 83.3 ± 3.9 mg/dL after 4 weeks); by contrast, no significant changes were found in the patients on diets 1 and 3 who had shown normal baseline values. Regardless of the diet eaten, elevated triglycerides, cholesterol, and transaminase concentrations invariably returned to normal, the alterations observed not being significant under any of the diets.
With all three diets, the blood pressures (systolic and diastolic) reverted toward normal. The changes measured during diet 2 were statistically significant (p < 0.05; fig. 4).

Discussion

The dietary study described was performed on 21 selected obese persons who could be classified into three groups with virtually identical somatic data.

Earlier studies have shown that, in reducing diets involving isocaloric exchange of carbohydrate and fat, the reduction in body weight was more marked during the diet restricted in carbohydrate and relatively rich in fat (10, 12, 13, 22-25, 30, 34, 36). The finding outlined in the present paper are in confirmation of these results, in that the mean weight reduction on the high-carbohydrate diet I was 9.5 kg, as compared to 11.4 and 12.5 kg, respectively, on the low-carbohydrate diets 2 (corn oil) and 3 (butter fat). The methodological design of the present study varied from the conditions previously described in the literature. It is felt that the conflicting results reported in the literature are causally related to the fact that the individual studies were performed over short periods and in small heterogenous groups receiving inaccurately defined diets (for references, see Rubaiz et al. 25).

The cause that underlies the different weight reduction achieved during high-carbohydrate and low-carbohydrate diets has been a moot point over the past years [for references, see Rubaiz et al., 25]. In light of the well-controlled experimental conditions, incomplete intake of food can be discounted as a plausible explanation in the present study. In much the same way, neither insufficient or varying utilization of nutrients [11, 13] nor an increased urinary excretion of organic substances [28] can be considered as causal factors. Despite the fact that 1 g of glycogen binds 3-4 g of water, the assumption that during isocaloric diets the glycogen stores are depleted to a variable extent appears an unlikely explanation [11, 13]. Even under fasting conditions, an initial depletion of the glycogen reserve has been found to be followed, after a short time, by restoration [8, 16]. So far, experimental work on the depletion of the glycogen stores during low-carbohydrate diets has been conducted over short
periods only [18]. Short-term studies on per- 
sons of normal weight failed to provide infor- 
mation pointing to enhanced gluconeogenesis 
or increased protein catabolism during low- 
carbohydrate diets [29]. On the other hand, 
comparative studies conducted over 28 days 
in groups of 4 obese individuals each again 
evidenced that the weight reduction was most 
distinct during the low-carbohydrate diet 
[56].

The nitrogen excretion measured at 
weekly intervals was significantly higher on 
the low-carbohydrate diet after the 3rd and 
6th week. Also the cumulatively calculated 
excretion of urinary potassium was found to 
be significantly higher on the low-carbohy- 
drate diet during the 3rd and 2nd week. 
Therefore the greater loss of lean tissue, espe- 
entially on the corn oil diet, is to be discussed 
as an explanation for the more pronounced 
weight loss on the low-carbohydrate diet. But 
there were no significant differences for po- 
assium excretion after 21 and 28 days, so the 
differences were not sufficiently conspicuous 
and offered a full explanation for the observed 
weight differences.

Alterations in the water and electrolyte 
balance have been suggested as a likely expla- 
ation [15, 20, 27, 32]. Diets restricted in 
carbohydrate cause an initial increase in so- 
dium excretion [4, 5]. Elevated glucagon lev- 
els, measured under fasting conditions [45] 
and on a low-carbohydrate diet [17] during 
the initial period, have been considered to be 
causative factors [28]. The increased appear- 
ance of ketones could likewise explain the ini- 
tially augmented proteinuria, which ceases 
after the start of ammonium synthesis by the 
renal tubule, thereby saving calcium for main- 
aining the electrical neutrality of organic 
acids [19]. In previous studies the surmise 
that has been made that the initially increased 
sodium excretion during a low-carbohydrate 
diet constitutes a reversible phenomenon [4, 
7]. The results reported in the present study 
support the accuracy of this assumption. On 
cumulative calculation of the amount of so- 
dium excreted over the total experimental 
period, the values obtained on the two low- 
carbohydrate diets were significantly higher 
after 7 days than on the high-carbohydrate 
diet. These differences failed to be significant 
as early as 14 days after starting the diet. 
After 28 days, the total excretion of sodium 
was found to be greater during the high-car- 
obhydrate diet, the difference compared to 
diet 2 (butter fat) being significant. In con- 
trast, earlier studies conducted in this labora- 
ory [22-25] and reports from other workers 
[13] did not reveal any significant differences 
in the excretion of electrolytes. However, 
these studies did not include a cumulative 
calculation of the electrolytes excreted 
throughout the experimental period.

Most controversial is the suggestion that 
differences in energy metabolism could pro- 
vide a likely explanation for the different 
weight reduction observed. Information sup- 
porting the accuracy of this assumption has 
come from animal experiments [35] and 
studies on healthy persons [29, 30]. It is con- 
vincing that a definitive classification of this 
most point could be achieved by means of a 
methodologically laborious approach involv- 
ing the determination of the body compo- 
nition. However, a decisive prerequisite for 
such studies would be the provision of metri- 
cological conditions that conform to those 
in the present study. But it must be pointed 
out that even under such conditions, intra-
individual differences in energy metabolism 
[33] and their influence on weight reduction 
can ultimately not be reliably excluded. 
In comparative studies conducted in this
laboratory, the low-carbohydrate diets given had invariably included corn oil (mainly polyunsaturated fatty acids) [22-25]. The present studies indicate that a marked weight reduction also occurs when butter fat (mainly saturated fatty acids) is administered. Inclusion of 100 g of butter fat (1314 mg of choles- terol) in the diet failed to exert an adverse effect on the lipid values in the persons treated with diet 2 (corn oil), the initially increased blood glucose concentrations and the systolic and diastolic blood pressures were found to have fallen. The question whether the influence on prosta glandin syn- thesis that has been observed during diets rich in linoleic acid may be a causal factor [6, 9, 13] or whether the observed significance is fortuitous in nature must remain unresolved at the present time.

References

20 Olsen, E.S., Quaas, P.: Fatly foods and obesity. Lancet i. 1048 (1940).
Lack of Weight, Sodium and Water on a High- or Low-Carboidratre Diet


Received: November 3, 1980
Accepted: March 20, 1981
PD Dr. U. Ratzlfl, Universitätssermonstrale 31.
D-6310 Hastingen 16 (FRG)