STUDENTS' MISCONCEPTION ABOUT ENERGY-YIELDING METABOLISM: GLUCOSE AS THE SOLE METABOLIC FUEL

Gabriel A. Oliveira,[1] Cristiane R. Sousa,[1,3] Andrea T. Da Poian,[1] and Maurício R. M. P. Luz[2,3]

[1]*Departamento de Bioquímica Médica, Instituto de Ciências Biomédicas, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ 21941-590;* [2]*Setor Curricular de Biologia, Colégio de Aplicação, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ 22470-130; and* [3]*Laboratório de Biologia Celular, Departamento de Ultra-estrutura e Biologia Celular, Fundação Oswaldo Cruz, Rio de Janeiro, RJ 21045-900, Brazil*

ADV PHYSIOL EDUC 27: 97–101, 2003;
10.1152/advan.00009.2003.

Energy-yielding metabolism is a subject that is particularly important, because energy production is a fundamental requirement for cells even though they execute many other processes simultaneously. An integrated view of metabolism is essential for understanding how the whole organism functions, including activities of students' daily life, such as eating, dieting, and physical exercise. In fact, the media constantly exert pressure on young people, stimulating students to undergo countless diet and exercise programs. Additionally, diabetes mellitus and obesity, which are diseases with close ties to metabolism, have been increasing among adolescents.

In Brazil, the education system is organized in 12 grades. Until the 9th grade (~14–15 years old), physics, chemistry, and biology are taught as one discipline, called "sciences." From 10th to 12th grade (~17–18 years old), physics, chemistry, and biology are taught as separated disciplines. "Metabolism" is traditionally taught in the 10th grade. Although the role and the general structure of macromolecules are taught in the 10th grade, 8th grade deals for the first time with these subjects.

To assess students' knowledge of the integration of human metabolism, we have presented questionnaires to be answered by students at the beginning of their first year at one of the largest and most prestigious Brazilian universities, the Federal University of Rio de Janeiro. The first questionnaire (Q1) contained two objective questions: *1*) What happens to the overall ATP production in an individual fed a low carbohydrate diet? *2*) What happens to the overall ATP production in an individual undergoing prolonged (many days of) fasting?

The students had the choices of answering "I do not know" or that ATP production "remains the same," "increases," or "decreases." In addition, after their answers for each question were selected, three lines were available for the students to briefly explain their answers. Students who did select an option but did not explain their answers were excluded from the sample.

Figure 1*A* summarizes the pattern of answers obtained from Q1. From the 304 students who answered the questionnaire, 175 came from biomedical-, 55 from technology-, and 74 from humanities-related courses. Although there was some diversity among the answers given by the students in each group, the pattern was found to be very similar (not shown). The proportion of students who presented correct answers to the questions was remarkably small, and a great proportion of them chose to answer "I do not know" or did not explain their answers. These proportions indicate that a significant number of students do not know how that metabolism is regulated in relatively common situations of their daily lives (diets,

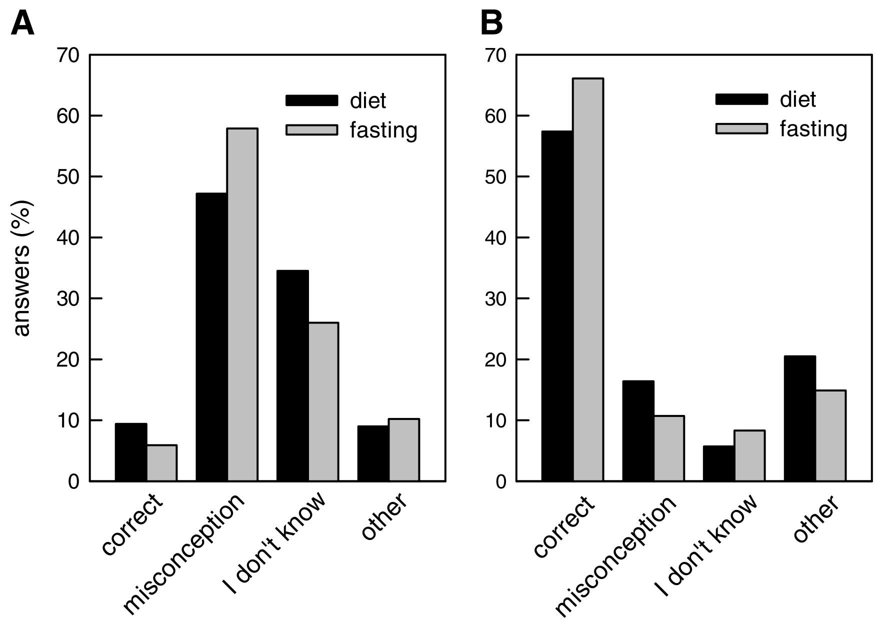


FIG. 1.
Students' misconception about ATP production by cells during a low-carbohydrate diet (filled bars) or fasting (grey bars). Answers to Q1 by 304 students from 9 different careers of the Universidade Federal do Rio de Janeiro (*A*) or 184 students from the Faculty of Medicine who had just finished the biochemistry course (*B*). Misconception refers to the answers that include that "glucose is the only fuel available for ATP production by the cells".

for instance). However, even more important is the fact that ~50% of the students presented very similar answers (which we considered the "misconception"), according to which ATP production falls dramatically during either a "low-carbohydrate diet" or "fasting." The explanations given by all students to the answers scored as the "misconception" were related to the fact that carbohydrates are the only source of glucose and that glucose is the only fuel available for ATP production by the cells. A small proportion of the students presented other "wrong" explanations for their answers.

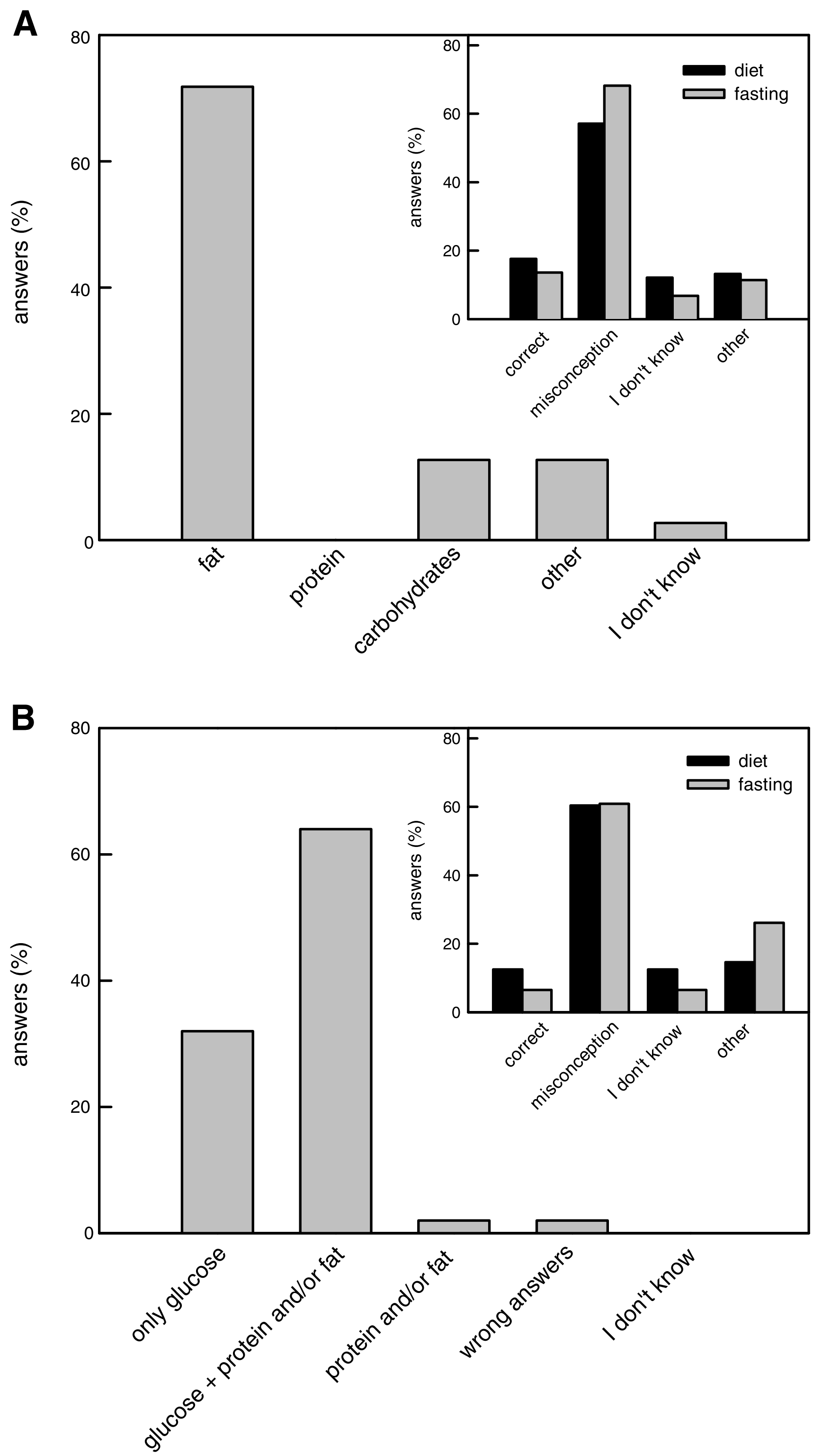
As a control, Q1 was presented to 154 students who had just finished the biochemistry course in the Faculty of Medicine. Sixty percent of them presented correct answers to the questions, and the proportion of misconception was only ~15% (Fig. 1*B*). Therefore, the high proportions of the misconception found among undergraduate students was not a consequence of Q2 structure.

The fact that Q1 dealt with deprivation situations (low-carbohydrate diet and fasting) could induce the students to answer that ATP production decreases. If this were true, any question dealing with deprivation situations would result in an answer pattern similar to that obtained for Q1. To this hypothesis, undergraduate students were asked to answer the following question:

What happens to the overall ATP production in an individual fed a diet containing low levels of calcium?

This question is similar to the first question of Q1, except for the substitution of the word "carbohy-

FIG. 2.
***A*: students' answers to the question of Q2. *Inset*: answer pattern of Q1 applied to the same students after answering Q2 (n = 101). *B*: students' answers to the question of Q3. *Inset*: answer pattern of Q1 applied to the same students before answering Q3 (n = 50).**


A
answers (%)
80
60
40
20
0
fat
protein
carbohydrates
other
I don't know
diet
fasting
correct
misconception
I don't know
other
B
only glucose
glucose + protein and/or fat
protein and/or fat
wrong answers
I don't know

drate" for the word "calcium" (an ion not directly related to ATP production). The answer pattern was quite different from that obtained for Q1, since the answers were randomly distributed among the four options (χ^2 = 3.49, 3 degrees of freedom, P = 0.32). Thus a question containing a deprivation situation per se does not induce students to answer that ATP production decreases.

In an attempt to investigate whether recalling daily situations related to energy-yielding metabolism could change the students' answer pattern, we presented a slightly modified version of Q1, which will be referred to as Q2, to a second sample of undergraduate students. Q2 contained, before the original questions, the following question, to which the students were asked to write down an answer:

A low-carbohydrate diet associated with extensive exercise usually leads to weight loss. Which molecule is decreasing in amount in the body to account for the weight loss?

Most of the students (71.8%) identified lipids, and few of them (12.7%) identified carbohydrates, as the molecules being consumed and responsible for weight loss. The remaining students presented other answers or chose to answer "I do not know" (Fig. 2*A*). No student identified more than one molecule as being responsible for weight loss. Q2 also contained the question:

What is/are that/those molecule(s) being used for?

Almost all the students (94%) answered that the molecule consumed during weight loss was used for energy production. However, when the same students answered Q1, only a small number of them answered that other molecules besides glucose could be used as fuels during a low-carbohydrate diet (17.6%) or fasting (13.6%). Such proportions were nearly identical to those found among students who answered only Q1 (compare Fig. 2, *inset*, with Fig. 1*A*). In fact, the proportion of students who acknowledged the use of other fuel molecules besides glucose was much smaller than those who identified lipids as responsible for weight loss (71.8%). The majority of the students still presented answers scored as misconception (57.1 and 68.2% to diet or fasting, respectively). This set of results indicates the presence of two distinct conceptions in the same student: one, more correct ("lipids and proteins, besides glucose, can be used in energy production by the cells"), which is applied by the students in a more informal situation, and the other, the misconception ("only glucose can be used in energy production by the cells"), which is used when a problem that requires more formal learning is presented.

To confirm the existence of two contradictory conceptions concerning energy-yielding metabolism in the same student, we submitted another questionnaire (Q3) to another group of undergraduate students. First, the students answered Q1, and, as expected, the result was similar to that obtained before (Fig. 2*B*, *inset*). Then they were asked:

What molecules are used in the cells for ATP production?

A greater proportion of the students (66%) was able to associate ATP production with other fuels besides glucose (Fig. 2*B*); approximately 32% of the students identified glucose as the only molecule involved in ATP production. This result confirms the coexistence of two contradictory conceptions in the students minds.

Students' answers about the regulation of metabolism in low-carbohydrate diets and fasting seem to indicate that they identify glucose as the sole fuel molecule available for ATP production in human cells. A more explicit attempt to stimulate students to connect energy-yielding metabolism and daily experience proved that, even after identifying the loss of lipids or proteins during diet and exercise, the students presented an identical profile of misconceptions. Thus the main finding reported here is that students fail to establish a correlation between ordinary daily experience and the formal study of metabolism.

We suggest that efforts should be made by textbook authors, teachers, and researchers to discuss metabolism in a more integrated way, emphasizing both catabolic and anabolic pathways involved in metabolism and discussing the multiple connections of central metabolic pathways such as the tricarboxylic acid cycle. Moreover, correlation of energy-yielding metabolism pathways with daily experience (e.g., diets and growth) should be also emphasized. It is our belief that this new approach is more likely to lead to a better understanding of the complexity of the metabolic pathways and their interconnections and also to a better comprehension of daily experiences, where an understanding of human metabolism is required for adequate decisions related to health and life style.

Address for reprint requests and other correspondence: A. T. Da Poian, Departamento de Bioquímica Médica, Instituto de Ciências Biomédicas, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ 21941–590, Brazil (E-mail: dapoian@bioqmed.ufrj.br).

Submitted 23 April 2003; accepted in final form 29 April 2003