Blood glucose monitoring as a teaching tool for endocrinology: a new perspective

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Submitted 11 February 2009; accepted in final form 17 June 2009

Moats RK II. Blood glucose monitoring as a teaching tool for endocrinology: a new perspective. Adv Physiol Educ 33: 209–212, 2009; doi:10.1152/advan.00009.2009.—The education of new allied health professionals and nurses in proper endocrine evaluation and care has become critical in recent years, especially considering the greatly increased prevalence of diabetes in adults and children. The evaluation of blood glucose levels in human volunteers over time is a powerful teaching tool for endocrinology that has the added benefit of exposing the student to the most fundamental task in diabetes management. The classic procedure involving the ingestion of sucrose followed by blood glucose monitoring was used here to teach the concepts of nonhormonal control of hormone release and blood glucose homeostasis. In addition, a number of volunteers did not ingest a sucrose solution but merely held it in their mouths and expectorated. This so-called “spit” technique has been successfully used to induce the cephalic phase of insulin release (CPIR), an example of neural control of hormone release. As expected, volunteers who ingested sucrose displayed a 38.5% increase in blood glucose 20 min postingestion and a concomitant decrease in blood glucose to near baseline by 60 min postingestion. Those volunteers who did not ingest the sucrose solution displayed a 12.9% reduction in blood glucose levels by 40 min postcompletion, suggestive of the CPIR, followed by a gradual increase in blood glucose levels to near baseline by 60 min postcompletion. The addition of the “spit” technique to this revised protocol of the evaluation of blood glucose exposes the student to the neural control of hormone release and a second example of energy homeostasis.

In recent years, the demand for nurses and other allied health professionals has placed the development of these careers at the forefront of higher education. As a result of this demand, graduates of these programs are very often called to function as primary providers, especially in the cases of smaller or rural communities. Thorough education of these students has become more critical than ever. Most institutions training nurses and allied health professionals require students to take a two-part, introductory anatomy and physiology course that includes laboratories. Historically, the focus of these laboratories has been on anatomy, with extensive animal or, less often, human dissection. This focus is reinforced by many laboratory textbooks available for these courses, which dedicate a large number of pages to descriptions of anatomy and dissections.

Laboratory exercises for physiology often involve potentially complex equipment and extensive preparation. Moreover, direct examination of physiological processes involves living organisms, such as rats, frogs, or fish, which many smaller institutions may be unable to support. To examine physiological processes in the allied health teaching laboratory, instructors commonly rely on evaluations of human parameters, such as heart and respiration rates and blood pressure, and/or computer simulations of experiments involving animals (see, for example, Ref. 7). Endocrine physiology, in particular, is frequently taught using computer simulations (5) or simple hormonal manipulations of fish or amphibians (4, 7).

A classic experiment of endocrine physiology teaching is the regulation of blood glucose levels by endogenous insulin in human volunteers (14). The simple procedure and modest equipment requirements allow for rapid preparation by the instructor, and the concise data acquired clearly expose a homeostatic response to the student. Unfortunately, this powerful teaching tool has appeared in fewer of the most popular laboratory textbooks used in allied health/nursing anatomy and physiology courses in recent years.

Advances in technology available for consumer diabetes care have made the evaluation of blood glucose levels simpler and safer. In particular, self-sheathing safety lancets and glucometers that dispense paper testing strips virtually eliminate the danger of blood cross-contamination. Moreover, the fully enclosed nature of some safety lancets improves the confidence of the test subject and their assistants, expediting sample acquisition and reducing the incidence of pain and potential routes of infection.

In mammals, blood glucose levels are regulated by a number of hormones, with the pancreatic hormones insulin and glucagon being the most active (8). Insulin is released by the β-cells of pancreatic islets in response to elevated blood glucose, increasing the absorption, utilization, and storage of glucose by the vast majority of body tissues. As blood glucose levels fall, the secretion of glucagon by the α-cells of pancreatic islets increases, countering the effects of insulin, most notably in the liver. Thus, continuous alterations in the secretion of these two hormones maintain blood glucose at a stable level.

The release of insulin is also controlled independent of an increase in blood glucose levels by the central nervous system (9). Neurological stimuli, including the sight, smell, or taste of food, reflexively activate the gastrointestinal tract. Insulin is also released in response to these and other neurological stimuli by a process termed the cephalic phase of insulin release (CPIR) (11). Induction of the CPIR without a concomitant increase in blood glucose would cause a slight decrease in existing blood glucose levels, leading to a more robust secretion of glucagon. Glucagon, in turn, would cause a slight increase in blood glucose, maintaining homeostasis.
The well-established protocol of evaluation of blood glucose levels over time after sucrose ingestion was supplemented by the induction of CPIR only in some subjects. The objective of the addition of CPIR to the protocol was to further expose the student to examples of homeostasis and to demonstrate the concept of neural control of endocrine secretion. This report presents sample data from a series of experiments involving student volunteers who had either ingested sucrose or had only tasted an identical sucrose solution. This latter condition resulted in the apparent activation of the CPIR, leading to measurable alterations in blood glucose levels.

LABORATORY COURSE PROCEDURES

The following protocol and data collected by way of the protocol have been reviewed by the Ohio University Institutional Review Board and have been found to be exempt under category 4 (IRB no. 08E255). All participants in these experiments were undergraduate students in BIOS 131: Principles of Human Anatomy and Physiology II or EVT 198D: Principles of Human Anatomy and Physiology Laboratory at Ohio University (Chillicothe, OH).

Approximately 1 wk before the experiment, students were verbally informed of the upcoming study and what would be required of participants (e.g., blood sample collection). At this time, they were also informed of conditions that would automatically exempt them from participation, in particular, blood-borne disease, blood glucose regulation disorders, or clotting disorders. Participation in the study was, in any case, entirely voluntary.

The day before the experiment, students who wanted to participate were asked to avoid highly sweetened food or drink and to fast (excepting water) for at least 1 h before their laboratory meeting time. Immediately before a laboratory session, the instructor added 50 g of sucrose (commercially available table sugar) to each of six 473- to 500-ml commercial bottles of drinking water and marked half the bottles with the letter “S.” The ingestion of 50 g of sucrose is consistent with the most recent recommendations for oral glucose tolerance tests, which limit the ingested amount of glucose to no more than 75 g in nonpregnant subjects (3).

Upon entering the laboratory on the day of the study, students were provided with a written protocol for the experiment. This document also included a statement, which was signed by each student, indicating that the student recognized that participation in the experiment was voluntary, that blood is a potentially hazardous fluid, that the student recognizes that all efforts have been made to insure the safety of all present in the laboratory, and that, regardless of participation status, the student was required to comply with all written and verbal instructions.

Students were then given a brief tutorial in proper finger-stick technique, the operation of the glucometer, and the disposal of biohazardous waste. The number of students who could volunteer as direct participants was limited by the availability of equipment, and those who did not participate directly functioned as assistants. The use of assistants is actually preferable as these students simplify the sample collection process and assure that blood is not transferred to common equipment from the fingers of the direct participants.

The experiment began with the determination of control blood glucose levels. Blood samples were collected from the volunteers using fully enclosed, self-sheathing lancets (MediPurpose, Norcross, GA). The style of instrument used in this case is a small plastic box containing a spring-loaded metal lancet (Fig. 1). The contact surface of the instrument is a contrasting color to the plastic box, and this surface was pressed to the lateral or medial aspect of a finger to discharge the lancet. Once discharged, the metal lancet retracted fully into the box, and the entire mechanism became nonfunctional, eliminating the possibility of accidental contact with another student. The entire instrument was then discarded into a plastic biohazard collection box. A blood glucose value was then determined using an Acsensia Breeze glucometer (kind gifts of Bayer Healthcare, Tarrytown, NY). This model of glucometer holds test strips internally and partially ejects them on demand from the top of the glucometer. The partially ejected test strip was then touched to the small amount of blood on the volunteer’s finger, the blood was absorbed to the paper test strip, and the blood glucose level was determined through a chemical reaction in the test strip itself. The removal of the strip was accomplished through a cutter located inside the glucometer, and the used strip was dropped directly from the glucometer into the trash. (Note that in the State of Ohio, routine patient care wastes, such as glucometer test strips, are not considered biohazardous.)

The student volunteers were given a bottle of sugar water and instructed to “sip” (sip group) or “spit” (spit group), with the latter indicated by the “S” label on half the bottles. Students in the sip group drank the contents of the bottle as rapidly as comfortably possible, and the time of completion was noted by a student assistant. Students in the spit group took the sugar water into their mouths and then immediately expectorated into a nearby sink. This process was repeated until the bottle was empty, and the time of completion was noted by a student assistant. Blood glucose values were then determined for all volunteers at 10, 20, 40, 60, and (if time allowed) 80 min postcompletion.

Students were then asked to complete a brief worksheet, which included the creation of a graph of average blood glucose levels for both experimental groups. This worksheet contained questions regarding the expected and actual outcomes of the experiments, the hormones and tissues responsible for the outcomes, and the implications for those with diabetes and other blood glucose regulation disorders.

RESULTS AND DISCUSSION

Despite the natural variation in the weights of test subjects (not determined), the ingestion of only 50 g of sucrose resulted in a robust increase in blood glucose in general (Fig. 2). Baseline blood glucose values for the sip group (i.e., before sucrose ingestion) were 104.7 ± 2.8 mg/dl (mean ± SE), and, within 10 min of the completion of ingestion, average blood glucose levels had risen nearly 26.5% above baseline (132.4 ± 4.5 mg/dl). Blood glucose levels in the sip group reached a

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Fig. 1. Example of the fully enclosed, self-sheathing safety lancet used for these experiments (SurgiLance model SLN200, MediPurpose, Norcross, GA). The 1.8-mm-diameter metal lancet enclosed by the container is released by pressure to the contact surface on the right. After discharge, the metal lancet retracts fully into the box and the mechanism is disabled.
stimuli combined with the simulated act of ingestion have an
process was repeated until the entire 500-ml sample had been
briefly, expectorated, and replaced with fresh solution, and the
it in their mouth for several seconds, and then expectorated the
lished reports, where subjects sipped a sweetened liquid, held
 postingestion, values were 8.4% above baseline (113.6
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identified the CPIR in humans, and it has been confirmed
(e.g., sweet taste) induced the secretion of insulin by the
pancreas. This release of insulin by CPIR was sufficient to decrease blood
glucose levels significantly by 20 min postcompletion. CPIR is an example of
the neural control of hormone release, which complements the nonhormonal
control of hormone release demonstrated through the ingestion of sucrose by
the sip group. Values are means ± SE, n = 19–22.

maximum of 38.5% above baseline (145.0 ± 4.0 mg/dl) by 20
min postingestion and began to steadily decline. By 60 min
postingestion, values were 8.4% above baseline (113.6 ± 5.1
mg/dl).

Subjects in the spit group showed a modest 7.9% reduction in blood glucose levels 10 min postcompletion from a baseline of 103.4 ± 5.4 mg/dl. Levels continued to decline, reaching a significant 12.9% reduction (89.9 ± 2.7 mg/dl) by 40 min postcompletion (Fig. 2). Blood glucose levels in the spit group thereafter increased and were 11.1% below baseline at 60 min postcompletion.

Increased pancreatic secretion of insulin in response to elevated blood glucose is a clear example of the nonhormonal (or humoral) control of endocrine secretion. However, CPIR in humans has been a somewhat controversial example of neural control of endocrine secretion, as many reports have failed to elicit an increase in insulin release in response to all oral sweet stimuli (1, 11).

The development of the "sip-and-spit" technique has since identified the CPIR in humans, and it has been confirmed recently (6). Although the role of CPIR in humans is unclear, it appears to be crucial to insulin and blood glucose regulation in the preprandial and early postprandial periods. Pharmacological blockade of the autonomic nervous system (ANS) prevents a slight but significant elevation in insulin levels at the onset of meal ingestion (2). This increase in insulin secretion before glucose absorption may moderate the expected postprandial elevation in blood glucose, as ANS blockade also results in hyperglycemia (2). The significant and reproducible decrease in blood glucose shown here is similar to that previously reported (12), despite differences in detection methods. The "sip-or-spit" technique independently developed for this teaching laboratory parallels the "sip-and-spit" method of published reports, where subjects sipped a sweetened liquid, held it in their mouth for several seconds, and then expectorated the liquid. In the present example, the subject mimicked the act of ingesting the sweet liquid: the liquid was held in the mouth briefly, expectorated, and replaced with fresh solution, and the process was repeated until the entire 500-ml sample had been used. It has been suggested that extended exposure to sweet stimuli combined with the simulated act of ingestion have an added (or synergistic) influence on the neural stimulation of the pancreas (9, 13).

Previously published reports also failed to detect any measurable change in glucagon secretion, likely because of the limited decline in blood glucose in response to CPIR (1, 11). Much of the data presented here support this result (Fig. 2), although in individual circumstances, blood glucose levels may return to baseline if the data collection period is extended beyond 60 min postcompletion (not shown). It is likely that in the present example, the measured drop in blood glucose apparently caused by CPIR was not sufficient to induce the secretion of glucagon. The blood glucose levels in both the sip and spit groups were determined at various times throughout the day, and the fast imposed on the subjects was extremely limited. Both these factors are known to influence pancreatic responses to changes in blood glucose (3, 8).

The self-contained nature of both the lancets and the glucometers and the use of assistants for each subject allowed for the rapid and consistent evaluation of blood glucose levels. Moreover, the reliability and confidence of the assistants and subjects were much improved due to the simplistic operation of the lancets and glucometers. Often, a suitable blood sample was collected and processed using a single lancet and a single glucometer test strip, decreasing the discomfort of the participants and the amount of waste produced.

The evaluation of blood glucose levels over time is a clear demonstration of homeostasis in action. It has also been recently used to educate students in the development of diabetes and the glycemic index of foods (10). Through the addition of CPIR induction to this procedure, students were exposed to a second example of homeostasis and an example of the neural control of endocrine secretion. Beyond the value for physiology teaching, the use of the evaluation of blood glucose in introductory anatomy and physiology laboratories for allied health students exposes these future frontline caregivers to the proper procedures for the acquisition and assessment of blood glucose values.

ACKNOWLEDGMENTS

The author thanks the students of EVT 198D summer 2006 and the students of BIOS 131 winter 2008, fall 2008, and winter 2009 who took part in the development of these procedures and whose sore fingers validated them.

REFERENCES


2. Ahre n B, Holst JJ. The cephalic insulin response to meal ingestion in humans is dependent on both cholinergic and noncholinergic mechanisms and is important for postprandial glycaemia. Diabetes 50: 1030–1038, 2001.


