

EVALUATION OF THE EFFECTIVENESS OF APPLYING AN INFORMATION HYBRID SYSTEM FOR THE CLASSIFICATION OF CELLULAR ATYPIA IN PAP TESTS

Hodnotenie efektívnosti aplikácie informačného hybridného systému pre klasifikáciu bunkovej atypie v PAP testoch

Bogdan O. SHCHEGLOV¹, Tatyana K. DUBOVAYA², Ivan V. REVA¹, Dmitry P. PUGA¹, Irina P. KOVAL¹, Svetlana N. SHCHEGLOVA¹, Marina B. KHAMOSHINA³, Artur R. BIKTIMIROV¹, Kirill V. STEGNIY¹, Galina V. REVA¹

¹Far Eastern Federal University, Russky Island, Vladivostok, Russian Federation

²Pirogov Russian National Research Medical University, Moscow, Russia

³Peoples' Friendship University, Moscow, Russian Federation

Abstract

Relevance. In modern healthcare, cervical cancer screening with Pap tests is a cornerstone of efforts for early detection of this disease in the female population. However, the interpretation of Pap test results applying traditional microscopy may be subject to variability and subjective assessment among different specialists, which requires the development of a reliable analytical framework. The introduction of digital microscopy into medical diagnostics will allow to objectify the diagnostic process and the effectiveness of detection and classification of cellular changes.

Objective. To evaluate the effectiveness of application of the developed architecture of the hybrid information system in diagnostics of cellular atypia in Pap tests.

Methods. The mechanism for developing a prototype of the information hybrid system for describing cellular transformations in Pap tests included the following steps: study of the subject area, construction of the conceptual apparatus of the system; study of parameters for objectification, determination of value ranges by analyzing the world literature; selection of a software platform for implementation, testing of the system together with medical experts by means of digital shooting of clinical material and comparison of hypotheses issued by the system and the opinion of medical staff with the compilation of a matrix of adjacency of hypotheses of cellular transformations according to the Bethesda classification from 2014 and calculation of the following parameters of the accuracy of the applied system: accuracy (Acc, Accuracy), specificity (Spec, Specificity), sensitivity (Sens, Sensitivity) and area under the curve (ROC AUC).

Results. Based on the conducted analysis, a prototype of the information hybrid system „Information hybrid system for describing cellular transformations of Pap tests“ was developed, which has two basic blocks: 1) „Objectifier of images with Pap tests cells“ – the section contains a program developed taking into account the structure of the knowledge base that automatically processes images and extracts objective parameters from them; 2) „Knowledge base for objective description of cellular changes and its Solver“ – the module contains objective indicators determined during the study of

Abstrakt

Východiská. V modernej zdravotnej starostlivosti je skrining rakoviny krčka maternice pomocou Pap testov základným kameňom úsilia o včasné odhalenie tohto ochorenia u ženskej populácie. Interpretácia výsledkov Pap testu s použitím tradičnej mikroskopie však môže podliehať variabilite a subjektívnemu hodnoteniu medzi rôznymi odborníkmi, čo si vyžaduje vývoj spoľahlivého analytického rámca. Zavedenie digitálnej mikroskopie do lekárskej diagnostiky umožní objektivizovať diagnostický proces a efektívnosť detekcie a klasifikácie bunkových zmien.

Cieľ. Vyhodnotiť efektívnosť aplikácie vyvinutej architektúry hybridného informačného systému v diagnostike bunkových atypii v Pap testoch.

Metódy. Mechanizmus vývoja prototypu informačného hybridného systému na popis bunkových transformácií v Pap testoch zahŕňal nasledujúce kroky: štúdium danej oblasti, konštrukcia pojmového aparátu systému; štúdium parametrov pre objektivizáciu, určenie rozsahu hodnôt analýzou svetovej literatúry; výber softvérovej platformy na implementáciu, testovanie systému spolu s medicínskymi expertmi pomocou digitálneho snímania klinického materiálu a porovnávania hypotéz vyplývajúcich zo systému a vyjadrenia zdravotníckeho personálu s následným zostavením matice podobnosti hypotéz bunkových transformácií podľa klasifikácie Bethesda (2014) a výpočtom parametrov presnosti aplikovaného systému (presnosť, špecifickosť, špecifikácia, citlivosť) a plochy pod krivkou (ROC AUC).

Výsledky. Na základe vykonanej analýzy sme vyvinuli prototyp informačného hybridného systému „Informačný hybridný systém na popis bunkových transformácií Pap testov“, ktorý má dva základné bloky: 1. Objektifikátor obrazov s bunkami Pap testov – obsahuje program vyvinutý s prihliadnutím na štruktúru bázy znalostí, ktorý automaticky spracúva snímky a extrahuje z nich objektívne parametre; 2. Znalostná база pre objektívny popis bunkových zmien a jej riešiteľ – modul obsahuje objektívne ukazovatele určené pri štúdiu svetovej literatúry s príslušnými vstupnými poľami pre používateľov, charakterizujúcich pomocou riešiteľa hypotézy priradenia ku konkrétnemu typu bunkovej transformácie.

global literature with the corresponding input fields for users, characterizing with the help of the Solver hypotheses of assignment to a particular type of cellular transformation. Together with cytologists of the FEFU Medical Complex, an assessment was made of the coincidence of reasoning about the belonging of cells to a particular class of atypia of the developed system with the opinion of experts on 100 images. The following parameters of the accuracy of the developed information architecture of the system were obtained: Accuracy = 78%, Sensitivity = 79% and Specificity = 89% with AUC = 83%.

Conclusion. The proposed prototype of the information hybrid system demonstrates the possibility of objectification of cellular transformations observed in Pap tests. By combining computational methods with expert knowledge, the system allows for a standardized approach to cytological analysis, thereby potentially increasing the accuracy and effectiveness of cervical lesion screening programs (Fig. 4, Ref. 15). Text in PDF www.lekarsky.herba.sk.

KEY WORDS: cellular atypia; cervix; Pap tests; hybrid medical systems.

Lek Obz 2025, 74 (6): 242-248

Spolu s cytológmi FEFU sa uskutočnilo hodnotenie zhody o príslušnosti buniek k určitej triede atypií medzi vyvinutým systémom s názorom odborníkov na 100 snímok. Získali sme nasledovné parametre presnosti vyvinutej informačnej architektúry systému: Presnosť = 78 %, Citlivosť = 79 % a Špecifickosť = 89 % s AUC = 83 %.

Záver. Navrhnutý prototyp informačného hybridného systému predstavuje možnosť objektivizácie bunkových transformácií pozorovaných v Pap testoch. Kombináciou výpočtových metód s odbornými znalosťami systém umožňuje štandardizovaný prístup k cytologickej analýze, čím potenciálne zvyšuje presnosť a efektívnosť programov skríningu cervikálnych lézií (obr. 4, ref. 15). Text v PDF www.lekarsky.herba.sk.

KLÚČOVÉ SLOVÁ: bunková atypia, krčok maternice, Pap testy, hybridné počítačové systémy v medicíne.

Lek Obz 2025, 74 (6): 242-248

Introduction

Cervical cancer (CC) remains a major global health burden, with significant morbidity and mortality in the female population, especially in regions with limited access to screening and scarce health resources (6, 11). According to WHO statistics, CC is among the most common malignant neoplasms, causing significant cancer-related deaths worldwide (2, 5).

In Russia, despite the development of health infrastructure and preventive measures, CC remains a common problem, creating a significant burden on the healthcare system, which requires modernization of existing research protocols (8, 9). Traditional CC screening methods, such as Pap tests, have played an important role in efforts to prevent this disease (3, 14, 15). However, their diagnostic accuracy is characterized by moderate sensitivity and specificity and usually ranges from 50% to 70% (6, 2,12). Such limitations may result in false negative or false positive results, potentially compromising patient outcomes and necessitating further and/or repeated diagnostic procedures (1, 4).

In recent years, the advent of digitalization and computational methods has opened new opportunities to improve the accuracy and objectivity of cervical cancer diagnostics (11, 15, 5, 14, 3). Digital imaging technologies allow for accurate recording and analysis of cell morphology, providing a more comprehensive assessment of Pap test results. Using machine learning algorithms and expert cytological knowledge, HIS represents a promising approach to complement traditional diagnostic methods (2).

The integration of digital technologies with cytological expertise in the proposed HIS has significant potential to improve the sensitivity and specificity of cervical cancer screening. With automated analysis and standardized criteria, the system facilitates objective assessment, reducing the variability and subjectivity inherent in manual "by eye" interpretation by cytologists

with varying experience (2, 5, 12). The use of HIS may lead to increased objectivity in the study of gynecological smears and diagnosis of the degrees of cellular atypia, ensuring timely intervention and, ultimately, contributing to a reduction in morbidity and mortality from cervical cancer.

Materials and Methods

The main aim of this research was to evaluate the effectiveness of the developed architecture of the hybrid information system in the diagnosis of cellular atypia in Papanicolaou tests.

The study is an experimental, non-randomized, single-center, uncontrolled study that does not involve intervention in standard clinical processes and was conducted in one medical institution – the Medical Complex of the Far Eastern Federal University (FEFU). The study is one-stage (cross-sectional), since all data were collected within one time. The purpose of the study was to test and evaluate the developed prototype of the information hybrid system for the diagnosis of cellular atypia in Pap tests in comparison with the experience of expert cytologists. The study included the stages of developing and testing the system. Initially, an analysis of the subject area and literature was carried out to identify objective parameters for describing cellular transformations. Then, a software platform was selected, and the system was tested on 100 digital images of clinical material from 10 patients. A comparison was made of the hypotheses of the developed IHS with the hypotheses of cytologists about the belonging of the observed cell to a particular type of cellular changes according to the Bethesda classification of 2014. To evaluate the effectiveness of the system, a hypothesis adjacency matrix was implemented, and the following parameters were calculated: accuracy, sensitivity, specificity, and area under the curve.

Pap test samples had to be digitalized and cover the spectrum of cellular transformations according to the 2014 Bethesda classification, annotated by expert cytologists for interpretation by the system. The development of modules was carried out in accordance with the rules for the implementation of software (7).

The study was conducted at the FEFU Medical Complex. It has the approval of the local ethics committee of the FEFU No. 6 dated 04/19/2023.

Specific factors that may affect the external generalizability of the results are that the system was tested in one medical center, which reduces the possibility of generalizing the data to other institutions with different technical equipment and levels of specialist training. Another important factor is the digital imaging method used in the study. Image quality and imaging standards may vary depending on the equipment and protocols used in other medical centers, which may affect the results when extrapolating the technology to other conditions.

The period of inclusion of patients in the study was planned for six months. During this time, digital images of Pap tests were collected for further testing of the system. The study did not provide for long-term observation of patients, since the focus was on processing the already collected clinical material.

The duration of the observation period was limited to testing the system on the collected data and lasted a week, considering the workload of the experts.

In the study, objects (cell images) were divided into eleven main groups based on the 2014 Bethesda classification of cellular atypia. Eleven images were assigned to each group. Since each class of cellular atypia is defined and assessed in each image, a total of 1,100 hypotheses were assessed for all images with the definition of the hypothesis type.

To record the hypotheses of cytologists about the observed cellular changes, a visual assessment of cell images was used. Physicians manually classified each image by the type of cellular transformation based on the 2014 Bethesda classification. This data was recorded for subsequent comparison with the hypothesis results issued by the system.

Comparison of the results of the system and physicians - an assessment of the coincidences and discrepancies between the system's hypotheses and expert opinions was recorded manually and used for statistical analysis of the system's accuracy.

To record feedback on the clinical applicability and usability of the system, questionnaires were used, which were filled out by physicians after working with the system. The survey included questions about the usability of the interface, the speed of operation, the correctness of the hypotheses proposed by the system, as well as general impressions and suggestions for improving the system.

Results

The study used 100 digital images of cells obtained from 11 glasses with Pap tests, which underwent

microscopic processing and subsequent digitalization. The sample was clinical material obtained from patients who underwent standard Pap tests to identify possible signs of cellular atypia. These images were collected and digitized for their further analysis using the developed hybrid information system (HIS).

As a result of the work, the HIS module „Objectifier of images with Pap test cells“ was developed for automatic extraction of objective cellular parameters, such as cell size, nucleus size, calculation of the nuclear-cytoplasmic ratio (NCR) (8, 9).

These parameters are automatically transferred to the knowledge base for subsequent formation of hypotheses about the presence of cellular atypia based on objective data. The algorithm of its operation is associated with the use of the Otsu algorithm, calculation of sizes based on the data of the entered image and the level of microscope magnification designated by the user, assessment of the average color of the nucleus and cell to classify them into different types of staining intensity.

The images corresponded to all cellular transformations: from cells without cellular atypia (type NILM – no intraepithelial atypia) to cells with varying degrees of atypia (LSIL, HSIL, ASC-US, etc.) in accordance with the Bethesda system of 2014.

All images were standardized in resolution and quality, ensuring the homogeneity of the original data for subsequent morphometric analysis. Images were obtained using digital microscopes, which minimized technical distortions. This material was used to test the developed system, and the hypotheses generated by the system based on morphometric analysis were compared with the conclusions of two cytologists from the Laboratory Diagnostics Center of the FEFU Medical Complex.

During the study, based on international experience in constructing hybrid systems for supporting medical decision making (HSSMDM), our own hybrid system was developed for diagnosing cellular atypia in gynecological cytology.

For this structure of the knowledge base, a Solver with a rational apparatus in the form of a separate microservice was developed, which is a site where, using the RestAPI protocol, applications can access it with input parameters in the service address line and receive a response in the form of a line with classified hypotheses-reasoning (SkiaAtlas site). Its main meaning is to consider and sum up the points scored for each of the hypotheses. If the input feature corresponds to the value from the knowledge base (falls into the range or corresponds to the string value of the dictionary), then the hypothesis gets +1 point, if not, then –1 point. As a result, one confirmed hypothesis with the highest number of points is formed. The remaining hypotheses are divided into non-rejected hypotheses with a smaller number of points scored and rejected hypotheses with a minimum number of points.

For the convenience of users, a web interface was developed in the form of a one-page site with a form for manual data entry or downloading a video stream from a digital device obtained during a cytological study to extract objective parameters from it (Fig. 1) (Web application).

To demonstrate the operation of the system, let us consider an example of a patient without gynecological diseases. A cell without cellular atypia was detected in the field of view, corresponding to the NILM status according to the Bethesda classification from 2014, determined by a cytologist. During the operation of the algorithm, the objective parameters of the cell were automatically determined: cell size 1500 μm , nucleus

size 50 μm , NCR 3%, normochromic cell and hyperchromic nucleus. As a result, the following reasoning of the system was obtained, corresponding to the reasoning of the cytologist (Fig. 2).

In addition, let us consider an example of a cell with a high level of HSIL atypia according to the conclusion of a cytologist in a patient with cervical cancer. As a result of the objectification algorithm, the following input parameters for the knowledge base were automatically determined: cell size 1000 μm , nucleus size 120 μm , NCR 12%, hyperchromic cell and hyperchromic nucleus. The following system reasoning was obtained, corresponding to the reasoning of the cytologist (Fig. 3).

Figure 1. Web Application Interface.

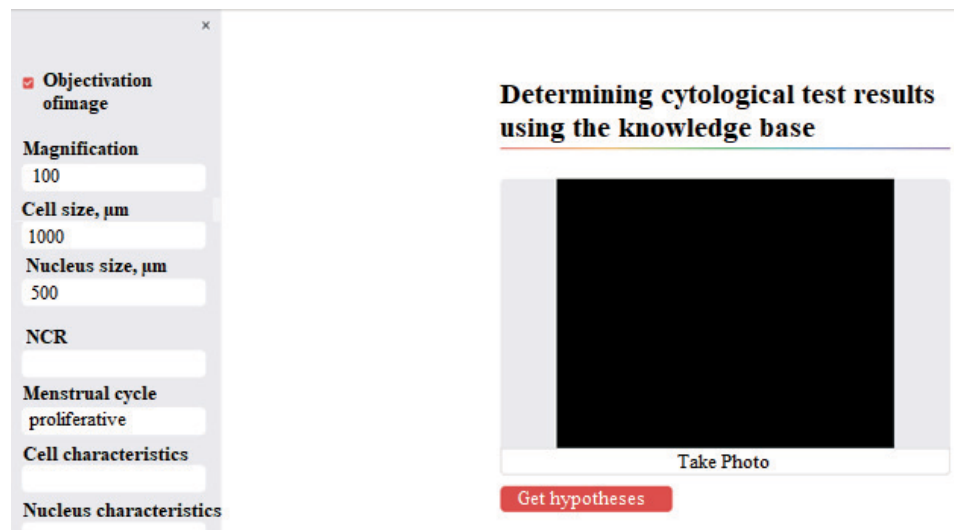


Figure 2. An example of forming hypotheses for a cell without atypia (NILM).

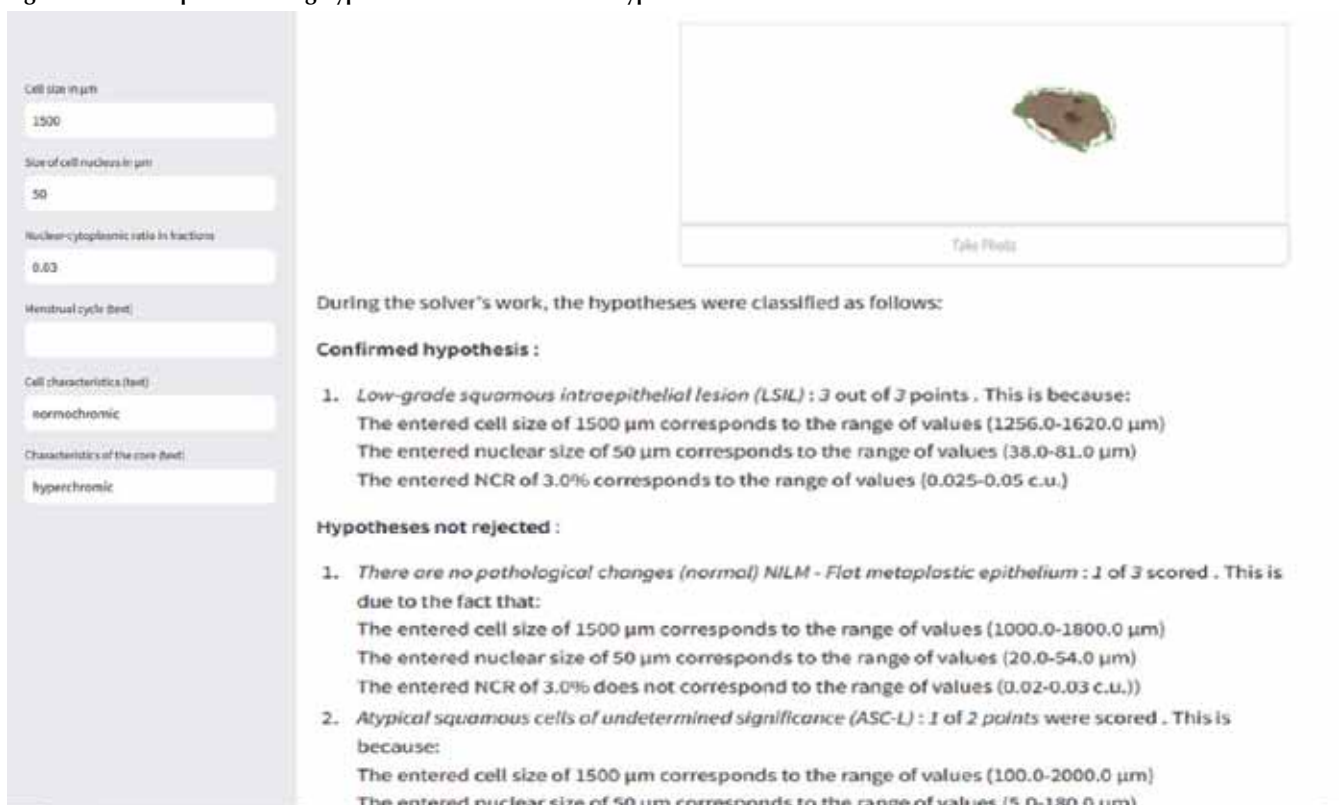


Figure 3. An example of forming hypotheses for a cell with severe atypia (HSIL).

Cell size in μm

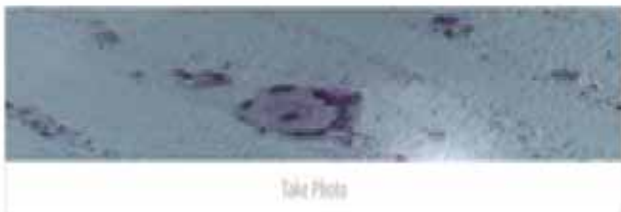
Size of cell nucleus in μm

Nuclear-cytoplasmic ratio in fraction

Menstrual cycle (text)

Cell characteristics (text)

Characteristics of the area (text)



During the solver's work, the hypotheses were classified as follows:

Confirmed hypothesis :

- High-grade squamous intraepithelial lesion (HSIL) : 2 out of 2 points . This is due to the fact that:*
 The entered cell size of 1200 μm corresponds to the range of values (1000.0-2000.0 μm)
 The entered nuclear size of 110 μm corresponds to the range of values (100.0-300.0 μm)
 The entered NCR of 3.0% does not correspond to the range of values (0.1-0.15 c.u.)
 The entered text characterizing the parameters of the nucleus "hyperchromic": match Hyperchromic, but lumpy chromatin can be detected

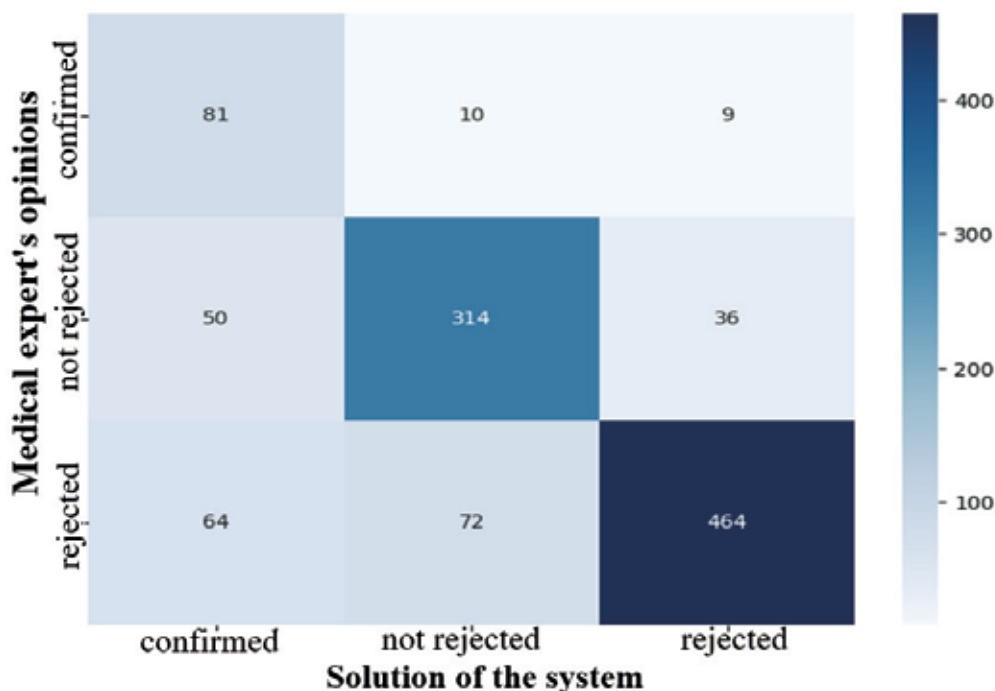
Hypotheses not rejected :

- Atypical squamous cells of undetermined significance (ASC-L) : 1 of 2 points were scored . This is because:*
 The entered cell size of 1200 μm corresponds to the range of values (100.0-2000.0 μm)
 The entered nuclear size of 110 μm corresponds to the range of values (5.0-180.0 μm)

The testing of the provided examples of the system's operation was carried out by two cytologists of the FEFU Medical Complex by assessing the coincidence of the reasoning of the developed system, formed based on objective analysis and segmentation of individual image components, with the subjective opinion of ex-

perts on 100 images. In each image, each of the atypia classes was determined and assessed. Thus, a total of 1100 hypotheses were assessed for all images with the determination of the hypothesis type and an adjacency matrix was compiled (Fig. 4). It was found that since rejected and non-rejected hypotheses are established in

Figure 4. Confusion matrix of comparison of hypotheses of cytologists and the developed HIS.



most cases, their number prevails in the developed adjacency matrix. The confirmed ones turned out to be the least, since one or none of them can be determined during one iteration. In general, the reasoning of the developed HIS quite successfully imitated the decision-making process of cytologists when assessing cellular atypia in the observed images using an automated algorithm for image analysis and segmentation and the reasoning module of the developed knowledge base. On average, the accuracy metrics of the system's responses when assessed by experts were Accuracy = 78%, Sensitivity = 79% and Specificity = 89% with AUC = 83%.

The implementation of the objective feature extraction algorithm includes a full set of methods and analyses that allow HIS to extract detailed information from images obtained during digital microscopy. The combination of detection of cell and nuclear contours, assessment of their morphometric parameters, provides a basis for objective image analysis, facilitating objective decision-making in cytological diagnostics and in training of novice specialists.

Discussion

The main result of the study was the creation of an HIS for the diagnosis of cellular atypia in Pap tests and the implementation of a method for checking it by comparing it with the subjective experience of cytologists. The system demonstrated increased specificity in classifying normal cells, as well as acceptable results in analyzing cells with different degrees of atypia. On average, the accuracy of the system reached 80% according to the obtained accuracy metrics.

The obtained results of the study confirm the hypothesis that the development of hybrid systems that combine both methods of searching and recognizing patterns and forming reasoning about the belonging of the object under consideration to one of the classes can be an effective tool for diagnosing cellular atypia in Pap tests. The developed system demonstrated high specificity in analyzing normal cells, which is consistent with the results of similar studies demonstrating the ability of modern automated analysis systems to improve the reproducibility of diagnostics in routine clinical practice. However, the system demonstrated slightly lower sensitivity when classifying cells with a high degree of atypia, which can be explained by the complexity of morphological changes and variability of such cells, which is also noted in scientific studies. This indicates the importance of further improvement of the algorithms for working with cells with complex atypia and the possibility of increasing the accuracy of the system by more accurately accounting for subtle morphological features.

One of the key limitations of the study is the relatively small sample size – only 100 images obtained from 11 slides, limiting the generalizability of the findings and the accuracy of the system when applied to broader clinical data. Another limitation is related to the

fact that the study was conducted in a single medical institution, also affecting the extrapolation of the results to other institutions with different levels of technical equipment and specialist experience. The quality of the digital images, despite their standardization, could also affect the accuracy of the system's analysis, since small distortions or artifacts in the images could complicate the classification of cellular changes. Despite moderate specificity and sensitivity, the system demonstrated lower accuracy when working with cells with an undefined degree of atypia (like ASC-US), which requires further refinement of the algorithms and the use of more advanced computer vision methods.

Conclusion

Experience from other studies demonstrates that automated systems for the analysis of cellular atypia can improve the accuracy and reproducibility of diagnosis by using objective image analysis algorithms and applying a formalized knowledge base approach, especially in cases of obvious pathological changes. However, unresolved issues remain related to the processing of cells with an uncertain degree of atypia, where automated systems often encounter difficulties in recognizing subtle changes.

In this study, an HIS for the diagnosis of cellular atypia in Pap tests was developed and tested. The system demonstrated moderate accuracy in classifying normal cells and acceptable results for cells with varying degrees of atypia. In the group of cells with a low degree of atypia, the system showed particularly high sensitivity, confirming its potential for use in clinical practice. However, the identified difficulties in recognizing cells with a low degree of atypia indicate the need for further improvement of the system algorithms. The results obtained demonstrate the development of automated diagnostic methods, offering a tool that can improve the efficiency and accuracy of routine cytological diagnostics. The results of the study can be used for further refinement of the system and its implementation in clinical processes to improve the quality of diagnostics of cellular atypia.*

***Acknowledgements.** The study was supported by the FEFU's program Priority-2030 and federal program Student startup.

Informed consent: Informed consent was obtained from all individual participants included in the study.

References

1. ALRAJJAL A, PANSARE V, CHOUDHURY MSR, KHAN MY, SHIDHAM VB. Squamous intraepithelial lesions (SIL: LSIL, HSIL, ASCUS, ASC-H, LSIL-H) of Uterine Cervix and Bethesda System. *Cyto Journal* 2021, 18: 16. https://doi.org/10.25259/Cytojournal_24_2021
2. ELAKKIYA R, SUBRAMANIASWAMY V, VIJAYAKUMAR V, MAHANTI A. Cervical Cancer Diagnostics Healthcare System Using Hybrid Object Detection Adversarial Networks. *IEEE jour-*

-
- nal of biomedical and health informatics 2022, 26 (4): 1464–1471. <https://doi.org/10.1109/JBHI.2021.3094311>
3. FEKRI-ERSHAD S, RAMAKRISHNAN S. Cervical cancer diagnosis based on modified uniform local ternary patterns and feed forward multilayer network optimized by genetic algorithm. *Computers in biology and medicine* 2022, 144: 105392. <https://doi.org/10.1016/j.combiomed.2022.105392>
 4. GOLIA D'AUGČ T, GIANNINI A, BOGANI G, et al. Prevention, Screening, Treatment and Follow-Up of Gynecological Cancers: State of Art and Future Perspectives. *Clinical and Experimental Obstetrics & Gynecology* 2023, 50: 160. Doi 10.31083/j.ceog5008160.
 5. HUSSAIN E, MAHANTA LB, DAS CR, TALUKDAR RK. A comprehensive study on the multi-class cervical cancer diagnostic prediction on pap smear images using a fusion-based decision from ensemble deep convolutional neural network. *Tissue & cell* 2020, 65: 101347. Doi.org/10.1016/j.tice.2020.101347
 6. NKWABONG E, LAURE BESSI BADJAN I, SANDO Z. Pap smear accuracy for the diagnosis of cervical precancerous lesions. *Tropical doctor* 2019, 49 (1): 34–39. Doi.org/10.1177/0049475518798532
 7. PROSHCHINA A, DREMIN Y, KHARLAMOVA A, OTLYGA D, et al. Information-reference system on human brain development. *Morphology* 2023, 161 (1): 27–36. Doi 10.17816/morph.603840.
 8. SHCHEGLOV BO, REVA GV, SHCHEGLOVA SN. Prototyping a knowledge base for determining cytological changes in the endocervix in gynecology. *Proceedings of the IX International Conference „Knowledge – Ontologies – Theories“ (ZONT-2023) October 2–6, Novosibirsk 2023*, pp. 313–320.
 9. SHCHEGLOV BO, REVA GV, SHCHEGLOVA SN. Certificate of state registration of the database No. 2023620481 Russian Federation. Determination of cell types by morphological characteristics for cytological diagnosis of cervical cancer: No. 2023620190: application. 02/01/2023: publ. 2023, 02/06/2023.
 10. Skia Atlas microservice with a developed solver and knowledge base of cellular atypia. Retrieved from: https://skiaatlas.pythonanywhere.com/detecting_CV (accessed: 04/14/2024).
 11. THRALL MJ. Automated screening of Papanicolaou tests: A review of the literature. *Diagnostic cytopathology* 2019, 47 (1): 20–27. <https://doi.org/10.1002/dc.23931>
 12. WANG CW, LIOU YA, LIN YJ, CHANG CC, et al. Artificial intelligence-assisted fast screening cervical high grade squamous intraepithelial lesion and squamous cell carcinoma diagnosis and treatment planning. *Scientific Reports* 2021, 11 (1): 16244. Doi 10.1038/s41598-021-95545-y.
 13. Web application for assessing cellular atypia from a digital device. Retrieved from: <https://skiaatlastest.netlify.app/labservice/labanalyticalservice> (accessed: 04/14/2024).
 14. WILLIAM W, WARE A, BASAZA-EJIR AH, OBUNGOLOCH J. A pap-smear analysis tool (PAT) for detection of cervical cancer from pap-smear images. *Biomedical engineering online* 2019, 18 (1): 16. <https://doi.org/10.1186/s12938-019-0634-5>
 15. WIN K, KITJAIIDURE Y, HAMAMOTO K, AUNG T. Computer-Assisted Screening for Cervical Cancer Using Digital Image Processing of Pap Smear Images. *Applied Sciences* 2020, 10 (5): 1800. Doi 10.3390/app10051800.
- Accepted for publication March 1, 2025.
- Address for correspondence:**
Bogdan O. Shcheglov
Far Eastern Federal University
10 Ajax Bay
Russky Island
Vladivostok 690922
Russian Federation
E-mail: b.shcheglov@mail.ru