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The postprandial thermogenesis of different diets in rats

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The increased heat production after ingestion of different food-stuffs and diets is known for long time as the so-called "specific dynamic action" or "thermic effect" of food (14, 23). Despite many data and many hypotheses about the nature of this effect, the causes of this increased metabolic rate have not yet been fully explained. The extent of the thermic effect depends not only on the protein moiety of the diet and its biological value, but also on the nature of the other food components and their proportions in the diet (8, 9. 12, 16).

The experiments reported in this communication were designed to study by direct calorimetry to what extent the postprandial heat production of growing rats could be increased by diets which had a high content of gelatine or/and medium chain triglycerides (MCT). In provisional experiments it could be shown that by such diets gain in body weight, fat accumulation and feed efficiency could be reduced in comparison with isonitrogenous and isocaloric diets which contained casein and lard as the main protein and fat components. In order to estimate the heat storage during the postprandial period, the core temperature of animals was determined in separate experiments after feeding the experimental diets. Usually under normal conditions the core temperature is kept constant (1, 7, 17, 19, 21, 26).

The development of diets which induce a high postprandial heat loss leading to lower efficiency of energy utilization could be of interest for special dietary treatments.

Material and methods

The experiments were carried out on young male albino rats of the wistar strain (VEB Versuchstierzucht, Schönerlinde near Berlin) with body weights of 80–100 g, fed with standard pellets (Type R, VEB Versuchstierproduktion, Berlin-Lichtenberg) and water ad libitum until 3 days before the experiments. The composition of the experimental diets is listed in table 1.

The heat production of rats was determined by a self-constructed calorimeter, which was based upon the following principle: The extent of the postprandially generated heat of the animal was measured as the difference of the temperature

Table 1. Composition (g) and energy content of the experimental diets.

	Control	Gelatine diet	MCT diet	MCT-gelatine diet
Casein	30	15	30	15
Gelatine	–	12.5	–	12.3
MCT	–	–	12	12
Sunflower Oil	3	3	3	3
Lard	12	12	–	–
Wheat starch	51.0	56.5	54.0	58.0
Salt mixture	4	4	4	4
Gross energy (kJ/g)	18.97	20.64	20.85	21.44
N content (mg/g)	39.1	41.6	38.9	39.2

between the air flowing into and out (3 l/min) of an isolated chamber, kept under constant temperature of 25 ± 1 °C by a thermostated water bath. To exclude uncontrolled movements, the animal was fixed in a small cage within the chamber. The food was offered in a small box, which could be opened from outside without any disturbance of the temperature equilibrium. During an initial experimental period of two hours, when the animal did not get access to food, the difference between the temperatures of the air flowing into and out was adjusted to zero until a steady state had been reached. After ingestion of food, the temperature of the air flowing out increased due to the postprandial heat production. The area below the recorded temperatures of the air flowing into and out was a measure of the heat generated. It could be calculated from calibration curves, which had been established by calibrating the calorimeter by the known heat production of a variable electrical resistance (for details, refer to 4). Prior to the experiments, the animals were adapted to be fixed in the chamber and kept on the experimental diet for three days. The experiment was started at 8 am., after a 12-hour fast. After the initial two hours, which were needed to stabilize the temperature and to adjust the temperature difference to zero, the food box was opened for 1 hour and the arising temperature of the air flowing out was recorded until it declined to the base-line, which lasted for about 6 hours. When the animals had access to the experimental diets, they took up an amount of food, which corresponded to an energy intake of 10.5 kJ to 42.5 kJ. The thermic effect of each experimental diet was studied in 10 animals.

In order to estimate the heat storage during the postprandial period, the core temperature was measured in separate experiments. A resistance feeler was put into the rectum in 2.3 cm depth. After determination of the basal core temperature, the rats got intra-gastrically 5 ml of the experimental diets (20.2 ± 0.3 kJ) by tube (1 part diet : 3 parts water). The measurement of the postprandial core temperature was started 1 hour after ingestion of the diets and continued in intervals of 1 hour till 6 hours after feeding. Arithmetic mean values ± standard deviation are given. Statistics are calculated using the Student's t-test.

Figure 1 shows the extent and time course of the postprandial thermogenesis of four selected animals, which took up the experimental diets in about identical amounts. Under our experimental conditions, the postprandial heat production after ingestion of the control and the gelatine diet occurs on the average 2.5 hours after food itake. The extent of the postprandial heat loss depends on the amount of energy intake. It lasts about 2–3 hours after an energy intake of 31 kJ. After this time, the temperature declines to the base line representing the basal metabolic rate, which is reproducible in all experiments.

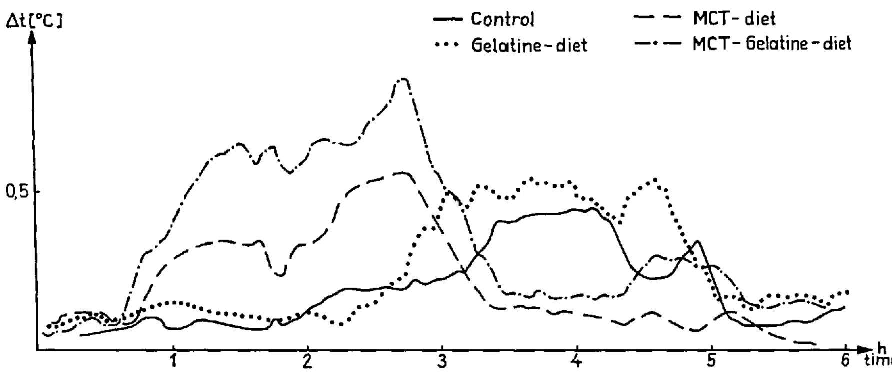

Fig. 1. The extent and time course of the postprandial thermogenesis of four selected animals, which took up the experimental diets in about identical amounts.

In contrast to the protein diets, the MCT-diets cause already 45 to 90 minutes after the food intake a significant increase of heat production, lasting likewise 2 to 3 hours.

In our experiments we found a very close correlation between food intake and postprandial heat production (fig. 2). The calculated regression coefficients point out that the postprandial heat production of gelatine and MCT-containing diets is significantly higher in comparison to the casein diet.

Table 2 summarizes the results of the calorimetric measurements of the induced postprandial thermogenesis by the different diets. Thermogenesis is expressed as that part of the ingested energy, which is lost as heat. It is significantly higher in gelatine and MCT-containing diets in comparison to the control diet. Compared with the control diet, the gelatine and MCT containing diets are producing the double amount of heat, respresenting one fifth of the ingested energy. Despite of a further significant increase of the postprandial heat production in the diet containing both gelatine and MCT, the extent of this increase is relatively small. It underlines the fact that the action of both foodstuffs in a mixed diet is not additive.

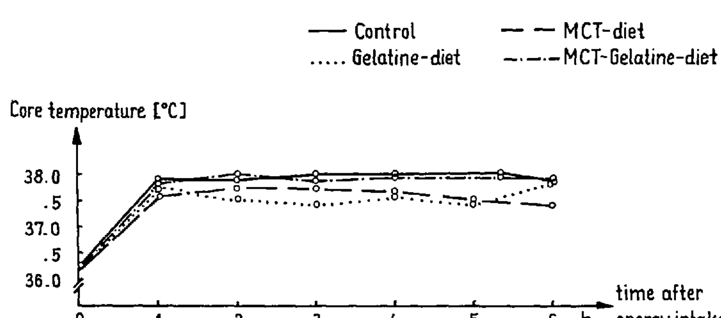

Fig. 2. Quantitative relationships between heat production and energy uptake from the experimental diets (regression lines), n = 10 in each group.

Table 2. Heat production in percent of the ingested gross energy [n = 10].

Control diet	8.3 ± 1.0 %
Gelatine diet	19.3 ± 1.4 %[1])
MCT diet	20.3 ± 2.5 %[1])
MCT-gelatine diet	22.6 ± 2.0 %[1])

[1]) significantly different with $p > 0.001$ from the control group.

Figure 3 shows the results of separate experiments to estimate the time course of the core temperature after ingestion of the four diets. In the fasting state, the average core temperature was 36.70 ± 0.22 °C. After application of equal amounts of the control, gelatine, MCT and MCT-gelatine diet (20.20 kJ), the core temperature increased significantly to 37.90 ± 0.42 °C; 37.60 ± 0.17 °C; 37.60 ± 0.11 °C and 37.90 ± 0.36 °C, respectively. The estimated core temperatures in the postprandial state do not differ from each other, and they are constant during 6 hours after food intake.

Discussion

The thermic effect of the control diet containing 30% of casein as protein moiety reaches a level of 8.3% of the ingested energy. Similar effects have been measured in human beings after ingestion of mixed diets (3, 6). The diet containing 15% casein and 15% gelatine induced a significantly higher postprandial heat production than the diet containing 30% casein. Depending on the amino acid composition, it can be calculated (18, 24) that under conditions of complete oxidation the yield of ATP

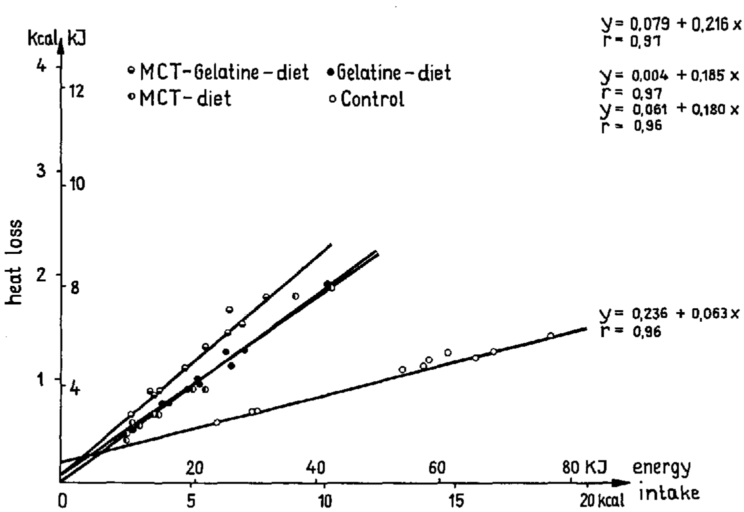

Fig. 3. The postprandial core temperature of rats after feeding the experimental diets.
n = 10 in each group.

(moles per 100 g of dietary protein) should be 20.2 for casein, 16.2 for gelatine, and 18.1 for the mixture of casein and gelatine (1:1). Using a factor 77.80 kJ per mole of ATP, the energy yield from these proteins can be calculated and then be compared with the net energy of the proteins (total energy content minus energy content of urea produced). This comparison gives an estimate of the energy for ATP-synthesis (available energy according to Schultz), which amounts to 77 %, 70.3 % and 73.3 % of the net energy of casein, gelatine and the mixture of casein and gelatine (1:1), respectively.

Another way to describe the energy utilization is the estimation of the fat yielding capacity, which has been found to be in terms of stearinic acid synthesized per 100 g of protein 0.109 moles for casein and 0.080 moles for gelatine (18). Both estimates indicate that the energy from gelatine and from mixtures of gelatine and casein is less available than that from casein, and that the heat production from the former proteins should be higher than from casein. This is in principal agreement with the presented data and agrees also with separate experiments in which the energy need for growth have been studied in long-term experiments. Nevertheless it cannot be assumed that a complete oxidation of ingested protein occurs under experimental conditions designed to estimate the postprandial thermogenesis within 6 hours. Furthermore, the heat production after ingestion of a mixture of casein and gelatine (1:1) is 2.3 times higher than the heat production after ingestion of an isonitrogenous amount of casein, whereas the calculated value of unavailable energy (net energy minus available energy) from casein/gelatine (1:1) is only 1.1 times higher than that from casein. These data point out that during short-term (postprandial) studies of dietary-induced thermogenesis other factors and relationships are of importance than during long-term studies of energy utilization. Such factors could be differences in the rate and amount of metabolization and degradation of amino acids, contributions of synthesizing and depositing processes, and metabolic interrelationships with other components of the experimental diet. In other words: the nutritional value of proteins, the actual nutritional and metabolic state of the animal and the composition of food (10, 13, 22, 25). It seems not to be probable that the energy needs for digestion and absorption of both protein sources were different, because both had the same digestibility.

The example of medium-chain triglycerides (MCT) demonstrates that synthesizing processes may contribute essentially to postprandial thermogenesis. MCT cannot be deposited as such and must be transformed into long-chain fatty acids before storage, mostly via acetyl CoA. These energy-requiring processes reduce the proportion of energy, which is available for storage, and induce an increased heat production. In case of acetate it could be shown that only 71 % of the energy can be conserved as long-chain fatty acids (2, 15).

The significant further increase of the postprandial heat production after substitution of half of the casein by gelatine and of 80 % of lard by MCT can be interpreted by the above-mentioned theoretical considerations.

The close linear correlation between the energy intake and the postprandially generated heat in our experiments underlines the reproducibility with which the thermic effect of diets can be determined in a wide range of food intake. The different regression lines (fig. 2) can be directly interpreted as differences in the heat production, since it could be shown in separate experiments that the digestibility of energy was identical in the four experimental groups.

We cannot confirm the results of other authors (5, 20) who found an independence of meal size and postprandial thermogenesis.

The combination of foodstuffs with a higher postprandial thermogenesis does not lead to additive effects. The relatively small increase in postprandial thermogenesis of the gelatine-MCT diet compared to the gelatine or MCT diet underlines certainly a possible mutual influence of the food components.

As the determination of the postprandial core temperatures demonstrates, the heat storage after ingestion of the different experimental diets is identical and does not exceed 0.5 % of the estimated thermogenic effect. Using small rats, the extent of heat storage during the postprandial phase can be neglected.

In conclusion, it can be said that direct calorimetric measurements are able to estimate the thermic effect of diets in laboratory animals with good reproducibility. Its application could be of importance for the development of such dietary treatments, which induce a high postprandial heat loss, leading to a lower efficiency of energy utilization. Such diets could be useful in the dietary therapy of states of obesity with high risk. But further basic research must be performed before the application of thermogenic diets in human beings can be recommended.

Summary

The postprandial thermic effect of diets containing different protein and fat moieties was estimated in young male growing rats by direct calorimetric measurements.

The postprandial thermogenesis after ingestion of the control diet, which contained 30 % of casein, corresponded to 8.3 % of the gross energy. After exchange of half the casein by gelatine, the postprandial heat loss increased to 19.3 % of the gross energy. Substitution of lard by medium-chain triglycerides and gelatine caused a further increase of thermogenesis to 20.3 % and 22.6 % of gross energy, respectively. Compared to the control diet, the differences are highly statistically significant.

The postprandial heat production after ingestion of the casein and casein-gelatine-containing diets occurred 2.5 hours after food intake and lasted about 2–3 hours. The medium-chain triglycerides-containing diets induced 45–90 minutes after food intake a significant increase of the heat production, lasting likewise 2–3 hours. The combination of dietary components with a high postprandial thermogenetic effect did not lead to an additive heat production.

A very close correlation could be found between the amount of food intake and the postprandial heat loss. The core temperature of rats increased significantly after ingestion of the experimental diets. In the postprandial state it did not differ between the four experimental groups.

The results demonstrate that the postprandial heat loss can be significantly increased by selected dietary components. The development of diets with a lower efficiency of energy utilization could be of interest for special dietary treatments, as for example, in certain states of obesity.

Zusammenfassung

Es wurde die postprandiale Thermogenese von Diäten unterschiedlichen Protein- und Fettanteils an jungen männlichen wachsenden Ratten mit der direkten Kalorimetrie bestimmt.

Die postprandiale Thermogenese nach Kontrolldiät, die 30 % Kasein enthält, betrug 8,3 % der aufgenommenen Bruttoenergie. Nach Austausch der Hälfte des Kasein durch Gelatine erhöhte sich die postprandiale Wärmeabgabe auf 19,3 % der aufgenommenen Bruttoenergie. Substitution von Schmalz durch mittelkettige Triglyceride und kombinierte Substitution durch mittelkettige Triglyceride und Gelatine verursachten einen weiteren Anstieg der Thermogenese auf 20,3 % bzw. 22,6 % der aufgenommenen Bruttoenergie. Verglichen mit der Kontrolldiät sind diese Differenzen statistisch hoch signifikant.

Die postprandiale Thermogenese nach Kasein- und Kasein-Gelatine-haltigen Diäten tritt 2,5 Stunden nach der Nahrungsaufnahme ein und dauert 2–3 Stunden. Die Diäten, die mittelkettige Triglyceride enthalten, rufen 45–90 Minuten nach der Nahrungsaufnahme einen signifikanten Anstieg der Wärmeabgabe hervor, der 2–3 Stunden dauert. Die Kombination von Diätkomponenten mit einer hohen postprandialen Wärmeabgabe führte nicht zu einer additiven Wärmeabgabe.

Es bestand eine enge Korrelation zwischen der aufgenommenen Nahrungsmenge und der postprandialen Wärmeabgabe.

Die Kerntemperatur der Ratten stieg nach Nahrungsaufnahme der Versuchsdiäten signifikant an. In der postprandialen Phase wurden jedoch keine signifikanten Unterschiede zwischen den vier Versuchsgruppen gefunden.

Die Ergebnisse zeigen, daß die postprandiale Wärmeabgabe durch ausgewählte Diätkomponenten signifikant gesteigert werden kann.

Die Entwicklung von Diäten mit einer geringen Effizienz der Energieverwertung könnte von Interesse sein für spezielle Diätbehandlungen wie zum Beispiel der Adipositas.

Key words: dietary induced thermogenesis, direct calorimetry, postprandial core temperature

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