Development of a manipulative for nephron physiology education

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SOME PHYSIOLOGICAL CONCEPTS, such physiology of filtration and absorption in the different nephron segments, are so detailed that they can be a challenge to be memorized. This article describes an exercise that solidifies learning as students manipulate, using paper models, “transporters” and “electrolytes” in the basolateral and luminal membranes of “nephron cells.” Most important is the opportunity for the students to apply and test their own knowledge related to changes that occur in physiological processes, such as excess of salt or water intake or blood volume alterations, or pathology, such as syndrome of inappropriate antidiuretic hormone secretion, among many other applications.

Description of the Manipulative

This study was applied to first-year medical students at the end of renal physiology lectures at Virginia Tech Carilion Medical School. The protocol was granted exempt status by the Virginia Tech Institutional Review Board (IRB no. 14-039). Students working in self-assigned groups of four or five were given packets containing all necessary materials. Figures 1–3 show examples of one cell, some transporters, and plasma used in this initial study. Complete material is available upon request. Each packet included paper diagrams (8.5 × 11 in.) of the major cell types of the nephron (see Fig. 1 for the early proximal tubule). Small pieces of color-coded cardstock were constructed to represent the major transporters and ion channels present within the epithelial cells of the nephron (see Fig. 2 for examples of some transporters). Strips of grid paper were used to represent several prominent ions, which were color coded to match the transporters. Ions used in the demonstration included Na⁺, Cl⁻, K⁺, HCO₃⁻, water, amino acids, and glucose, where each box of the grid paper represented 10% of the filtered load of the respective ions (Fig. 3).

One important benefit of this teaching methodology is the ability to adapt the manipulative to best fit the instructor’s learning objectives. Lecturers may add or subtract pieces from the model to best suit their own classroom needs. In the work described here, we did not cover the transport of Mg²⁺, Ca²⁺, urea, organic anions, organic cations, carbohydrates, urate, and ammonia, but they can easily be included using the manipulative.

Use of the Manipulative

Part 1: basics of the nephron manipulative. Initially, groups were asked to place the cell types of the nephron in sequential order, beginning with the early proximal convoluted tubule and ending with cells of the collecting duct. Groups were then challenged to place the pieces representing the various transporters and ion channels present in the tubular epithelium in their correct locations. Correct placement required students to know not only the appropriate region of the nephron (e.g., the early proximal tubule, late proximal tubule, early distal tubule, and collecting duct) but also the correct side of the epithelial cell (i.e., basolateral or lumen interface). This setup allowed students to assess their knowledge of the nephron and provided an opportunity for peer teaching and discussion among students.

Students were then asked to move a “plasma sample” (see Fig. 3) consisting of ions, glucose, amino acids, and water through the glomerulus and then through the cells of the nephron sequentially, demonstrating as they move along how the concentrations of various solutes and molecules changed (in terms of approximate percentage of the filtered load in each nephron segment) until the sample reached the collecting duct to be excreted into the bladder and form the “urine.”

Once students had arranged the cells, transporters, and electrolytes to their satisfaction, they were debriefed in a large group format on the correct placement with open discussion among students and faculty members. Questions that checked for comprehension and promoted critical thinking were also posed to the large group during the debriefing session. For instance, when discussing the proximal convoluted tubule, students were asked what percentage of HCO₃⁻ is reabsorbed (answer: 80–90%). Students were then asked whether or not there is a HCO₃⁻ transporter in the luminal membrane of the proximal tubule (answer: no; HCO₃⁻ moves indirectly via Na⁺/H⁺ exchanger 3).

Part 2: application and integration of knowledge. In the second part of the activity, students were asked to select a scenario that they would present to the rest of the class using the nephron model. Examples of scenarios used are shown in Table 1, but this content can be modified based on the instructor’s content needs. For our purpose, as a supplement to the first-year medical education curriculum, we attempted to select scenarios that we felt best highlighted the core physiological principals. Students were encouraged to get creative and were allowed to create additional transporters or hormones out of paper as needed to adequately explain their assigned scenario.

As an example, one group of students was tasked with explaining syndrome of inappropriate antidiuretic hormone secretion to the class and used the model to demonstrate the activation of the V2 receptor by antidiuretic hormone and the subsequent insertion of aquaporins into the apical membrane of principle cells of the collecting duct. Another group discussing hemorrhagic shock decided to draw angiotensin II because they felt it was an essential piece of the scenario that was not included in the initial packet. Each group then presented and described the physiological consequences of their patient scenario, with instructor-led discussion after each presentation.
Discussion

Student feedback immediately after the session was positive and suggested that the activity served as a self-assessment tool that allowed students to gauge their understanding of renal physiology. In a brief postactivity survey, 81% of participants rated the activity as “useful,” “very useful,” or “extremely useful,” and 73% of students found the activity “effective” or “very effective” compared with studying on their own. We intend to further evaluate the model in the upcoming academic year by evaluating student performance on a renal physiology knowledge assessment before and after the manipulative session.

One interesting aspect of this model is that the format allowed for the incorporation of all four of the learning styles described in Fleming’s revised VARK system (where V is visual, A is auditory, R is reading/writing, and K is kinesthetic) (7). While standard lectures are able to reach visual, aural, and read/write learners to an extent, this hands-on model also incorporates kinesthetic learning styles, which appears to be the most common overall learning preference in studies of medical (10), dental (11), and nursing students (1).

The first part of the activity checked for basic knowledge of nephron structure and the second portion, where students applied their knowledge using case scenarios, allowed for an in-depth discussion and application to real-world scenarios. This is important because activities that are authentic and applicable to other areas are more highly valued by learners (4). Furthermore, the ability to solve problems and gain an in-depth understanding of the underlying concepts will be of more use to students in the long run than any particular piece of factual information (8).

A growing body of evidence suggests that students do not retain physiology concepts presented in passive, lecture-based formats (3, 5), suggesting that instructors should implement more active learning into their classrooms. Several active learning techniques have been described for physiology, including neurophysiology (9) and cardiovascular physiology (2). Specific strategies for renal physiology education have also been discussed previously in the literature. Dietz and Stevenson (6) described the successful implementation of active learning in a large medical classroom for renal physiology instruction. They broke students up into small groups and used PowerPoint slides describing medical cases related to renal physiology. TurningPoint clicker questions were then posed to the groups to check for comprehension and encourage class discussion. Through the implementation of such active learning sessions, they were able to reduce renal didactic lecture hours by 25% while enhancing student satisfaction and maintaining student academic performance (6). Here, we describe a different approach to implementing active learning into renal physiology instruction through the use of a manipulative model of the nephron. Our model can be used by itself or to supplement didactic lectures.

Transporters

![Transporters diagram](http://advan.physiology.org/)

Fig. 2. An example of some transporters that were cut out and distributed to students for placement along the basolateral and luminal interfaces of the cells of the nephron. Instructors may easily add or subtract transporters based on their educational goals. NKCC, Na⁺\(\rightarrow\)K⁺\(\rightarrow\)2Cl⁻ cotransporter; SGLT, Na⁺\(\rightarrow\)glucose transporter; AQP, aquaporin; GLUT, glucose transporter; aa, amino acid; ENaC, epithelial Na⁺ channel; NHE3, Na⁺/H⁺ exchanger 3; AE, anion exchanger.
Conclusions

In summary, we have developed a nephron manipulative model that is simple and inexpensive to implement. It may be particularly useful in educational settings with limited financial resources that seek to implement small- or large-group active learning sessions. The manipulative also gives instructors a great deal of flexibility in its use. Components can be added or removed to adapt the activity to any given education setting. A variety of different plasma and urine samples may be created to demonstrate how urine laboratory values change with physiological processes. Undergraduate students could focus only on electrolyte movement with or without the transporters. Pharmacy educators could have students use the manipulative to demonstrate the sites of action of various diuretic drugs. Furthermore, the activity can be adapted to different teaching formats. It can be used during a large-group didactic session by the instructor to illustrate key concepts to the entire class or, as it was in our school, as a small-group activity where students were responsible for setting up materials on their own. The manipulative serves as a flexible teaching tool that incorporates multiple learning styles, including kinesthetic learning styles, in an effort to engage students and promote long-term retention of basic and applied nephron physiology concepts.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

Table 1. Examples of scenarios students were asked to demonstrate using the model

<table>
<thead>
<tr>
<th>Na+ (100%)</th>
<th>K+ (100%)</th>
<th>Cl- (100%)</th>
<th>HCO3- (100%)</th>
<th>H2O (100%)</th>
<th>AA (100%)</th>
<th>Glucose (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na+ K+ Cl-</td>
<td>H C O2- H2 O</td>
<td>aminoacids</td>
<td>Glucose</td>
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<td>Na+ K+ Cl-</td>
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Fig. 3. Plasma sample. The columns representing ions, water, glucose, and amino acids (AA) were cut into strips and distributed to students, with each strip representing 100% of the respective filtered load of that substance. Students were then able to tear the strips apart to represent reabsorption and secretion as they moved through the cells of the nephron in terms of the percentage of filtered load. The paper strips were presented to students as a “plasma sample,” and the remaining pieces at the end of the activity, after students have moved through all of the cells sequentially, was said to be the “urine” produced.

REFERENCES


AUTHOR CONTRIBUTIONS

Author contributions: Z.C.G. and H.C. performed experiments; Z.C.G. and H.C. interpreted results of experiments; Z.C.G. and H.C. prepared figures; Z.C.G. and H.C. edited and revised manuscript; H.C. conception and design of research; H.C. approved final version of manuscript.

Table 1. Examples of scenarios students were asked to demonstrate using the model

A person consumes a bag of salty potato chips, causing an increase in plasma osmolality
A patient with hemorrhagic shock
A patient with hypertension treated with diuretics
A patient with syndrome of inappropriate antidiuretic hormone secretion

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