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Computer production of facial epitheses

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ABSTRACT

BACKGROUND: Patients with facial defects require urgent rehabilitation. In addition to the annual increase in the number of patients with cancer of the maxillofacial region, in recent years, the number of people with shrapnel and gunshot wounds to the face has increased as a result of local wars and conflicts.

Traditional methods of orthopedic rehabilitation of patients and the manufacture of facial epitheses are quite complex and lengthy. Postoperatively, the quality of life of these patients sharply decreases, basic body functions necessary for vital activity are impaired, and patients have poor social adaptation.

Direct application of facial prosthetics in the postoperative period is impossible owing to the lack of appropriate digital modeling technologies and structural materials for additive or subtractive production methods. Thus, the production of immediate facial epitheses using digital technologies is an urgent task to improve the social and functional living conditions of patients.

AIM: To develop three-dimensional (3D) modeling technology for additive manufacturing of immediate facial prostheses.

METHODS: The first task was to develop specialized 3D software for modeling defects in the facial area. The functionality of the program should allow virtual simulation of the missing parts of the face (ear, eye, nose, and orbit). Together with IT specialists, a digital platform was created using the following programming languages: C++ (for writing the software core and UI/UX interaction modules and interacting with the Windows operating system), C# (a complex assembly of the entire project), Python (for the automated assembly of virtual library modules), OpenGL HSLS (a shader language for graphical visualization of objects), and C (creation of functions for interacting with shaders that require high speed).

RESULTS: A specialized computer program was developed for the 3D modeling of prostheses for patients with midface defects using combined facial scanning and computed tomography data (Computer program. Apresyan SV, Stepanov AG. A program for 3D modeling of facial epitheses. Registration number (certificate) 2023663490, Registration date: 07/04/2023).

Instead of obtaining analog impressions with plaster or silicone material, the developed technology uses a special 3D facial scanner, which greatly eases the suffering of patients. A virtual 3D database of ears, noses, orbits, and zygomatic bones of patients of various ages and sexes was integrated into the developed program. This allowed the specialist to select the most adaptive part of the face to make up for the defect. Built-in modeling tools allowed for the personalization of a 3D model of a part of the face based on the structural features of the maxillofacial region of a person. The finished 3D model of a part of the face can be exported in various formats.

CONCLUSION: The developed 3D program for modeling defects helps avoid invasive prosthetics approaches to coordinate the shape of future structures with the patient. The built-in library of structures with a database provides remote manufacturing of the prosthesis without the presence of the patient if replacement is needed. Among the undeniable advantages of the technology, prostheses can be made directly on the day of surgery for the removed part of the face, completely restoring lost functions and providing rapid social adaptation.

Keywords: digital technologies; 3D printing; facial prosthetics; facial epitheses.

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Разработка технологии компьютерного производства эпитезов лица

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АННОТАЦИЯ

Обоснование. Помимо ежегодного роста числа пациентов с онкологическими заболеваниями челюстно-лицевой области в последние годы увеличилось количество людей с осколочными и огнестрельными ранениями лица в результате локальных войн и конфликтов. В связи с этим вопрос реабилитации таких пациентов стоит крайне остро.

Традиционные методы ортопедической реабилитации пациентов и изготовление эпитезов лица — довольно сложный и длительный процесс. В постоперационный период наблюдаются резкое снижение качества жизни данной категории пациентов, нарушение основных необходимых для жизнедеятельности функций организма и плохая социальная адаптация.

Непосредственное протезирование лица в постоперационном периоде ранее было невозможным ввиду отсутствия необходимых цифровых технологий моделирования и конструкционных материалов для аддитивных или субтрактивных методов производства. Изготовление непосредственных (иммедиат) эпитезов лица с использованием цифровых технологий является актуальной задачей, способной улучшить социальные и функциональные условия жизни пациентов.

Цель исследования — разработка технологии 3D-моделирования для аддитивного производства иммедиат-эпитезов лица.

Методы. Была поставлена задача разработки специализированного трёхмерного программного обеспечения для моделирования дефектов лицевой области. Функциональные возможности программы должны позволять виртуально моделировать недостающие части лица (ухо, глаз, нос, орбита). Для создание цифровой платформы совместно со IT-специалистами было принято решение использовать следующие языки программирования: C++ — написание ядра программного обеспечения, написание модулей взаимодействия UI/UX, взаимодействие с операционной системой Windows; C# — комплексная сборка всего проекта; Python — автоматизированная сборка модулей виртуальных библиотек; OpenGL HSLS — язык шейдеров для графической визуализации объектов; C — создание функций для взаимодействия с шейдерами, требующих высокой скорости.

Результаты. Разработана специализированная компьютерная программа для 3D-моделирования протезов у пациентов с дефектами средней зоны лица по совмещённым данным лицевого сканирования и компьютерной томографии (Программа ЭВМ. Апресян С.В., Степанов А.Г. Программа для 3D-моделирования эпитезов лица. Номер регистрации (свидетельства) 2023663490, дата регистрации: 04.07.2023).

Вместо получения аналоговых оттисков из гипса или силиконового материала в разработанной технологии используется лицевой 3D-сканер или данные компьютерной томографии головы, что в значительной степени облегчает страдания пациентов. В разработанную программу интегрирована виртуальная трёхмерная база ушей, носов, орбит, скуловых костей пациентов различных возрастов и гендерной принадлежности. Это даёт возможности специалисту подобрать максимально адаптивную часть лица для восполнения дефекта. Встроенные инструменты моделирования позволяют персонализировать 3D-модель части лица исходя из особенностей строения челюстно-лицевой области человека. Готовую трёхмерную модель части лица возможно экспортировать в различных форматах или отправить непосредственно на производство методом аддитивных технологий.

Заключение. Разработанная 3D-программа для моделирования дефектов лица позволяет избежать инвазивных подходов протезирования, согласовать форму будущих конструкций с пациентом. Встроенная библиотека конструкций с базой данных обеспечивает дистанционное изготовление протеза без присутствия пациента в случае необходимости замены. К неоспоримым преимуществам технологии можно отнести тот факт, что протезы могут изготавливаться непосредственно в день операции по удалению части лица, полностью восстанавливая утраченные функции и обеспечивая быструю социальную адаптацию.

Ключевые слова: цифровые технологии; 3D-печать; лицевое протезирование; эпитезы лица.

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BACKGROUND

Rehabilitation in individuals with facial defects requires complex technological stages of treatment and further psychoemotional adaptation [1, 2]. The loss of part of the face may be due to oncological diseases, congenital defects, gunshot wounds, specific lesions of the maxillofacial region, and suicide attempts [3]. Additionally, according to the World Health Organization, a child with a facial defect is born every 3 minutes.

Surgical interventions in the maxillofacial region may cause patients to experience disruption of vital body functions, such as breathing, digestion, speech production, etc., which reduces the overall quality of life and aggravates the psychosomatic status of the patient. As a result, the social adaptation of patients worsens, and their ability to work is lost [4–7].

The main rehabilitation method of such patients is maxillofacial prosthetic repair. Face epitheses are used to replace facial defects and restore vital functions of the body. Improved appearance leads to social adaptation of the patient and normalization of his/her quality of life [8].

The technological process of producing face epitheses includes several surgical, orthopedic and dental stages. A coordinated work of all participants and comprehensive treatment planning are required to achieve a successful and guaranteed treatment [5, 6].

Currently, face epitheses are manufactured according to analog algorithms. At the start of the orthopedic stage of rehabilitation, silicone impressions are obtained from the wound surface; this alone already causes extreme discomfort to the patient. The subsequent stages of producing a plaster model of the defect and the creation and individualization of the final prosthesis take several weeks [9, 10].

The traditional methods of producing epitheses use platinum-based silicones. When mixing the two components, the silicone is polymerized, which should show an elastic and durable structure with a Shore A hardness of 10–30 [11–13].

The use of digital technologies in the manufacture of facial prostheses is limited by the lack of software for three-dimensional (3D) modeling of defects and material for making an epithesis with the required physical and mechanical properties. Additive production of facial epitheses revealed in other studies are non-demanded and inaccessible owing to the complexity of the technological process itself and economic inaccessibility of equipment for everyday dental practice [14, 15].

Thus, postoperatively, the patient is forced to live with a disfigured face until the epithesis is manufactured. Suicide attempts have been reported in such patients who could not withstand the psychoemotional stress. The fast and high-quality production of immediate facial prostheses the patient can use while waiting for the final design has not been fully studied. Further study is warranted to search for a method for direct rehabilitation of patients with facial defects using digital technologies for modeling and producing epitheses.

This study aimed to develop a 3D modeling technology for additive production of immediate facial epitheses.

MATERIALS AND METHODS

In the present study, the primary task was to develop a specialized 3D software for modeling facial epitheses. The program functionality should allow for virtual modeling of missing parts of the face (i.e., the ear, eye, nose, or orbit). In creating a digital platform, with recommendations from IT specialists, the following programming languages were used: C++ for writing the software core, writing UI/UX interaction modules, and interaction with the Windows operating system; C# for comprehensive assembly of the entire project; Python for automated assembly of virtual library modules; OpenGL HSLS as a shader language for graphic visualization of objects; and C for creating functions for interaction with shaders that require high speed.

The software being developed was expected to integrate 3D models of facial parts (i.e., the ear, nose, eye, or orbit) of various shapes and sizes for subsequent automatic adaptation of virtual epitheses to the wound surface, with the possibility of manual correction of the final virtual model. Hence, 287 computed tomographic (CT) images measuring 15×15 cm were analyzed, whereas 50 images of male and female patients of various ages with intact facial parts of various shapes and sizes were selected.

The development of the technology was aimed at manufacturing direct facial epitheses without preliminary obtaining silicone impressions from the wound surface. Writing the program code enables automatic conversion of the CT image of the patient's head from the.dicom to the.stl format for subsequent virtual modeling of epitheses.

RESULTS

Considering the specified functional requirements, the 3D software “Phoenix 3D” was developed.

The use of this 3D program for modeling defects avoids invasive approaches to prosthetics and allows coordinating with the patient regarding the shape of future structures. In cases of a replacement, the built-in library of structures with a database ensures manufacturing of the prosthesis even without the patient's presence. Moreover, the advantages of the technology include the fact that the prostheses can be manufactured on the day of surgery to remove part of the face while restoring completely lost functions and ensuring rapid social adaptation.

The technology is unique owing to the complete automation of all processes necessary for the manufacture of facial epitheses. Obtaining silicone impressions from the wound surface of the face is not required. To ensure the process of epithesis modeling, a CT image of the patient's head should be exported in the.dicom format. Then, the 3D model is automatically converted into the.stl format (Fig. 1).

The 3D program includes a virtual 3D database of the ears, noses, orbits, and zygomatic bones of patients of different ages and sexes. This enables the specialist to select the most adaptive part of the face to compensate for the defect. Following the analysis of 50 CT images of patients with intact parts of the face, the ears, eyes, nose, and orbits were selected separately to create a virtual digital library and for further integration into the Phoenix 3D software (Fig. 2).

After converting CT images into the.stl format, the defect boundary is marked using the built-in editing tools, and the desired face model is selected from the virtual library. The Phoenix 3D program places automatically a virtual model of the epithesis in the defect area, considering the presence of undercuts and topography of the prosthetic bed tissues (Fig. 3).

Then, specialists manually make corrections to the design using built-in editing tools. Further, a 3D virtual model of a part of the face is exported in.stl or.obj format, with subsequent production using additive or subtractive technologies (Fig. 4).

DISCUSSION

In recent years, in addition to the annual increase in the number of patients with oncological diseases of the maxillofacial region, the number of patients with shrapnel and gunshot wounds to the face caused by local wars and conflicts has increased. Thus, rehabilitation of such patients is extremely relevant.

Traditional orthopedic rehabilitation methods and the production of facial epitheses are complex and long-lasting processes. Postoperatively, in this category of patients, a sharp decrease in the quality of life, decline of the basic vital functions of the body, and poor social adaptation are noted.

Direct facial prosthetics in the postoperative period was previously impossible owing to the lack of the necessary digital modeling technologies and structural materials for additive or subtractive production methods. The manufacture of temporary or permanent facial epitheses using digital technologies is critical to improve the social and functional living conditions of patients.

A specialized computer program has been developed for 3D modeling of prostheses for patients with midface defects based on combined facial scanning and computed tomography data (Computer program. S.V. Apresyan, A.G. Stepanov, Program for 3D modeling of facial epitheses; registration number (certificate) 2023663490, dated 07/04/2023). Instead of obtaining analog impressions using plaster or silicone material, this technology uses a special 3D facial scanner. The developed program comprises a virtual 3D database of the ears, noses,

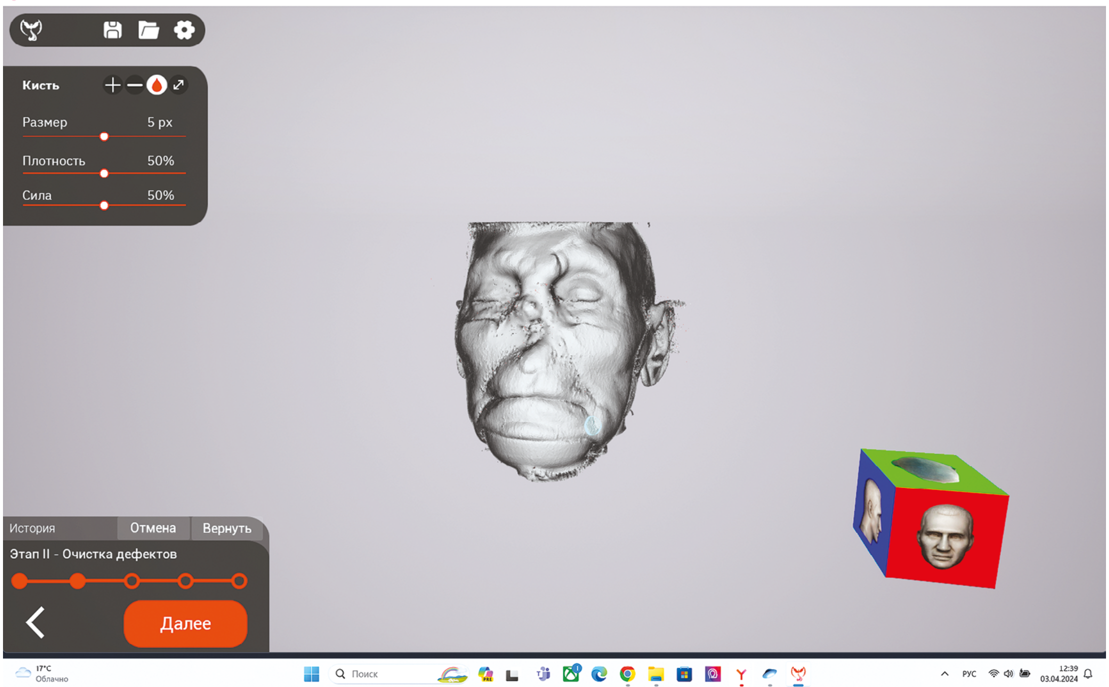

Fig. 1. Conversion of computed tomography data into .stl format in the developed program.

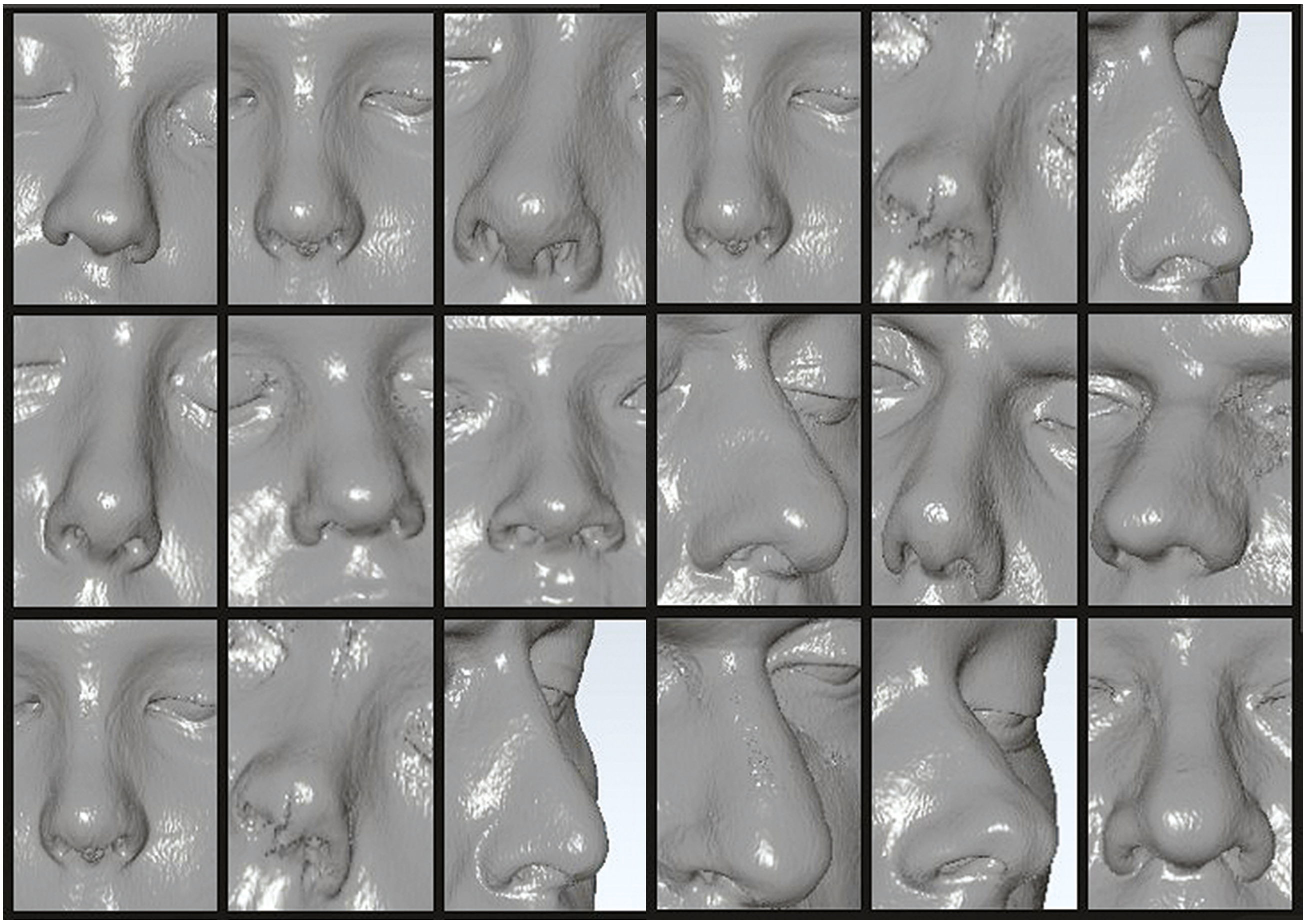

Fig. 2. Virtual library of nose models of the Phoenix 3D program.

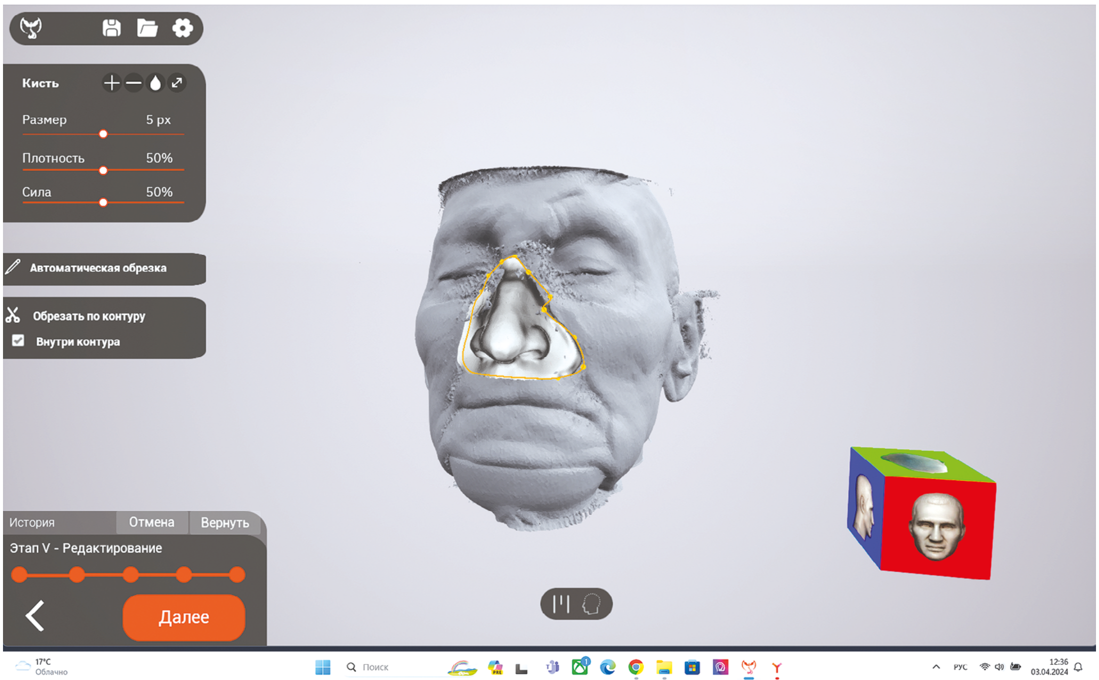

Fig. 3. Automatic adaptation of the virtual nose model to the tissues of the prosthetic bed in the Phoenix 3D program.

Fig. 4. Appearance of a patient with a nose defect of oncological origin before and after prosthetics with a temporary epithesis made by 3D printing using the proposed technology.

orbits, and zygomatic bones of patients of different ages and sexes. This enables the specialist to select the most adaptive part of the face to compensate for the defect. Built-in modeling tools are useful in personalizing the 3D model of a part of the face, considering the structural features of the human maxillofacial region. The finished 3D model of a part of the face can be exported in various formats or sent directly to production using additive technologies.

CONCLUSION

The developed 3D modeling technology for additive manufacturing of temporary facial epitheses enables manufacturing a facial prosthesis on the day of surgery. Clinical testing of this technology has confirmed its efficiency. However, its further implementation into clinical practice requires more clinical randomized studies.

ADDITIONAL INFORMATION

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Authors' contribution. S.V. Apresyan — curation of research, development of a program for modeling facial epitheses, preparation and writing of the text of the article; A.G. Stepanov — literature review, collection and analysis of literary sources, development of a program for modeling facial epitheses, preparation and conduct of clinical trials, writing and editing the article; A.P. Zrazhevskaya — literature review, collection and analysis of literary sources, formation of a database of virtual data, statistical data processing; V.K. Suonio — literature review, collection and analysis of literary sources, formation of a database of virtual data, statistical data processing. All authors confirm that their authorship meets the international ICMJE criteria (all authors have made a significant contribution to the development of the concept, research and preparation of the article, read and approved the final version before publication).

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