P.A. Kobeza

Dnipro State Medical University
Dnipro, Ukraine

Надійшла: 14.10.2024
Прийнята: 15.12.2024

DOI: https://doi.org/10.26641/1997-9665.2024.4.126-132

UDC 611.019

MORPHOMETRY. GENERAL METHOD FOR HISTOLOGY, CYTOLOGY AND EMBRYOLOGY. OVERVIEW AND PROSPECTS OF INTEGRATION INTO THE EDUCATIONAL PROCESS

Kobeza P.A. ✉ **Morphometry. General method for histology, cytology and embryology. Overview and prospects of integration into the educational process.**
Dnipro State Medical University, Dnipro, Ukraine.
ABSTRACT. Background. Morphological analysis provides insights into the intricate architecture of cells and tissues, revealing how their specific configurations support their biological roles. The relevance of mastering morphometric techniques in modern scientific inquiry cannot be overstated. **Objective.** The primary aim of this article is to elucidate the significance of morphometry in the analysis of morphological structures within the framework of foundational courses in histology, cytology, and embryology. This analysis will emphasize its application in both normal physiology and pathological conditions, illustrating how morphometric data can inform clinical practice and research. **Methods.** Morphometry relies on precise measurements of the structural elements of tissues using light or electron microscopy, along with specialized software for image processing. **Results.** Described levels of organization and general approach to defining the morphofunctional unit. The structural-functional unit is a fundamental component of tissue, organs, or organ systems, characterized by a specific morphological organization that performs functions unique to that organ. This unit represents the minimal structural entity capable of independently executing biological processes inherent to a given organ or tissue, thereby sustaining vital activities across various levels of biological organization. **Conclusion.** In summary, the concept of structural-functional units is fundamental in histology, as it defines how tissues and organs are organized and function. The integration of morphometry with emerging technologies will undoubtedly pave the way for new insights into cellular behavior and disease mechanisms, reinforcing its pivotal role in the fields of medicine and biology.
Key words: morphometry, histology, cytology, embryology, educational process.

Citation:
Kobeza PA. Morphometry. General method for histology, cytology and embryology. Overview and prospects of integration into the educational process. Morphologia. 2024;18(4):126-32.
DOI: https://doi.org/10.26641/1997-9665.2024.4.126-132

Kobeza P.A. 0000-0003-1113-4007
✉ **kobeza.pavel@gmail.com**

Background

Morphology is the science that studies the form, structure, and spatial relationships of tissues and cells in living organisms. It serves as a foundational component of biological and medical sciences, as it enables an understanding of how structure is intimately linked to function at all levels of organization [1]. Morphological analysis provides insights into the intricate architecture of cells and tissues, revealing how their specific configurations support their biological roles. For instance, the arrangement of muscle fibers in cardiac tissue is critical for efficient contraction and blood circulation, while the layered structure of the skin contributes to its protective functions. Within the fields of histology, cytology, and embryology, morphology examines tissues and cells under the microscope, revealing their structural features and interconnections. This microscopic analysis is fundamental for identifying cellular components, such as organelles and extracellular matrices, as well as understanding developmental processes during embryogenesis. The ability to observe and describe these features allows researchers to establish baselines for normal structure and identify deviations associated with pathological conditions. Morphometry, on the other hand, is a quantitative method for assessing morphological characteristics. It provides precise measurements of sizes, shapes, and proportions of structural elements within tissues, enabling researchers to generate statistically significant data that can be compared across different conditions and populations [2]. This quantitative approach is essential in modern research, allowing for objective evaluations of morphological parameters, which is crucial for a comprehensive understanding of both normal and pathological processes in cells and tissues.

By employing morphometric techniques, researchers can uncover subtle variations and relationships that contribute to our understanding of health and disease. For example, morphometric analysis can reveal changes in cell size and shape in response to injury or disease [3], offering insights into underlying mechanisms of pathology. Additionally, morphometric methods can assist in the identification of biomarkers and facilitate the assessment of therapeutic interventions by providing measurable outcomes. The integration of morphology and morphometry enhances our diagnostic and therapeutic strategies. Mastery of these techniques not only enriches our understanding of biological systems but also paves the way for innovations in clinical practices, contributing to improved patient care and outcomes. By emphasizing the importance of these methodologies in education and research [4,5], we can foster a new generation of scientists and clinicians equipped to tackle the complex challenges in health and disease.

Purpose

With the advancement of cutting-edge technologies and microscopy methods, there is an increasing demand for precise quantitative assessments of morphological structures. Traditional descriptive morphology often falls short in providing sufficient data to evaluate dynamic changes within tissues, particularly in the context of disease progression or embryonic development. In many instances, qualitative observations alone cannot capture the nuanced alterations that occur at cellular and tissue levels. Morphometry offers a solution by enabling researchers to obtain objective, quantitative data that can be systematically analyzed. This capability transforms the study of morphology from a predominantly descriptive science into a rigorous quantitative discipline, allowing for the identification of subtle morphological variations that may be critical in understanding pathological conditions. For instance, in cancer research, morphometric techniques can reveal changes in cell shape, size, and arrangement, providing insights into tumor behavior and prognosis.

The integration of morphometry into contemporary morphological research is indispensable, as it enhances the ability to track changes over time and under varying physiological or pathological conditions. As the landscape of biological research becomes increasingly complex, the precision afforded by morphometric analysis becomes essential. It not only contributes to the understanding of normal physiological processes but also plays a pivotal role in elucidating the mechanisms underlying various diseases. The application of morphometry is not limited to basic research; it extends to clinical settings where accurate morphological assessments can inform diagnosis and treatment strategies. For instance, in histopathology, quantitative analysis of tissue samples can assist pathologists in identifying disease states and determining the aggressiveness of tumors, ultimately guiding therapeutic decisions.

In summary, the relevance of mastering morphometric techniques in modern scientific inquiry cannot be overstated. As research progresses towards a more quantitative framework, the ability to provide detailed, objective analyses of morphological changes will be crucial in advancing our understanding of health and disease, thereby significantly impacting both basic and applied biomedical research.

Objective

The primary aim of this article is to elucidate the significance of morphometry in the analysis of morphological structures within the framework of foundational courses in histology, cytology, and embryology. Morphometry serves a dual purpose: it not only facilitates the description of tissue structure but also enables the quantitative assessment of its parameters, thus contributing to a more precise understanding of both normal and pathological processes. In a rapidly evolving scientific landscape, the ability to quantitatively analyze morphological characteristics is becoming increasingly vital. By employing morphometric techniques, researchers and students can delve deeper into the intricacies of tissue organization and cellular architecture. This quantitative approach allows for the identification of specific morphological features that may correlate with functional outcomes, thereby enhancing the interpretative power of histological observations. The objectives of this article include exploring the various morphometric methods available, discussing their applications in different biological contexts, and demonstrating how these techniques can be integrated into educational curricula. By highlighting specific case studies where morphometry has provided critical insights, we aim to underscore its importance as a complementary tool for traditional descriptive methods. Additionally, we will address the challenges and limitations associated with morphometric analyses, including issues related to measurement precision and the need for standardized protocols. Understanding these challenges is essential for ensuring the reliability and reproducibility of morphometric studies. Ultimately, this article seeks to advocate for the inclusion of morphometric techniques in the training of future professionals in the biomedical field. By fostering an appreciation for the quantitative dimensions of morphology, we can empower students and researchers to make informed, data-driven conclusions that advance both scientific knowledge and clinical practice.

Overview of key concepts and definitions of morphometry. this section will provide a comprehensive introduction to the fundamental principles and terminology associated with morphometry, establishing a clear understanding of its relevance in biological and medical contexts. Analysis of historical development and contemporary approaches to morphometry. This objective will trace the evolution of morphometric techniques from their inception to the present day, highlighting key milestones and advancements that have shaped current methodologies. We will also explore modern approaches, including the integration of digital imaging and computational tools. Determination of the role of morphometry in tissue research. we will examine how morphometry contributes to the study of tissues, particularly in understanding structural and functional changes. This analysis will emphasize its application in both normal physiology and pathological conditions, illustrating how morphometric data can inform clinical practice and research.

Methods

Morphometry relies on precise measurements of the structural elements of tissues using light or electron microscopy, along with specialized software for image processing. The primary parameters measured in morphometric studies include cell dimensions, tissue thickness, surface area, volume, and the ratios of various tissue components [6]. The application of these techniques enables researchers to obtain quantitative data that can be statistically analyzed, enhancing the objectivity of morphological assessments. For instance, light microscopy allows for the visualization of tissue architecture at a cellular level, while electron microscopy provides insights into ultrastructural details that are critical for understanding the intricacies of tissue organization [7]. Specialized software tools facilitate the analysis of acquired images, enabling the extraction of morphometric data with high precision. These tools often include automated measurement capabilities, which reduce human error and increase the efficiency of data collection. By employing these methodologies, researchers can generate robust datasets that inform our understanding of the dynamic nature of tissues and their responses to various physiological and pathological stimuli.

The integration of advanced morphometric techniques into research and clinical practice is essential for elucidating the complexities of biological systems and enhancing our ability to address health-related challenges [8].

Light Microscopy. This foundational technique is widely used for the assessment of histological sections. Light microscopy allows researchers to visualize tissue architecture and cellular components, providing essential insights into the organization and characteristics of various tissues. It is particularly useful for routine histopathological examinations, where stained tissue sections can reveal important morphological details.

Electron Microscopy. This advanced method provides highly detailed images of ultrastructural elements within tissues. Electron microscopy, including transmission and scanning techniques, allows for the examination of cellular structures at a much higher resolution than light microscopy. This capability is crucial for studying intricate features such as organelles, membrane structures, and the extracellular matrix, enabling a deeper understanding of cellular function and pathology.

Computer Image Analysis. This method involves the use of specialized software to perform precise measurements of morphological parameters from acquired images. Computer-assisted image analysis enhances the accuracy and efficiency of morphometric assessments by automating the process of data extraction. Parameters such as cell size, shape, and spatial relationships can be quantified, allowing for robust statistical analyses that can inform research conclusions.

The materials utilized in morphometric studies primarily consist of tissue samples from various organisms. These samples can be derived from healthy and diseased tissues, providing a comprehensive basis for comparative analysis [9]. By examining diverse tissue types—such as epithelial, connective, muscular, and nervous tissues—researchers can gain valuable insights into the structural variations that correlate with different physiological and pathological states.

In preparation for microscopic examination, tissue samples are typically fixed, embedded, and sectioned to appropriate thicknesses. Staining protocols may also be employed to enhance contrast and highlight specific structures, thereby facilitating more effective visualization under the microscope. By utilizing these materials and methods, researchers can systematically investigate morphological changes, contributing to the advancement of knowledge in both basic and applied biological sciences.

Results

The structural-functional unit is a fundamental component of tissue, organs, or organ systems, characterized by a specific morphological organization that performs functions unique to that organ [9]. This unit represents the minimal structural entity capable of independently executing biological processes inherent to a given organ or tissue, thereby sustaining vital activities across various levels of biological organization. The structural-functional unit possesses a well-defined architecture typical of a particular tissue or organ [10, 11]. Most commonly, it is represented by a cell or a group of closely associated cells specialized in carrying out specific functions. Additionally, it may include extracellular components that facilitate the realization of these functions. For instance, in cardiac tissue, the structural-functional unit is the cardiomyocyte, a specialized cell responsible for contraction, which enables the heart to function as an effective pump. The primary role of the structural-functional unit lies in the execution of specific functions associated with the tissue or organ [12]. This function is dictated by the specialization of the cells and their morphology. For example, in nervous tissue, a neuron is responsible for transmitting nerve impulses, whereas in muscular tissue, the sarcomere performs the contraction function. The sarcomere is a structural-functional unit of striated muscle tissue, particularly found in cardiomyocytes and skeletal muscles. It constitutes the fundamental building block of the contractile system and is essential for generating mechanical force through the interaction of actin and myosin filaments [13]. This intricate relationship is crucial for muscle contraction and overall movement.

Histological Context. In histology, structural-functional units form the basis for understanding the organization and functional specialization of tissues. Histological studies investigate how cells and tissues are organized within organs to ensure the fulfillment of their specific functions. For instance, in the kidneys, the nephron serves not only as the primary structural unit but also as a functional one [14]. It is responsible for blood filtration, reabsorption of useful substances, and waste elimination, thus playing a critical role in maintaining the body's homeostasis. Morphometric analysis of nephrons enables the assessment of renal functional capacity under both normal and pathological conditions. By employing morphometric techniques, researchers can quantitatively evaluate the morphological characteristics of structural-functional units, thereby providing valuable insights into their physiological roles and contributions to health and disease [15]. This approach enhances our understanding of tissue organization and function, ultimately informing clinical practices and therapeutic interventions.

Levels of Organization. Structural-functional units can be organized at various levels:

1. Cellular Level: This is the most basic level of organization, where an individual cell acts as a functional unit. For example, an epithelial cell in the skin performs specific tasks essential for barrier protection and sensory perception [16]. The unique morphology of epithelial cells, such as their tight junctions and polarity, contributes to their specialized functions.

2. Tissue Level: At this level, groups of cells that interact closely together perform a common function. An example is epithelial tissue, which lines internal surfaces of organs and cavities [17]. The coordinated action of these cells facilitates processes such as absorption, secretion, and protection, highlighting the importance of cellular organization in maintaining homeostasis.

3. Organ Level: In complex organs, such as the kidneys or liver, structural-functional units may encompass not only individual cells but also intricate complexes, like nephrons in the kidneys or hepatic lobules in the liver. These units integrate various cell types and extracellular matrices to perform specialized functions critical for the organ's overall performance, such as filtration and metabolic regulation [18].

Extracellular Matrix and Microenvironment. In histology, the significance extends beyond the cell as a structural-functional unit; the surrounding microenvironment also plays a crucial role [19]. The extracellular matrix (ECM) is vital for supporting cellular structure and regulating cellular functions. It consists of a complex network of proteins and carbohydrates that provide structural integrity and biochemical signals. For instance, in connective tissue, fibroblasts are the structural-functional units responsible for producing collagen and elastin fibers, which form the tissue framework. The interaction between fibroblasts and the ECM is essential for providing mechanical support to tissues and facilitating processes such as wound healing [20]. This relationship underscores the importance of the extracellular matrix in maintaining tissue architecture and promoting cellular functions. The microenvironment can influence cellular behavior, impacting processes such as differentiation, migration, and response to injury. Understanding the interplay between structural-functional units and their extracellular surroundings is essential for elucidating the mechanisms underlying tissue development, repair, and pathology [21]. This comprehensive perspective is crucial in advancing our knowledge of both normal physiology and disease states, paving the way for innovative therapeutic approaches in regenerative medicine and tissue engineering.

Morphometry and Quantitative Assessment. The application of morphometry to evaluate structural-functional units is critical for objective tissue analysis [22]. Morphometric studies quantitatively determine changes in size, shape, and quantitative ratios of structures, enabling conclusions about their functional activity. For instance, in cardiac research, morphometry can be employed to assess the density and orientation of sarcomeres in cardiomyocytes, which directly influences the contractile ability of cardiac muscle [23].

Examples of Structural-Functional Units in Various Systems.

1. Epithelial Cells: These are the primary structural-functional units in epithelial tissue, responsible for barrier functions and secretion. Their organization and morphology are vital for processes such as absorption and protection.

2. Osteon: This is the structural-functional unit of bone tissue, ensuring bone strength and its ability to withstand mechanical loads. The arrangement of osteons and their interaction with surrounding bone matrix is essential for skeletal integrity.

3. Hepatocyte: As the main cell type in the

liver, hepatocytes are responsible for metabolic and detoxification functions. Their structural adaptations facilitate various biochemical processes critical for maintaining homeostasis.

Dysfunction of structural-functional units often underlies the development of pathological conditions. For example, impaired function of sarcomeres in cardiomyocytes can lead to heart failure. Morphological changes in these structural-functional units during disease processes—such as hypertrophy, atrophy, or destruction—can be quantitatively assessed using morphometric methods for diagnosing and monitoring disease progression [24, 25].

The application of morphometry has enabled the acquisition of quantitative data regarding the structure of tissues and cells, which assists in the objective evaluation of their changes during normal development and pathological states. For instance, morphometric studies have revealed significant alterations in the sizes of cell nuclei associated with specific diseases, as well as changes in arterial wall thickness during the progression of atherosclerosis [26]. These findings underscore the critical role of morphometry in understanding disease mechanisms and developmental biology.

Discussion

This section includes a comparison of various morphometric methods and an evaluation of their effectiveness in tissue analysis. Common techniques such as light microscopy, electron microscopy, and image analysis software are discussed in terms of their strengths and limitations [27]. Each method offers unique insights, yet their reliability often hinges on factors such as the quality of sample preparation and the precision of measurements. Potential limitations include variability in results due to sample heterogeneity and the challenge of standardizing measurement protocols across different studies [28]. By addressing these aspects, the discussion highlights the importance of selecting appropriate morphometric techniques tailored to specific research questions and emphasizes the need for rigorous methodological standards to ensure data integrity [29, 30]. This comprehensive approach not only enhances the validity of findings but also contributes to the overall advancement of morphometric applications in both basic and clinical research.

Conclusion

1. In summary, the concept of structural-functional units is fundamental in histology, as it defines how tissues and organs are organized and function. Studying these units provides insights into how cellular-level changes affect overall organism function, laying the groundwork for further investigation into pathological processes and the development of therapeutic strategies. By integrating morphometric analysis into research, we can deepen our understanding of normal physiology and disease mechanisms, ultimately enhancing clinical outcomes.

2. Morphometry serves as a crucial tool for the quantitative analysis of morphological characteristics of tissues, making it indispensable in modern histological and cytological research. It allows for precise measurements and objective evaluations of changes in tissues, thereby fostering a deeper understanding of both normal and pathological processes.

3. In future studies, the significance of morphometry is likely to increase further due to advancements in image processing technologies and automated tissue analysis. These innovations are expected to enhance the accuracy and efficiency of morphometric assessments, enabling researchers to uncover intricate details about tissue architecture and dynamics.

4. The integration of morphometry with emerging technologies will undoubtedly pave the way for new insights into cellular behavior and disease mechanisms, reinforcing its pivotal role in the fields of medicine and biology.

Information on conflict of interest

There are no potential or apparent conflicts of interest related to this manuscript at the time of publication and are not anticipated.

References

1. Weibel ER, Elias H. Introduction to stereology and morphometry. In: Quantitative Methods in Morphology/Quantitative Methoden in der Morphologie. Berlin, Heidelberg: Springer Berlin Heidelberg; 1967:3-19.

2. Anderson RH, Brown NA. The anatomy of the heart revisited. Anat Rec. 1996;246(1):1-7. doi: 10.1002/(SICI)1097-0185(199609)246:1<1::AID-AR1>3.0.CO;2-Y. PMID: 8876818

3. Larkin S, Ansorge O, authors; Feingold KR, Anawalt B, Blackman MR, Boyce A, Chrousos G, Corpas E, de Herder WW, Dhatariya K, Dungan K, Hofland J, Kalra S, Kaltsas G, Kapoor N, Koch C, Kopp P, Korbonits M, Kovacs CS, Kuohung W, Laferrère B, Levy M, McGee EA, McLachlan R, New M, Purnell J, Sahay R, Shah AS, Singer F, Sperling MA, Stratakis CA, Trence DL, Wilson DP, editors: Development And Microscopic Anatomy Of The Pituitary Gland. Endotext [Internet]. South Dartmouth (MA): MDText.com, Inc.; 2017.2000–. PMID: 28402619

4. Dogan KK, author: Histology and Embryology 4.0. Perspectives on Artificial Intelligence in Times of Turbulence: Theoretical Background to Applications. IGI Global; 2024:119-134.

5. Pawlina W, Drake RL. Anatomical models: don't banish them from the anatomy laboratory yet.

Anat Sci Educ. 2013;6(4):209-210. doi: 10.1002/ase.1380. PMID: 23825081

6. Trelease RB, Nieder GL. Transforming clinical imaging and 3D data for virtual reality learning objects: HTML5 and mobile devices implementation. Anat Sci Educ. 2013;6(4):263-270. doi: 10.1002/ase.1330. Epub 2012 Dec 4. PMID: 23212750

7. Preece D, Williams SB, Lam R, Weller R. "Let's get physical": advantages of a physical model over 3D computer models and textbooks in learning imaging anatomy. Anat Sci Educ. 2013;6(4):216-224. doi: 10.1002/ase.1345. Epub 2013 Jan 24. PMID: 23349117

8. Khot Z, Quinlan K, Norman GR, Wainman B. The relative effectiveness of computer-based and traditional resources for education in anatomy. Anat Sci Educ. 2013;6(4):211-215. doi: 10.1002/ase.1355. Epub 2013 Mar 18. PMID: 23509000

9. Nguyen N, Nelson AJ, Wilson TD. Computer visualizations: factors that influence spatial anatomy comprehension. Anat Sci Educ. 2012;5(2):98-108. doi: 10.1002/ase.1258. Epub 2012 Jan 9. PMID: 22232125

10. Nguyen N, Nelson AJ, Wilson TD. Computer visualizations: factors that influence spatial anatomy comprehension. Anat Sci Educ. 2012;5(2):98-108. doi: 10.1002/ase.1258. Epub 2012 Jan 9. PMID: 22232125

11. Trelease RB, Rosset A. Transforming clinical imaging data for virtual reality learning objects. Anat Sci Educ. 2008;1(2):50-55. doi: 10.1002/ase.13. PMID: 19177381

12. Hisley KC, Anderson LD, Smith SE, Kavic SM, Tracy JK. Coupled physical and digital cadaver dissection followed by a visual test protocol provides insights into the nature of anatomical knowledge and its evaluation. Anat Sci Educ. 2008;1(1):27-40. doi: 10.1002/ase.4. PMID: 19177376

13. Khalil MK, Paas F, Johnson TE, Su YK, Payer AF. Effects of instructional strategies using cross sections on the recognition of anatomical structures in correlated CT and MR images. Anat Sci Educ. 2008;1(2):75-83. doi: 10.1002/ase.19. PMID: 19177385

14. Amalinei C, Timofte AD, Căruntu ID, Wierzbicki PM, Żmijewski MA, Sirmakessis S, Girela JL, Martínez-Ruiz N, Vizcaya-Moreno MF, Pérez-Cañaveras RM, Harizanova Z, Popova F, Colibaba C, Kmieć Z. Digital morphology network for effective teaching of cytology, histology and histopathology for medical and biology curriculum. VM3.0 Erasmus+ project. Folia Histochem Cytobiol. 2024;62(2):61-75. doi: 10.5603/fhc.100875. Epub 2024 Jun 24. PMID: 38912571

15. Triola MM, Holloway WJ. Enhanced virtual microscopy for collaborative education. BMC Med Educ. 2011;11:4. doi: 10.1186/1472-6920-11-4. PMID: 21269474; PMCID: PMC3037351

16. Megarani DV, et al. Comparative morphology and morphometry of blood cells in zebrafish (Danio rerio), common carp (Cyprinus carpio carpio), and tilapia (Oreochromis niloticus). Journal of the American Association for Laboratory Animal Science. 2020;59(6):673-680.

17. Neel JA, Grindem CB, Bristol DG. Introduction and evaluation of virtual microscopy in teaching veterinary cytopathology. J Vet Med Educ. 2007;34(4):437-444. doi: 10.3138/jvme.34.4.437. PMID: 18287470

18. Dee FR, Meyerholz DK. Teaching medical pathology in the twenty-first century: virtual microscopy applications. J Vet Med Educ. 2007;34(4):431-436. doi: 10.3138/jvme.34.4.431. PMID: 18287469

19. Heidger PM Jr, Dee F, Consoer D, Leaven T, Duncan J, Kreiter C. Integrated approach to teaching and testing in histology with real and virtual imaging. Anat Rec. 2002;269(2):107-112. doi: 10.1002/ar.10078. PMID: 12001217

20. Dehaan RL, Ebert JD. Morphogenesis. Annu Rev Physiol. 1964;26:15-46. doi: 10.1146/annurev.ph.26.030164.000311. PMID: 14147456

21. O'Rourke J, Bode G, authors; Mobley HLT, Mendz GL, Hazell SL, editors: Morphology and Ultrastructure. Helicobacter pylori: Physiology and Genetics. Washington (DC): ASM Press; 2001. Chapter 6. PMID: 21290748

22. Duerr JS. Immunohistochemistry. WormBook; 2006:1-61. doi: 10.1895/wormbook.1.105.1. PMID: 18050446; PMCID: PMC4780882

23. Weibel ER, author: "Morphometry: stereological theory and practical methods."Models of lung disease. CRC Press; 2020:199-252.

24. Khan RH, Rhodes JS, Girard IA, Schwartz NE, Garland Jr T. Does Behavior Evolve First? Correlated Responses to Selection for Voluntary Wheel-Running Behavior in House Mice. Ecological and Evolutionary Physiology. 2024;97(2):97-117.

25. Ashburner J, Friston KJ. Voxel-based morphometry--the methods. Neuroimage. 2000;11(6):805-821. doi: 10.1006/nimg.2000.0582. PMID: 10860804

26. Goto M, Abe O, Aoki S, Kamagata K, Hori M, Miyati T, Gomi T, Takeda T. Combining Segmented Grey and White Matter Images Improves Voxel-based Morphometry for the Case of Dilated Lateral Ventricles. Magn Reson Med Sci. 2018;17(4):293-300. doi: 10.2463/mrms.mp.2017-0127. Epub 2018 Jan 18. PMID: 29343657; PMCID: PMC6196303

27. Diagone KV, Vicente WR, Pacheco MR, Mateus O. Oocyte morphometry in female dogs (Canis familiaris, Linnaeus, 1758). Anat Histol Embryol. 2008;37(2):81-85. doi: 10.1111/j.1439-0264.2007.00801.x. PMID: 18333852

28. Chou SH, Vokes T. Vertebral Morphometry. J Clin Densitom. 2016;19(1):48-53. doi: 10.1016/j.jocd.2015.08.005. Epub 2015 Sep 6. PMID: 26349790

29. Sanfélix-Genovés J, Arana E, Sanfélix-Gimeno G, Peiró S, Graells-Ferrer M, Vega-Martínez M. Agreement between semi-automatic radiographic morphometry and Genant semi-quantitative method in the assessment of vertebral fractures. Osteoporos Int. 2012;23(8):2129-2134. doi: 10.1007/s00198-011-1819-3. Epub 2011 Dec 15. PMID: 22170523

30. Gómez-Torres FA, Sebastian R, Ruíz-Sauri A. Morphometry and comparative histology of sinus and atrioventricular nodes in humans and pigs and their relevance in the prevention of nodal arrhythmias. Res Vet Sci. 2020;128:275-285. doi: 10.1016/j.rvsc.2019.12.008. Epub 2019 Dec 5. PMID: 31869593

Кобеза П.А. Морфометрія. Загальний метод для гістології, цитології та ембріології. Огляд та перспективи інтеграції в освітній процес.

РЕФЕРАТ. Актуальність. Морфологія — це наука, яка вивчає форму, структуру та просторові взаємовідносини тканин і клітин у живих організмах. Морфологічний аналіз надає уявлення про складну архітектуру клітин і тканин, показуючи, як їх специфічні конфігурації підтримують біологічні функції. **Мета.** Значення оволодіння морфометричними техніками в сучасних наукових дослідженнях важко переоцінити. Основна мета, прояснити важливість морфометрії в аналізі морфологічних структур у рамках базових курсів гістології, цитології та ембріології. У цьому аналізі буде підкреслено її застосування як в нормальній фізіології, так і в патологічних умовах, ілюструючи, як морфометричні дані можуть впливати на клінічну практику та дослідження. **Методи.** Морфометрія ґрунтується на точних вимірюваннях структурних елементів тканин за допомогою світлової або електронної мікроскопії, а також спеціалізованого програмного забезпечення для обробки зображень. **Результати.** Описані рівні організації та загальний підхід до визначення морфофункціональної одиниці. Ця одиниця представляє собою мінімальну структурну одиницю, здатну самостійно виконувати біологічні процеси, властиві даному органу чи тканині, забезпечуючи життєво важливу діяльність на різних рівнях організації. **Висновок.** Морфометрія слугує важливим інструментом для кількісного аналізу морфологічних характеристик тканин, що робить її незамінною в сучасних гістологічних і цитологічних дослідженнях. Вона дозволяє проводити точні вимірювання та об'єктивні оцінки змін у тканинах, сприяючи глибшому розумінню як нормальних, так і патологічних процесів. Інтеграція морфометрії з новітніми технологіями безумовно відкриє нові можливості для вивчення клітинної поведінки та механізмів захворювань, підкреслюючи її ключову роль у медицині та біології.

Ключові слова: морфометрія, гістологія, цитологія, ембріологія, освітній процес.