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REVIEW ARTICLE

Modern 3D technologies combined with computed tomography imaging for identification and visualization of nasal septum and adjacent structures – a literature review

Wykorzystanie nowoczesnych technologii 3D w połączeniu z tomografią komputerową w celu identyfikacji i wizualizacji przegrody nosowej i sąsiednich struktur – przegląd literatury

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ABSTRACT: Three-dimensional (3D) reconstruction of nasal structures based on computed tomography (CT) data is playing an increasingly important role in the preoperative planning of ENT procedures. This literature review examines the current state of knowledge on the integration of 3D technologies – specifically the Blender and Unreal Engine 5 software – with CT imaging in the context of anatomical evaluation of the nasal septum and the cartilaginous and bony structures of the nose. Reports comparing various visualization tools, such as Osirix, Horus, Blender, and UE5, in terms of the quality of anatomical representation and clinical applicability have been included. Along with the more accurate representation of deviations and simulation of tissue movements, models created in advanced graphics environments facilitate the prediction of airflow and biomechanical stresses. In light of the analyzed studies, a combination of CT scans with modern spatial modeling is a promising path towards the improvement of the diagnosis, planning, and safety of nasal reconstructive procedures.

KEYWORDS: 3D visualization, Blender, CT scan, ENT surgery, nasal septum, Unreal Engine

STRESZCZENIE: Trójwymiarowa (3D) rekonstrukcja struktur nosa na podstawie danych z tomografii komputerowej (TK) odgrywa coraz większą rolę w przedoperacyjnym planowaniu zabiegów laryngologicznych. Niniejszy przegląd literatury analizuje aktualny stan wiedzy na temat integracji technologii 3D – w szczególności programów Blender i Unreal Engine 5 – z obrazowaniem TK w kontekście oceny anatomicznej przegrody nosowej oraz struktur chrzęstnych i kostnych nosa. Uwzględniono doniesienia porównujące różne narzędzia do wizualizacji, takie jak: Osirix, Horus, Blender i UE5, pod kątem jakości odwzorowania anatomicznego i ich zastosowania klinicznego. Modele tworzone w zaawansowanych środowiskach graficznych umożliwiają nie tylko dokładniejsze odwzorowanie krzywizn i symulację ruchów tkanek, lecz także przewidywanie przepływu powietrza i naprężeń biomechanicznych. W świetle analizowanych badań połączenie TK z nowoczesnym modelowaniem przestrzennym stanowi obiecującą ścieżkę dla poprawy diagnostyki, planowania oraz bezpieczeństwa zabiegów rekonstrukcyjnych nosa.

SŁOWA KLUCZOWE: Blender, chirurgia laryngologiczna, przegroda nosowa, tomografia komputerowa, Unreal Engine 5, wizualizacja 3D

ABBREVIATIONS

2D – two-dimensional
3D – three-dimensional
AI – artificial intelligence
CFD – computational fluid dynamics
CT – computed tomography
DICOM – Digital Imaging and Communications in Medicine
DL – deep learning
ENT – ear, nose, and throat
VR – virtual reality
XR – extended reality

INTRODUCTION

Computed tomography (CT) has long been used in ENT surgery to evaluate anatomical features of the nasal cavity and paranasal sinuses. However, standard CT image data are provided in three planes, which limits detailed visualization of the nasal septum, especially in cases of complex deviations. Thanks to technological advances, the quality of CT images has improved significantly – the thickness of imaging layers, previously at 5–10 mm, can now be reduced to 0.5–1 mm, facilitating clearer and more detailed visualization of anatomical structures [1]. The development of three-dimensional (3D) technology has opened up new possibilities for the mapping of the septum and its structural features. Integrating CT data with 3D modeling software, such as Blender and Unreal Engine 5, renders highly accurate reconstructions, providing the surgeon with a deeper understanding of the patient's individual anatomy [2, 3]. In addition, a reduction in the radiation dose has become feasible with the advent of spiral CT; compared to classic CT, spiral technology can reduce the exposure by up to 30–50%. For the sake of comparison, while classic CT of the nose requires a dose of ca. 2 mSv, spiral CT can bring this value down to 0.5–1 mSv [4]. This facilitates more frequent testing and improves preoperative modeling capabilities. Although CT images are provided in three planes, it is not always sufficient for a full assessment of the spatial shape of the septum; the process of integrating the planes is complex and time-consuming, and its correctness depends on the skill of the person analyzing the data. Even with modern CT technology, full 3D reconstruction of the septum remains a challenge, as CT alone does not permit unambiguous establishment of the shape of the septum or its cartilaginous components. It therefore becomes necessary to combine CT data with modern 3D software to obtain reliable and accurate virtual models. However, a risk of diagnostic errors arises in cases of inadequate competence in interpreting 3D images. In addition, full visualization and analysis of the septum shape, directions, and vectors requires computational algorithms and machine learning methods so that a more accurate interpretation of both bony and cartilaginous structures can be obtained. The integration of CT with modern 3D technologies is therefore becoming increasingly important. 3D imaging facilitates a comprehensive analysis of the shape of the septum along with the upper lateral cartilages, which, while constituting an integral part of the septum, play an important role in its stabilization, anchoring, airflow regulation, and nasal valve formation. One of the roles of these cartilaginous structures is to maintain the appropriate position of the nasal bones, which is particularly important when performing surgeries involving bony elements. Software tools such as Blender or Unreal Engine 5 offer new capabilities for creating detailed 3D reconstructions of the nasal septum, thereby supporting more accurate preoperative analysis and reducing the risk of complications [5]. They make it possible not only to model the shape of the septum, but also to evaluate stress, pressure, stability, or airflow, as well as to simulate potential postoperative changes. This provides a better insight into the possible displacements of adjacent structures, such as the upper lateral cartilage or bone components. As a result, better planning of treatments can follow in the context of both aesthetic and functional surgeries, with future deformities and dislocations being taken into account. The purpose of this review is to present the current capabilities of integrating CT data with 3D technologies and to analyze their applicability in the preoperative evaluation of the nasal septum, including structural, functional, and aesthetic aspects of surgical planning (Fig. 1.).

CURRENT APPLICATIONS OF COMPUTED TOMOGRAPHY IN NASAL SURGERY

CT is an essential imaging tool in otolaryngology, especially in the diagnosis and planning of surgery within the nasal and paranasal sinus cavities. It facilitates the evaluation of the bony and, partially, cartilaginous structures of the nose in three planes, which is important for the microcalcification of nasal septal deformities and sinus pathologies. However, despite the high resolution achievable with classic CT, the cartilaginous structures, such as the upper lateral cartilages, are poorly visualized, mostly as diffuse shades with blurred borders [1]. In the context of nasal reconstructive surgery, preoperative CT imaging facilitates the determination of anatomical relationships between the nasal septum and the surrounding structures, which is crucial for selecting the appropriate surgical technique. In cases of asymmetry or complex deformities, it is necessary that both bony and cartilaginous components be evaluated in order to properly plan the stabilizing grafts and structural repositioning. However, a simple CT scan is not sufficient to accurately represent biomechanical interactions, which are important when planning aesthetic and functional procedures. Therefore, increasingly, classic tomography becomes the starting point for further stages of analysis – especially involving the integration of DICOM data into 3D modeling tools. Despite its limitations, CT remains indispensable in the diagnostic process, providing data on septal thickness, deviation angle, and the presence of additional bony pathologies. Spiral CT techniques facilitate an additional reduction of the radiation dose, supporting more frequent and safer examinations for planning purposes [4]. In clinical practice, CT data are analyzed using dedicated systems such as Osirix or Horus, designed to support the classic two-dimensional (2D) diagnostics [6]. While offering basic modeling functionality, these tools do not allow full spatial reconstruction of the septal cartilage, nor are they capable of predicting the dynamics of its behavior after surgery. This is where the need to integrate advanced 3D modeling, enabling more accurate

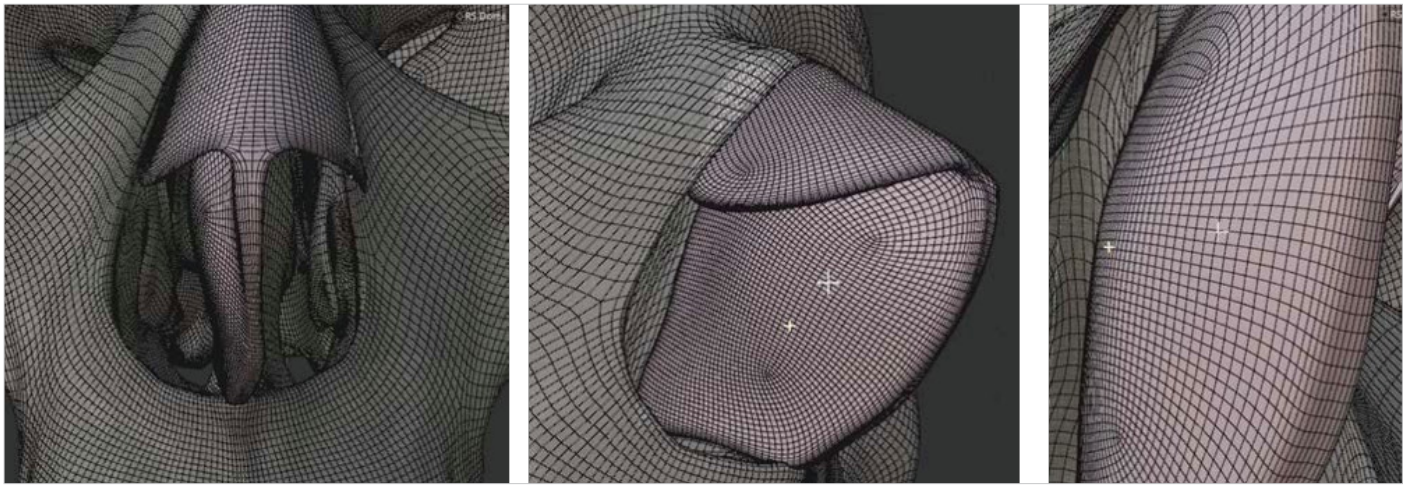


Fig. 1. Graphic representation of the scanned and modeled cartilaginous portion of the nasal septum with cartilage direction vectors. Modeling example showing the possible shape of the nasal septum.

visualization, biomechanical analysis, and personalization of surgical procedures, arises.

NEW PROSPECTS FOR 3D MODELING IN NASAL SURGERY PLANNING

In response to the limitations of classic CT in the imaging of cartilaginous structures and complex nasal deformities, advanced 3D modeling is playing an increasingly important role in otolaryngology. In particular, integration of DICOM data with open graphics platforms such as Blender or Unreal Engine 5 opens up new possibilities for accurate reconstruction of patient anatomy and planning of individual surgical procedures [7, 8]. The tools facilitate the creation of interactive anatomical models that include both bony components (e.g., vomer, ethmoid bone) as well as cartilage tissues (septal cartilage, superior lateral cartilage). What is more, simulation of biomechanical stresses, air flow, post-operative changes, and the impact of implants is possible in addition to visualization with the use of these environments. This approach significantly improves the planning precision in reconstructive and aesthetic nasal procedures [7]. In addition to the visualization of the anatomy, modern approaches facilitate the modeling of skin tissues, including mucosa and skin. Integration of ultrasound data with 3D reconstructions facilitates the assessment of tissue thickness and extensibility, which influences the choice of surgical technique and graft type [9]. As a result, the models facilitate, e.g., the mapping of the areas of increased stress and deformation risk, simulation of various surgical scenarios, personalization of grafts (e.g., columellar, lateral, spreader grafts), and prediction of the aesthetic and functional outcomes of the procedure. Despite the significant benefits, the complexity of the modeling process and the need for support from engineering teams remain a challenge. However, the development of semi-automatic segmentation algorithms and the use of artificial intelligence (AI) are gradually simplifying this process, reducing model preparation time and increasing the clinical availability of models [10]. Thus, the use of 3D modeling integrated with CT imaging may become the standard for planning nasal reconstructive procedures to provide better predictability, reduced complications, and greater safety for the patient.

EXTENDED REALITY, BIOMECHANICS, AND ARTIFICIAL INTELLIGENCE IN NASAL SURGERY

Modern approaches to rhinoplasty planning are increasingly using integrated technologies of extended reality (XR), biomechanical simulations, and AI algorithms. These systems not only improve the visualization of anatomical structures but also facilitate interactive analysis and simulation of procedures in a virtual environment [10]. Virtual anatomical models created from CT data and processed in environments such as Blender and Unreal Engine 5 are used as the basis for virtual reality (VR) applications, as used in education and surgical planning. An example can be provided by the OtoVIS project, which successfully uses the Blender software to photorealistically represent anatomical structures of the ear and skull, and the Unreal Engine software as a simulation environment [2]. Similar approaches are already being implemented in the imaging of cranial anatomical structures [11]. In addition to supporting surgical education and training, XR also facilitates preliminary evaluation of various surgical scenarios and analysis of biomechanical consequences of specific surgical strategies. With the help of computational fluid dynamics (CFD), it is possible to simulate stresses within the septal cartilage or assess the impact of obstruction on airflow resistance in the nasal cavity [12]. AI, on the other hand, is entering the field of diagnostics and automating the modeling process. Through deep learning (DL), automatic segmentation of anatomical structures from DICOM images becomes possible to significantly reduce model preparation times and manual work input [10]. For example, AI-based segmentation platforms are already being used in the preparation of surgical models of the heart and skull, suggesting their easy adaptability in otolaryngology [13, 14]. Through the synergy of XR, AI, and biomechanics, it becomes possible to predict surgical outcomes (both aesthetic and functional), design customized grafts for 3D printing, and fully personalize the procedures, taking into account the dynamic changes in nasal tissues and structures [13, 15, 16]. This holistic approach not only increases the effectiveness of surgical planning but also reduces the risk of complications and shortens the recovery time. The development of these technologies marks a new direction for nasal surgery: one based on digital precision, predictability, and adaptation to individual anatomical conditions.

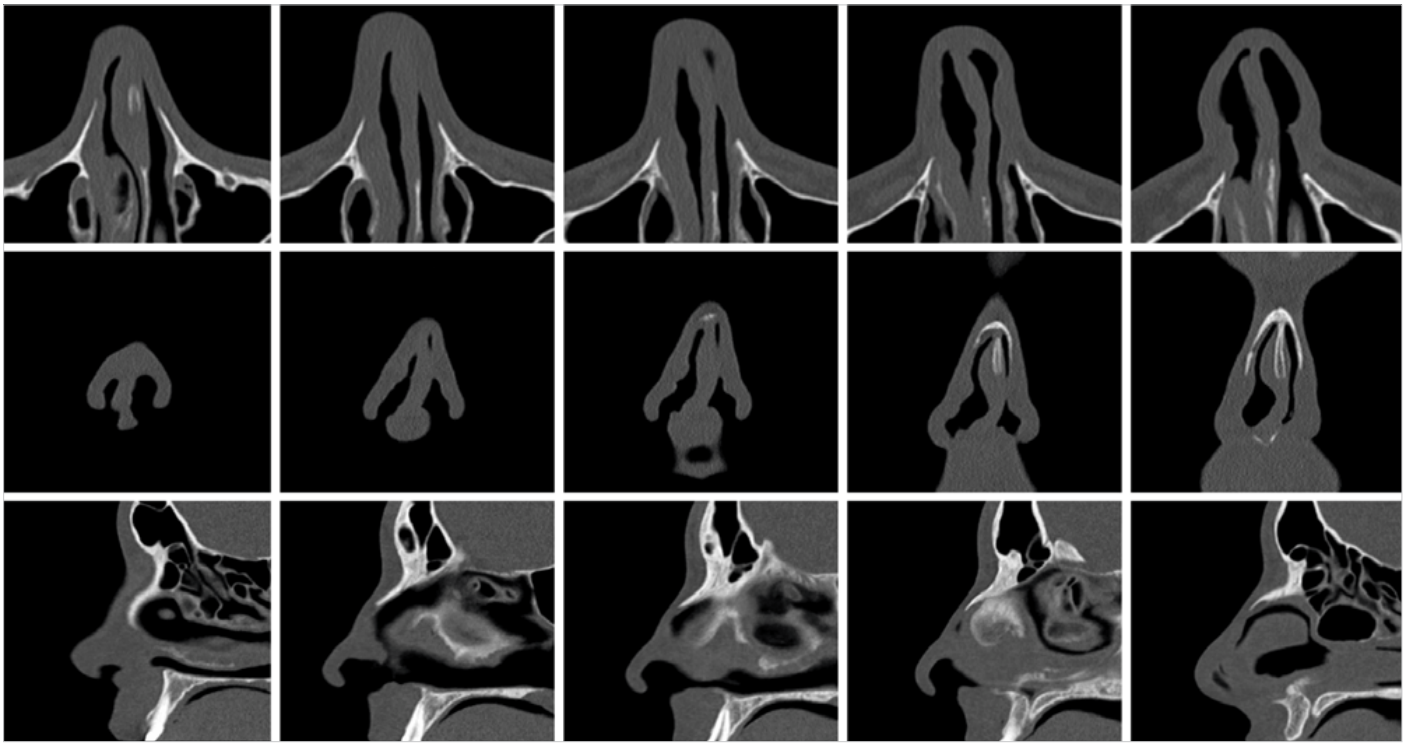


Fig. 2. CT imaging in sagittal, axial, and coronal projections showing nasal septum deviation.

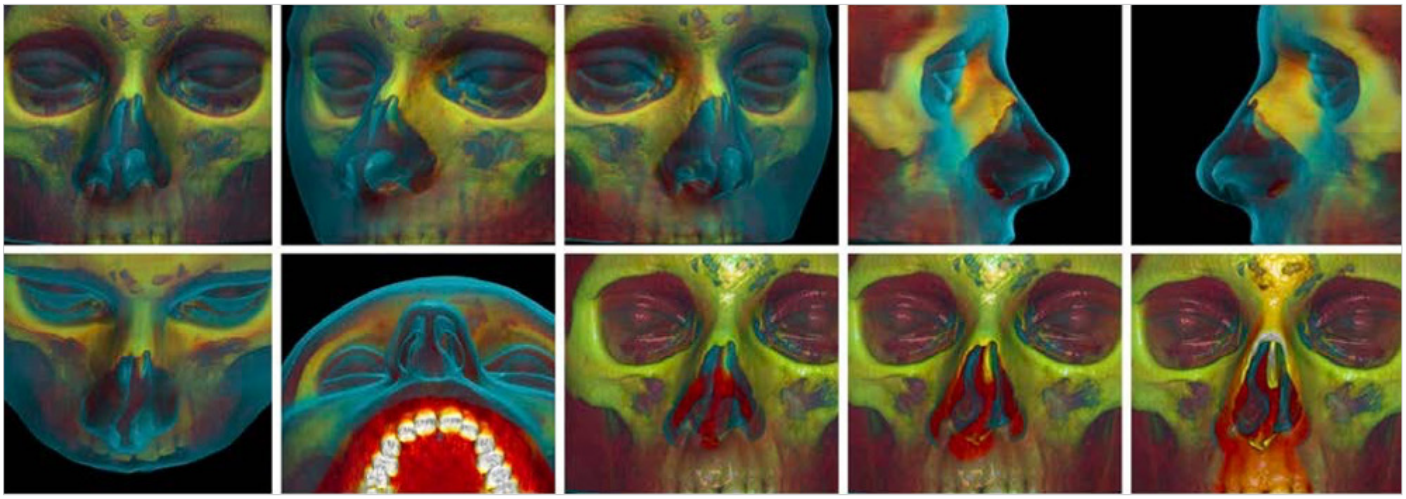


Fig. 3. Results of 3D visualization using Osirix and Horus software. The 3D CT models were capable of rendering clearly defined bony structures while not allowing full reconstruction of the shape of cartilaginous structures.

AN EXAMPLE VISUALIZATION

As an example of comparative imaging of a patient, CT scans acquired in three projections (sagittal, axial, and coronal) are first presented (Fig. 2.).

3D visualization was then applied using Osirix and Horus software (Fig. 3.).

A third option consists in the modeling of cartilage structures on the basis of DICOM CT data (Fig. 4.). This can be implemented using professional software such as Blender and Unreal Engine 5, complete with the ability to animate the future movement of the cartilage or its fixation using additional stabilizing structures. Such modeling helps more accurate decisions regarding the intervention techniques being made by the surgeon.

In addition, the use of mathematical models makes it possible to predict future changes in airflow and potential turbulences, as well as to assess the impact of additional cartilage implants, such as spreader grafts. This contributes to a better understanding of the extent of the impact the grafts should have on the stabilization of the nasal septum or the osteochondral nasal pyramid. It is also possible to predict changes in the external shape of the nose, which is important for patients undergoing not only functional but also aesthetic correction (Fig. 5.).

CONCLUSIONS

The progressive integration of CT scans with modern 3D modeling, XR, and AI technologies is significantly changing the approach to nasal surgery diagnosis and planning. Previous

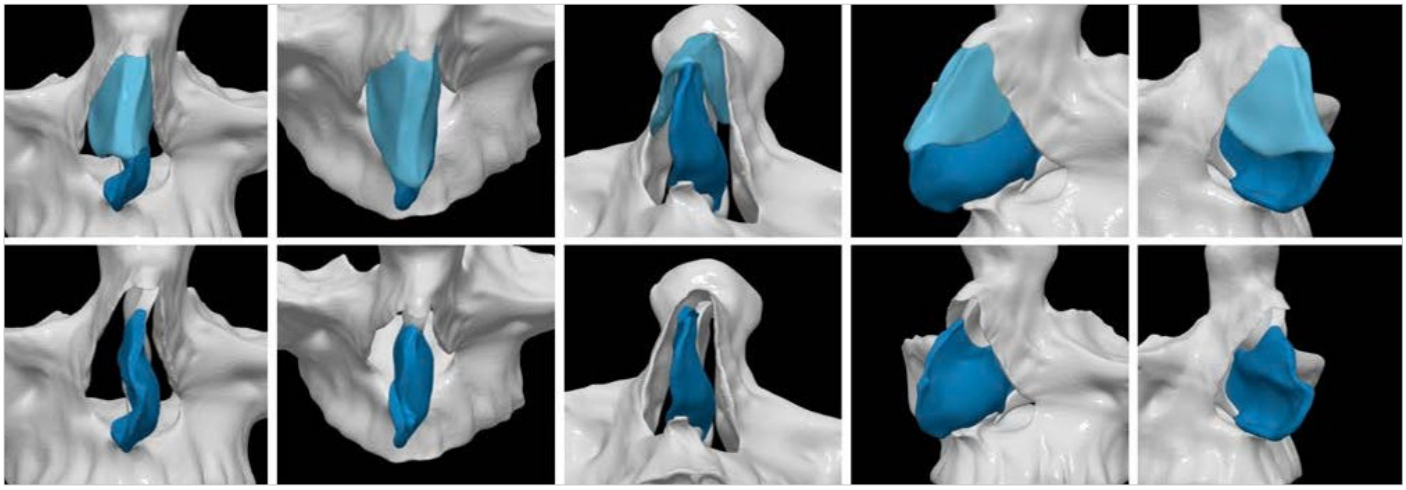


Fig. 4. Visualization of cartilage structures based on DICOM CT imaging in Blender and Unreal Engine 5 software.



Fig. 5. Example cartilaginous septal deviation with the marking of the cartilage directions and visualization of all deformities.

limitations of classic CT, including the difficulty in accurately mapping the cartilage and soft tissue structures, can be effectively overcome with environments such as Blender and Unreal Engine 5 or the FEM simulation tool. These platforms make it possible not only to accurately reproduce anatomy, but also to simulate tissue biomechanics and predict postoperative effects. The development of integrated imaging methods based on DICOM data, mathematical modeling, and digital tissue analysis is creating new opportunities for nasal surgery. Further research in this area will help improve the technology, automate the reconstruction processes, and increase the availability of the method in routine clinical practice. Also, the development of 3D-printed grafts based on patient data is creating new opportunities for nasal surgery, combining reconstructive precision with aesthetics and functionality. The integrated approach, combining the imaging, digital analysis, and simulation, could become the foundation for the future of nasal reconstructive surgery – safer, more effective, and individually tailored to the patient. In the future, it would be worthwhile to focus on validating the effectiveness of these technologies in a clinical setting, comparing the results of procedures planned in a classic manner with those planned with the help of XR and AI tools. Simultaneously, the development of customized, 3D-printed grafts based on digital models of the patient could revolutionize aesthetic and functional nose surgery.

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