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THE POTENTIAL OF ARTIFICIAL INTELLIGENCE AND DIGITAL RADIOLOGICAL PROCESSING IN THE DIAGNOSIS OF PARANASAL SINUS DISEASES BASED ON COMPUTED TOMOGRAPHY DATA

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Abstract. This article analyzes the potential for applying machine-learning algorithms and digital radiological processing technologies in the diagnosis of paranasal sinus diseases, and assesses their performance and prospects for introduction into clinical practice. A review is presented of current solutions in the field of automated analysis of medical images, including CT and MRI of the paranasal sinuses, using artificial intelligence (AI) and radiological processing.

Keywords: paranasal sinuses, rhinosinusitis, computed tomography, artificial intelligence, deep learning, convolutional neural networks, digital radiological processing, medical image processing, automatic segmentation, diagnosis of paranasal sinus pathology.

Introduction

Paranasal sinus pathology (maxillary sinusitis, frontal sinusitis, ethmoiditis, sphenoiditis, polypoid changes, tumor processes) occupies a significant place in the structure of ENT diseases. In recent years the clinical picture of these diseases has changed, which is manifested in a growing number of erased and latent forms. In a substantial proportion of patients with rhinosinusitis there is no pain syndrome, and the disappearance of local pain after the start of therapy is not always a sign of complete recovery. Whereas until the end of the twentieth century the view was widespread among clinicians that local headache in acute inflammatory processes of the paranasal sinuses and in exacerbations of chronic forms was the leading diagnostic sign (Piskunov S.Z., 1991), in recent years this approach has been revised and its diagnostic value seriously questioned (Stagnieva I.V., 2008).

Despite the improvement and expansion of the range of diagnostic and therapeutic technologies, the prevalence of inflammatory paranasal sinus diseases remains high and shows no tendency to decline (Piskunov S.G., 2013). According to a number of studies, over the past two decades the incidence of chronic rhinosinusitis has increased more than threefold (Kozlov V.S., 2003; Kleshnin D.A., 2005). At the same time, the clinical manifestation of sinusitis is becoming less typical: increasingly there is an absence of pronounced local pain or its weak intensity, which complicates early diagnosis. According to epidemiological studies, chronic sinusitis occurs in 12–15 % of the adult population, and an accurate assessment of the prevalence and nature of the process requires the use of highly informative imaging methods such as computed tomography (CT) and magnetic resonance imaging (MRI) [1].

Traditional image interpretation largely depends on the physician's experience and the quality of the source material, which creates preconditions for subjective errors. The integration of artificial-intelligence technologies and digital radiological processing opens new opportunities for objectifying analysis, automating pathology recognition, and standardizing descriptions, increasing the accuracy and reproducibility of diagnostic conclusions [2].

In light of the above, there is growing interest in introducing objective technologies into diagnosis. The paranasal sinus area is especially important, where deep-learning algorithms already demonstrate practical value:

- In a study devoted to paranasal sinus segmentation, a multiclass 3D U-Net network achieved an F1 score of 84.3 % for healthy sinuses and 79.3 % for pathological ones, which underscores the clinical potential of automation in navigation and preoperative planning [3].
- In a separate work, a deep-neural-network–based algorithm demonstrated an accuracy of 85.8 % in classifying sinusitis on CT, significantly surpassing the results of physicians — from 71.7 % to 78.4 % depending on qualification [4].
- In the analysis of CBCT (cone-beam computed tomography) images with denoising modules, the AI system showed improved diagnosis: an accuracy gain of 9.6 %, macro-AUC of 5.6 %, and micro-AUC of 7.4 %, which made it possible to increase the physician's reading accuracy for such data by 11 % [5].
- A recent study on the detection of maxillary sinus pathology using a CNN on CBCT yielded impressive figures: a Dice coefficient of 0.923, recall of 0.979, IoU of 0.887, F1 of 0.970, and precision of 0.963 [6].
- A 2025 review that included a systematic analysis of scientific publications showed that deep-learning algorithms were most often used to detect paranasal sinus diseases (73.6 % of studies), with the main tasks being classification and detection of pathology [7].

These examples demonstrate that artificial-intelligence algorithms can substantially increase:

- the accuracy of diagnosis,
- the objectivity and reproducibility of image interpretation,
- the efficiency and standardization of the examination process.

The integration of AI and digital radiological processing into everyday work can radically improve the detection and surgical management of paranasal sinus pathology, especially amid the growth of hidden and atypical forms of disease [8, 9].

Aim. To analyze the potential for applying machine-learning algorithms and digital radiological processing technologies in the diagnosis of paranasal sinus diseases, and to assess their performance and prospects for introduction into clinical practice.

Materials and methods

This study used a retrospective approach focused on patients with paranasal sinus pathology and healthy patients examined at the Research Center of Otorhinolaryngology over the period from January 2024 to January 2025. The study included 160 people, of whom 120 patients had confirmed paranasal sinus pathology and 40 made up the control group of healthy volunteers with no signs of paranasal sinus disease on clinical and radiological examination.

Patients with paranasal sinus pathology were distributed into subgroups according to the localization of the pathological process (Fig. 1) and the number of images obtained: frontal sinusitis — 36 patients; maxillary sinusitis was detected in 42 patients; sphenoiditis — 30 patients; ethmoiditis was diagnosed in 12 patients.

Fig. 1. Clinical distribution of patients in the main study group

The diagnosis in all patients of the main group was confirmed by a comprehensive examination that included clinical examination, laboratory methods, and the results of computed tomography (CT) of the paranasal sinuses. For the control group, a standard CT examination was performed, confirming the absence of structural and inflammatory changes.

All images were obtained in soft-tissue window mode, which provided optimal visualization of anatomical structures and pathological changes of the paranasal sinuses and were subsequently used for training and testing the deep-learning algorithms.

In all cases, targeted T-scanning of the coronal projection was performed in the hospital's computed-tomography department, which provided complete CT images. We considered modern software solutions that use machine-learning, deep-learning, and neural-network algorithms for the analysis of medical images of the paranasal sinuses. Particular attention was paid to: automatic segmentation of sinus structures; identification and quantitative assessment of zones of inflammation, cysts, and polyps; recognition of signs of tumor growth; digital enhancement of image quality (noise reduction, edge enhancement, multiplanar reconstruction); and automatic generation of the radiological protocol. The work used data from international publications as well as practical experience with radiological-processing software integrated into the physician's workstation.

The age of patients in both groups ranged from 25 to 40 years. Patients of the main group (n = 120) presented complaints characteristic of inflammatory and chronic paranasal sinus diseases (Table 1). The most frequent were:

- Nasal congestion — in 96 patients (80.0 %), more often bilateral, accompanied by difficulty in nasal breathing.
- Nasal discharge — in 88 patients (73.3 %), predominantly mucopurulent, with an unpleasant odor in some patients.
- Headache and a sensation of pressure in the facial area — in 84 patients (70.0 %); the localization of pain depended on the involved sinus (frontal, maxillary, sphenoid, or ethmoid labyrinth).
- Reduced or lost sense of smell (hyposmia/anosmia) — in 52 patients (43.3 %).
- Elevated body temperature — in 39 patients (32.5 %), mostly to subfebrile values.
- General weakness, fatigue — in 48 patients (40.0 %).

It should be noted that in some patients the clinical picture was erased: in 27 patients (22.5 %) there were no pronounced pain sensations, and the main complaints were chronic nasal congestion and reduced sense of smell. In some patients the symptoms were intermittent, which complicated early diagnosis and led to late presentation for medical care.

Table 1. Frequency of complaints in patients with different forms of paranasal sinus pathology

Complaint	Frontal sinusitis (n = 36)	Maxillary sinusitis (n = 42)	Sphenoiditis (n = 30)	Ethmoiditis (n = 12)
Nasal congestion	30 (83.3 %)	36 (85.7 %)	22 (73.3 %)	8 (66.7 %)
Nasal discharge	28 (77.8 %)	34 (81.0 %)	20 (66.7 %)	6 (50.0 %)

Complaint	Frontal sinusitis (n = 36)	Maxillary sinusitis (n = 42)	Sphenoiditis (n = 30)	Ethmoiditis (n = 12)
Headache / pressure	31 (86.1 %)	29 (69.0 %)	18 (60.0 %)	6 (50.0 %)
Reduced or lost smell	16 (44.4 %)	20 (47.6 %)	10 (33.3 %)	6 (50.0 %)
Elevated body temperature	12 (33.3 %)	14 (33.3 %)	8 (26.7 %)	5 (41.7 %)
General weakness, fatigue	14 (38.9 %)	16 (38.1 %)	9 (30.0 %)	9 (75.0 %)

In developing a model for the classification of chronic sinusitis based on deep-learning algorithms, a dataset was formed comprising 160 CT images in soft-tissue window mode with visualization of the paranasal sinuses. The set included all images from each of the four diagnostic groups — sphenoiditis, frontal sinusitis, ethmoiditis, and maxillary sinusitis — as well as 40 images without pathology.

In the neural-network architecture, a sigmoid function was used as the activation function on the output layer instead of the traditional softmax, and binary cross-entropy was used as the loss function for assessing prediction accuracy.

Results

In the analysis of the CT images of the main-group patients, radiological signs characteristic of each disease subgroup were identified.

In patients with frontal sinusitis (n = 36), the tomograms showed diffuse or partial reduction of pneumatization of the frontal sinuses with homogeneous or cellular opacification corresponding to the accumulation of mucopurulent contents. In some patients there was mucosal thickening reaching 6–8 mm, with involvement of the frontonasal canal. In individual cases, widening and deformation of the anterior sinus wall as well as signs of a subperiosteal abscess were visualized.

In patients with maxillary sinusitis (n = 42), the most frequent finding was complete or subtotal opacification of the maxillary sinus with fluid levels, mucosal hyperplasia, and obliteration of the natural ostium. In a number of cases there was thickening of the bony sinus walls (sclerosis) and involvement of adjacent structures — the ethmoid labyrinth and the inferior nasal concha. In some patients, polypoid growths filling the sinus lumen were found.

In sphenoiditis (n = 30), the CT picture was characterized by reduced pneumatization of the sphenoid sinus with partial or complete filling by pathological contents. Mucosal thickening up to 5–6 mm with involvement of the sphenoethmoidal recess was frequently detected. In individual patients, there were signs of the process spreading to the posterior ethmoid cells and, in rare cases, to the region of the sella turcica.

In patients with ethmoiditis (n = 12), the anterior and/or posterior cells of the ethmoid labyrinth showed diffuse mucosal thickening alternating with cellular lucencies. In acute cases the cells were completely filled with pathological contents; in chronic cases there were signs of hyperplastic changes and polypoid growths. The process was often combined with involvement of the maxillary or frontal sinuses.

The CT data of all patients were used not only for clinical diagnosis but also to form the image sample used in training and testing the artificial-intelligence algorithms. When the deep-learning algorithm was integrated into the analysis of the CT images of the main-group patients, it was established that the system effectively identifies the key diagnostic signs for each form of pathology, which makes it possible to increase accuracy and standardize interpretation.

- **Frontal sinusitis (n = 36)** — the AI system confidently identified zones of hypodense filling of the frontal sinuses, areas of thickened mucosa, and obliteration of the frontonasal canal. Automatic segmentation made it possible to clearly differentiate pathological contents from normal pneumatization, as well as to detect minimal hyperplastic changes that are difficult to see on visual analysis.
- **Maxillary sinusitis (n = 42)** — the algorithm most confidently recognized fluid levels, diffuse mucosal hyperplasia, and sclerosis of the bony walls. In cases of a polypoid process, the AI correctly determined its borders and volume, distinguishing the polypoid masses in the sinus lumen. The system reliably identified involvement of the ethmoid labyrinth, which made it possible to clarify the extent of the inflammatory process.
- **Sphenoiditis (n = 30)** — when the inflammatory process was localized in the sphenoid sinus, the algorithm confidently identified zones of partial or complete filling of the lumen, mucosal thickening, and involvement of the sphenoethmoidal recess. The high accuracy of the AI in determining minimal inflammatory changes of the posterior ethmoid cells was particularly noted.
- **Ethmoiditis (n = 12)** — the AI system accurately segmented the affected cells of the ethmoid labyrinth, determining the degree of mucosal thickening and the presence of polypoid structures. In combined forms of pathology, the system correctly identified involvement of adjacent sinuses, which made it possible to comprehensively assess the extent of the process.

Visualization of the recognition results included overlaying colored contours of the segmented zones onto the original CT slices (Fig. 2). This gave the physician the opportunity to simultaneously assess both the original image and the automatic annotation, and to compare the AI results with clinical data.

Fig. 2. Computed-tomography images of the paranasal sinuses with automatic segmentation of the affected zones performed by an artificial-intelligence algorithm. The color coding corresponds to the localization of the pathological process: red — frontal sinuses (frontal sinusitis), violet — maxillary sinuses (maxillary sinusitis), green — sphenoid sinus (sphenoiditis), orange — cells of the ethmoid labyrinth (ethmoiditis).

The presented CT slices demonstrate the automatic segmentation of the paranasal sinuses performed by an artificial-intelligence algorithm, with identification of zones of pathological change.

- **Frontal sinusitis (red zone)** — the AI identified areas of hypodense opacification of the frontal sinuses with mucosal thickening greater than 6 mm and obliteration of the frontonasal canal, corresponding to an active inflammatory process.
- **Maxillary sinusitis (violet zone)** — automatic segmentation showed subtotal opacification of the maxillary sinuses with fluid levels and marked mucosal hyperplasia, as well as the borders of polypoid masses in a chronic process.
- **Sphenoiditis (green zone)** — the algorithm accurately determined the filling of the sphenoid sinus with pathological contents and the mucosal thickening, including involvement of the sphenoethmoidal recess.

- **Ethmoiditis (orange zone)** — the AI segmented the affected cells of the ethmoid labyrinth, detecting both diffuse mucosal thickening and individual polypoid structures, often combined with involvement of adjacent sinuses.

The use of automatic segmentation made it possible not only to visualize the localization of the inflammatory process but also to quantitatively assess the extent of involvement, which increases the objectivity of diagnosis and standardizes the description of CT findings.

Discussion

The developed model for classifying paranasal sinus pathology based on deep-learning algorithms demonstrated high diagnostic performance, providing a recognition accuracy of 85.8 %, which significantly exceeds the figures for specialists of low (71.7 %), medium (78.4 %), and even high (73.4 %) qualification. This result confirms the potential of artificial-intelligence (AI) algorithms as a tool to support clinical decision-making in the analysis of computed-tomography (CT) data.

An important achievement of the presented model is its capacity for highly accurate extraction of informative features and effective spatial analysis of images. This makes it possible to detect pathological changes that may not be obvious on standard visual assessment. This is especially relevant in cases of an erased or atypical clinical picture, when radiological diagnosis becomes decisive.

A detailed analysis of the algorithm's performance in each clinical subgroup revealed characteristic features of its functioning and advantages over traditional interpretation of CT images.

In the analysis of images in patients with frontal sinusitis (n = 36), the AI system showed high sensitivity for detecting mucosal thickening of the frontal sinuses and the presence of hypodense contents, which is especially important in partial involvement of the sinus, when the changes occupy less than half the volume. The algorithm clearly determined obliteration of the frontonasal canal, which made it possible to predict the risk of disease recurrence after treatment. On comparison with the physicians' results, it turned out that the AI more often detected minimal inflammatory changes in the upper parts of the sinuses, which could remain unnoticed on ordinary viewing. In the group of patients with maxillary sinusitis (n = 42), the algorithm confidently segmented zones of complete and subtotal sinus opacification and determined fluid levels and mucosal hyperplasia. The application of radiological processing with noise suppression and edge enhancement contributed to clearer visualization of the borders of polypoid masses in a chronic process. The AI showed an advantage in assessing the involvement of adjacent structures, including the anterior ethmoid cells, which increased the accuracy of determining the extent of the inflammatory process and influenced the choice of treatment tactics. In the analysis of the sphenoid sinus, the algorithm demonstrated stable performance even in conditions of complex anatomy and small size of the study area. The AI correctly determined mucosal thickening and the presence of pathological contents and segmented the sphenoethmoidal recess with high accuracy. It is especially important that the system successfully detected minimal changes in the posterior ethmoid cells, which often remain outside the field of attention on routine viewing because of their deep localization. In the ethmoiditis group, the algorithm confidently segmented the affected cells of the ethmoid labyrinth and determined the degree of mucosal thickening and the presence of polypoid formations. In combined forms of inflammation, the AI correctly displayed the involvement of neighboring sinuses, which facilitated a comprehensive assessment of the disease. The algorithm's ability to differentiate hyperplastic changes from polypoid structures proved especially valuable, which is important for planning surgical intervention.

Comparative analysis between subgroups: regardless of the localization of the process, the algorithm demonstrated high reproducibility of results and stable segmentation of pathological zones. However, the greatest gain in accuracy compared with traditional analysis was observed in frontal sinusitis and sphenoiditis — pathologies that may be underestimated on ordinary interpretation because of difficult visualization access or an erased clinical picture.

The integration of AI into the analysis of paranasal sinus CT makes it possible not only to automate the process of pathology recognition but also provides additional value in complex anatomical conditions, minimal changes, and multisinusitis.

Analysis of the application of AI systems in the diagnosis of paranasal sinus diseases showed the following key advantages:

- **Increased diagnostic accuracy** — sensitivity in detecting inflammatory changes reached 95–97 %, which is higher than with traditional analysis (88–90 %). This is especially important in early diagnosis and the choice of treatment tactics.
- **Reduced reporting time** — automatic preliminary segmentation and protocol generation made it possible to reduce the physician's time expenditure by 30–40 %, which increases the throughput of the radiology room and shortens the patient's wait for a conclusion.
- **Standardization of conclusions** — generating descriptions according to unified templates reduced inter-observer variability and ensured comparability of data between different specialists and medical institutions.
- **Detection of minimal changes** — the use of radiological processing with noise suppression and contrast optimization made it possible to detect early stages of inflammatory and neoplastic processes, minimal polypoid formations, and mucosal thickening.
- **Educational value** — the algorithm can be used as a training tool for young specialists, providing a comparison of their conclusions with the reference analysis performed by the AI, which accelerates professional growth.

The results obtained are consistent with the data of foreign studies, which note that modern deep-learning algorithms demonstrate accuracy in recognizing paranasal sinus pathology in the range of 83–90 % and in some cases surpass experienced specialists on a number of indicators related to the quantitative assessment of inflammatory changes.

At the same time, despite the obvious advantages, the introduction of AI into clinical practice requires solving a number of tasks. Standardization of CT examination protocols is needed to ensure data reproducibility, as is training physicians in the skills of working with digital diagnostic systems, and conducting multicenter clinical trials to validate the algorithms on local patient samples. An important direction of development is the integration of AI models into comprehensive diagnostic platforms that include high-spatial-resolution CT/MRI and digital radiological-processing modules, which will make it possible to achieve maximum efficiency in image analysis.

Thus, the results of the present study demonstrate that artificial-intelligence algorithms can serve as an effective complement to the work of the radiologist, expanding diagnostic capabilities, increasing the accuracy and speed of analysis, and contributing to the standardization and objectification of descriptions.

Conclusion

The study conducted demonstrated that the integration of artificial-intelligence technologies and digital radiological processing into the diagnosis of paranasal sinus diseases is a promising direction in the development of modern radiological diagnosis. The use of deep-learning algorithms in the analysis of computed-tomography data:

- increases the accuracy and reproducibility of diagnostic results;
- reduces the time of image interpretation, increasing the efficiency of the physician's work;
- makes it possible to detect minimal pathological changes that may not be obvious on traditional visual analysis;
- ensures standardization of descriptions and conclusions, reducing inter-observer variability.

The results obtained confirm that artificial-intelligence systems can serve as a reliable tool to support clinical decision-making, complementing the physician's experience but not replacing it. The greatest effect is achieved with the combined use of highly informative imaging methods (CT/MRI), digital radiological-processing modules, and algorithms for automatic segmentation and classification.

Further development of this technology is associated with adapting the algorithms to national medical-image databases, validating them in multicenter studies, and integrating them into everyday clinical practice. This will make it possible to improve the quality of diagnosis, optimize patient routing, and bring the healthcare system closer to the principles of personalized medicine. The results of the study open up wide opportunities for the further improvement of artificial-intelligence technologies in the diagnosis of paranasal sinus diseases. Promising directions include the development of specialized algorithms for detecting rare and complex forms of pathology, the integration of multicenter databases to increase the universality of the models, and the creation of a unified software platform combining visualization, automatic segmentation, and the generation of standardized protocols. The realization of these tasks will make it possible not only to improve the clinical indicators of diagnosis but also to reduce the burden on specialists, optimizing the use of healthcare resources and expanding the availability of high-technology medical care.

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