HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

MORPHOLOGICAL AND FUNCTIONAL CHARACTERISTICS OF MUSCLE TISSUES: SMOOTH, CARDIAC, AND SKELETAL MUSCLES

Rukhshona Olimjon qizi Odilova
Medical Treatment Faculty, Group 25–01
Email: mailto@gmail.com

Scientific Supervisor
Dilyorakhon Khusanjon qizi Muhammadjonova
Trainee Lecturer, Department of Histology, Cytology and Embryology
Email: qurbonaliyevadilyora@gmail.com

ABSTRACT

Muscle tissue is a specialized tissue responsible for movement, posture maintenance, circulation, and the functioning of internal organs. This study presents a comparative analysis of the morphological and functional characteristics of smooth, cardiac, and skeletal muscle tissues. Histological examination revealed significant differences in cellular structure, nuclear arrangement, fiber organization, and contractile properties among the three muscle types. Smooth muscle consisted of spindle-shaped non-striated cells adapted for involuntary contractions, cardiac muscle displayed branched fibers connected by intercalated discs for synchronized rhythmic activity, and skeletal muscle was composed of multinucleated striated fibers specialized for voluntary movement. The findings demonstrate the close relationship between muscle structure and physiological function and emphasize the importance of muscle tissue specialization in maintaining normal body functions.

Keywords: muscle tissue, smooth muscle, cardiac muscle, skeletal muscle, histology, morphology, muscle fibers, physiology, contraction.

АННОТАЦИЯ

Мышечная ткань представляет собой специализированную ткань, обеспечивающую движение, поддержание позы, кровообращение и функционирование внутренних органов. В данной работе проведён сравнительный анализ морфологических и функциональных особенностей гладкой, сердечной и поперечно-полосатой скелетной мышечной ткани. Гистологическое исследование выявило существенные различия в клеточном строении, расположении ядер, организации волокон и сократительных свойствах трёх типов мышц. Гладкая мышечная ткань представлена веретеновидными неисчерченными клетками, сердечная мышца характеризуется разветвлёнными волокнами и вставочными дисками, а скелетная мышца состоит из многоядерных поперечно-полосатых волокон. Полученные результаты подтверждают тесную взаимосвязь между строением мышечной ткани и её физиологической функцией.

Ключевые слова: мышечная ткань, гладкая мышца, сердечная мышца, скелетная мышца, гистология, морфология, мышечные волокна, физиология, сокращение.

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ANNOTATSIYA

Mushak to‘qimasi harakat, tana holatini saqlash, qon aylanishi va ichki organlar faoliyatini ta’minlovchi maxsus to‘qima hisoblanadi. Ushbu tadqiqotda silliq, yurak va ko‘ndalang-targ‘il skelet mushak to‘qimalarining morfologik hamda funksional xususiyatlari qiyosiy tahlil qilindi. Gistologik tekshiruv natijasida uchala mushak turida hujayra tuzilishi, yadrolarning joylashuvi, tolalar tashkil topishi va qisqarish xususiyatlarida sezilarli farqlar mavjudligi aniqlandi. Silliq mushaklar ixtiyorsiz qisqarishga moslashgan duksimon hujayralardan tashkil topgan bo‘lsa, yurak mushagi tarmoqlangan tolalar va interkalyar disklar bilan tavsiflandi. Skelet mushaklari esa ko‘p yadroli va ko‘ndalang-targ‘il tuzilishga ega bo‘lib, ixtiyoriy harakatlarni amalga oshiradi. Natijalar mushak to‘qimalari tuzilishi va ularning fiziologik vazifalari o‘rtasidagi uzviy bog‘liqlikni tasdiqlaydi.

Kalit so‘zlar: mushak to‘qimasi, silliq mushak, yurak mushagi, skelet mushagi, gistologiya, morfologiya, mushak tolalari, fiziologiya, qisqarish.

Introduction

Muscle tissue is one of the four fundamental tissue types of the human body and plays a crucial role in movement, posture maintenance, circulation, and the functioning of internal organs. It is specialized for contraction and is composed of elongated cells known as muscle fibers, which possess the unique ability to convert chemical energy into mechanical force. Through coordinated contractions, muscle tissues enable voluntary and involuntary movements that are essential for survival and physiological homeostasis [1].Based on their structural and functional characteristics, muscle tissues are classified into three major types: smooth muscle, cardiac muscle, and skeletal muscle. Although all three types share the common property of contractility, they differ significantly in their microscopic structure, location, mode of control, and physiological functions [2].Smooth muscle tissue is found primarily in the walls of hollow internal organs, including the gastrointestinal tract, blood vessels, urinary bladder, and reproductive organs. Unlike skeletal and cardiac muscles, smooth muscle cells lack visible striations and are controlled involuntarily by the autonomic nervous system. Their slow and sustained contractions are essential for processes such as peristalsis, regulation of blood vessel diameter, and movement of substances through internal organs [3].Cardiac muscle tissue forms the muscular wall of the heart and is responsible for maintaining continuous blood circulation throughout the body. Histologically, cardiac muscle exhibits striations similar to skeletal muscle; however, its cells are shorter, branched, and interconnected by specialized structures known as intercalated discs. These unique features allow rapid electrical communication between cells and ensure synchronized contraction of the myocardium. Cardiac muscle functions involuntarily and possesses intrinsic rhythmicity, enabling the heart to beat continuously throughout life [4].

Skeletal muscle tissue is attached to bones and is responsible for voluntary body movements, posture, and locomotion. It consists of long, cylindrical, multinucleated fibers characterized by distinct cross-striations resulting from the highly organized arrangement of actin and myosin filaments. Skeletal muscles are controlled by the somatic nervous system and can generate rapid and powerful contractions necessary for physical activity and interaction with the environment [5].The structural diversity among smooth, cardiac, and skeletal muscles reflects their adaptation to specific physiological functions. Understanding the morphological and functional characteristics of these muscle tissues is essential for studying normal human physiology, developmental biology, and various

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ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

pathological conditions affecting the muscular system. Furthermore, advances in histology, molecular biology, and regenerative medicine have increased scientific interest in muscle tissue organization and function [6].

Therefore, the aim of this study is to analyze the morphological and functional characteristics of smooth, cardiac, and skeletal muscle tissues and to compare their structural adaptations to their specific physiological roles in the human body.

Materials and Methods

This study was conducted as a descriptive and comparative histological investigation of the three major types of muscle tissue: smooth muscle, cardiac muscle, and skeletal muscle. The research was based on the examination of standard histological specimens obtained from anatomical and histological collections used for educational and scientific purposes. Tissue samples representing smooth muscle from the wall of the small intestine, cardiac muscle from the myocardium, and skeletal muscle from voluntary muscles attached to bones were included in the analysis.The collected tissue specimens were fixed in 10% neutral buffered formalin to preserve cellular and tissue architecture. Following fixation, the samples were dehydrated through a series of graded alcohol solutions, cleared in xylene, and embedded in paraffin blocks. Histological sections with a thickness of 5–7 μm were prepared using a rotary microtome. The sections were subsequently mounted on glass slides and stained with hematoxylin and eosin (H&E) for general morphological evaluation.Microscopic examination was performed using a light microscope at different magnifications. Particular attention was paid to the structural characteristics of muscle fibers, cellular morphology, nuclear arrangement, presence or absence of striations, connective tissue components, and intercellular junctions. Smooth muscle specimens were evaluated for spindle-shaped cell morphology and the organization of muscle layers. Cardiac muscle samples were analyzed for branching fibers, centrally located nuclei, and intercalated discs. Skeletal muscle tissues were examined for multinucleated fibers, peripheral nuclear localization, and distinct cross-striations.Morphometric analysis was conducted to compare selected histological parameters among the three muscle tissue types. Measurements included average muscle fiber diameter, nuclear dimensions, and the relative density of muscle fibers within the examined fields. Digital microphotographs were obtained and analyzed using image-processing software to ensure accuracy and reproducibility of measurements.

The obtained data were organized and analyzed using descriptive statistical methods. Quantitative results were expressed as mean values (M) and standard deviations (SD). Comparative evaluation of morphological characteristics was performed to identify structural differences and functional adaptations among smooth, cardiac, and skeletal muscle tissues. All procedures were carried out in accordance with accepted scientific and ethical standards for histological research.

Results

The comparative histological analysis revealed significant structural and functional differences among smooth, cardiac, and skeletal muscle tissues. Microscopic examination demonstrated that each muscle type possesses unique morphological adaptations that correspond to its physiological role within the human body.Smooth muscle tissue was characterized by elongated spindle-shaped cells with a single centrally located nucleus. The cells lacked visible cross-striations and were arranged in

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compact layers. Histological sections obtained from the intestinal wall showed closely packed smooth muscle fibers organized into circular and longitudinal layers. The absence of sarcomere organization contributed to the non-striated appearance of the tissue. Smooth muscle fibers exhibited relatively small diameters and demonstrated a uniform cellular arrangement. These structural characteristics are associated with slow, sustained, and involuntary contractions required for the propulsion of contents through hollow organs and regulation of vascular tone [4].

Cardiac muscle tissue exhibited distinctive branching fibers interconnected by intercalated discs. The muscle cells contained one or occasionally two centrally positioned nuclei and displayed clear transverse striations. Intercalated discs were readily visible under light microscopy as dark transverse lines connecting adjacent cardiomyocytes. These specialized junctions facilitate mechanical and electrical coupling between cells, allowing coordinated myocardial contraction. The branching architecture of cardiac muscle fibers creates a functional syncytium that enables efficient propagation of electrical impulses throughout the heart muscle [5].Skeletal muscle tissue demonstrated the most prominent striated appearance among the examined muscle types. Long cylindrical muscle fibers were arranged in parallel bundles and contained multiple nuclei located at the periphery of the cell beneath the sarcolemma. Well-defined alternating dark and light bands reflected the highly organized arrangement of actin and myosin filaments within sarcomeres. The large diameter of skeletal muscle fibers and their extensive contractile apparatus are consistent with their role in generating rapid and forceful voluntary movements [6].

Morphometric evaluation showed notable differences in fiber diameter and nuclear distribution among the three muscle tissues. Skeletal muscle fibers possessed the greatest average diameter, whereas smooth muscle fibers were the smallest. Cardiac muscle fibers exhibited intermediate dimensions. The number and location of nuclei also varied considerably. Smooth and cardiac muscle cells generally contained a single central nucleus, while skeletal muscle fibers contained numerous peripheral nuclei resulting from the fusion of myoblasts during development [7].The connective tissue organization surrounding muscle fibers differed among the studied tissues. Skeletal muscle displayed well-developed endomysium, perimysium, and epimysium layers that support muscle bundles and facilitate force transmission. Cardiac muscle contained a delicate connective tissue network rich in capillaries, ensuring adequate oxygen and nutrient supply for continuous contraction. Smooth muscle tissue was associated with a relatively thin connective tissue framework that supported coordinated contraction of neighboring cells [8].

Table 1

Comparative Morphological Characteristics of Smooth, Cardiac, and Skeletal Muscle Tissues

Characteristic	**Smooth Muscle**	**Cardiac Muscle**	**Skeletal Muscle**
Cell shape	Spindle-shaped	Branched cylindrical cells	Long cylindrical fibers
Number of nuclei	One	One or two	Multiple
Nuclear location	Central	Central	Peripheral

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Striations	Absent	Present	Prominent
Intercalated discs	Absent	Present	Absent
Control mechanism	Involuntary	Involuntary	Voluntary
Fiber diameter (μm)	4.8 ± 0.5	14.2 ± 1.3	52.6 ± 4.1
Branching	Absent	Present	Absent
Contraction speed	Slow	Moderate	Fast
Fatigue resistance	High	Very high	Variable

The quantitative findings confirmed that skeletal muscle fibers had the largest average diameter, measuring 52.6 ± 4.1 μm, whereas smooth muscle fibers had the smallest diameter, measuring 4.8 ± 0.5 μm. Cardiac muscle fibers demonstrated intermediate values of 14.2 ± 1.3 μm. These differences reflect the specific functional requirements of each muscle tissue type. Skeletal muscles require large contractile units to generate substantial force, whereas smooth muscles perform prolonged contractions with minimal energy expenditure. Cardiac muscle combines structural strength with continuous rhythmic activity necessary for maintaining circulation [5, 7].

Overall, the results demonstrated that the morphology of muscle tissues is closely related to their physiological functions. Smooth muscle is specialized for involuntary and sustained contractions, cardiac muscle for rhythmic and synchronized pumping activity, and skeletal muscle for voluntary and powerful body movements. The observed structural variations emphasize the remarkable adaptation of muscle tissues to the diverse mechanical and physiological demands placed upon them [4–8].

Discussion

The findings of this study highlight the remarkable structural diversity of smooth, cardiac, and skeletal muscle tissues and demonstrate how their morphological characteristics are closely related to their specific physiological functions. Although all three muscle types share the fundamental ability to contract, significant differences in cellular organization, nuclear arrangement, contractile apparatus, and connective tissue support reflect their adaptation to different functional demands within the human body.The absence of striations in smooth muscle tissue observed during microscopic examination is consistent with its specialized role in generating slow and sustained contractions. Unlike skeletal and cardiac muscles, smooth muscle cells do not possess highly organized sarcomeres, resulting in a non-striated appearance. This structural arrangement allows smooth muscle to maintain prolonged contractions with relatively low energy expenditure. Such an adaptation is particularly important in the walls of blood vessels, gastrointestinal organs, and other hollow structures where continuous regulation of lumen diameter and movement of contents are required [4].

Cardiac muscle tissue demonstrated several unique characteristics, including branched fibers, centrally located nuclei, and intercalated discs. These features distinguish cardiac muscle from other muscle types and contribute directly to its physiological role. Intercalated discs provide both

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mechanical attachment and electrical communication between adjacent cardiomyocytes, enabling the myocardium to function as a coordinated unit. The ability of cardiac muscle cells to transmit electrical impulses rapidly ensures synchronized contraction of the atria and ventricles, which is essential for efficient blood circulation throughout the body [5]. The presence of abundant mitochondria and a rich capillary network further supports the continuous metabolic demands of the heart. Skeletal muscle tissue exhibited the most pronounced striations and the largest fiber diameter among the examined muscle types. These findings are consistent with the functional requirement for generating powerful voluntary contractions. The highly organized arrangement of actin and myosin filaments into sarcomeres allows skeletal muscles to produce rapid and forceful movements. Furthermore, the multinucleated nature of skeletal muscle fibers reflects their developmental origin through the fusion of numerous myoblasts. Multiple nuclei facilitate increased protein synthesis and maintenance of the extensive cytoplasmic volume required for muscle contraction and repair [6].

The morphometric results revealed substantial differences in fiber diameter among the three muscle tissues. Skeletal muscle fibers showed the greatest diameter, while smooth muscle fibers exhibited the smallest dimensions. These differences can be explained by variations in functional requirements and mechanical workload. Skeletal muscles are responsible for locomotion and posture, requiring large contractile units capable of generating significant force. In contrast, smooth muscles perform regulatory functions that depend more on endurance and coordination than on maximal force production [7]. The connective tissue organization observed in this study also reflects the functional specialization of muscle tissues. Skeletal muscle contains well-developed connective tissue layers that distribute mechanical forces and provide structural support during movement. Cardiac muscle is surrounded by a delicate connective tissue framework rich in blood vessels, ensuring a constant supply of oxygen and nutrients. Smooth muscle, on the other hand, relies on a relatively simple connective tissue arrangement that supports coordinated contractions among neighboring cells [8].

Another important observation is the relationship between cellular architecture and control mechanisms. Smooth and cardiac muscles function involuntarily under the regulation of the autonomic nervous system and intrinsic signaling pathways. Their structural features support continuous and automatic activity without conscious control. Skeletal muscle, however, is under voluntary control and is designed to respond rapidly to neural stimulation. The specialized neuromuscular junctions and highly organized contractile apparatus allow precise regulation of movement and force generation [5, 6]. The results obtained in this study are in agreement with previous histological and physiological investigations that emphasize the close relationship between structure and function in muscle tissues. The observed differences in cell morphology, nuclear organization, striation patterns, and connective tissue support illustrate how evolutionary adaptations have enabled each muscle type to perform specialized roles efficiently. Understanding these characteristics is essential for interpreting pathological changes associated with muscular disorders, cardiovascular diseases, and gastrointestinal dysfunctions [4, 7].

Overall, the comparative analysis confirms that smooth, cardiac, and skeletal muscles possess distinct morphological features that correspond directly to their physiological functions. These findings contribute to a deeper understanding of muscle tissue organization and provide a histological basis for studying normal muscle physiology as well as disease-related alterations affecting the muscular system.

HSR (LONDON),
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Conclusion

The present study demonstrated that smooth, cardiac, and skeletal muscle tissues possess distinct morphological and functional characteristics that reflect their specialized roles within the human body. Histological examination revealed significant differences in cell shape, nuclear arrangement, fiber organization, connective tissue support, and contractile structures among the three muscle types. Smooth muscle tissue was characterized by spindle-shaped, non-striated cells with centrally located nuclei, making it well adapted for slow and sustained involuntary contractions in the walls of hollow organs and blood vessels. Cardiac muscle tissue exhibited branched striated fibers connected by intercalated discs, which facilitate synchronized contraction and continuous pumping activity of the heart. Skeletal muscle tissue consisted of long multinucleated striated fibers with peripheral nuclei, enabling rapid, forceful, and voluntary movements of the body. Morphometric analysis confirmed substantial differences in muscle fiber diameter and cellular organization, reflecting the varying mechanical and physiological demands placed upon each muscle type. The structural adaptations observed in this study demonstrate a close relationship between tissue architecture and functional performance. In conclusion, the comparative evaluation of smooth, cardiac, and skeletal muscle tissues highlights the remarkable specialization of muscle cells in response to specific physiological requirements. Understanding these morphological and functional differences is essential for the study of normal human physiology, histology, pathology, and clinical medicine. Furthermore, the findings provide a valuable foundation for future research on muscle development, regeneration, and diseases affecting the muscular system.

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