

## CLINICAL CALORIMETRY.

THIRTY-FIFTH PAPER.

### A GRAPHIC REPRESENTATION OF THE RESPIRATORY QUOTIENT AND THE PERCENTAGE OF CALORIES FROM PROTEIN, FAT, AND CARBOHYDRATE.

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In the human metabolism there are always three factors: protein, fat, and carbohydrate. If, therefore, we wish to represent graphically the changes which may occur, it seems best to employ a triangle with each corner representing one of these foodstuffs. Irving Fisher (1) has used a right-angled triangle to show the composition of foods and diets. For metabolic mixtures we may draw a triangle which shows the respiratory quotient as well as the percentages of calories.

Lusk (2) has summarized the calculations of Loewy and has given the method for estimating the total metabolism and the percentage of calories furnished by carbohydrate, fat, and protein, using the following figures.

	R. Q.	Calorific value of 1 liter of oxygen.
Fat.....	0.707	4.686
Protein.....	0.801	4.485
Starch.....	1.000	5.047

In the preceding article Lusk (3) gives the formulas on which the calculations are based and makes a slight correction in the relative percentages furnished by fat and carbohydrate. These formulas served to establish the points on the base lines of the triangles here presented.

In each triangle the lower left-hand corner, at the respiratory quotient of 0.707, represents the theoretical point at which 100 per cent of the calories are derived from fat. The lower right-hand corner, over the respiratory quotient of 1.00, represents the point, never quite attained, where all the calories would be derived from carbohydrate. The peak, which is never even approached in man, is set at the point where 100 per cent of the calories would be derived from protein. This peak is, of course, placed directly over the respiratory quotient of 0.801. The subdivisions on the base line, as we have said before, are made according to the formulas given by Lusk. The subdivisions on the side lines are made according to similar formulas, using the appropriate factors for protein. In Fig. 1 these subdivisions are unevenly spaced on account of the nature of the formula.<sup>1</sup>

By means of Fig. 1 we can rapidly find the percentage of calories furnished by carbohydrate if we know the total respiratory quotient and the percentage of calories furnished by protein.

The abscissæ represent the total respiratory quotient; the ordinates on the left-hand side of the chart, the percentage of calories from protein. The percentage from carbohydrate is determined from the diagonal lines with the figures on the right side of the triangle. Adding the percentages from protein and carbohydrate, we can subtract this sum from 100 and find the percentage from fat. For example, if the respiratory quotient were 0.90 and protein furnished 20 per cent of the calories, we can see that carbohydrate furnished 61 per cent and fat 19 per cent.

The accuracy of this chart has been tested by the data from many calorimeter experiments calculated according to the method of Zuntz and Schumburg, as given by Lusk (2), using the correction given in the preceding article. In no case was the divergence for

<sup>1</sup> I wish to thank Mr. A. M. Michaelis for his aid in checking my calculations. He has called my attention to the fact that the lines in this triangle should theoretically show curves which, however, are so slight that they may be disregarded. In the following paper of this series he gives two diagrams of a slightly more complicated construction. One of them is of great help in determining the total calories, the other may be used to correct the slight errors which have been published in the previous papers on "Clinical calorimetry" as a result of employing the uncorrected chart referred to by Lusk (3).

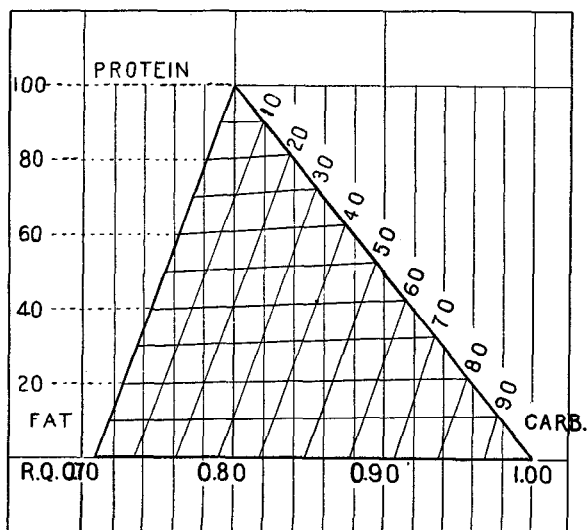


FIG. 1. Diagram showing the percentages of calories derived from protein, fat, and carbohydrate according to the respiratory quotient. The base line gives the total respiratory quotient; the ordinates reading on the left-hand side give the percentage of calories from protein; the diagonals reading on the right of the triangle give the percentage from carbohydrate.

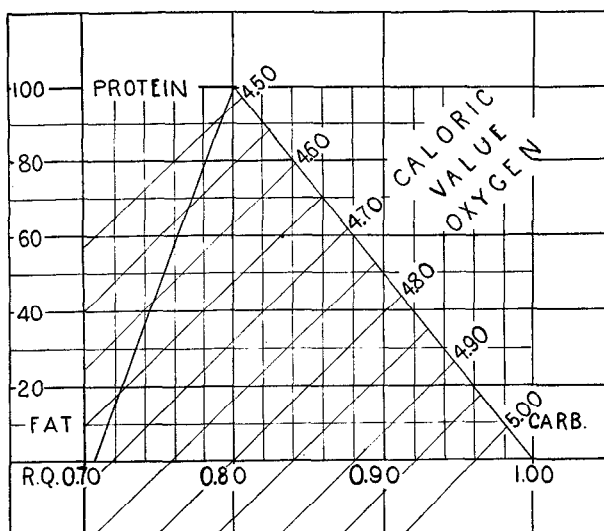


FIG. 2. The caloric value of 1 liter of oxygen in its relationship to the total respiratory quotient (base line) and the percentage of calories from protein (ordinates on the left of chart). The caloric value is found by means of the diagonals which read on the right of the triangle.

carbohydrate percentage changed more than seven points in the third significant figure, and this is well within the experimental error.

There has been a growing tendency among those who use the basal metabolism in clinical medicine to neglect the protein factor and to make all their calculations of the indirect calorimetry from the tables given by Lusk for the calorific value of a liter of oxygen according to the non-protein respiratory quotient. The errors in doing this are shown in Fig. 2, which gives the approxi-

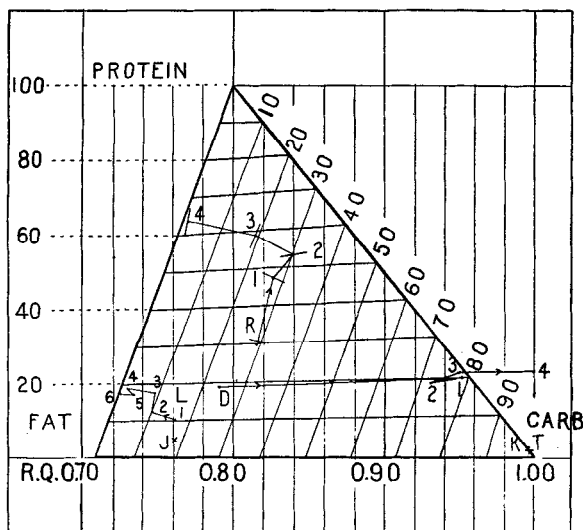


FIG. 3. Triangle used to show changes in metabolism. *R*, the effect of a large protein meal; *D*, the effect of 200 gm. of glucose; *L*, the first 6 days of starvation; *KT* and *J*, low protein diets with muscular exercise.

mate calorific value of a liter of oxygen, plotted according to the respiratory quotient and the percentage of calories furnished by protein. Here the diagonal lines are evenly spaced on account of the nature of the formula. If, for example, the respiratory quotient were 0.90 and protein furnished 20 per cent of the calories, each liter of oxygen used in the metabolism would indicate the production of 4.85 calories.

The triangle shown in Fig. 1 may be used as a "metabolism map." In Fig. 3 we have drawn lines which show on this map the

course of the metabolism during certain experiments in the calorimeter. The starting point *R* gives the position of the basal metabolism of the achondroplastic dwarf, Raphael de P. (4) on March 15, 1916. On this line the point *I* represents his metabolism the next day in the period starting 1 hour after he had finished a breakfast consisting of chopped beef, containing 23.2 gm. of nitrogen. This was an enormous meal for a dwarf weighing 90 pounds. It will be noted that during the 2nd, 3rd, and 4th hours the percentage of calories derived from protein rose until it reached 64 per cent, perhaps the highest percentage ever demonstrated in a respiration experiment on a man. During the 4th hour metabolism was on an exclusively protein-fat basis, similar to that of the Eskimos, but, as we shall see later, safely beyond the zone of ketosis. In this graph we have shown the specific dynamic action and the increase in metabolism due to the protein meal by drawing cross lines whose length is proportional to the height of the metabolism. In this same figure the point *D* represents the position of the usual basal metabolism of the normal control, E. F. D. B. (5). The point *I* on this line shows the position in the calorimeter period starting 1 hour after he had taken 200 gm. of dextrose on May 8, 1914. In the next period there was a slight fall in quotient but a subsequent rise to 1.00. In the lower left-hand corner the line *L* represents the metabolism of Benedict's subject, Levanzin (6), during the first 6 days of his fast.

There are certain positions outside the triangle which are of importance from a metabolic standpoint, as shown in Fig. 4. To the right of the carbohydrate corner there is a zone in which the organism is transforming carbohydrate into fat, and it is of interest to note that this may occur with quotients below 1 when any considerable portion of protein is being metabolized. With very excessive amounts of protein, such as have been attained in dog experiments by Lusk (7), protein can be partially transformed to fat and deposited as such.

To the left of the original triangle is a second triangle which represents the conversion of a portion of the protein molecule into carbohydrate and its storage as glycogen or excretion as glucose. Lusk (8) has shown that the respiratory quotient falls as low as 0.632 if, during the metabolism of 100 gm. of beef protein, 59.41 gm. of glucose, derived from this protein, are excreted in the urine

(dextrose : nitrogen ratio = 3.65). It is only in the lower portion of this triangle that we find patients with diabetes, since they seldom derive more than 35 per cent of their calories from protein.

The line *KA* in the "fat corner" of the original triangle represents the threshold of ketosis, as determined by the equimolecular ratio of fatty acids and glucose, according to Shaffer (9) or the F. A. : G. = 1.5 ratio of Woodyatt (10). This line corresponds to the ingenious and useful graph devised by Hannon and McCann

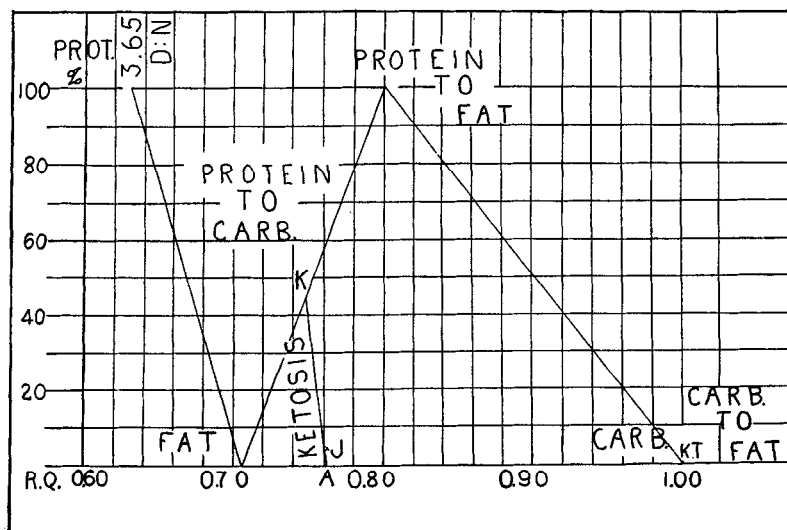


FIG. 4. Zones of metabolism.

(11). To the left of this line diabetic patients, fasting men, or men on a high fat diet, should all theoretically excrete abnormal amounts of ketones.

There is a narrow zone along the bottom of this chart which is probably never reached by man, since we can conceive with difficulty of a state in which protein furnishes less than 1 per cent of the total calories. Perhaps the lowest percentage yet demonstrated is the 1.5 per cent attained by Karl Thomas (12) in a nitrogen minimum experiment in which, on an extremely low protein diet, he performed a large amount of work on an ergometer. This is shown by the point *KT* in Fig. 4. The lowest point near the "fat" end of the scale that I have been able to find was the old

experiment of Atwater and Benedict (13) on the subject, J. C. W., who expended 9,981 calories in a single work day while he was on a diet containing 5,138 calories.

We must remember that this chart shows only the net transformations within the body and expresses the actual loss of protein, fat, and carbohydrate in a given period. It is quite possible that fat is deposited in one part of the body while it is being withdrawn from another organ for purposes of combustion. Krogh and Lindhard (14) have recently emphasized the probability of extensive transformations of this nature.

#### SUMMARY.

Triangular graphs have been constructed which make it possible to determine rapidly the percentage of calories furnished by protein, fat, and carbohydrates. Using these graphs as maps, one may follow the changes in metabolism caused by disease or by the administration of various diets.

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