Curricular Integration of Physiology

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INTRODUCTION

Nursing is a diverse profession that attracts entrants with a wide range of prior educational experience. The challenge that educators face is to ensure that physiology and the other bioscience topics are engaging and support knowledge and skill development. They must show the relevance of the biosciences to the “real world” clinical practice that is experienced by all students and practitioners. Patient and public safety require a practice built on a sound foundation of knowledge. The purpose of this study was to provide guidance to educators, reduce variability, and set a benchmark in terms of level and breadth for the foundational physiological knowledge that supports professional development and safe patient care.

This project provides a clear definition of the relevant physiological knowledge that is required by nurses to support their clinical practice at registration. Consensus-driven, core learning outcomes were developed to define the key physiological concepts on which nurses will build throughout their future careers, supporting their lifelong learning, through ongoing reflective practice and continual professional development.

The United Kingdom (UK) shift in professional regulation to a competency-based standards framework supports educators in developing an approach more aligned to student learning. Locating student learning across both university- and practice-based environments supports the understanding of the skills they are developing, in relation to their subject learning (1). However, in terms of the subject knowledge to support practice, the standards-based framework is less helpful requiring students to gain

... a comprehensive knowledge of the sciences on which general nursing is based, including sufficient understanding of the structure, physiological functions and behaviour of healthy and sick persons, and of the relationship between the state of health and the physical and social environment of the human being [Nursing and Midwifery Council (25), Standards Part 3, Annexe 1.6].

The Bioscience in Nurse Education (BiNE) group is a specialist reference group of the Higher Education Academy, consisting of academics with experience in pre- and post-registration nurse education (https://www.advance-he.ac.uk/knowledge-hub/bioscience-nurse-education-bine-special-interest-group). This group, established in 2012, developed the Biosciences Quality Assurance Framework learning outcomes (Table 1) to provide more guidance to educators, but this resource lacked specificity within the discrete subject areas (5).
The demand for nurses and other healthcare professionals worldwide underpins the laudable aim of “Health for All,” which is enshrined within current development policies and practices such as the sustainable development goals (SDG) (29). Achieving universal health coverage will rely on substantial development of both health personnel and the way they work in society. Currently, there is a worldwide deficit in the healthcare workforce, which is set to increase over the coming years, unless major steps are taken to recruit, train, and retain staff (1). The nature of healthcare is also changing as it adapts to a relative reduction in infectious disease morbidity and mortality and to a growing global epidemic of noncommunicable diseases (11). Recent experiences with COVID-19 required the redeployment of nurses and other healthcare staff into acute care areas. This action illustrated the need for all nurses to have a consistent underpinning of bioscience knowledge to support them in any area of practice.

This COVID-19 pandemic will change the future healthcare environment, and true advances toward the SDGs require community-based, patient-centered care delivered with an interdisciplinary focus, addressing social, political, environmental, and economic factors over and above the traditional biomedical approaches (13). Within this context, nurses are pivotal, because patient-centered care is central to nursing practice, and they form the majority of the healthcare workforce. The definition of nursing from the International Council of Nurses states:

Nursing encompasses autonomous and collaborative care of individuals of all ages, families, groups and communities, sick or well and in all settings. Nursing includes the promotion of health, prevention of illness, and care of ill, disabled and dying people. Advocacy, promotion of a safe environment, research, participation in shaping health policy, and in
patient and health systems management, and education are also key nursing roles (14).

“In many parts of the world, nurses are the first, and sometimes the only, health professional that patients see . . .” (8) and are increasingly influential in the healthcare provision. Nurse education must respond and adapt to changing expectations placed on the profession to equip the nurse at the point of registration with fundamental conceptual knowledge appropriate to their future practice in any clinical context. This project aimed to develop a set of core physiology learning outcomes with a specific nursing focus. This will assist educators to meet the requirements of the nursing role, nursing students, and professional regulators so that students are equipped with the knowledge to support their future role as a nurse in practice to safeguard patient care.

MATERIALS AND METHODS

A modified Delphi process was used to facilitate the aims of this project (16, 17). The Delphi approach allowed for consensus to be gained through a structured process (27), where group opinion from expert members was then circulated anonymously for comment to interested relevant parties who met the inclusion criteria (Tables 2 and 3).

The modified Delphi approach began in round 1 with initial identification and revision by the expert panel of the set of learning outcomes. Rounds 2 and 3 were online e-mail questionnaires in line with the classical Delphi approach and expert panel review for typographical changes. The project outline is shown in Fig. 1.

Round 1. Within UK nursing higher education, there is no shared physiology curriculum to follow or assess, unlike other professions or subject areas. The study by Connolly et al. (5) used an existing anatomy syllabus as the starting point from another profession. Although physiology learning outcomes in science and medicine exist (4), none was available that was specific to nursing. Here a similar topic identification approach as that of Moxham et al. (23) was used in the modified Delphi approach. The project leads (A.F.W. and C.C.) defined the initial set of learning outcomes derived from existing curricula, textbooks, and online resources. This provided the starting point of the core curriculum, with 360 learning outcomes focused on topic rather than the taxonomy. This focus on detailed outcomes was to avoid a “broad brush” approach, which is already covered within the BiNE framework.

Expert panel discussion reduced and modified the learning outcomes. The expert panel was recruited by invitations to the membership of the BiNE network and comprised eight physiologists and nurses with extensive experience (10 yr plus) of teaching, organizing, and evaluating physiology modules in pre-registration nurse education. They discussed the initial set of 360 learning outcomes, considering them from both a conceptual and systems-based approach at their meeting. The initial 360 learning outcomes were refined and organized with a systems-based approach, as this provided a clear structure and related well to the majority of textbooks and other available resources. The learning outcomes were also revised in line with Bloom’s taxonomy to ensure an academic level consistent with the requirements of university graduate nurses. These refinements resulted in 195 outcomes for inclusion in the round 2 survey.

Round 2. This first online questionnaire was circulated as part of the modification phase. Participants were introduced to the survey via an e-mail sent to all university departments in the UK who provided pre-registration nurse education identified through an online search. The BiNE network was also used for dissemination of the survey. The following questions introduced the survey: “Have you considered if pre-registration nursing students are learning enough physiology for qualification?” and “Would you like to share your views on what physiology nursing students should know by their graduation?” The invitation stated: “We would like to invite you to help and share your views to produce a set of learning outcomes for pre-registration nursing students related to physiology.” The anonymous questionnaire allowed participants to state their experience and disciplinary background. The survey contained the 195 intended learning outcomes from the Delphi expert panel. Participants were asked to accept, reject, modify, and/or comment on each outcome.

Round 3. The second online questionnaire was circulated to the identified HEIs and again also through the BiNE network. Participants were asked to accept or reject the 182 modified list of outcomes with comments requested on each system, which could include typographical modifications or suggestions. All outcomes with 80% or more consensus were automatically included, and any with less than 80% were rejected.

Ethical approval for this study was obtained through Edinburgh Napier University, and informed consent was obtained from the members of the expert panel. The project and use of the data were explained clearly on the first pages of the questionnaire, alongside instructions for completing and submitting the responses. Simple demographic information was requested in the early section of the

Table 3. Inclusion and exclusion criteria for the national online consensus survey

| Inclusion Criteria | Exclusion Criteria |
|--------------------|--------------------|
| A minimum of 3 yr teaching experience in physiology for undergraduate nurses | Advanced Nurse Practitioners |
| Actively employed at a nursing school | Postgraduate programs |
| Teaches on the nursing common foundation program and applied | No physiology teaching experience |
| pathophysiology programs at undergraduate level | Physiology teaching experience of 1–3 yr |
| Expert panelist members | |

1 The following is the list of textbooks and other sources: Primal Pictures. Anatomy.TV (Online) (https://www.anatomy.tv/); Barrett KE, Barman SM, Boitano S, Brooks H. Ganong’s Review of Medical Physiology (25th Ed). New York: McGraw-Hill Education, 2016; Boron WF, Boulpaep EL, Medical Physiology (3rd Ed). Philadelphia, PA: Elsevier, 2017; Hall JE, Guyton and Hall Textbook of Medical Physiology (13th Ed). Philadelphia, PA: Elsevier, 2016; Kibbble JD, Halsey CR. Medical Physiology: The Big Picture. New York: McGraw-Hill, 2009; Michael J, Cliff W, McFarland J, Modell H, Wright A. The Core Concepts of Physiology: A New Paradigm for Teaching Physiology. New York: Springer, 2017; Martini FH, Bartholomew EF. Essentials of Anatomy and Physiology (7th Ed). New York: Pearson, 2017; Tortora GI, Derrickson B. Principles of Anatomy and Physiology (13th Ed). New York: Wiley, 2011; Waugh A, Grant A, Ross and Wilson Anatomy and Physiology in Health and Illness (12th Ed). London: Churchill Livingstone, 2014.
form to establish that respondents met the eligibility criteria for the survey, but no specific personal data were collected. Respondents confirmed their consent to participate at the start of the questionnaire and reconfirmed it at the point of submission. The survey system used (Novi Survey) ensured that data were held securely on the university server.

RESULTS

The progressive development and refinement process of the learning outcomes was shown above in MATERIALS AND METHODS.

Round 1. The expert panel discussion confirmed the approach based on learning outcomes as one that would allow a definition of topic and level to be achieved at the point of registration, regardless of the educational model and delivery pattern. This also raised the issue of the level of knowledge that students could be expected to have on entry to a program; hence, although some learning outcomes were seen as too basic, they were retained from the expert panel discussions to be tested in the Delphi survey rounds. The decision to follow a systems-based approach for the learning outcomes was debated within the expert panel and drew more on the traditional structures of existing physiology curricula while equally able to support curricula based on integrated systems biology, applied, clinical, or life course approaches.

Round 2. Fourteen full responses were received from the 65 UK HEIs contacted (22% response rate). With a consensus of at least 80% agreement for the proposed learning outcomes for inclusion, 11 learning outcomes were identified for rejection, 3 were identified as duplicates, and 32 were flagged for modification. The rejected outcomes were either seen as too basic, not clinically relevant, or suitable at post-registration level. One outcome was added following the comments from the questionnaire and panel review, leaving 182 outcomes to be circulated in round 3, the second online questionnaire.

The majority of learning outcomes were retained, but those rejected were judged to be either too basic or too advanced (Table 4). For example, some were seen as too basic, “Distinguish between atoms, elements, molecules, and compounds” and “Distinguish between ionic, covalent, and hydrogen bonds,” and raised concern within the expert panel, as, without these fundamental concepts, a student may lack the scientific literacy to engage with many of the other learning outcomes. These entry level threshold concepts may be an obstacle to understanding physiology for some students who lacked sufficient science background in this interdisciplinary profession.

Round 3. This second circulation of the Delphi survey confirmed and refined the learning outcomes. This round received 15 full responses from the 65 UK HEIs (23% response rate), with 178 outcomes at or above the 80% consensus automatically included. However, minor typographical modifications were made to 17 outcomes following commentary and review by the project team and expert panel. The majority, 106
of these 178 outcomes reached 100% consensus from both the expert panel and the second round Delphi survey. One outcome was removed by the panel due to repetition within another agreed outcome, and four were automatically rejected as they fell below the 80% consensus (Table 5). This resulted in consensus on the 177 learning outcomes grouped within a systems approach (see the Appendix).

**DISCUSSION**

The decision to present the learning outcomes in a systems-based approach drew more on the traditional structures of existing physiology curricula. While it may provide a logical framework for learning, it could equally support curricula based on integrated systems biology, applied, clinical, or life course approaches and may be integrated into nursing modules where the assessments may not specifically test the physiology component. For example, using an integrated approach to the body’s response to exercise could draw on elements of all of the systems listed and be part of a clinically relevant package of teaching around obesity or extreme weight loss. However, from an educational point of view, this could be overwhelming for the student early in their learning journey, but could help senior students and qualified staff to draw these topics into their practice relevance. This integration to support nursing practice is known to be valued by students (6). Considering the applied nature of some learning outcomes to clinical practice helps students see the relevance; for example, highlighting the learning outcome of bone formation to understand healing and repair for patients with fractures indicates the necessity and importance of this topic. Similarly, in phlebotomy, knowledge about the clotting process explains the need for removing the needle to press on the site so that patients do not bleed, and this directly applies to the development of practical skills.

It was noted that while these learning outcomes provide a structured list, they do not imply the structure of delivery and may be interpreted quite differently, depending on the nursing program within which they are delivered. Within the UK, they should be integrated into clinically relevant programs, supporting and meeting the requirements of the Nursing and Midwifery Council standards expressed as skills and proficiencies.

### Table 5. Final rejections from round 3 online questionnaire

| Learning Outcome                                                                 | Rationale for Rejection                                                                 |
|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Distinguish between local and humoral control of tissue blood flow.             | Not specifically related to a relevant clinical application.                           |
| Describe the regulation and different stages of labor.                          | Applicable to midwives rather than pre-registration nursing students.                  |
| Outline the process, regulation, and benefits of lactation.                     | Applicable to midwives rather than pre-registration nursing students.                  |
| Describe the structure, normal stimulus, and function of the semicircular canals | Too specific, combined with a more general outcome of vestibulo-cochlear function.    |
| and otolith organs and outline the equilibrium pathways.                        |                                                                                        |

REM, rapid eye movement; NREM, non-rapid eye movement; V\textsubscript{O2}\textsubscript{max}, maximum O\textsubscript{2} uptake.
(25), thus providing the physiological backdrop across the life course to support experience in specific areas of care (e.g., maternity, child, psychotic, and care of the older person), as required by the European Union directives (9). The shift to competency-based standards places practice at the forefront, these learning outcomes can be used to reduce variability, improve understanding, and support the application of science to healthcare, where technology demands more of health workers, especially nurses.

The overall aim of the nursing curriculum must be to underpin the competent practice of the newly qualified nurse. However, bioscience is perceived to be a difficult subject within a pre-registration nursing course (7), with physiological concepts known as challenging to students and a particular cause of anxiety to them (22). Sound knowledge of anatomy and physiology can be an indicator of success in both pre-registration courses (3) and post-qualification support for patient care and safety (15). These learning outcomes define the range of physiological knowledge that can support clinical decision making and ongoing learning.

Understanding key concepts of the body’s functions equips practitioners in their reflective learning and ongoing development throughout their careers. Such concepts can be used as thresholds to fuller understanding and better situational decision making in practice. Some students at the start of their nursing studies may not be equipped with the language and basic scientific concepts to engage with this area of study. This was reflected in the round 2 rejection of some of the fundamental learning outcomes around the structure of atoms and molecules, the nature of chemical bonds, and chemical reactions. These were seen as too basic to be included, although, for some students, support may be needed with these fundamental threshold concepts.

In other proposed learning outcomes, the overlap with related disciplines was evident, in particular anatomy and pathology. These could represent false divisions to nursing students who are seeking to understand the integrated nature of the human body with all of its changes over a lifetime, through normal development and aging with the overlay of degenerative, infective, or noncommunicable diseases. These learning outcomes present a core level of physiological knowledge for all fields of practice in nursing at the point of registration, which will also provide a starting point for advanced professional practice. Combining learning outcomes from the different bioscience disciplines represents the next step in supporting nursing education by joining up the subjects to facilitate the interdisciplinary profession of nursing. A strong bioscience background is needed to support further postgraduate study and role development in relation to independent prescribing, advanced clinical examination and diagnosis, and expanding nursing roles as they develop across the world. In this context, these learning outcomes underpin safe practice and patient care, congruent with licensing approaches in other countries.

Nursing is fundamentally interdisciplinary and, as such, may suffer from the challenges of language and conceptual differences between the individual disciplines (24). The majority of nurse educators that the students encounter, both in academia and clinical practice, will not be bioscience specialists; hence learning outcomes need to be sufficiently explicit, accessible, and clinically relevant to support student learning and staff engagement. In summary, these learning outcomes, constructed by a panel of experienced physiologists and nurse educators, aim to support the education of the current and future pre-registration nursing students by identifying the core foundational knowledge essential for delivery of safe patient-centered care and future nursing practice.

APPENDIX: PHYSIOLOGY LEARNING OUTCOMES

The 177 learning outcomes are given in Table A1.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

A.F.W. and C.C. conceived and designed research; A.F.W., C.C., S.C., C.R., J.J., A.D.P., C.D., and A.G. performed experiments; A.F.W. and C.C. interpreted results of experiments; A.F.W. and C.C. prepared figures; A.F.W. and C.C. drafted manuscript; A.F.W., C.C., S.C., G.F., C.R., J.J., A.D.P., C.D., and A.G. edited and revised manuscript; A.F.W. and C.C. approved final version of manuscript.

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Table A1. Physiology learning outcomes (177 learning outcomes)

A. Foundations of Physiology
Science of Life
1. Define the terms acids, bases, and salts.
2. Apply the terms mixture, solution, solute, solvent, colloid, and suspension, for example in relation to blood and body fluids.
3. Understand how the structure of carbohydrates, proteins, lipids, and nucleic acids contributes to function in cellular control, metabolism and nutrition.
4. Explain how energy is acquired, transformed and transferred to maintain life: heat transfer, metabolic rate, redox environment, ATP, and enzymes by:
   a. Identifying and explaining the factors that can affect the rate of chemical reactions.
   b. Identifying the structural features of an enzyme and their relationship to enzyme function.
   c. Identifying the properties of ATP and its role in energy transfer.
5. Describe systems of control and give examples of:
   a. Feedback (cell to cell and to systems).
   b. Adaptation and compensation.
   c. Dysregulation.

The Cell—The Fundamental Unit of Life
6. Describe the structure and function of the components of the cell.
   a. Plasma membrane and membrane proteins and carbohydrates in relation to excitability, active and passive transport, cell recognition and receptors.
   b. Nucleus and the nuclear membrane.
   c. Cell organelles.
   d. Cytosol constituents.
7. Explain how changes of tonicity of body fluids (diffusion, osmosis, active transport) can alter fluid balance and may lead to various disease states.
8. Describe intracellular processes involved with the metabolic control of cell function and second-messenger systems in health and disease.
9. Describe the cell cycle and the factors that influence cell growth, development, aging, and death in nuclear and cell division.
10. Engage with contemporary knowledge of the contribution of genetics and genomics to health and disease by explaining in relation to the cell cycle:
    a. The significance of chromosomes in heredity and genomics.
    b. The difference between mitosis and meiosis and their purpose in the body.
    c. The processes of DNA replication, gene expression and protein synthesis.
    d. Adaptation to cellular stress (e.g., hypertrophy, hyperplasia, neoplasia).
    e. Cell death (e.g., apoptosis, necrosis, senescence).

The Body Fluid Compartments: Extracellular and Intracellular Fluids, Homeostasis
11. Compare the distribution and composition of fluid compartments in the body and the importance of maintaining them within tight controls (electrolyte/ionic, pH, temperature, volume).
12. Identify the causes and types of edema and the factors involved in its formation.

Tissues
13. Identify the function of the basic tissue types:
    a. Epithelia.
    b. Connective tissue.
    c. Muscle.
    d. Nerve.

Integumentary
14. Discuss the following functions of the skin and its appendages:
    a. Thermoregulation.
    b. Protection (physical, chemical, immunological, microbiological, sunlight).
    c. Sensation.
    d. Synthesis of vitamin D.
    e. Excretion.
    f. Indicator of health and aging.
    g. Pigmentation and responses (sunlight, shock/pallor, emotion, psychology, culture).
15. Discuss the response of the skin to injury and wound healing.

Musculoskeletal Physiology and Movement
16. Identify the functions of the musculoskeletal system.
17. Compare and contrast the properties and function of skeletal muscle with cardiac and smooth muscle and outline the mechanism of contraction and its control.
18. Define the term motor unit and describe the function of the neuromuscular junction.
19. Explain the processes of bone formation, remodeling and repair and describe the differences across the life course.
20. Identify the role of joints in facilitation of movement.
21. Discuss the changes in the musculoskeletal system.
    a. Across the life course.
    b. Through use and disuse.
22. Explain the hormonal and nutritional factors that affect the musculoskeletal system.

B. Immunology
23. Discuss the components of innate immunity:
    a. Physical defenses (e.g., mucous membranes).
    b. Chemical (e.g., lysozymes).
    c. Cellular (e.g., phagocytes).
    d. Mechanical (e.g., vomiting).
    e. Microbiological (e.g., gut microbiota).

Continued
Table A1.—Continued

24. Explain the role and process of inflammation and identify the chemical mediators involved.
25. Discuss the development and significance of fever/pyrexia.
26. Discuss the components of adaptive immunity:
   a. Humoral responses.
   b. Cell-mediated responses.
27. Discuss the antibody-mediated response, including immunoglobulin isotypes and their functions.
28. Discuss the significance of immunological memory and acquired immunity.
29. Explain the concept of self-recognition and tolerance.
30. Identify the characteristics of the primary and secondary immune responses.
31. Distinguish between active and passive immunity.
32. Discuss the role of vaccination programs and herd immunity in public health.
33. Explain the role of the lymphatic system in immunity.
34. Discuss immune responses and altered health status in:
   a. Hypersensitivity
   b. Autoimmunity
   c. Immunosuppression.
35. Discuss the impact of the interactions between the nervous and immune systems on health (psychoneuroimmunology), in particular how responses to stress can affect health.
36. Describe the human microbiome and the interaction of microbiota with body systems in health and disease across the life course.

C. Cardiovascular Physiology

The Heart
37. Relate the structure of the heart to its function.
38. Describe the conducting system of the heart.
39. Explain the events of the cardiac cycle, the pressure changes, blood flow, and the state of the valves during each stage.
40. Relate the standard electrocardiogram to the cardiac cycle and explain the alteration in conduction responsible for common arrhythmias.
41. Discuss cardiac output and its relationship to stroke volume and heart rate.

The Circulation
42. Distinguish the functional differences between the different types of blood vessels with regard to their structure.
43. Discuss tissue perfusion and its relationship to cardiac output, blood pressure, flow, and peripheral resistance.
44. Discuss the regional distribution of blood to organs and systems within the body.
45. Explain the factors that influence exchange between the blood, lymph and interstitial fluid.
46. Explain the importance of coronary perfusion to heart function.
47. Discuss the importance of venous return to cardiovascular function and control.

CVS Control
48. Discuss the neural and hormonal regulation of heart rate and contractility.
49. Describe the baroreceptor reflex and its role in blood pressure control.
50. Describe the renin-angiotensin-aldosterone system (RAAS) in the control of arterial blood pressure.
51. Explain how blood flow and cardiac output changes during exercise in response to the metabolic requirements of muscle cells.
52. Recognize the systemic compensatory mechanisms during challenged cardiovascular function (e.g., shock).
53. Discuss the changes to cardiovascular function across the life course.

Blood
54. List the basic functions of whole blood.
55. Identify the cellular and noncellular components of blood and state their functions.
56. Outline the stages of hematopoiesis.
57. Discuss the potential for stem cell research to improve health.
58. Identify the characteristics of the red blood cell in relation to its function.
59. Describe the ways in which oxygen is transported in blood, the structure of hemoglobin, and the factors that influencing the binding of these.
60. Describe the ways in which carbon dioxide is transported in blood.
61. Describe the life cycle of the red blood cell and explain the recycling of the hemoglobin molecule.
62. Distinguish between the ABO blood groups and the Rh factor and their significance to safe transfusion practice.
63. Recognize and interpret blood profiles (venous and arterial) as indicators of health status.
64. Discuss the factors that influence blood coagulation.
65. Explain the sequence of events and factors that influence hemostasis and blood clotting.

Acid-Base Regulation
66. Identify the normal range of pH values and describe their significance in a variety of body fluids.
67. Describe the role of buffers in maintaining pH and specifically the role of respiratory and renal regulation in maintaining plasma pH.

D. Respiratory Physiology
68. Describe the functions of the respiratory system.
69. Identify the structure-function relationships at all levels of the respiratory system, from the mouth and nose to the alveoli and its components.
70. Define and compare the three factors that affect pulmonary ventilation:
   a. Airway resistance
   b. Lung compliance
   c. Surface tension.
71. Explain how gas laws relate to intrapleural and alveolar pressures and volumes during ventilation.
72. Define and distinguish between various pulmonary volumes and capacities and how they are measured.
73. Describe the gaseous exchange of oxygen and carbon dioxide between the alveolus, blood, and body cells.
74. Explain the control of ventilation and the factors that influence the rate of pulmonary ventilation including:
   a. Chemoreceptors.
   b. Stretch receptors.
   c. Proprioceptors.
Table A1.—Continued

75. Identify the location and state the functions of the regulatory respiratory centers.
76. Describe the function of the muscles of ventilation and recognize signs of respiratory compensation.
77. Relate normal and abnormal breath sounds to the quality of ventilation and the processes causing these changes.
78. Describe the factors affecting pulmonary ventilation and outline how these may give rise to alterations in alveolar ventilation in disease states.
79. Describe the changes during the life course and the effect of environment (air quality, altitude, diving) on respiratory function.

E. Exercise Physiology.
80. Explain the control mechanisms responsible for increased ventilation and heart rate during exercise and how they can occur without any measurable change in arterial blood gas values.
81. Discuss the effects of exercise training on the heart and coronary circulation.
82. Describe the impact of exercise on the health of whole person and the individual body systems.

F. Gastrointestinal (GI) System Physiology.
83. List and describe the functions of the gastrointestinal system and associated organs.
84. Describe the movement of food through the digestive system (from entry to exit) and the changes that occur as food is digested and the nutrients absorbed.
85. Identify the components and functions of gastric, hepatic, pancreatic, and duodenal secretions.
86. Describe the cephalic, gastric and intestinal phases of digestion and explain the neural (central and enteric), endocrine and paracrine controls of:
   a. GIT movement.
   b. Secretion.
87. Explain the mechanism of control and phases of swallowing and identify situations in which it can become compromised.
88. Distinguish between endocrine and exocrine functions of the pancreas.
89. Describe the functions of the liver and gallbladder.
90. Explain the role of the liver and gallbladder in the carbohydrate, lipid, and protein metabolism.
91. Describe the digestion, assimilation and absorption of the major nutrients (fats, carbohydrates, and proteins).
92. Identify the sources and approximate requirements of fluid and nutrients entering and leaving the gastrointestinal tract daily for individuals at different stages of life.
93. Describe the functions of the large intestine.
94. Describe the sequence of events in the colon that contribute to the processes of compaction and movement of fecal matter for defecation.
95. Differentiate between movements under voluntary and involuntary (autonomic and enteric) control throughout the small and large intestine and describe the defecation reflex.
96. Understand the characteristic differences in digestive function across the life course (specifically in babies and aging individuals):
   a. Motility.
   b. Absorption.
   c. Secretion.
   d. Sensitivity.
97. Describe the alterations in motility that can lead to gastroparesis, achalasia, diarrhea, constipation, megacolon and irritable bowel syndrome.

G. Endocrine Physiology
98. Explain the functional difference between endocrine and exocrine glands.
99. Explain the principle of negative feedback, positive feedback, and feed-forward control of hormone secretion.
100. Identify the different chemical classes of hormones (peptide, steroid, and amines) and distinguish between their mechanisms and actions.
101. Describe the mechanisms that regulate blood glucose concentration.
102. Describe the mechanisms that regulate blood calcium levels and its storage.
103. Describe hormonal effects on energy metabolism and growth.
104. Explain the role of the endocrine system in stress responses.

H. Reproductive Physiology
105. Outline the role of the hormones produced by the ovaries and pituitary gland in the development and maintenance of the female reproductive function.
106. Describe the age-related changes in the hypothalamo-pituitary-gonadal axis that lead to puberty, reproductive maturity, and reproductive senescence (menopause) in the female.
107. Describe the ovarian and menstrual cycles and how this impacts on fertility.
108. Describe the processes of fertilization leading to implantation of a zygote.
109. Describe the secondary sexual characteristics of the female body.
110. Outline the processes of gestation and parturition.
111. Identify the key developmental changes during embryonic and fetal development.
112. Outline the hormonal and physical changes that occur during pregnancy.
113. Describe the male secondary sexual characteristics and the physiological functions of the major components of the male reproductive tract.
114. In males, explain the age-related hormonal changes that lead to puberty, reproductive maturity, and reproductive senescence (andropause).

I. Nervous System Physiology
115. Describe the properties of the neuron membrane that establish the resting membrane potential.
116. Illustrate the relationship between resting membrane potential and cellular excitability.
117. Describe the generation of an action potential in terms of the changes that occur to the membrane (including graded potential and all-or-none phenomenon).

Continued
Table A1.—Continued

| Number | Description |
|--------|-------------|
| 123.   | Describe the significance of the refractory period (absolute and relative) in nerve function. |
| 124.   | Explain the physiological significance of myelination in the nervous system. |
| 125.   | Discuss the propagation of an action potential and factors that affect the speed of propagation. |
| 126.   | Explain the transmission of an action potential from one neuron to another in the synapse (chemical and electrical synapses) and their role in temporal and spatial summation. |
| 127.   | List the major groups of neurotransmitters and identify their actions and functions. |
| 128.   | Understand the relationship between sensory and motor functions in the nervous system. |
| 129.   | List the types of sensory receptors, based on location and stimulus modality. |
| 130.   | Describe the organization of the nervous system in terms of functional significance of the central and peripheral nervous system (including autonomic and somatic components). |
| 131.   | Identify the functions of peripheral nerves (spinal nerves and the 12 cranial nerves) and relate these to their sensory and motor distributions. |
| 132.   | Differentiate between the sympathetic and parasympathetic nervous systems and explain how their structure supports their distinct functions. |
| 133.   | Discuss the neuroendocrine regulation by the hypothalamic pituitary axis as an essential regulator of homeostatic processes. |
| 134.   | Describe ways the autonomic nervous system (ANS) contributes to maintaining homeostasis. |
| 135.   | List the types of sensory receptors, based on location and stimulus modality. |
| 136.   | Identify the composition and function of cerebrospinal fluid. |
| 137.   | Outline the functions of the ascending and descending tracts. |
| 138.   | Describe the stretch, tendon, flexor, and extensor reflexes and their role in human health. |

Special Senses

| Number | Description |
|--------|-------------|
| 139.   | Describe the function of the eye and outline the visual neural pathways. |
| 140.   | Describe the function of the outer, middle, and inner ear structures (including vestibulo-cochlea) and outline the auditory and postural neural pathways. |
| 141.   | Discuss how taste and smell can influence perception and behavior, such as appetite and disgust. |

The Cerebellum and Basal Ganglia in Motor Control

| Number | Description |
|--------|-------------|
| 142.   | Outline the role of the cerebellum in the regulation of skilled movement and in motor learning. |
| 143.   | Explain the neurological disturbances that can result from disease or damage in different regions of the cerebellum. |
| 144.   | Outline the role of the basal ganglia in the initiation and control of movement and their links with the cerebellum and cerebral cortex. |
| 145.   | Recognize the common physical signs associated with neurological disease: |
|        | a. Rigidly. |
|        | b. Dyskinesia. |
|        | c. Akinesia. |
|        | d. Tremor. |
|        | e. Spasticity. |
| Cerebral Cortex

| Number | Description |
|--------|-------------|
| 146.   | Discuss the vulnerability of brain tissue to different types of injury: |
|        | a. Trauma. |
|        | b. Hypoxia. |
|        | c. Degenerative change. |
|        | d. Inflammation. |
|        | e. Demyelination. |
|        | f. Biochemical and nutritional neurotoxins. |
| 147.   | Understand the significance of neurological observation to determine brain function. |
| 148.   | Describe the major areas of the cerebral cortex, their roles, and connections for: |
|        | a. Perception. |
|        | b. Movement control. |
|        | c. Vision. |
|        | d. Hearing. |
|        | e. Somatosensory. |
|        | f. Speech. |
|        | g. Emotion. |
|        | h. Executive function. |
| 149.   | Describe the different types of memory and outline the ways in which they are formed and retained. |
| 150.   | Describe the characteristics of common types of dementia. |
| 151.   | Discuss the consequences of damage to the corticospinal tract (CST) and contrast the effects of CST (pyramidal/upper motor neuron) lesions to lesions of the motor cortex. |
| 152.   | Describe the cortical areas important for language and their functional interconnections. |
| 153.   | Describe how aging affects the brain and how emerging research might help to limit cognitive decline and promote cognitive function. |

The Limbic System

| Number | Description |
|--------|-------------|
| 154.   | Describe the main functions of the limbic system and relate how it works with other areas of the cerebral cortex to produce cognitive emotional behaviors. |
| 155.   | Discuss how emotion and the reward systems interact with the limbic system and the ANS to influence homeostasis, with emphasis on addiction. |

Sleep

| Number | Description |
|--------|-------------|
| 156.   | Define sleep and discuss the importance of sleep to health. |

Temperature

| Number | Description |
|--------|-------------|
| 157.   | Define the thermoregulatory set point and the negative feedback control of body core temperature, including the role of the hypothalamic set point. |
| 158.   | Contrast the stability of body core with that of skin temperature. Include the control and mechanisms of cutaneous blood flow and sweating on skin temperature. |
| 159.   | Discuss the thermoregulatory mechanisms that maintain a stable core temperature with changes in environmental conditions, exercise, and infection. |

Continued
Table A1.—Continued

J. Renal Physiology
160. Outline the functions of the structures of the urinary system.
161. Identify the structure of the kidneys in relation to function.
162. Describe the relationship of a nephron and its surrounding structure to its three basic functions: glomerular filtration, tubular reabsorption (passive and selective), and tubular secretion.
163. Explain glomerular filtration, how it is regulated, and identify factors that influence glomerular filtration rate (GFR) e.g., pressure, charge, size.
164. Contrast the contents of the filtrate with whole blood e.g., H₂O, Na⁺, inulin, albumin, and red blood cells.
165. Discuss how renal blood flow, renal plasma flow, glomerular filtration rate, and filtration fraction affect renal function.
166. Explain the creatinine/inulin clearance principle to estimate the glomerular filtration rate, renal plasma flow, and renal blood flow and demonstrate its significance in assessing renal function.
167. Describe the roles of the different areas of the nephron in water and electrolyte reabsorption, including the glucose threshold.
168. Describe the roles of the different areas in the nephron in tubular secretion.
169. Describe the role of the key hormones associated with the kidney, indicating their major stimuli, site of action, and effects.
  a. Renin and angiotensin II.
  b. Aldosterone.
  c. Anti-diuretic hormone.
  d. Atrial natriuretic peptide.
  e. Parathyroid hormone.
  f. Erythropoietin.
170. Describe the mechanism and significance of the kidney’s ability to produce either a dilute or a concentrated urine.
171. Explain the role of the kidneys in the immediate and long-term control of arterial blood pressure.
172. Contrast the male and female urinary systems.
173. Explain the micturition reflex.
174. Explain the impact of changes that occur over the life course on the urinary system.
Fluid Balance
175. Describe the significance of water to physiological processes in the body and identify its distribution in the fluid compartments of the body.
176. Explain the regulation of water balance through intake, metabolism and excretion.
177. Discuss the potential causes and effects of water imbalance.

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