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FORMATION OF A SYSTEM OF CONCEPTS ON THE TOPICS OF BLOOD CIRCULATION AND LYMPH CIRCULATION IN PHYSIOLOGY TRAINING

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Abstract

The topics of blood circulation and lymph circulation occupy a key place in human physiology courses. Their study makes a fundamental contribution to the successful introduction to physiological science of students from a wide range of specialties (human and veterinary medicine and various fields of sport, biology, etc.). From a private-methodological point of view, the physiology of the circulatory and lymphatic systems appears to be one of the most problematic areas in the didactic process of physiology. The reasons for this are the specifics of knowledge in this area of physiology and, in particular, its highly integrative nature requiring the transfer of knowledge from many other scientific fields (physics, chemistry, molecular biology, etc.). In this respect, the quality and level of students' prior knowledge and the quality of the teaching process are important. In the presented report, a didactic model is developed for the formation of a comprehensive system of concepts integrating the topics of blood circulation and lymph circulation.

Keywords: *physiology education, blood circulation, lymph circulation, cardiovascular system, circulatory system, teaching physiology*

INTRODUCTION

Dynamic development of the natural sciences, especially their biological branches, is a fundamental challenge for private teaching methodologies and exerts an increasingly significant impact on the quality and effectiveness of the teaching process. The latter is particularly pronounced in higher education, where teachers lack the private methodological support and theoretical infrastructure provided to secondary school teachers. The main problem is related to the need for permanent revision of teaching content and rethinking of the related didactic models and conceptual systems. In this regard, the lagging pace of methodological and didactical conceptualization of the constantly incoming new scientific information emerges as a key challenge. This hinders adequate and effective reflection in the teaching process of what is going on in the field of scientific research.

Physiology is a dynamically expanding biological science of life processes and their mechanisms of functioning and control in organisms. A characteristic indicator of its high level of development is the widespread application of causal-mechanistic models in the research and teaching of physiology. In consequence, physiology as an academic discipline has become perceived by students as increasingly difficult and more challenges are emerging in the learning process (Slominski et al. 2019). This requires physiology-based academic courses to be permanently rethought and updated in structure and curricular content. Sometimes, entirely new didactic solutions and models have to be developed and applied.

A key challenge for the authors of modern physiology courses is to develop and present a concept of physiological science that meets the specific educational needs of the audience and faithfully reveals the nature and mechanisms of living processes in the body. The latter must be presented in the didactic process not in isolation, but in their systematic integrity and functional interrelation.

The topics of blood circulation and lymphatic circulation occupy a key place in any basic physiology course. Their study is fundamental in mastering physiological science and is embedded in the disciplines of physiology for students of human and veterinary medicine and in many other specialties related to health care, sports, biology, etc. This is because topics of blood circulation and lymphatic circulation consider key integrative processes without which the existence of complex multicellular organisms such as those of mammals (including humans) is practically impossible. They represent a kind of entry point in studying many other important topics in physiology, such as the processes of respiration, nutrition, excretion, endocrine regulation, etc.

From the point of view of the educational needs of students of various medical specialties, the fact that disorders in blood circulation and lymph circulation are the main cause (or accompanying factor) of mortality among the population in modern economically developed countries is very important. Familiarity with the mechanisms of blood circulation and lymph circulation is also a main focus in the training of personnel for various fields of sports and physical culture. In-depth knowledge of these processes is also needed by future specialists in the field of veterinary medicine and in several areas of biology of a theoretical and applied nature.

The physiology of the blood circulation and lymphatic system is one of the most problematic areas in the didactic process of physiology (Bordes et al. 2021). Reasons for this are the specifics of knowledge in this field and, in particular, its highly integrative nature, which requires students to be able to transfer knowledge from many other fields of science (for example, physics, chemistry, molecular biology, and anatomy). The latter, in turn, depends strongly on the quality and level of their prior training and education in the university and pre-university system.

In this regard, besides the gaps and shortcomings in knowledge, preconceptions and misconceptions are often a serious problem. From the perspective of the didactic process, preconceptions can be corrected relatively easily, whereas misconceptions are seen as much more enduring and difficult to eradicate (Chi & Roscoe 2002). Identifying and correcting preconceptions and misconceptions on the one hand and preventing the formation of new ones on the other hand appears to be one of the key tasks in teaching and learning the physiology of blood circulation and lymph circulation. It is particularly important because once formed and allowed to take hold in the minds of trainees, misconceptions hinder the adequate acquisition

not only of knowledge about blood circulation and lymph circulation but also of subsequent new knowledge in physiology as well as in many other sciences and disciplines (Ahopelto et al. 2011; Arnaudin & Mintzes 1985; Özgur 2013; Kaufman & Keselman 2012).

The content analysis of the contemporary textbooks of physiology and associated didactic models show quite different and often logically contradictory and ineffective approaches in the construction and hierarchization of conceptual systems related to the physiology of blood circulation and lymph circulation. A typical example of this is the diversity and disagreement associated with the terminology used and the content embedded in such basic concepts as the circulatory system, circulation, cardiovascular system, lymphatic circulation, and lymphatic system. As a result, serious additional problems arise concerning their interrelation and hierarchization in the didactic process.

According to the classical definition in physiology, the cardiovascular system is considered to be composed of two main parts - heart and blood vessels. This understanding of the cardiovascular system was "inherited" by physiology from anatomy and is still widely accepted in the contemporary educational literature and didactic practice (Costanzo 2018; Khurana & Khurana 2015; Sembulingam & Sembulingam 2012; Pal 2017; Smirnov et al. 2019; Vitanova & Garchev 2020). It could be labeled as "anatomical". Its incorrect use and positioning in modern physiology teaching and learning led to several logical and didactic problems. The main one is that, from a system-functional point of view, circulatory processes cannot be logically, scientifically and didactically fully represented within the anatomical understanding of the cardiovascular system. This, in turn, gives rise to serious semantic dissonances between terminology and conceptual content.

Over the last two decades, the concept of the circulatory system as made up of blood, heart and vessels has gained widespread popularity among the leading authors of modern educational literature on physiology (Barret et al., 2019; Boron & Boulpaep, 2017; Sherwood & Ward 2019; Silverthorn 2019; Stanfield 2017; Widmaier et al. 2019). Many use the terms "circulatory system" and "cardiovascular system" as synonyms (Boron & Boulpaep, 2017; Pal 2017; Widmaier et al. 2023). Despite the obvious dissonance between the anatomically-based term ("cardiovascular system") and the process-oriented content of the concept ("circulation"), this is a step forward in the functional understanding and didactic presentation of circulation and circulatory processes in general. It is noteworthy that some authors didactically develop this concept by starting with the topic of blood and hemodynamics (Boron & Boulpaep, 2017), while others prefer to start with the heart and vessels and put the blood at the end (Sherwood & Ward, 2019; Silverthorn 2019; Stanfield 2017). There are also author collectives that position the topic of blood between the themes of the heart and vessels (Barrett et al. 2019).

So far without a satisfactory and generally accepted solution in physiology education is another significant problem. It concerns the interrelation and inter-positioning of blood circulation and lymph circulation. Regardless of the specific terminology used, in the physiology teaching literature lymphatic circulation system is never defined as part of the blood circulatory system. However, in modern didactic practice, the lymphatic system in most cases is attached to the topic of the blood circulatory system or the topic of the cardiovascular system. For example, most authors introduce the lymphatic system in the context of the topic of the vascular system (Barrett et al. 2019; Widmaier et al. 2019; Silverthorn 2019) and, in particular, capillaries (Khurana & Khurana 2015; Boron & Boulpaep 2017; Hall & Hall 2021; Koeppen & Stanton 2018; Sherwood & Ward 2019). This is done even though according to textbook definitions the lymphatic circulation, respectively the lymphatic system, is not a part of the circulatory and cardiovascular system. Exotic solutions can also be found in the educational literature, such as considering the topic of the lymphatic system as part of a general topic on blood and body fluids (Sembulingam & Sembulingam 2012; Sembulingam & Sembulingam 2016; Vitanova & Garchev 2020) or blood and immunity (Pal 2017).

By their essence, the processes of blood circulation and lymph circulation, respectively the functional systems within which they occur are regulated, as concepts are not in a genus-species relationship. Although interconnected, they are different processes of the same rank (Fig. 1.). In this regard, the question naturally arises as to how logically justified and didactically effective it is to attach one as part to the other. Interestingly, this is done even in the very rare cases where the authors are fully aware of this fact and explicitly point it out. For example, in one modern textbook is stated that "...the lymphatic system is not essentially part of the circulatory system..." (Widmaier et al. 2019). However, in the same textbook, the topic of lymphatic circulation is positioned under the general heading "Vascular System". The situation is similar in another prestigious textbook (Stanfield 2017), where the lymphatic system is said to be "…sort of the silent partner of the cardiovascular system…". Obviously, in such cases, it is much easier for the authors to follow an established tradition instead of looking for innovative and effective solutions in the didactic process.

Against the background of the prevailing mass practice, the thesis stated in Fox's textbook (2019) that the circulatory system is composed of two main parts - the cardiovascular system and the lymphatic system, is looking innovative and promising. Unfortunately, this idea is only declared and is not developed fully and consistently on a logical level and as a didactic concept. For example, there is no generalized definition of the circulatory system, which means that its presence in the textbook is in the form of a term but not as a developed concept. As a result, the general structural, functional and physiological characteristics of the circulatory and lymphatic system have not been deduced. Instead, the functions of the circulatory system are represented solely through the functions of the blood circulatory system. It is also quite indicative that the heading "Lymphatic System" is placed under the section "Blood, Heart and Circulation", which is in complete contradiction to the declared logical rank-equality of the cardiovascular and lymphatic systems. Another notable fact is that the cardiovascular system and lymphatic system are defined as anatomical rather than functional systems.

The existence of a circulatory system as a concept is also implied in the leading Bulgarian textbook on human physiology for medical students (Vitanova & Garchev 2020), where the first sentence under the heading "Lymphatic system" begins as follows: "The lymphatic system is a specialized part of the circulatory system. ..". However, what exactly the authors and editors mean by "circulatory system" is nowhere specified. It can only be assumed that it has at least two parts of the same rank. The conceptual chaos is further enhanced by the fact that the heading "Lymphatic System" is placed in a section entitled "Physiology of Blood and Lymph." On this basis, the reader may conclude that the lymphatic system is a part of... the lymph! It is noteworthy that in both cited cases (Fox 2019; Vitanova & Gurchev 2020), the concepts "lymphatic system" and possibly "cardiovascular system" are implicitly assigned the role of forming the content and volume of what should be "circulatory system".

The idea of blood circulation and lymph circulation as equal-rank concepts is also present in Smirnov et al. (2019) where they are discussed under the general heading "Circulatory and Lymphatic System". With such a structuring of the educational content, the possibility remains open to considering the circulatory and lymphatic systems as elements forming the volume of the concept of the circulatory system.

The examples presented above clearly demonstrate a lack of consensus among the academic and expert community on how the concepts of blood circulation and lymph circulation should be structured and arranged in the didactic process. The search for effective models to build optimal conceptual systems in this field of scientific knowledge is still far from over. The diversity of solutions and approaches among the teachers and authors of educational literature can be seen as a consequence of an intensive process of searching for ways to improve teaching and learning topics on blood and lymph circulation. Not all approaches applied in modern didactic practice can be considered effective and optimal for achieving the goals and objectives of the teaching process. The latter is particularly significant in the case of specific audiences with the same or similar educational needs, such as medical students. The application of didactically ineffective and logically contradictory approaches and solutions when introducing trainees to topics relevant to blood and lymph circulation is a prerequisite for the formation of critical incompleteness and misconceptions among future specialists.

METHODS

The development of the described didactic model is based on a content analysis of the established modern pedagogical concepts in Bulgaria and worldwide concerning the physiology of blood circulation and lymph circulation mainly in the field of medical education. For this purpose, a sample of educational literature in the field of human physiology was used. The selected books are published since 2010 and they have undergone more than two editions (Vitanova & Garchev 2020; Yankov 2013; Smirnov et al. 2012; Smirnov et al. 2019; Barret et al. 2016; Boron & Boulpaep 2012; Costanzo 2018; Fox 2016; Hall & Hall 2021; Katch et al. 2011; Koeppen & Stanton 2018; Plowman & Smith 2014; Rhoads & Bell 2013; Sembulingam & Sembulingam 2012; Sherwood 2016; Silverthorn 2019; Stanfield 2017; Widmaier et al. 2014). The literature was selected based on its current relevance and validity in the field of physiology education. In the development of the didactic model, the results of the author's research and experience in teaching Human Physiology to students with different medical profiles, future sports education teachers, etc. are also taken into consideration.

Didactic model on formation of a system of concepts on circulation

Building a circulatory system concept in the didactic process can be done by an algorithm based on the general scheme presented in Fig. 1. It includes three main steps - forming a general concept on circulation, forming a concept on the circulatory system and hemodynamics and developing concept on lymphatic system and lymph circulation.

Forming a concept on the circulatory system. The concept of a circulatory system can be built based on two essential functions - a transport function (related, for example, to nutrition and excretion) and an immune function. From a structural and functional point of view, two common features can be highlighted - the presence of vessels and circulating fluid tissue inside. The latter consists of fluid (composed of more than 90% water) and cellular elements. Based on the function and direct contact with the circulating fluid, other organs and structures such as the heart and lymph nodes can also be pointed out.

Further, the circulatory system of the body can be represented as composed of two main interrelated parts - the blood circulatory system, which can also be designated as the system of rapid circulation, and the system of lymph circulation or system of slow circulation (Fig. 1.). For illustrative purposes it is desirable to indicate and compare the different linear and volume velocities of circulation of the fluid media within them.

A convenient illustrative example can be presented in the following way. Assuming that in a healthy 70 kg. man at rest the minute volume of the heart (i.e. the blood which the heart pumps into the aorta in one minute) is approximately 5 liters, then in the same period, the volume of lymph which enters blood circulation through the great lymphatic vessels is only about 1.5 ml/min. A comparison of the linear velocities of lymph in the large lymph vessels and blood in the hollow veins (venae cavae) may serve as a good illustrative example. In the hollow veins, the linear velocity of blood varies in a range of about 30 cm/s (Wexler et al. 1968), whereas in the ductus thoracicus the lymph moves at only about 1.5 mm/s.

After presenting the generalized concept of a circulator system, it can proceed to the consideration of its main parts.

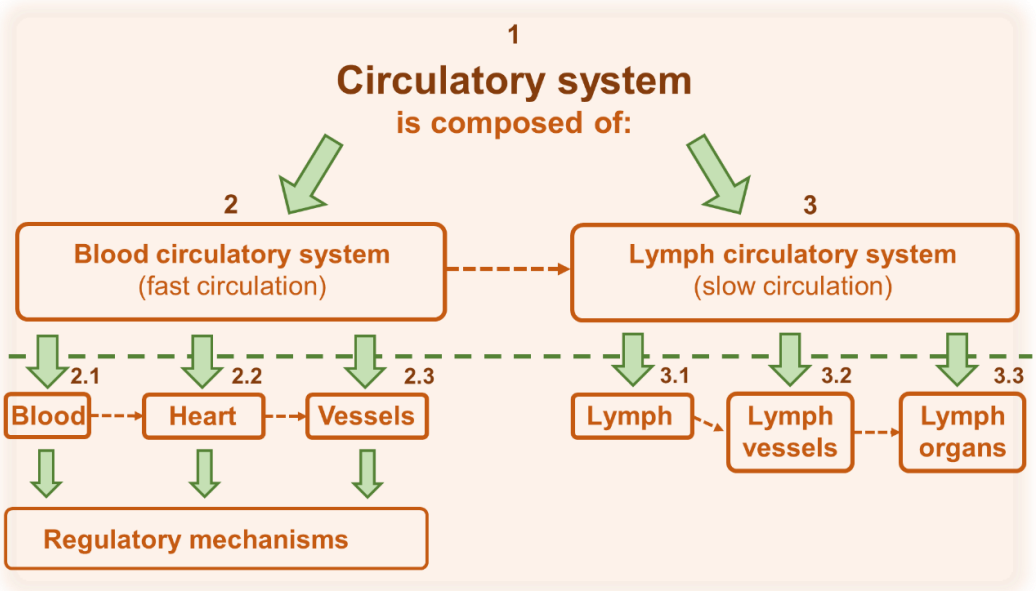

Fig. 1. General diagram of a didactic model for the formation of the circulatory system concept and related concepts in physiology

education. The numbers indicate the sequence in which the respective main topics are introduced in the didactic process. The dashed line highlights the same-rank logic nature of the circulatory and lymphatic systems. In the presented model, the blood circulatory and lymphatic systems are considered as content-related concepts of the circulatory system.

Formation of a concept on the blood circulatory system.

In the teaching process of physiology, the blood circulatory system must be defined as a functional system, i.e., as a system within which certain processes and functions take place that are relevant to the whole organism. The blood circulatory system can be defined as a functional system within which one basic process takes place – blood circulation. The latter is the basis of the transport and integrative functions involved in the transfer of substances, information and energy (Fig. 2.).

The circulatory system can be logically, structurally and functionally decomposed into two basic elements - blood and cardiovascular system.

Blood.

It is appropriate in the didactic process for the topic of blood to precede the topic of the cardiovascular system. This is based on the fact that knowledge of the physical and physiological properties of blood is a necessary prerequisite for the subsequent introduction of trainees to the functions of the cardiovascular system and hemodynamics.

The consideration of blood as a functional system can be done by its decomposition into cellular elements and plasma. The cellular elements can be considered in the traditional division into three groups: erythrocytes, leukocytes, and platelets. Each of these groups is presented in the context of its main functions - gas exchange, immune defense, hemostasis, etc.

The functions of plasma, in turn, can also be related to its main components: proteins (e.g. antibodies with immunity, transport proteins with hormones, etc.), lipoproteins, electrolytes (here a link can be made to their importance for various physiological processes and overall homeostasis in the body), hormones, etc.

Cardiovascular system.

The formation of a concept of the cardiovascular system as a functional system in the trainees should be based on its main functions in providing blood circulation:

- The pumping function of the heart by which the pressure gradient in the blood vessels is created and maintained;

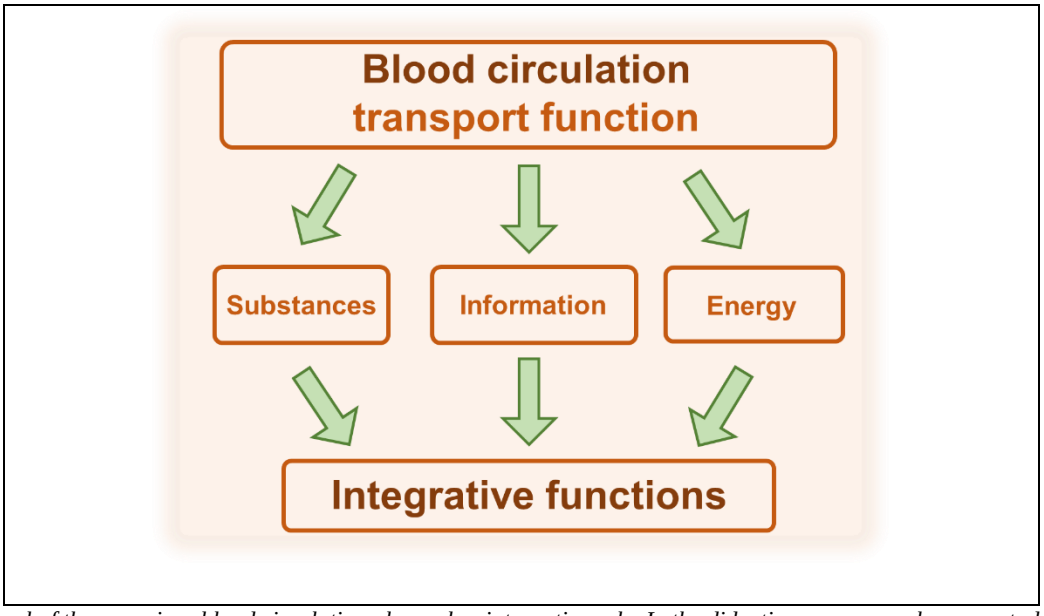

Fig. 2. At the level of the organism, blood circulation plays a key integrative role. In the didactic process, can be presented as the result of the processes (usually bidirectional or multidirectional) transfer of substances, information and energy between different tissues, organs and systems

- the conductive function of the vascular system, thanks to which the blood can circulate and reach almost all parts of the body;
- the exchange function of the vascular system (via capillaries), which ensures the two-way exchange of substances, information, and energy between blood and tissues.

On this basis, from a structural and functional perspective, the cardiovascular system can be decomposed into the heart, different types of vessels (organs with conductive and metabolic functions), and regulatory mechanisms (central, local, nervous, hormonal and metabolic).

Introduction to the physiology of the heart can be realized in two main steps. The first step involves an introduction to the pumping function of the heart, within which the working myocardium, the valvular apparatus and the cardiac cycle are studied (e.g. using the Wiggers diagram). The second step is an overview of the bioelectrical processes and mechanisms in the heart by which the pumping function of the heart is regulated and synchronized. It also includes revealing how the functioning of the excitation-conduction system is going on. The educational needs of the majority of the target audiences also require their familiarity with intra- and extracardiac regulatory mechanisms and electrocardiography.

The consideration of blood vessels in the didactic process of physiology should be based on their functions and the

specific morphology associated with them. On this basis, and depending on the educational needs of the audience, they can be broadly divided into at least four functional groups:

- arterial vessels, which carry blood from the heart to the organs and tissues and cushion the fluctuations in blood pressure caused by the heart cycle,
- arterioles or resistance vessels,
- venous vessels, which return blood from the organs and tissues to the heart,
- capillaries or exchange vessels in which bidirectional transport processes take place between blood and tissues.

System of lymph circulation.

This topic can be developed in the learning process through the following basic concepts - lymph formation, lymph, lymph vessels, lymphatic nodes and lymphatic organs.

Lymph formation and its relation to the processes of filtration in blood capillaries can be used as a convenient entry point to the topic. Further analysis of the composition and functions of the lymph may be done. The latter is conveniently integrated with the topics of lymphatic vessels and lymph circulation as a process. The differences between blood and lymph and the much more variable composition of the latter according to the organs and systems in which it resides are emphasized.

The consideration of lymphatic vessels can be made based on their size (large and medium-sized lymphatic vessels and lymphatic capillaries) and function (drainage, transport, etc.). It is important to associate their structure and, in particular, the presence of valves (similar to veins) with the mechanisms creating the necessary pressure gradients and ensuring the unidirectional movement of lymph.

RESULTS AND DISCUSSION

Physiology is the science of life processes at the organismal level. Therefore, they should be the organizational centers of scientific knowledge in this field and serve as the main landmarks and structural determinants of the didactic process. Above all, this means that the formation of concepts and systems of concepts in learning activities about various processes, objects, systems and interrelationships between them should be based on processes and functions. In this sense, concepts such as the cardiovascular, respiratory, or excretory systems in the didactic process of physiology should be defined as functional systems, i.e. systems within which the respective processes of circulation, respiration and excretion take place. In this way, they acquire a much broader, physiologically and functionally oriented, meaning than their purely anatomical substrate suggests.

The formation of a concept of the circulatory system (Fig. 1.) serves as the main unifying and organizing center of the physiology of blood circulation and lymph circulation curriculum and represents an important starting point of the didactic process. The circulatory system is viewed as an overall functional system through which the common characteristics and functional relationship of the lymphatic and circulatory systems can be highlighted. Thus, in the didactic process, the topics of blood circulation and lymphatic circulation can be positioned logically correctly both about each other and about the other physiology topics.

From a logical point of view in forming the concept of the "circulatory system" there are two possible approaches to the blood circulation system and the lymphatic system. One approach is to construct genus-species relationships between the concepts, whereby the circulatory and lymphatic systems are represented as separate types of circulatory systems that together form the volume of the concept of "circulatory system." The other approach is to view the cardiovascular and lymphatic systems as content-related concepts relative to the circulatory system, i.e. as two distinct but structurally and functionally related parts of a common system.

Content analysis of contemporary physiology teaching literature shows that authors and teachers prefer the second approach. An indication of this is the already emphasized fact that in the vast majority of the analyzed textbooks, lymphatic circulation and the lymphatic system are presented in sections devoted to blood circulation and the cardiovascular system (Barrett et al. 2019; Widmaier et al. 2019; Silverthorn 2019; Khurana & Khurana 2015; Boron & Boulpaep 2017; Hall & Hall 2021; Koeppen & Stanton 2018; Sherwood & Ward 2019). The latter reveals the tendency (and perhaps need!) of authors of educational literature to consider the two themes in the context of some common whole, the nature of which remains debatable and unclear. At the same time, the arbitrary positioning of lymphatic circulation and the lymphatic system as part of the blood and blood circulation sections can hardly be perceived as logically correct and didactically justified. The problem arises because the lymphatic system and lymph circulation on the one hand and the blood circulatory system and blood circulation on the other hand are concepts of the same rank.

It is important to point out that several ‘core concepts’ in physiology converge in the circulatory system as a theoretical framework (Michael & McFarland 2020). These are the concepts of the necessity of a constant exchange of information between cells, the necessity of a constant transfer of substances between different levels of organization of the body, the dependence of the contents of each system or compartment of the organism on the balance between the processes of intake and excretion of substances, etc.

Considering the blood circulation system as a specific functional subsystem of the circulatory system aims to improve the efficiency of the learning process and to ensure the stability of its results through better logical organization ot the topic. It ensures that learning content is structured coherently and logically around its main components (blood, cardiovascular system and regulatory mechanisms) and avoids dilution with content from other subjects.

Delving into the topic of hemodynamics generally assumes knowledge of the basic properties of blood and the functional-anatomical and physiological features of the cardiovascular system. Therefore, the introduction of the topic of blood to students should precede other topics associated with blood circulation. Knowledge of the physical, biophysical, and chemical properties of the blood is a precondition for entry into the physiology of the cardiovascular system, hemodynamics, and such specific areas as hemostasis.

From a scientific and logical point of view, it is more effective to consider the topic of the circulatory system first and then the topic of the lymphatic system, which is in line with established modern practice. Prior clarification of the structure and functions of the blood circulation system is an important prerequisite for the development of the topic of the lymphatic system in the teaching process. The rationale for introducing the topic of lymphatic circulation after (rather than in!) the topic of blood circulation is based primarily on the fact that lymph formation is mainly associated with the processes of filtration in blood capillaries. It is also important that the process of lymphatic circulation has the blood vessels as its entry (although not directly) and exit points.

The process of lymph formation is of key importance from a didactical perspective because it reflects the functional relationship between the blood circulatory system and the lymphatic system. On the other hand, it can be further used to bridge and integrate the processes of blood circulation and filtration of plasma in the glomeruli during urine production.

CONCLUSION

The proposed didactic model aims to unite the topics of blood circulation and lymphatic circulation in a comprehensive concept of the processes of circulation in human and mammalian organisms. By improving the logical organization of the learning content, the optimization and improved efficiency of the physiology educational process is pursued. An attempt is made to overcome some of the most significant problems in the organization and structure of the teaching content associated with the topics of blood and lymph circulation in physiology courses. The didactic model described has been developed based on identifying and integrating into a comprehensive concept the innovative and traditional, but still useful and effective, ideas and practices in teaching and learning in this field.

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