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Teaching renal physiology in the 21st century: focus on acid–base physiology

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Abstract

A thorough understanding of renal physiology, and in particular acid–base physiology, is essential for an understanding of nephrology. Difficulties in both teaching and learning this material are major impediments to attracting medical trainees into nephrology. Approaches to teaching renal physiology include collaborative learning, computer-based learning and laboratory-based learning. Computer-based learning applications are becoming increasingly popular and can be useful, but are most successful when they incorporate interactive components. Students also note that the presence of a live instructor remains desirable. Some concepts of renal and in particular acid–base physiology can be taught using structured self-experimentation, a practice with a long tradition that possibly should be revitalized.

Key words: acid–base, education, electrolytes, physiology

Introduction

Academic nephrologists at many medical centers in the USA have leadership roles and are generally considered excellent teachers and mentors [1]. However, there is a dearth of innovation and research in nephrology education. This may be in part the reason why nephrology programs have recently been having difficulty attracting excellent prospective medical students and residents into nephrology [2, 3]. Indeed, nephrology ranks next to last in career choices among US medical school graduates [4]. Although several factors may play a role in attracting medical trainees into nephrology, an important factor may be how nephrology is presented to trainees [5]. One of the reasons that interest in nephrology has been declining among medical students and residents may be the quality of teaching of renal physiology and pathophysiology in medical school and residency. For example, complex acid–base or electrolyte disorders may be seen as intimidating or even irrelevant rather than exciting and intellectually stimulating.

The American Society of Nephrology (ASN) established a Workforce Committee to help address this issue. In October 2011, preclinical kidney physiology and pathophysiology course directors at US medical schools were surveyed about teaching methods, curricular content, resources and institutional support for teaching to identify what worked well and what impairs their teaching efforts [4]. A Listserv of these educators, the American Society of Nephrology Renal Educators Listserv, was used to electronically administer the survey. Course leaders from 62 of 114 (54%) surveyed medical schools responded. Most of these educators were nephrologists, but physiologists and other clinicians also were included in the sample. Nearly all respondents used large-group teaching (i.e. lectures) as well as small-group sessions for portions of their teaching. Sixty percent of course directors noted that lectures were videotaped, resulting in decreased live attendance. Some technological resources such as audience response systems were frequently used (employed by about

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two-thirds); however, other resources, such as simulation and social media (such as Twitter or Facebook), were used sparingly if at all. Kidney educators noted that students found several topics to be especially difficult, namely sodium and water homeostasis, acid–base disorders and, to a somewhat lesser extent, glomerular disease. Of note, most respondents were not specifically paid for their teaching efforts. Course directors using the ASN Renal Educators Listserv cited incorporation of case scenarios and integration of clinical exposure during preclinical years as methods that inspired interest. They also believed that teaching of preclinical courses by non-clinicians could have a negative effect on the number of students who might consider nephrology in the future. A recent survey of nephrology fellows indicated that ~25% developed an interest in nephrology during medical school [1], pointing to the importance of early exposure in career decisions.

Teaching methods advocated on the ASN Renal Educators Listserv have indicated a number of possible options to improve physiology teaching to medical students [4]. Suggestions made and quoted included the following. (i) Active learning using the audience response system in small groups. Each group is given six to eight electrolyte problems after hearing a lecture on that topic. The questions are framed in a clinical context and become progressively more difficult. One faculty member in each group moderates the discussion and discusses the correct answers (going more quickly through those questions that most of the class gets correct). (ii) Case simulation, in which a discussant is given successive bits of information and reasons out the answer in front of the students. (iii) Team-based learning, in which students in the lecture hall are divided into groups of five to six students in order to facilitate discussion. (iv) Integration of clinical and preclinical curricula, in which pre-clinical students rotate through the clinical consult service or the fellows take the students to see patients in the hospital. (v) Evoking emotion by incorporating drama, such as death from hyponatremia during athletic events or other contests. It is of note that none of these methods require a great deal of technical sophistication, but do make the learning of nephrology more exciting and relevant.

Nephrology is a rather young specialty, having evolved only about half a century ago. For much of its early history, the principal focus was on renal physiology and, in the clinical realm, electrolyte and acid–base disorders. Acid–base disorders are still considered difficult by many trainees. Indeed, in a recent survey of US non-nephrology subspecialty fellows, acid–base disorders were chosen as the most difficult topic to grasp in nephrology [6]. Therefore, this article will focus on the teaching of acid–base physiology.

Collaborative learning

Certainly, understanding acid–base disorders is one of the most difficult tasks for most medical students. Collaborative teaching strategies may enhance student performance in physiology courses [7, 8]. In particular, the so-called peer instruction technique [9] has been reported to enhance both the transfer and retention of learned material. In this teaching approach, specific questions are integrated in the conventional lecture format; in an initial ‘individual phase’, students mark down their answer and rate how confident they are about the correctness of their answer; this is followed by a ‘pair phase’, where students are asked to convince their neighbor of their answer. After this, they may revise the answer and again rate their confidence in their second answer. This teaching differs substantially from conventional group work, where students typically discuss questions in small groups and mark down their answer. In a recent study from Denmark, the peer instruction technique was compared with conventional group work for teaching acid–base disorders to second-year medical students [10]. The first part of the lesson consisted of a 45 min introduction to the basic principles of acid–base physiology and disorders. The mnemonic rule, ‘paper cut bleeding’ (PCB; pH–CO_2–base excess), was used as a structure to the interpretation of blood gases. (For students from the USA, B might better stand for bicarbonate.) During the lesson, students received a sheet with normal ranges for all arterial acid–base variables and were introduced to a PCB-structured flow chart. This was followed by a 20 min session during which students solved eight different arterial blood gases problems using two different collaborative strategies: Group A interpreted each problem in groups of two and rated how confident they felt about the answer, whereas Group B first assessed each problem individually (individual phase) and rated how confident they were about the answer; students then reassessed the problem in groups of two students (pair phase) and again rated how confident they were about their second answer. All students underwent an identical test immediately before and after the 20 min session of collaborative activities. During the 20 min session of collaborative activities, 97% of the arterial gases were interpreted correctly in Group A, with confidence levels of 100% (range: 95–100%). In Group B, 73% of the answers were correct after the individual phase, with confidence levels of 90% (range: 60–100%), which increased to 91% correct answers with confidence levels of 100% (range: 90–100%) after the pair phase. These two methods were not found to be significantly different. Student satisfaction ratings were high with either technique.

Computer-based learning

A more technological approach is to use computer-based learning. E-education, in which computers are used so that students and teachers do not have to sit in the classroom, has become popular. Physician and university-based blogs have played an increasing role in nephrology education. Most contain interesting nephrology cases, journal clubs, quizzes and current news in nephrology. In addition to blogs, university-based and non-university-based nephrology teaching websites are available. Case-based teaching websites have also been initiated with substantial success (http://www.kidneycaseplace.com). Interactive simulation-based physiology teaching is available at http://www.learnphysiology.org/sim1. Whereas social media has not been used extensively in education from teacher to student, student-to-student use appears to be more prevalent.

One of the early attempts (described in a publication in 2002) was the development of The Acid/Base Primer for the College of Veterinary Medicine at Cornell University [11]. The first author designed a software program called Acid/Base Primer that would help students with this topic. The material consisted of six problem sets featuring cases of acute respiratory acidosis, chronic respiratory acidosis, metabolic acidosis, respiratory alkalosis and two cases involving metabolic alkalosis. The program used two frames—an upper frame containing history, physical examination, laboratory work and a table containing a series of questions, and a lower frame containing a data set of blood gas results for the patient and the clinical setting. Two frames were used so that the data were visible as the student scrolled through the questions in the upper frame, eliminating frustration that might arise from scrolling back and forth between question and data. Seventy-five first-year veterinary students took tests both before and after using the program, following which each student filled out a survey evaluating the features of the program and describing his/her use and experience of it. Scores improved from 53 ± 2% on the pretest to 74 ± 1% on an immediate posttest. On surveys and in interviews, students reported that the program helped them construct their own understanding of acid/base physiology.

Although this initiative was only modestly successful in achieving its goal of improving student knowledge of acid–base physiology, several important principles emerged that the authors believed could be useful in the development of other computer-based instructional resources. (i) Use simple navigation; students do not want to learn a new piece of software. (ii) On-screen text should appear in relatively short segments or, alternatively, should start with a summary, followed by a more extended discussion. (iii) Use clinical cases, and provide enough cases so that students get sufficient practice with the concepts included in the program. (iv) Repeat concepts in a variety of contexts and from more than one perspective. (v) Emphasize understanding concepts over rote memorization. (vi) Be explicit with students about the overall goals. (vii) Construct the program and the physical environment so that it encourages collaboration among students and encourages a slow and thoughtful progression through the material. (viii) Provide a means for students to compare and contrast cases or concepts. (ix) Explain why some answers are wrong as well as why the right answer is correct. (x) Encourage transfer of learning between cases, and be explicit that students should be applying previously learned material as they progress through the program. (xi) Provide direction for student learning without usurping student involvement altogether. (xii) At regular intervals, encourage students to reflect on what they have learned thus far about both content and the thought process; this will help them appreciate not only what experts know, but how experts think about the content. (xiii) Formulate textual material in the program on the basis of an understanding of students' preconceptions, areas of ignorance and misconceptions about the subject matter.

More recently, in 2014, an interactive computer-assisted instruction for mobile computer platforms was used by Longmuir [12]. In this project, the traditional lecture hall presentation of acid–base physiology in the first-year medical school curriculum was replaced by interactive, computer-assisted instruction designed for the iPad and other mobile computer platforms. Three learning modules were developed, each with ~20 screens of information, on the subjects of the CO_2-bicarbonate buffer system, other body buffer systems and acid–base disorders. Five clinical case modules were also developed with cases covering acute respiratory alkalosis (asthma), chronic respiratory acidosis (COPD), high anion gap metabolic acidosis (diabetic ketoacidosis), normal anion gap (hyperchloremic) acidosis (diarrhea) and metabolic alkalosis (bicarbonate ingestion). Interactive, active learning was based on step-by-step learner control of explanations. For the clinical cases, active learning was primarily question-and-answer exercises that related clinical findings to the relevant basic science concepts. Students reported liking the self-paced instruction, extensive use of interactive graphics and side-by-side presentation of text and graphics. Most students reported that it took less time to study the subject matter with this online instruction compared with the lecture hall. One caveat was that this individual approach to learning resulted in some procrastination, with most students delaying the study of the subject matter until a few days before the scheduled examination. The author suggested that for this approach to be maximally effective, students need to accept the responsibilities of independent learning, and institutions need to measure instructional effort by criteria other than scheduled hours of instruction.

The computer-assisted instruction in this study was implemented using the authoring software AppCobra, developed by Kookaburra Studios (Capalaba, Queensland, Australia; www.appcobra.com). This software has numerous features suitable for the implementation of interactive computer learning. The user interface is entirely menu-driven and does not require line-by-line programming. The AppCobra software exported the finished applications in HTML5-compatible format, so that the instructional modules could be viewed by the learner using a variety of mobile computing devices, including the iPad tablet. Alternatively, the modules could be viewed using laptop and desktop computer systems with standard Internet browsers. Each screen of each module was implemented with 1024 × 640-pixel resolution in landscape orientation; on the iPad, this allowed for viewing a full screen of information using the Safari browser, with up to three lines of browser menu bars, without any vertical scrolling. Website creation for the instructional modules was fully automated and did not require programmer assistance. User access to the instructional modules could be restricted either by password or by domain. With menu-driven secure file transfer protocol software (FileZilla), an entire instructional module could be uploaded in under 10 s from the author's desktop computer to the institutional server. The acid–base physiology modules described in this study are available online for review by individual educators interested in this project (longmuir@uci.edu).

Some of the issues the students brought up about the program were the inability to highlight and annotate content as well as the inability to immediately ask questions. Most students felt that online instruction was useful but should not completely replace other forms of teaching. A variety of combined teaching formats were suggested. These included (i) online instruction, combined with case presentation in the simulation center; (ii) initial presentation of clinical cases online, followed by a discussion of the case by an expert physician in the lecture hall; and (iii) online instruction, combined with a small-group or lecture hall question-and-answer session with the professor. Some students felt that given the complexity of the acid–base physiology subject matter, access to the professor in the lecture hall was important. Several students indicated that, regardless of the merits of online instruction and distance learning, meaningful contact between students and faculty members is valued.

Laboratory-based learning

Another way of teaching acid–base is in the laboratory. The idea here is that theory and practice are linked in order to hopefully help students to develop a deeper understanding of acid/base homeostasis. Friis *et al.* [13], again from Denmark, developed a laboratory exercise in acid/base physiology in order to illustrate theory in practice. Data were collected from 56 groups of medical students that participated in two experiments.

Experiment 1: interval exercise. The student would be seated on an exercise bike with his or her hand in hot water (45°C) for 5 min (in order to dilate the capillaries in the fingers, thus 'arterializing' the capillary blood). During this period, the student would cycle slowly without any significant workload. Blood samples would then be drawn (two capillary tubes for blood gas analysis and two capillary tubes for hematocrit measurements) after thoroughly drying the hand. The student would then start cycling against 4 kg resistance as fast as he or she could for 15 s, rest for 30 s, cycle for 15 s, etc., for a total of 5 × 15 s 'all-out' intervals. During the rest periods, the hand would be kept in hot water, and the student would cycle at a slow pace and without any significant workload on the bike. After the last interval, two capillary blood samples would be drawn with the student still sitting on the bicycle.

Experiment 2: maximal voluntary ventilation (MVV). The student was seated with his or her hand in hot water (45°C) for 5 min. Blood samples were then drawn as described for Experiment 1. Now the student was instructed to hyperventilate as much as possible (with the hand kept in hot water until the next blood sampling). MVV was performed for 30 s followed by 30 s of rest. During the second hyperventilation period, two blood samples were collected.

The blood samples were then analyzed for pH, PCO_2, PO_2, bicarbonate and base excess. The student was then asked to diagnose the acid–base disturbance and the compensatory mechanism. During Experiment 1, there was a marked drop in pH (from 7.43 to 7.21) accompanied by a large decrease in bicarbonate (from 24 to 13 mM) and a small decrease in PCO_2 (from 37 to 34 mmHg). The students correctly diagnosed an acute metabolic (lactic) acidosis with early respiratory compensation. The hematocrit was utilized to calculate the actual base deficit. During Experiment 2, there was a marked increase in pH (from 7.43 to 7.56) accompanied by a large decrease in PCO_2 (from 37 to 24 mmHg) and a small decrease in bicarbonate (from 24 to 21 mM), leading the students to diagnose acute respiratory alkalosis.

The authors chose this set of two experiments because they wished to provide the students with unambiguous results. Indeed, all 56 groups of students obtained similar data and made the correct diagnoses. The authors reported that the students worked hard and there was even a bit of competition to see who could achieve the greatest alteration in pH. Moreover, performing the experiment on oneself has the benefit of fixing the experience (and physiologic concept) in memory.

Once quite widespread in scientific and medical education, the practice of self-experimentation has waned over the last several decades. However, for exercise physiologists working today, the practice of self-experimentation is 'alive and well' [14]. Indeed, the Harvard Fatigue Laboratory under the direction of D. Bruce Dill, has played a large role in legitimizing the practice of self-experimentation in exercise physiology, and is discussed in detail in the above article. Perhaps it is time to return to this time-honored practice to revitalize the teaching of renal physiology.

Conclusions

Acid–base physiology is a difficult subject to master but is one of the foundations of renal physiology. Understanding acid–base physiology is essential for understanding of nephrology. Several innovative methods have been utilized to teach this subject. Unfortunately, in many of these studies, a control group was not employed, and none of the studies used a randomized controlled design. Moreover, much of the data reported were obtained from surveys rather than objective measures of improved knowledge or skills. Rigorous studies, preferably randomized controlled in design, comparing different teaching methods are needed.

Conflict of interest statement

None declared.

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