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Тел.: +380974584284. E-mail: morphology.ivt@gmail.com

Olena Aliyeva
Hanna Zviahina
Olena Pototska
Lyudmyla Makyeyeva
Tetiana Hromokovska

Zaporizhzhia State Medical and Pharmaceutical University
Zaporizhzhia, Ukraine

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THE USE OF ARTIFICIAL INTELLIGENCE IN MEDICAL MORPHOLOGY AND MEDICAL EDUCATION

Aliyeva O., Zviahina H., Pototska O., Makyeyeva L., Hromokovska T. **The use of artificial intelligence in medical morphology and medical education.**
Zaporizhzhia State Medical and Pharmaceutical University, Zaporizhzhia, Ukraine.
ABSTRACT. Background. Modern science is experiencing a stage of rapid development due to the integration of innovative digital technologies, among which artificial intelligence (AI) occupies a leading position. In morphology, AI opens up new opportunities for analyzing large datasets, automating image analysis, and modeling complex processes. In the field of medical education, the implementation of AI transforms traditional approaches to teaching morphological disciplines and determines new directions for the development of medical training. **Objective.** To analyze the possibilities and approaches to the use of AI in medical morphology and in the educational process of histology, cytology, and embryology. **Methods.** The study employed comprehensive methods of practical orientation, including analysis, synthesis, induction, and deduction, as well as specialized methods such as component analysis. **Results.** The use of AI in morphological science enables the automation of cell and tissue analysis, the identification of subtle patterns, and the creation of large-scale digital databases of histological images. The application of CNNs, U-Net, and Vision Transformers allows automated histological slide analysis, improves morphometric accuracy, and ensures standardized evaluation of morphological changes. In the educational process, the integration of digital platforms, virtual microscopes and simulators (Labster, Anatomage, Organon, QuPath, PathPresenter), VR/AR technologies, and Explainable AI provides interactivity, personalization, and deep immersion of students into the structure of tissues and organs, fostering the development of critical thinking and analytical skills. **Conclusion.** The use of AI in morphology and histology teaching is not only a technological trend but also a strategic direction in the development of medicine and education. The integration of digital platforms, virtual laboratories, and VR/AR systems makes learning interactive, personalized, and practice-oriented. The combination of traditional teaching methods with AI enhances motivation, cultivates critical thinking, and prepares future physicians for work in the era of digital medicine.
Key words: artificial intelligence, histology, medical education, digital technologies, VR/AR technologies, convolutional neural networks.

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Aliyeva O. 0000-0003-1287-674X; Zviahina H. 0000-0002-9778-6833;
Pototska O. 0000-0002-7635-5129; Makyeyeva L. 0000-0002-3188-2638;
Hromokovska T. 0000-0003-0729-8818

Background

Artificial Intelligence (AI) is a field of computer science that trains computational systems to think in a human-like manner. It is a relatively young discipline that originated in 1955 to solve mathematical problems and has since undergone periods of rapid development and stagnation, from the First National

Conference in 1980 to assisting in the development of COVID-19 vaccines in 2020, and, finally, to the current technological boom in AI [1-3]. We are now witnessing the rapid expansion of its applications across diverse domains of knowledge and the growing diversity of ways in which its capabilities can be utilized.

Convolutional neural networks (CNNs) are widely applied across different fields. The first task solved with neural networks was image classification. However, their applications have extended into medicine, where they are used for disease or symptom classification in MRI diagnostics, automated recognition of cellular structures, tissue segmentation, classification of cell damage types, disease progression prediction, and the generation of synthetic histological samples for pathology using generative models (VAE, GAN) [4,5].

Artificial intelligence has provided a new perspective on both medicine as a discipline and medical education. The teaching of fundamental medical sciences—particularly morphological disciplines such as histology, cytology, and embryology, which form the foundation for understanding the structure and functions of the human body—is now inseparable from the integration of modern AI technologies [6].

This trend became especially pronounced during the coronavirus pandemic and the subsequent wartime period, when teaching was conducted online and in hybrid formats. Interactive and personalized distance learning increasingly relies on digital platforms that provide access to microscopy tools, tissue samples, and virtual laboratories.

Therefore, the **objective** of our study is to analyze the possibilities and methods of applying artificial intelligence in medical morphology and in the training of medical students at Zaporizhzhia State Medical and Pharmaceutical University in such morphology-related disciplines as histology, cytology, and embryology.

Materials and methods

The study employs both general methods—analysis, synthesis, induction, and deduction—as well as specialized methods, such as component analysis.

Results and discussion

Artificial intelligence is increasingly integrated into morphological science and the educational process related to the teaching of morphological disciplines. The use of computer vision algorithms and deep learning makes it possible to automate the recognition of cellular structures, tissue segmentation, and detection of pathological changes with high accuracy and reproducibility. This opens opportunities for the creation of large-scale digital databases of histological images, which can be utilized both for research and educational purposes.

Automated morphometric analysis enables the collection of data on cell dimensions and the ratios of cellular populations, thereby reducing the subjectivity of results [7,8].

In morphological science, AI provides a new level of morphometric analysis, allowing precise measurement of cell size, membrane thickness, ratios of cellular and intercellular components, vascular network density, and tissue architecture features [9]. Such quantitative indicators obtained through automated methods minimize result subjectivity and create conditions for the standardization of morphological diagnostic criteria [10]. Moreover, machine learning algorithms allow for the identification of subtle patterns in tissue organization, which may serve as a basis for discovering new biomarkers of functional changes in cells and tissues [11].

Convolutional neural networks (CNNs), a class of deep learning architectures most suited for image analysis, are widely applied. Models such as U-Net, ResNet, EfficientNet, DenseNet, and the more recent Vision Transformer (ViT) architecture provide the ability to detect key morphological markers, including Ki-67, p63, and features of spatial cellular organization within the microenvironment, thus enabling a shift toward quantitative tissue analysis in disease diagnostics [12].

In cytology, neural networks are successfully applied for karyotype classification, detection of dysplastic changes in Papanicolaou smears, as well as for the analysis of the cytomorphology of lymphocytes, plasma cells, macrophages, and other cell types [13].

In embryology, AI is used to model tissue development and predict anomalies based on images obtained from prenatal screening. The application of segmentation models to 3D embryological structures assists in diagnosis.

A novel approach to building a foundation for integrated digital morphology involves combining multi-omics data (histology + transcriptomics + proteomics) with morphometry and medical imaging. Such approaches are currently employed in the interpretation of tumors of the pancreas, prostate, and brain [14].

The use of artificial intelligence in medical education opens new opportunities, expanding teaching practices from simple information transfer in the teacher–student model toward the creation of immersive learning environments. Modern medical education is rapidly advancing due to the integration of digital technologies, which optimize the learning process and make it more interactive and visually engaging. In histology, traditionally based on the analysis of microscopic specimens, virtual simulators and digital platforms are increasingly used [15].

The virtual Labster laboratory immerses students in a digital environment where they can perform experiments, conduct microscopic studies, and explore tissue structures without constant access to physical equipment. In histology, this enables realistic simulators for repeated practice in handling specimens, analyzing tissue sections, and receiving instant feedback—especially valuable for early-stage students with limited experience using real microscopic preparations.

For instance, in histology, we employ the following Labster simulation models: “Microscopy,” “Light Microscopy,” “Fluorescence Microscopy,” “Sudan IV Test for Lipids,” “Cell Structure: Cell Theory and Internal Organelles,” “Cell Membrane and Transport: Learn How Transporters Keep Cells Healthy,” “Cell Membrane and Transport: Modifying the Cell Membrane,” “Cell Membrane and Transport: Types of Transporter Proteins,” “Cell Division (Principles): Mitosis and Meiosis,” “Cell Culture Basics: Plate, Split and Freeze Human Cells,” “Embryology: Discover the Genetics of Limb Development,” “Exploring Human Reproductive Cells,” “Hematology: Introduction to Blood,” “Introduction to Immunology: Organs and Cells of the Immune System,” “Skin Layers and Organ Anatomy: Follow a Skin Cell’s Journey!,” “Counting Cells: Control the Epidemic,” “Microanatomy of a Neuron: Build Your Own Neurons!,” and “The Peripheral Nervous System: Create a Model of the Nervous System.”

Particular attention should also be paid to the prospects of three-dimensional modeling of tissue structures. The use of AI in combination with data from confocal microscopy or electron tomography enables the creation of highly accurate virtual tissue models. Existing 3D reconstructions of renal glomeruli or lung alveoli are already applied both in research and in medical education. Such models make it possible to study the spatial organization of cellular elements, intercellular interactions, and organ architecture in a new dimension [16].

The Anatomage Table, an interactive anatomical platform mainly for macroanatomy, also supports histology education. Its high-quality 3D visualization and zoom capabilities help students connect microscopic and macroscopic structures, deepening understanding of tissue architecture and its functional significance.

Another promising tool is Organon 3D Anatomy, which combines virtual and augmented reality. In histology, it enables visualization of tissues and microstructures in 3D, demonstrates their relationships with organs and systems, and supports interactive sessions where students can “immerse” into structures at the cellular level. VR/AR fosters engagement and deepens understanding of biological spatial organization.

The integration of these tools provides a strong foundation for modernizing histology teaching. Labster develops microscopy skills in virtual settings, Anatomage links histological knowledge with macroanatomy, and Organon offers a three-dimensional view of tissues and organs in functional context. Together, they boost motivation, strengthen analytical thinking, and support more effective learning.

Convolutional neural networks (CNNs) are widely applied for automated tissue classification, cellular recognition, and pathology detection. In education, they underpin interactive simulators, enabling students to test answers and receive real-time feedback [17].

U-Net, among the most effective medical image segmentation models, ensures precise delineation of cells, tissue structures, and pathological regions. In practice, students can compare their segmentations with reference examples, making study more visual, hands-on, and oriented toward complex specimens.

These tools offer multiple educational advantages: they improve visualization and interactivity, facilitate knowledge assessment, personalize learning, and boost motivation through modern technologies. Combining traditional histology methods with AI algorithms deepens understanding of tissue morphology and develops analytical thinking essential for medical practice. In the long term, such approaches are likely to become integral to medical education, creating a more efficient and cohesive learning system.

A key application is automated histological slide classification using deep CNNs and their variants, including ResNet, DenseNet, and EfficientNet. These models distinguish tissue types, identify normal versus structures, and can be integrated into educational simulators. Students can test diagnostic hypotheses, compare results with model outputs, and receive immediate feedback, fostering critical thinking and more accurate mastery of morphological criteria [18].

Another important direction is histological image segmentation, which enables the identification of individual cells, nuclei, tissue regions, or pathological formations. Particularly effective in this regard are the architectures U-Net, U-Net++, and Attention U-Net, as well as algorithms such as Mask R-CNN and DeepLab. For students, this translates into the ability to clearly visualize annotated tissue samples, making navigation in the complex microscopic environment easier. Moreover, the interactive combination of manual segmentation by the student and automatic results proposed by AI not only accelerates the acquisition of recognition skills but also allows assessment of individual accuracy [19].

Tools for digital histological scans, or whole-slide images (WSIs), play a crucial role. Many universities now use virtual microscopes with high-resolution digital specimens (e.g., Histology Guide, HistoViewer, Michigan Histology, Histology Lab Manual, Indiana University Virtual Microscopy, PEIR, Human Protein Atlas, PathPresenter). Due to their size and complexity, classical CNNs often struggle, whereas Vision Transformers, Swin Transformers, and other modern architectures can analyze large images while capturing global relationships between cellular structures. These models enable virtual microscopes where students can view specimens with AI-generated hints and highlights of key areas.

Equally important is the implementation of software platforms that integrate AI algorithms for both scientific and educational purposes. Among these, QuPath provides histological image analysis powered by AI algorithms, while PathPresenter serves as an educational resource for working with digital slides and supports elements of automated structure recognition. These tools can be employed both within lectures and for students' independent study.

Explainable AI methods, such as Grad-CAM and heatmaps, add educational value by highlighting image regions that influence model decisions. This helps students understand algorithm logic and better grasp diagnostic criteria and key morphological features. When combined with VR/AR platforms, these tools create immersive learning, allowing students to "see" tissues in 3D with automatically highlighted critical structures [20].

Modern histology education actively integrates digital technologies and artificial intelligence tools, creating new opportunities for comprehensive acquisition of knowledge about the structure of tissues and organs. An example of such an approach in histology teaching at Zaporizhzhia State Medical and Pharmaceutical University is an integrated practical class on the microscopic structure of the liver and pathological changes of hepatocytes, which combines the use of VR/AR platforms, QuPath, and PathPresenter.

Initially, the student explores a 3D liver model in VR/AR, studying spatial organization, portal tracts, central veins, and hepatic lobules, with AI algorithms highlighting key structures to connect macro- and microscopic features. Next, using QuPath, liver section scans undergo segmentation via U-Net or Mask R-CNN for automatic identification of cell nuclei, sinusoidal spaces, and other morphological elements. Comparing their annotations with the algorithm's output provides immediate feedback and promotes analytical thinking. Then, in PathPresenter, students access digital histological images and AI tools to recognize normal and pathological structures, receiving real-time guidance and accuracy evaluation. Finally, students integrate knowledge and discuss results, formulating conclusions about the liver's microscopic structure and function. The instructor links macro- and microanatomy with digital analysis, fostering comprehensive understanding, critical evaluation, and competence in modern digital tools essential for medical practice.

Conclusion

Thus, the use of artificial intelligence in the morphological sciences and in the teaching of histology is not merely a technological trend but a strategic direction in the development of modern medicine and education. In the educational domain, AI integration facilitates the creation of digital platforms, virtual microscopes, and simulators that make the study of histology interactive, accessible, and personalized. The use of VR/AR systems (Anatomage, Organon), virtual laboratories (Labster), as well as platforms such as QuPath and PathPresenter, enables students to gain a comprehensive understanding of tissue structures and practice analytical skills in a safe and flexible digital environment. The combination of traditional teaching methods with intelligent technologies enhances motivation, fosters critical thinking, and provides conditions for integrated, personalized, and practice-oriented learning. This not only simplifies the acquisition of complex structural concepts but also equips future physicians with the competencies required to work in the era of medical digitalization.

Prospects for further development

The use of artificial intelligence in histology education is not limited to a few models such as CNN, U-Net, or Vision Transformers. It encompasses a wide spectrum of tools—from classification and segmentation systems to virtual platforms, adaptive simulators, and explainable AI methods. Exploring the possibilities of integrating these tools into the educational process, thereby enhancing the clarity and accessibility of material, fostering analytical skills, personalizing learning, and preparing students for future practice in digital medicine, represents, in our view, a highly promising direction for further research.

Conflict of interest information

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

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Алієва О.Г., Звягіна Г.О., Потоцька О.І., Макєєва Л.В., Громоковська Т.С. **Використання штучного інтелекту в медичній морфології та медичній освіті.**

РЕФЕРАТ. Актуальність. Сучасна наука переживає етап стрімкого розвитку завдяки інтеграції інноваційних цифрових технологій, серед яких провідне місце посідає штучний інтелект (ШІ). У морфології ШІ відкриває нові можливості для аналізу великих масивів даних, автоматизації аналізу зображень та моделювання складних процесів У сфері медичної освіти впровадження ШІ змінює традиційні підходи до викладання морфологічних дисциплін і визначає нові напрями розвитку медичної освіти. **Мета.** Аналіз можливостей і способів використання ШІ у медичної морфології та у навчальному процесі з гістології, цитології та ембріології. **Методи.** Серед використаних нами присутні комплексні – практичного спрямування – аналізу, синтезу, індукції та дедукції та спеціальні – компонентного аналізу. **Результати.** Використання ШІ у морфологічній науці дозволяє автоматизувати процеси аналізу клітин і тканин, виявляти малопомітні закономірності та створювати масштабні цифрові бази гістологічних зображень. Застосування CNN, U-Net та Vision Transformers дозволяє автоматизувати аналіз препаратів, підвищити точність морфометрії та забезпечити стандартизовану оцінку морфологічних змін. У навчальному процесі інтеграція цифрових платформ, віртуальних мікроскопів і симуляторів (Labster, Anatomage, Organon, QuPath, PathPresenter), VR/AR-технологій та Explainable AI забезпечує інтерактивність, персоналізацію та глибоке занурення студентів у будову тканин і органів, сприяє розвитку мислення та аналітичних навичок. **Підсумок.** Використання ШІ у морфології та викладанні гістології є стратегічним напрямом розвитку медицини та освіти. Інтеграція цифрових платформ, віртуальних лабораторій, VR/AR-платформ робить навчання інтерактивним, персоналізованим і практикоорієнтованим. Поєднання традиційних методів із ШІ підвищує мотивацію, формує критичне мислення та готує майбутніх лікарів до роботи в умовах цифрової медицини.

Ключові слова: штучний інтелект, гістологія, медична освіта, цифрові технології, VR/AR-технології, згорткові нейронні мережі.