Outcome assessment of a computer-animated model for learning about the regulation of glomerular filtration rate

Jody L. Gookin,1 Dan McWhorter,2 Shelly Vaden,1 and Lysa Posner2

Departments of 1Clinical Sciences and 2Molecular Biomedical Sciences and 3Unit of Educational Media and Design, College of Veterinary Medicine, North Carolina State University, Raleigh, North Carolina

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Gookin JL, McWhorter D, Vaden S, Posner L. Outcome assessment of a computer-animated model for learning about the regulation of glomerular filtration rate. Adv Physiol Educ 34: 97–105, 2010; doi:10.1152/advan.0012.2010.—The regulation of the glomerular filtration rate (GFR) is a particularly important and challenging concept for students to integrate into a memorable framework for building further knowledge and solving clinical problems. In this study, 76 first-year veterinary students and 19 veterinarians in clinical specialty training (house officers) participated in separate online exercises to evaluate the use of a computer-animated model of GFR regulation (www.aamc.org/mededportal) on learning outcome. Students were randomly allocated to study either the animated model or written materials before completion of a 10-question multiple-choice quiz. House officers completed a 35-question test before and after study of the animated model. Both groups completed a survey about the learning exercise. The ability of the model to enhance learning was demonstrated by a significant improvement (P < 0.001) in the test performance of house officers after studying the model. The model performed similarly to written materials alone in affecting the subsequent quiz performance of the students. The majority of students and house officers agreed or strongly agreed that the animated model was easy to understand, improved their knowledge and appreciation of the importance of GFR regulation, and that they would recommend the model to peers. Most students (63 of 76 students [83%]) responded that they would prefer the use of the animated model alone over the study of written materials but acknowledged that a combination of hardcopy written notes and the animated model would be ideal. A greater applicability of the model to more advanced students and an introduction in a didactic setting before individual study were suggested by the house officers. The results of this study suggest that the animated model is a useful, effective, and well-received tool for learning and creating a visual memory of the regulatory mechanisms of GFR.

medical education; veterinary; interactive; renal physiology

THE KIDNEY is one of the most complex internal organs. This is due, in large part, to the multiple and integrated functions of the kidneys and their highly dynamic regulation by a variety of neurohormonal and hemodynamic inputs. Accordingly, it is challenging to teach renal physiology in a manner that promotes an integrated concept of dynamic kidney function. One of the primary functions of the kidneys is to remove watersoluble waste products from the blood and to precisely and rapidly control the volume and composition of the extracellular fluid.

These functions depend on the exquisite regulation of plasma filtration by ~2 million specialized capillary tufts within the kidneys called glomeruli. The glomerular filtration rate (GFR) is largely dependent on intraglomerular hydrostatic pressure, which is governed by the control of afferent and efferent arteriolar resistance. In turn, the control of afferent and efferent arteriolar resistance is regulated by dynamic myogenic (autoregulation), neurocrine, paracrine (tubuloglomerular feedback), and endocrine (ANG II, endothelin, atrial natriuretic peptide, and arginine vasopressin) stimuli, which each have unique and overlapping sensory mechanisms. Multiple diseases (e.g., heart failure, renal failure, and systemic hypertension) and therapeutic drugs [e.g., inhibitors of angiotensin-converting enzyme (ACE), ANG II receptors, and cyclooxygenase] converge on these pathways to impact the GFR in clinically significant ways. Consequently, the regulation of GFR is a particularly important and challenging concept for students to integrate into a memorable framework for building further knowledge and solving clinical problems.

In the present study, we investigated use of an animated model for teaching veterinary medical students and veterinarians in specialty training about the regulation of GFR. We hypothesized that students would prefer the use of the animated model over the use of written materials alone for learning about GFR regulation and that a significant increase in knowledge would be obtained by the use of the model.

MATERIALS AND METHODS

Animated Model of GFR Regulation

The computer animated model (2) was designed to provide an interactive platform for learning the regulatory mechanisms of GFR (Fig. 1). The educational objectives of the model were to demonstrate 1) the effect of afferent and efferent arteriolar resistance on renal blood flow, glomerular hydrostatic pressure, GFR, filtration fraction, and tubular flow; 2) autoregulatory and tubuloglomerular feedback mechanisms for the regulation of GFR by changes in afferent arteriolar resistance; and 3) the effect of the renin-angiotensin-aldosterone system on the regulation of GFR in response to systemic hypotension. The model is capable of animating the direct effect of afferent and efferent arteriolar resistance and systemic blood pressure on renal blood flow, glomerular hydrostatic pressure, GFR, filtration fraction, and tubular flow. In the program, afferent and efferent arteriolar resistance (increase or decrease) and systemic blood pressure (180-, 80-, or <60-mmHg positions) are user controlled by moving designated sliders. In addition to animating the uncompensated effects of changes in afferent and efferent arteriolar resistance or systemic blood pressure, the model animates renal autoregulation and tubuloglomerular feedback control of afferent arteriolar resistance and the effect of renin-angiotensin-aldosterone activation on the control of GFR. Selection of a “show notes” feature provides a written explanation of the observed physiological responses. The model is accessible at www.aamc.org/mededportal. This website is available to all users provided...
Recruitment of Study Participants

Veterinary students. All students enrolled in the first year of the veterinary medical curriculum (n = 78) were invited to participate in the study. Students were currently enrolled in a semester-long course in veterinary physiology. An invitation was made on the first day of class instruction in renal physiology and then followed up by a same-day e-mail solicitation. Students were informed that participation in the study would entail their accessing, via the internet, a learning exercise on the regulation of GFR. After studying the materials, they would be directed to take an online closed-book quiz. Subsequently, they would be directed to an alternative method of learning the same material and then directed to complete an online survey. Study was required to be completed within a 2-wk period, during which didactic instruction in renal physiology was ongoing. As an incentive to participate in the study, students were awarded 5 points toward any points lost on an upcoming midterm examination in renal physiology. The midterm examination was worth a total of 120 points (or 23.5%) of the total course grade. As an alternative to participating in the study other than a statement that the model was likely to contain material relevant to board certification examinations. Informed consent was provided by participating students and house officers, and the study was approved by the Institutional Review Board of North Carolina State University.

Study Design

Veterinary students. Students were randomly allocated to one of two learning methods with the use of a random integer generator (www.random.org). Even-numbered students were sent an e-mail containing a URL address enabling access to a secure internal webpage containing the animated model of GFR (ANIM group). Odd-numbered students were sent an e-mail containing a URL address enabling access to a secure internal webpage containing written materials describing the regulation of GFR and a still image of the glomerulus (TXT group). Both groups of students were instructed to spend as much time as they needed to study the material and then directed to complete an online survey.
At the termination of the quiz, students were instructed to select a link that directed them to a secure internal webpage containing the alternative learning materials. Accordingly, students in the ANIM group were directed to access the animated model. Students were shown the alternative learning materials so that their preference could be queried in the final survey. At the bottom of the alternative learning materials webpage, all students were instructed to select a link that directed them to an eight-question survey about the learning exercise (APPENDIX B).

House officers. All house officers expressing an interest in participating in the study were sent an e-mail containing a URL address enabling access to a secure internal webpage containing a 35-question pretest (APPENDIX C). At the bottom of the webpage, house officers were instructed to select a link that directed them to the animated model of regulation of GFR. House officers were not randomized to the study of written materials because we anticipated a smaller sample size of house officers willing to participate in the study compared with veterinary students. Upon exiting the animated model, they were instructed to select a link that directed them to a posttest of identical question composition as the pretest. Finally, at the bottom of this webpage, all house officers were instructed to select a link that directed them to a 14-question survey about the animated model (APPENDIX D).

Statistical Analysis

All data were analyzed for normality (Kolmogorov-Smirnov) and variance (Levene median) using a statistical software package and tested for significance using parametric or nonparametric tests as appropriate (SigmaStat, Jandel Scientific). The proportion of students responding correctly to each test or survey item was compared using a z-test. Pre- and posttest result scores were compared using a Student’s paired t-test. Statistical significance was assigned to P values of <0.05.

RESULTS

Participant Demographics

Veterinary students. Seventy-six first-year veterinary medical students participated in the study, including 37 of 37 students assigned to the ANIM group and 39 of 41 students assigned to the TXT group. Two students elected not to participate, both of which would have been assigned, based on a priori allocation, to the TXT group. No students elected to prepare an essay examination as an alternative means to obtain equivalent credit.

House officers. Twenty-nine house officers expressed an interest in participating, of which 19 completed the study. These house officers included 5 interns and 13 residents, the latter of which were pursuing board certification in small animal internal medicine (6), critical care (2), large-animal internal medicine (2), neurology, anesthesia, and clinical pathology. The status of one house officer was unspecified.

Influence of the Model on Learning Outcome

Veterinary students. After studying their assigned primary learning material, students in the ANIM and TXT groups achieved similar item-specific and total scores on the subsequent quiz (ANIM group: mean 7.2 points, range 3–10 points; and TXT group: mean 7.4 points, range 2–10 points).

House officers. After studying the animated model, house officers demonstrated a significant improvement in test performance [pretest mean: 23 of 35 (65%) points, range 13–31; and posttest mean: 32 of 35 (92%) points, range 29–34, P < 0.001 by Student’s paired t-test]. The improved test performance could be attributed to a significant improvement in the response to 14 of 35 (40%) specific test questions (Fig. 2). Examination subject areas in which house officers initially performed poorly and demonstrated significant improvement after study of the model included the differential role of afferent and efferent arteriolar resistance on filtration fraction, the anatomic location of juxtaglomerular and macula densa cells, understanding of myogenic and tubuloglomerular feedback control of GFR, identification of the specific stimuli responsible for stimulating renin release, and the effect of endogenous prostaglandins on afferent arteriolar resistance.

General Impressions of the Animated Model

The majority of students agreed or strongly agreed that the animated model was easy to understand, improved their knowledge and appreciation of the importance of GFR regulation, and that they would recommend the model to other students. Less than enthusiastic responses were obtained from ~20% of students. Compared with the veterinary students, house officers were significantly more likely to strongly agree that the ani-
ated model improved their knowledge and appreciation of the importance of GFR regulation and that they would recommend the model for use by other house officers (Fig. 3).

Preferences for Learning Method

Sixty-three of seventy-six (83%) veterinary students responded that they would prefer the use of the animated model over the study of written materials alone. Students preferring the use of the animated model voluntarily identified themselves as visual learners. The reasons provided for their choice of the animated model included the ability to test their knowledge by predicting the regulatory responses before executing the animation, the benefit of forming a lasting visual memory, and the enjoyment of active participation in the learning process. These students liked the combination of written information and animation in a single resource. Most commented that the written descriptions included in the program were essential to a full understanding of the material. In contrast, 13 of 76 students (17%) responded that they would prefer the use of the written materials alone if only one of the two learning methods was available. These students found the written materials to be a concise, time efficient, and orderly way in which to learn the subject content. In contrast, the use of the animated model alone they found disorienting, time consuming to master the use of, and lacking direction in how to navigate through the program. Most of these students volunteered that the animated model would be helpful to their learning and make better sense if the written materials were also provided and studied first. There were no statistically significant differences in the preference of learning material based on whether students were initially randomized to study the written material rather than the animated model.

While house officers were not provided with alternative study materials or asked about their learning preferences, attributes that they liked about the model included the responsiveness of the program to user input and the ability of the user to manipulate individual variables and control the pace and repetition of the program. They appreciated that the model could appeal to both visual and reading learning styles and provided both basic and clinically applicable knowledge. Dis-

Fig. 3. Percentage of veterinary students and house officers responding to Likert scale-type questions pertaining to the animated model of GFR regulation. *P ≤ 0.05; **P ≤ 0.01 (by z-test).
likes about the model were that it was graphically “busy” and somewhat difficult to confidently identify all of the responses being animated simultaneously.

**House Officer Opinions on the Target Audience**

Most house officers (66%) felt that the model would be best used as a learning tool if introduced in a didactic setting and then made available for individual study. Lesser numbers indicated the best use of the model as an independent study aid (28%) or visual aid during didactic lecturing on glomerular physiology (5%). It was the opinion of the house officers that use of the model would most greatly benefit interns and residents (percent responding very beneficial: 89%) followed by continuing education presentations (83%) and senior medical students (e.g., veterinary, medical, nursing, and pharmacy, 80%). Less enthusiasm was provided for use of the model for learning by first-year veterinary students (50%).

**Recommendations for Improvements to the Animated Model**

Both students and house officers provided similar recommendations for improvement to the model. The program text was considered by many to be too small, and its location interfered with the visualization of animation at the bottom of the screen. In addition to increasing the font size and relocating the text box, users suggested that a feature enabling the text to be advanced in sequence with the animation would be desirable. Additionally, the ability to pause or advance the animation stepwise rather than continuously was sought by several users. Many were unable to discern a change in the animation of tubular flow or arteriolar contraction/relaxation. Some suggestions to improve this included the use of superimposed arrows or highlighting regions of interest to draw attention to the timing, location, and magnitude of these events.

Extended features that the users suggested would improve the program included animations of the effect of drugs (cyclooxygenase, ACE, and Ca2+ channel inhibitors) on GFR, an audio narration describing the animated responses, and written instructions on how to navigate through the program. A number of users commented that they would like to see a similar program depicting Na+ and water transport by the nephron.

**DISCUSSION**

There was no evidence that independent study of the animated model improved student test performance compared with the use of text alone as the primary study material. This could reflect a similar acquisition of knowledge or, alternatively, an inability of the quiz to differentiate the depth of differences in understanding between the two groups. The significance of these results compared with similar studies is uncertain because only a handful of controlled studies, with conflicting results, have ever been undertaken to ascertain the effectiveness of animations in medical education (7). However, students volunteered that the formation of a visual memory of GFR regulation was a key impact of the model. It would be compelling to investigate whether these visual memories provide a superior platform for later recall, advancement, and application of knowledge. We could find few published studies directly evaluating the effect of animation on memory retention. In one of these studies (6), students retained significantly more information 21 days after studying an unnarrated animation compared with the use of a static graphic.

While veterinary students studying either the animated model or written materials performed similarly on a subsequent test of their knowledge of GFR regulation, our use of a pretest and posttest with house officers demonstrated a remarkable improvement in learning after use of the animated model. Although house officers were not aware that the pretest and posttest questions were identical, it is possible that the pretest increased an awareness of deficiencies in the knowledge base that enhanced the learning potential of the model. Likewise, preexisting knowledge of a posttest may have contributed to the similar performance by the veterinary students regardless of learning material. Our use of a pretest additionally identified specific topics where background knowledge of glomerular physiology was deficient. Lack of understanding of the influence of arteriolar resistance on filtration fraction, for example, was not surprising; however, the inability to identify the specific mechanisms responsible for mediating renin release was unexpected and suggests that greater emphasis on this topic in the veterinary curriculum may be warranted.

The majority of first-year veterinary medical students and house officers participating in this learning exercise agreed or strongly agreed that the animated model was easy to understand, improved their knowledge and appreciation of the importance of GFR regulation, and that they would recommend the model to others in their peer group. If given a choice, most veterinary students would prefer the use of the animated model rather than written materials alone for learning about GFR regulation. Most acknowledged, however, that a combination of hardcopy written notes and the animated model would be ideal. This finding agrees with recent studies (1, 3) identifying that most premedical students [55 of 80 (69%) students] and first-year medical students [166 of 250 (76%) students] have multimodal learning preferences.

Several observations from this study suggest that the animated model may be best suited for use by house officers or students in the final year rather than first year of the veterinary medical curriculum. House officers responded more favorably to questions pertaining to the usefulness of the model and whether they would recommend it for use by others. The greater appeal of the model to house officers may reflect a stronger working knowledge of renal physiology, cultivated interest in the physiological basis of renal disease, or perceived relevance of the subject to certifying examinations. Several house officers identified first-year veterinary students as a group that would be unlikely to benefit from use of the model, perhaps because they perceived the model and subject material to be challenging for students with a minimal knowledge of renal physiology. There is some evidence to suggest that the learner’s level of knowledge or expertise in the subject area will impact the outcome of learning using animation (4, 5, 7). Novice learners may not possess the metacognitive skills or prior knowledge to correctly extract and process information from the animation, particularly if it contains complex content or requires attention to simultaneous screen events. This may explain why some veterinary students found the model disorienting and somewhat difficult to confidently identify responses that were animated simultaneously. In contrast to animation, static images allow more novice learners to review the information for as long as they need to achieve understanding.

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Evidence has suggested that breaking animations into smaller segments reduces extraneous cognitive load and that control of the pace of animation improves learning efficiency (7).

The results of this study suggest that the animated model is a useful, effective, and well-received tool for learning and creating a visual memory of the regulatory mechanisms of GFR. The program may be best suited for students already having some background knowledge of renal physiology and should be accompanied by a set of hardcopy notes or text on glomerular physiology. An introduction to the program in class or use of the accompanying instructor’s guide (at www.aamc.org/mededportal) is likely to facilitate use of the model as an independent learning tool.

APPENDIX A: MULTIPLE-CHOICE QUIZ ADMINISTERED TO THE VETERINARY STUDENTS

Without using the instructional materials provided, please answer the following multiple-choice questions pertaining to the regulation of GFR. Please give your best effort to your answers; however, your responses will not be used in determining your grade.

1. Which one of the following is normally filtered by the renal glomeruli into Bowman’s space:
   A. Red blood cells
   B. Plasma fluid
   C. Albumin and globulins
   D. White blood cells

2. Which one of the following is the best definition of GFR:
   A. The volume of plasma that is filtered by the renal glomeruli over a given time
   B. The fraction of plasma that is filtered by the glomeruli over a given time
   C. The volume of urine produced by the kidneys over a given time
   D. The volume of blood that is flowing into the afferent arterioles over a given time

3. Which one of the following is under the direct control of both afferent and efferent arteriolar tone:
   A. Colloid osmotic pressure within the glomerulus
   B. Glomerular filtration coefficient
   C. Filtration fraction
   D. Hydrostatic pressure within the glomerulus

4. Constriction of the afferent arteriole results in which one of the following:
   A. Decrease in glomerular hydrostatic pressure
   B. Decrease in filtration fraction
   C. Increase in GFR
   D. Increase in tubular flow rate

5. Mild to moderate constriction of the efferent arteriole results in which one of the following:
   A. Decrease in glomerular hydrostatic pressure
   B. Increase in filtration fraction
   C. Decrease in GFR
   D. Decrease in tubular flow rate

6. How does the kidney respond to a direct increase in blood pressure and GFR?
   A. Contraction of the afferent arteriole
   B. Contraction of the efferent arteriole
   C. Relaxation of the afferent arteriole
   D. Relaxation of the efferent arteriole

7. How does the kidney respond to a direct increase in mean arterial blood pressure (~80 mmHg) and GFR?
   A. Contraction of the afferent arteriole
   B. Contraction of the efferent arteriole
   C. Relaxation of the afferent arteriole
   D. Relaxation of the efferent arteriole

8. When blood pressure drops precipitously low (<60 mmHg), which one of the following mediators is NOT responsible for stimulating the release of renin from the juxtaglomerular cells?
   A. ANG II
   B. Decreased flow rate in the distal renal tubule
   C. Decreased stretch of the afferent arteriole
   D. Secretion of norepinephrine by renal nerves

9. When mean blood pressure drops precipitously low (<60 mmHg), which one of the following mediators prevents the afferent arteriole from constricting in response to the actions of norepinephrine?
   A. Prostaglandins
   B. ATP
   C. Renin
   D. ANG II

10. Which one of the following results from the effects of ANG II on the efferent arteriole?
    A. Constriction of the efferent arteriole, increased filtration fraction, and more efficient reabsorption of fluid from the renal tubules back into the bloodstream.
    B. Relaxation of the efferent arteriole, decreased filtration fraction, and less efficient reabsorption of fluid from the renal tubules back into the bloodstream.
    C. Release of renin from the juxtaglomerular cells
    D. Release of prostaglandins from the macula densa

Answer Key

Correct answers to the questions are as follows: question 1, B; question 2, A; question 3, D; question 4, A; question 5, B; question 6, A; question 7, C; question 8, A; question 9, A; and question 10, A.

APPENDIX B: SURVEY ADMINISTERED TO THE VETERINARY STUDENTS

1. Please indicate which learning material you were assigned before taking the quiz.
   A. The written description of regulation of GFR
   B. The animated model of regulation of GFR

2. I found the model easy to understand.
   Strongly agree
   Agree
   Somewhat agree
   Disagree
   Strongly disagree

3. The model improved my understanding of the regulation of glomerular filtration.
   Strongly agree
   Agree
   Somewhat agree
   Disagree
   Strongly disagree
4. The model improved my appreciation of the importance of the regulation of glomerular filtration.
   - Strongly agree
   - Agree
   - Somewhat agree
   - Disagree
   - Strongly disagree
5. I would recommend the model to other veterinary students.
   - Strongly agree
   - Agree
   - Somewhat agree
   - Disagree
   - Strongly disagree
6. If you had to learn this material using only one of the two learning approaches, which one would you prefer?
   - A. The written description of regulation of glomerular filtration
   - B. The animated model of regulation of glomerular filtration
7. Please explain why you chose the approach indicated above.
8. Please provide any suggestions for improvement to the animated model of glomerular filtration.

APPENDIX C: PRETEST AND POSTTEST ADMINISTERED TO THE HOUSE OFFICERS

Please answer the following questions regarding the regulation of glomerular filtration using your memory alone (no supplemental material please).

What happens to each of the following hemodynamic parameters in response to contraction of the afferent arteriole:
1. Blood flow to the glomerulus?
   - Increase
   - Decrease
   - No change
2. Intraglomerular hydrostatic pressure?
   - Increase
   - Decrease
   - No change
3. GFR?
   - Increase
   - Decrease
   - No change
4. Filtration fraction?
   - Increase
   - Decrease
   - No change
5. Flow of filtrate through the renal tubules?
   - Increase
   - Decrease
   - No change

What happens to each of the following hemodynamic parameters in response to relaxation of the afferent arteriole:
6. Blood flow to the glomerulus?
   - Increase
   - Decrease
   - No change
7. Intraglomerular hydrostatic pressure?
   - Increase
   - Decrease
   - No change

What happens to each of the following hemodynamic parameters in response to contraction of the efferent arteriole:
8. GFR?
   - Increase
   - Decrease
   - No change
9. Filtration fraction?
   - Increase
   - Decrease
   - No change
10. Flow of filtrate through the renal tubules?
   - Increase
   - Decrease
   - No change

What happens to each of the following hemodynamic parameters in response to relaxation of the efferent arteriole:
11. Blood flow to the glomerulus?
   - Increase
   - Decrease
   - No change
12. Intraglomerular hydrostatic pressure?
   - Increase
   - Decrease
   - No change
13. GFR?
   - Increase
   - Decrease
   - No change
14. Filtration fraction?
   - Increase
   - Decrease
   - No change
15. Flow of filtrate through the renal tubules?
   - Increase
   - Decrease
   - No change

What happens to each of the following hemodynamic parameters in response to relaxation of the efferent arteriole:
16. Blood flow to the glomerulus?
   - Increase
   - Decrease
   - No change
17. Intraglomerular hydrostatic pressure?
   - Increase
   - Decrease
   - No change
18. GFR?
   - Increase
   - Decrease
   - No change
19. Filtration fraction?
   - Increase
   - Decrease
   - No change
20. Flow of filtrate through the renal tubules?
   - Increase
   - Decrease
   - No change
21. Please provide a one-sentence definition for GFR.
22. Please provide a one-sentence definition for filtration fraction.
23. Anatomically within the kidney, where are the juxtaglomerular cells located?
24. Anatomically within the kidney, where are the macula densa cells located?
25. The mechanisms by which the kidney controls the tone of the afferent arteriole to maintain a constant GFR are collectively termed “autoregulation.” What is the “myogenic mechanism” of autoregulation, and how does it control the tone of the afferent arteriole?
26. The mechanisms by which the kidney controls the tone of the afferent arteriole to maintain a constant GFR are collectively termed “autoregulation.” What is the “tubuloglomerular feedback” mechanism of autoregulation, and how does it control the tone of the afferent arteriole?
27. Anatomically within the kidney, where does renin come from?
28. Name three stimuli that act upon renin-producing cells to cause the release of renin.
29. Which one of the following is correct regarding the mechanism of action of renin:
   A. Renin stimulates ACE
   B. Renin converts ANG I to ANG II
   C. Renin converts angiotensinogen to ANG I
   D. Renin stimulates the synthesis of angiotensinogen by the liver
30. ANG II has which one of the following effects on the glomerulus:
   A. Contraction of the afferent arteriole
   B. Contraction of the efferent arteriole
   C. Relaxation of the afferent arteriole
   D. Relaxation of the efferent arteriole
31. Why would it be advantageous to constrict the efferent arteriole in the face of systemic hypotension?
32. Endogenous prostaglandins have which one of the following effects on the glomerulus:
   A. Contraction of the afferent arteriole
   B. Contraction of the efferent arteriole
   C. Relaxation of the afferent arteriole
   D. Relaxation of the efferent arteriole
33. Which one of the following is likely to be a physiological consequence of administering a prostaglandin synthesis inhibitor to a patient with systemic hypotension:
   A. Decreased constriction of the afferent arteriole
   B. Decreased renal blood flow
   C. Increased glomerular hydrostatic pressure
   D. Increased tubular flow rate
34. Which one of the following is an anticipated result of the systemic administration of an ACE inhibitor:
   A. Increase in the filtration fraction
   B. Increase in GFR
   C. Decrease in glomerular hydrostatic pressure
   D. Decrease in renal blood flow
35. What is the rationale for administering an ACE inhibitor (e.g., benazepril) before initiating treatment with a Ca$^{2+}$ channel blocker (e.g., amlodipine) in a patient with systemic hypertension?

Answer Key for Multiple-Choice Questions

Correct answers to the questions are as follows: question 1, decrease; question 2, decrease; question 3, decrease; question 4, no change; question 5, decrease; question 6, increase; question 7, increase; question 8, increase; question 9, no change; question 10, increase; question 11, decrease or no change; question 12, increase; question 13, increase; question 14, increase; question 15, increase; question 16, increase or no change; question 17, decrease; question 18, decrease; question 19, decrease; question 20, decrease; question 29, C; question 30, B (or A); question 32, C; question 33, B; and question 34, C.

APPENDIX D: SURVEY ADMINISTERED TO THE HOUSE OFFICERS

Please answer the following questions pertaining to your experience using the animated model of GFR.

1. I found the model easy to understand.
   Strongly agree
   Agree
   Somewhat agree
   Disagree
   Strongly disagree

2. The model improved my understanding of the regulation of glomerular filtration.
   Strongly agree
   Agree
   Somewhat agree
   Disagree
   Strongly disagree

3. The model improved my appreciation of the importance of the regulation of glomerular filtration.
   Strongly agree
   Agree
   Somewhat agree
   Disagree
   Strongly disagree

4. I would recommend the model to other house officers.
   Strongly agree
   Agree
   Somewhat agree
   Disagree
   Strongly disagree

5. First-year veterinary students (basic science curriculum)?
   Very beneficial
   Somewhat beneficial
   Not very beneficial
   Not beneficial

6. Third-year veterinary students (clinical science curriculum)?
   Very beneficial
   Somewhat beneficial
   Not very beneficial
   Not beneficial
7. Interns and residents?
   - Very beneficial
   - Somewhat beneficial
   - Not very beneficial
   - Not beneficial
8. Continuing education presentations?
   - Very beneficial
   - Somewhat beneficial
   - Not very beneficial
   - Not beneficial
9. Are there any other groups of individuals that you think would benefit from use of the model?
10. What do you think would be the best way to use the model as a learning tool?
    - A. As a visual aid during a didactic lecture on glomerular physiology
    - B. As an independent study tool
    - C. Introduced in a didactic setting and then available for individual study
    - D. Other
11. What did you like about the animated model?
12. What did you dislike about the animated model?
13. Please provide any suggestions for improvements to the animated model of glomerular filtration.
14. Which one of the following best describes your current position?
    - A. Intern
    - B. Resident
    Please indicate specialty area.

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REFERENCES