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METHODOLOGICAL FEATURES OF THE PRESENTATION OF CARDIAC MUSCLE MORPHOLOGY IN A HISTOLOGY COURSE

Cherkas O.A. ✉ Methodological features of the presentation of cardiac muscle morphology in a histology course. Dnipro State Medical University, Dnipro, Ukraine.

ABSTRACT. Background. Cardiac muscle, with its unique structural and functional characteristics, plays a crucial role in maintaining cardiovascular health. Understanding the intricacies of cardiac muscle morphology is a fundamental aspect of histology education, offering students insights into the specialized structure and function of the heart. Cardiac muscle is striated, similar to skeletal muscle, but it possesses unique characteristics that set it apart. Comprising individual cells known as cardiomyocytes, cardiac muscle forms the muscular layer of the heart, the myocardium. These cells are cylindrical, branched, and interconnected, forming a three-dimensional network that allows for coordinated contraction. A defining feature of cardiac muscle is the presence of intercalated discs, specialized regions where adjacent cardiomyocytes connect. These disc-like structures not only physically link cells but also facilitate rapid communication. This article provides an overview of the background and key methodological features of the presentation of cardiac muscle. Exploring the microscopic details of myocardium morphology is essential for comprehending how the heart functions as a dynamic pump. Knowledge of cellular architecture underlies the study of cardiac function. Understanding the structure of cardiac muscle fibers, the structural features of its sarcomeres and intercalated discs allows us to look for new opportunities in the prevention of diseases of the cardiovascular system. **Methods.** Lecture-based teaching, microscope-based teaching, computer-based teaching, problem-based learning, group-based learning. To effectively study cardiac muscle morphology, students and teachers will need access to high-quality histology textbooks, online resources, microscopes, and tissue slides. **Results and conclusion.** Cardiac muscle is not a static entity; it adapts dynamically to changing physiological demands. In response to increased workload, such as during exercise or pregnancy, cardiac muscle cells can undergo hypertrophy, enlarging to meet the increased demand. While this adaptation is beneficial in the short term, prolonged stress can lead to pathological hypertrophy and contribute to heart diseases. A comprehensive understanding of cardiac muscle structure is crucial for unraveling various cardiac pathologies. Diseases such as cardiomyopathies, heart failure, and arrhythmias often manifest as alterations in the structural components of cardiac muscle. Histological examination provides valuable insights into the cellular and molecular changes associated with these conditions, aiding in diagnosis and treatment. In conclusion, the intricate structure of cardiac muscle is a testament to the remarkable adaptation and specialization required for the heart to function as a continuous, efficient pump. From the macroscopic organization of the myocardium to the microscopic details of sarcomeres and intercalated discs, each structural component contributes to the harmonious symphony of cardiac function. As our understanding of cardiac muscle structure deepens, so does our ability to unravel the complexities of cardiovascular health and disease, paving the way for advancements in medical science and patient care.

Key words: cardiac muscle, cardiomyocyte, T-tubule, sarcoplasmic reticulum, muscle contraction, intercalated discs, sarcomere.

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Introduction

The heart is one of the most important organs in the human body. It begins its beating even before a person is born. With the cessation of cardiac activity, human life stops. Therefore, it is important to know some facts and information about the structure and activity of this wonderful organ, on which our vital functions depend. Cardiac muscle is a specialized type of muscle tissue that forms the walls of the heart. It has characteristics of both skeletal and smooth muscle, combining the striated appearance of skeletal muscle with the involuntary contraction of smooth muscle. The heart muscle is responsible for the rhythmic contractions of the heart, which

pumps blood throughout the body.

Methods and materials

To teach the topic of cardiac muscle in a histology course, several methods and techniques can be used, including:

- Lecture-based teaching: This involves the teacher presenting information to students in a traditional lecture format. The lecture can be accompanied by visual aids such as slides, diagrams, and models to help students understand the topic better.
- Microscope-based teaching: This involves the use of light microscopes. To truly grasp the intricacies of cardiac muscle, transmission electron microscopy comes into play. This method allows students to explore ultrastructural details such as sarcomere organization, myofibril composition, and the presence of specialized structures like T-tubules and sarcoplasmic reticulum.
- Computer-based teaching: This involves the use of computer programs and software. The teacher can use interactive 3D models, virtual slides, and other computer-based tools. Understanding cardiac muscle morphology gains depth through comparative analyses with skeletal and smooth muscle. Highlighting both similarities and differences provides students with a broader context for appreciating the unique characteristics of cardiac muscle within the spectrum of muscle types in the body.
- Problem-based learning: This involves presenting students with real-world problems related to structure of cardiac muscle and challenging them to solve the problems using their knowledge of the topic. This method encourages students to think critically and apply their knowledge to solve real-world problems.
- Group-based learning: This involves dividing students into small groups and assigning them tasks, which helps to develop teamwork and collaborative skills. Discussions delve into the role of intercalated discs in facilitating synchronous contractions, the significance of T-tubules in excitation-contraction coupling, and the cellular adaptations that support the heart's continuous pumping action. This functional perspective enhances the relevance and applicability of the histological knowledge acquired.

The methodological features employed in the presentation of cardiac muscle morphology in a histology course aim to transform a seemingly intricate subject into an accessible and engaging exploration. By combining structural overviews, advanced microscopy techniques, functional correlations, and interactive elements, educators empower students to unravel the complexities of cardiac muscle, fostering a profound appreciation for the histological intricacies that sustain the heartbeat. As technology advances, these methodologies continue to evolve, ensuring that the presentation of cardiac muscle morphology remains a dynamic and enriching aspect of histology education.

Content

Cardiac muscle tissue is a specialized type unique to the heart. Here are some key features and functions of cardiac muscle tissue:

- Location and structure: Cardiac muscle tissue is found exclusively in the walls of the heart, especially the myocardium. It forms a thick middle layer between the outer layer of the epicardium and the inner layer of the endocardium. Heart muscle cells, known as cardiomyocytes, have an elongated and branched structure that allows them to connect to each other.
- Involuntary and striated: Like skeletal muscle, cardiac muscle tissue is striated, meaning that under a microscope it shows alternating light and dark stripes. However, unlike skeletal muscles, cardiac muscle is involuntary, meaning it works without conscious control. The contraction of the heart muscle is regulated by specialized conductive cells of the heart and the autonomic nervous system.
- Unique properties of cardiomyocytes: Cardiomyocytes have one – two centrally located nuclei, which distinguish them from multinucleated skeletal muscle fibers. These cells are interconnected by intercalated discs that contain tight junctions, desmosomes and gap junctions. Desmosomes help maintain the structural integrity of the heart muscle, and gap junctions facilitate the rapid transmission of electrical impulses between cells, allowing coordinated contraction of the heart [1,2].
- Contractions and Pumping Action: The primary function of cardiac muscle tissue is to create contractions that propel blood throughout the body. Coordinated contractions of cardiac muscle cells in the atria and ventricles ensure efficient pumping of blood into the systemic and pulmonary circulation. This process of contraction and relaxation is known as systole and diastole, respectively, and is responsible for maintaining the circulation of oxygenated and deoxygenated blood.
- Oxygen and Nutrient Supply: Cardiac muscle cells have high energy requirements and require a constant supply of oxygen and nutrients to function effectively. The coronary arteries branching from the aorta provide the necessary blood supply to the myocardium. These arteries deliver oxygen and nutrients while removing waste products such as carbon dioxide from the heart muscle cells.
- Syncytium and coordinated contraction: Cardiac muscle cells form a functional syncytium, that is, they behave as a single unit. The intercalated discs allow the cells to synchronize their actions, allowing the heart to beat quickly and in a coordinated manner. This synchronization ensures efficient blood pumping and keeps the heart rhythmic.

Thus, cardiac muscle tissue has a unique structure and is specialized for its role in involuntary contractions of the heart. Interconnected cardiomyocytes, intercalated discs, and coordinated contractions help efficiently pump blood throughout the

body, providing essential oxygen and nutrients to support overall cardiovascular function [2,3].

Structural features of cardiac muscle

A distinctive feature of the cardiac muscle is transverse striation, and its basis is made up of muscle cells – myocytes, interconnected by fibrillar protein structures into single bundles, which allows summing up the efforts of individual cells. A few organelles of general importance are located near the nucleus. Unlike skeletal muscle cells, which are multinucleated, most cardiomyocytes contain a single nucleus, though some may have two centrally located nuclei. Cardiomyocytes are rich in mitochondria, which supply the energy needed for contraction in the form of adenosine triphosphate (ATP). This high mitochondrial content makes cardiomyocytes highly fatigue resistant. The smooth endoplasmic reticulum, which is here, is well developed has a structure similar to the structure of the sarcoplasmic reticulum of a skeletal muscle fiber [2,3].

The cardiomyocyte consists of bundles of myofibrils that contain myofilaments. Within the myofibrils, there are distinct, repeating microanatomical units called sarcomeres, which serve as the fundamental contractile units of the myocyte. These sarcomeres are defined as the regions between two Z-lines, where myofilament structures are located. The I-band of the sarcomere is primarily composed of actin filaments, which are thin filaments. These actin filaments extend into the A-band. On the other hand, the A-band consists of myosin filaments, which are thick filaments. These myosin filaments are bipolar and extend throughout the A-band. They are connected at the center by the M-band [3,4].

The sarcomere also contains a large protein called titin (also known as connectin). Titin extends from the Z-line of the sarcomere, where it binds to the myosin filament system, all the way to the M-band. It is believed that titin interacts with the thick filaments at the M-band. Titin is the largest single highly elastic protein found in nature and it provides binding sites for numerous other proteins. It is thought to play a crucial role as a sarcomeric ruler and as a blueprint for the assembly of the sarcomere [5,6].

Another significant protein in the sarcomere is nebulin, which is hypothesized to extend along the thin filaments and the entire I-band. Similar to titin, nebulin is believed to act as a molecular ruler for the assembly of the thin filaments [7].

The Z-line and M-band of the sarcomere contain several proteins that are important for maintaining the stability of the sarcomeric structure. Actin filaments and titin molecules are cross-linked at the Z-disc by a protein called alpha-actinin. The thick filament system (myosins) and the elastic filaments of titin at the M-band are crosslinked by myomesin and C-protein [8,9].

Additionally, the M-line binds creatine kinase, which facilitates the reaction between ADP and phosphocreatine to produce ATP and creatine.

The interaction between actin and myosin filaments in the A-band of the sarcomere is responsible for muscle contraction, as described by the sliding filament model [10].

Intercalated discs serve as intricate connecting structures that link individual cardiomyocytes to form an electrochemical syncytium, in contrast to skeletal muscle which forms a multicellular syncytium during embryonic development [11]. These discs primarily facilitate the transmission of force during muscle contraction. Comprising three distinct types of cell-cell junctions, namely the fascia adherens junctions that anchor actin filaments, the desmosomes that anchor intermediate filaments, and the gap junctions, intercalated discs enable the propagation of action potentials between cardiac cells by allowing the passage of ions. This, in turn, leads to depolarization of the heart muscle. Together, these three types of junctions function as a unified area [12,13].

Cardiomyocytes have T-tubules, invaginations of the cell membrane that extend from the cell surface into the interior. They are connected to the cell membrane, made up of the same phospholipid bilayer, and are open to the extracellular fluid surrounding the cell. But the T-tubules in the cardiac muscle fiber, unlike the skeletal one, are located at the level of the Z-lines. T-tubules help improve the efficiency of contraction. In cardiac muscle, T-tubules are larger and wider compared to skeletal muscle, but they are fewer in number. Within the cell, they converge and form a transverse-axial network. They are positioned near the sarcoplasmic reticulum, the cell's internal calcium store. A single tubule pairs with a section of the sarcoplasmic reticulum called a terminal cisterna, creating a structure known as a diad. T-tubules serve multiple functions within the cell. Firstly, they efficiently transmit action potentials from the cell surface to the core, facilitating rapid electrical impulse transmission. Additionally, they play a crucial role in regulating the concentration of calcium within the cell through a process called excitation-contraction coupling. Moreover, T-tubules are involved in mechano-electric feedback, as observed through the exchange of content within the T-tubules induced by cell contraction [14,15].

Cardiomyocytes are divided into: contractile (typical), conductive (atypical) and secretory. The structure of contractile (working) cardiomyocytes was described above. Conductive cardiomyocytes have a smaller number of myofibrils and their arrangement is less ordered. The sarcoplasmic reticulum is poorly developed, the T-system absent, there are many pinocytotic vesicles and caveolae with Ca2+ ions. Cells contain many glycogen inclusions. Their function is generation and conduction of electrical impulses to contractile cardiomyocytes. Driv-

ers of the rhythm are capable of spontaneous depolarization of the plasma membrane [16,17].

Secretory cardiomyocytes are found in the atria. Unlike working cardiomyocytes, they have a better developed Golgi apparatus and available secretory granules. Secretory cardiomyocytes secrete atriopeptide (natriuretic factor), which takes participation in blood pressure regulation [18,19].

Understanding the diversity of cardiomyocytes is crucial for comprehending the complex interplay of electrical and mechanical activities that sustain cardiac function. Each type of cardiomyocyte plays a specific role in ensuring the heart's coordinated and efficient performance. The heterogeneous nature of cardiomyocytes contributes to the heart's adaptability and responsiveness to various physiological demands and pathological conditions [20].

The conductive system of the heart

The conductive system of the heart is a specialized network of cells responsible for generating and transmitting electrical impulses, coordinating the contraction of the heart muscle (myocardium), and regulating the cardiac cycle. This system ensures that the heart beats in a rhythmic and coordinated manner to pump blood effectively. The key components of the cardiac conduction system include:

- Sinoatrial node;
- Atrioventricular node;
- Atrioventricular bundle of His (right and left bundle branches);
- Purkinje fibres.

The cardiac conduction system ensures a coordinated sequence of electrical events, known as the cardiac cycle, that results in the contraction and relaxation of the atria and ventricles. The rhythmic depolarization and repolarization of cardiac cells during each cycle create the characteristic electrocardiogram (ECG or EKG) pattern [21]. The following sequence of electrical events occurs during one full contraction of the heart muscle:

- An excitation signal (an action potential) is created by the sinoatrial (SA) node.
- The wave of excitation spreads across the atria, causing them to contract.
- Upon reaching the atrioventricular (AV) node, the signal is delayed.
- It is then conducted into the bundle of His, down the interventricular septum.
- The bundle of His and the Purkinje fibres spread the wave impulses along the ventricles, causing them to contract.

Proper functioning of the cardiac conduction system is crucial for maintaining an effective and synchronized heartbeat. Disturbances in this system can lead to arrhythmias, which may affect the heart's ability to pump blood efficiently. Understanding the anatomy and function of the cardiac conduction system is essential for diagnosing and treating various cardiac conditions [21,22].

Myocardial regeneration

Myocardial regeneration refers to the process of restoring or replacing damaged or lost myocardial (heart muscle) tissue. The myocardium has limited regenerative capacity, and extensive damage, such as that caused by a heart attack, can lead to scar formation rather than complete tissue regeneration. However, ongoing research aims to understand and enhance the regenerative potential of the myocardium [23].

A report published in 2009 contradicted the commonly held belief that cardiac muscle cells could not be regenerated. Olaf Bergmann and his colleagues at the Karolinska Institute in Stockholm conducted a study on heart muscle samples from individuals born before 1955 who had limited cardiac muscle around their heart, resulting in disabilities. By analyzing DNA samples from multiple hearts, the researchers estimated that a 4-year-old renews approximately 20% of heart muscle cells each year, and around 69% of the heart muscle cells in a 50-year-old were generated after birth.

One mechanism of cardiomyocyte regeneration occurs through the division of existing cardiomyocytes during the natural aging process. Additionally, in the 2000s, the discovery of adult endogenous cardiac stem cells was reported. Studies suggested that various stem cell lineages, including bone marrow stem cells, could differentiate into cardiomyocytes and potentially be utilized in the treatment of heart failure [24,25].

While significant progress has been made, myocardial regeneration remains a complex challenge, and translating experimental findings into effective clinical therapies is an ongoing process. Researchers continue to explore innovative approaches to enhance the regenerative capacity of the myocardium and improve outcomes for individuals with heart conditions.

Conclusion

Cardiac muscle tissue exhibits an intricate structural design, from the macroscopic arrangement of cardiomyocytes in the myocardium to the microscopic details of sarcomeres. This complexity is essential for the heart's efficient pumping function. As our comprehension of cardiac muscle deepens, avenues for future advancements in medical science and patient care open. Unraveling the mysteries of cardiac structure holds the key to innovative treatments and interventions aimed at promoting cardiovascular health.

The presence of intercalated discs is a hallmark feature, facilitating cellular connectivity. Gap junctions within these discs ensure rapid communication between cardiomyocytes, enabling synchronized contractions essential for effective pumping of blood. The sarcomere, as the functional unit of cardiac muscle, houses the actin and myosin filaments responsible for contraction. The intricate arrangement of these filaments reflects the specialized na-

ture of cardiomyocytes and their role in generating force for the heartbeat. T-tubules and the sarcoplasmic reticulum play pivotal roles in coordinating muscle contraction. T-tubules ensure the swift transmission of electrical signals, while the sarcoplasmic reticulum regulates calcium ions, critical for the intricate dance of contraction and relaxation. The high density of mitochondria within cardiomyocytes underscores the heart's continuous demand for energy. This reliance on oxidative metabolism ensures a constant supply of ATP, fueling the relentless contractions required to sustain blood circulation throughout the body. Cardiac muscle demonstrates dynamic adaptations in response to varying physiological demands. While hypertrophy may occur in response to increased workload, a balance must be maintained to prevent pathological hypertrophy, emphasizing the importance of cardiac plasticity [26].

In conclusion, cardiac muscle tissue stands as a marvel of biological engineering, seamlessly blending intricate structure with specialized function. The symphony of contractions orchestrated by this tissue sustains life, and ongoing research continues to unveil new chapters in the understanding of cardiac health and disease.

Prospects for further investigations

There are many exciting prospects for further investigations that could lead to significant advances in our understanding of the structure and function of the body. Unlocking the molecular mechanisms behind endogenous cardiomyocyte renewal is a promising avenue. Identifying factors that regulate this process could lead to therapeutic strategies enhancing the heart's intrinsic regenerative capacity. Advancements in imaging technologies, such as super-resolution microscopy and non-invasive imaging modalities, offer the potential to delve deeper into the dynamic and real-time visualization of cardiac muscle structure and function at the cellular and molecular levels. The application of CRISPR/Cas9 technology holds immense potential for precise gene editing in cardiac cells. This technology could aid in studying gene functions, correcting genetic mutations, and developing targeted therapies for cardiac disorders. Further exploration of cardiac progenitor cells and their role in myocardial regeneration is crucial. Elucidating the signaling pathways and microenvironmental cues that regulate these cells could pave the way for targeted regenerative therapies [27].

As we stand on the cusp of a new era in cardiac research, these prospects illuminate the exciting pathways that lie ahead. Continued exploration into the intricacies of cardiac muscle and its regulatory mechanisms promises breakthroughs that will reshape our approach to cardiovascular health and disease management.

Conflicts of interest

Potential or obvious conflicts of information interests related to this article at the time publication does not exist and is not expected.

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Черкас О.А. Методологічні особливості викладання морфології серцевого м'яза в курсі гістології.

РЕФЕРАТ. Актуальність. Серцевий м’яз з його унікальними структурними та функціональними характеристиками відіграє вирішальну роль у підтримці здоров’я серцево-судинної системи. Розуміння тонкощів морфології кардільного м’яза є фундаментальним аспектом гістологічної освіти, що надає студентам уявлення про спеціалізовану структуру та функції серця. М’язова тканина цього вітального органа є поперечно-посмугованою і за своєю структурою подібна до скелетної, але існують певні морфологічні особливості, що відрізняють її від інших тканин. У цій статті подано огляд передумов і основних методологічних особливостей викладання теми серцевої м’язової тканини в курсі гістології. **Методи**. Лекційний матеріал, мікроскопічне дослідження, комп’ютерні техніки, групове навчання є найбільш ефективними методами для вивчення морфології серцевого м’яза як студентами, так і викладачами. Також рекомендовано доступ до високоякісних підручників з гістології, онлайн-ресурсів, мікроскопів і слайдів тканин. **Результати та підсумок**. Серцевий м'яз не є статичним утворенням; він динамічно адаптується до мінливих фізіологічних вимог організму. У відповідь на збільшення робочого навантаження (наприклад, під час фізичних вправ чи вагітності) клітини серцевого м’яза можуть гіпертрофуватися, щоб задовольнити підвищені потреби. Хоча ця адаптація є корисною в короткостроковій перспективі, тривалий стрес може призвести до патологічної гіпертрофії та сприяти серцевим захворюванням. Повне розуміння структури серцевого м’яза має ключове значення для диференціальної діагностики різних серцевих патологій. Такі захворювання, як кардіоміопатії, серцева недостатність та аритмії, часто проявляються у вигляді змін структурних компонентів міокарда. Гістологічне дослідження надає цінну інформацію про клітинні та молекулярні перебудови, пов’язані з цими захворюваннями, допомагаючи в діагностиці та лікуванні. Підсумовуючи, складна структура міокарда є свідченням чудової адаптації та спеціалізації, необхідних для здійснення серцевої функції. Від макроскопічної організації кардіальної м’язової тканини до мікроскопічних деталей будови саркомерів і вставних дисків, кожен структурний компонент сприяє гармонійній роботі. Поглиблюючи розуміння структури серцевого м’яза зростає і здатність вирішувати складні діагностичні моменти серцево-судинних захворювань, прокладаючи шлях до прогресу в науково-медичній сфері.

Ключові слова: серцевий м’яз, кардіоміоцит, Т-система, саркоплазматичний ретикулум, м’язове скорочення, вставні диски, саркомер.