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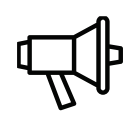


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A REVIEW OF THE LITERATURE ON CAD/CAM TECHNOLOGIES IN DENTAL
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A REVIEW OF THE LITERATURE ON CAD/CAM TECHNOLOGIES IN DENTAL ECTOPROSTHETICS

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Abstract: The rapid development of digital technologies has significantly transformed maxillofacial orthopedic dentistry, particularly in the field of facial ectoprosthetics. This article reviews contemporary approaches to the fabrication of facial prostheses with a focus on CAD/CAM technologies and their integration into clinical and laboratory workflows. The study analyzes traditional impression-based techniques and compares them with computerized digital methods, highlighting differences in accuracy, efficiency, patient comfort, and reproducibility. Special attention is given to modern data acquisition techniques, including computed tomography, magnetic resonance imaging, laser surface scanning, and three-dimensional photography, as well as to digital modeling, rapid prototyping, and additive manufacturing methods. The results demonstrate that CAD/CAM-based ectoprosthetic fabrication improves predictability, reduces treatment time, enhances patient safety, and allows long-term digital archiving of prosthetic data. Despite these advantages, the study emphasizes that successful clinical outcomes depend on professional expertise, correct method selection, and interdisciplinary collaboration. CAD/CAM technologies are therefore considered not as a replacement for clinical judgment, but as an advanced tool that significantly augments modern facial prosthetic rehabilitation.

Key words: facial ectoprosthetics; CAD/CAM technologies; digital dentistry; maxillofacial prosthetics; rapid prototyping; implant-supported prostheses.

Annotatsiya: Raqamli texnologiyalarning jadal rivojlanishi jag'-yuz ortopedik stomatologiyasi sohasida, xususan, yuz ektoprotezlarini tayyorlashda tub o'zgarishlarga sabab bo'ldi. Ushbu maqolada CAD/CAM texnologiyalariga asoslangan zamonaviy yuz ektoprotezlarini ishlab chiqarish usullari tahlil qilinib, ularning an'anaviy qolip olishga asoslangan metodlar bilan solishtirma bahosi keltiriladi. Tadqiqotda kompyuter tomografiyasi, magnit-rezonans tomografiya, lazerli skanerlash va uch o'lchamli fotografiya kabi ma'lumot olish usullari, shuningdek, raqamli modellashtirish va tezkor prototiplash bosqichlari ko'rib chiqiladi. Natijalar CAD/CAM texnologiyalaridan foydalanish davolash aniqligi va bashorat qilinuvchanligini oshirishini, davolash muddatini qisqartirishini hamda bemorlar uchun qulaylik yaratishini ko'rsatdi. Shu bilan birga, muvaffaqiyatli reabilitatsiya jarayoni mutaxassislarning bilim va tajribasi, shuningdek, klinik holatga mos metodni to'g'ri tanlash bilan chambarchas bog'liqligi ta'kidlanadi.

Kalit so'zlar: yuz ektoprotezlari; CAD/CAM texnologiyalari; raqamli stomatologiya; jag'-yuz protezlash; tezkor prototiplash; implantga tayangan protezlar.

Аннотация: Бурное развитие цифровых технологий привело к существенным изменениям в челюстно-лицевой ортопедической стоматологии, особенно в области лицевой эктопротетики. В данной статье представлен обзор современных методов изготовления лицевых протезов с акцентом на технологии CAD/CAM и их внедрение в клиническую и лабораторную практику. Проведён анализ традиционных методик, основанных на физических оттисках, и их сопоставление с компьютеризированными цифровыми подходами по критериям точности, воспроизводимости, комфорта пациента и продолжительности лечения. Рассмотрены современные методы получения трёхмерных данных, включая компьютерную томографию, магнитно-резонансную томографию, лазерное сканирование и трёхмерную фотосъёмку, а также этапы цифрового моделирования и быстрого прототипирования. Полученные результаты подтверждают, что применение CAD/CAM технологий повышает предсказуемость лечения, снижает его длительность и улучшает качество реабилитации пациентов. В то же время подчёркивается необходимость высокой квалификации специалистов и индивидуального подхода при выборе методики лечения.

Ключевые слова: лицевая эктопротетика; CAD/CAM технологии; цифровая стоматология; челюстно-лицевая ортопедия; быстрое прототипирование; имплант-опорные протезы.

INTRODUCTION

The quick development of digital technology is causing a major paradigm change in the area of maxillofacial orthopedic dentistry. One of the most difficult parts of prosthodontics has historically been the rehabilitation of patients with significant facial malformations, whether from congenital abnormalities, traumatic injuries, or oncological resections. Conventional techniques for creating ectoprostheses—artificial substitutes for orbits, ears, noses, or mid-face structures—heavily depend on manual laboratory procedures, such as hand-sculpted wax patterns and physical impressions. Despite their effectiveness, these traditional methods can require a lot of time, are physically demanding for the patient, and heavily rely on the technician's creative ability.

REVIEW OF LITERATURE ON THE SUBJECT

The rehabilitation of patients with facial defects has long represented one of the most complex challenges in maxillofacial prosthetics due to the combined functional, aesthetic, and psychological implications of such conditions. Early studies emphasized that the loss of facial structures such as the auricle, nose, orbit, or midfacial tissues leads not only to anatomical deficiencies but also to significant psychosocial distress, thereby necessitating highly individualized prosthetic solutions. Traditional prosthetic rehabilitation methods, based on physical impressions and manual sculpting, were historically regarded as the clinical standard; however, their limitations in terms of accuracy, reproducibility, and patient comfort have been repeatedly documented.

From the late 1990s onward, researchers began exploring the integration of computer-aided design and computer-aided manufacturing (CAD/CAM) technologies into facial prosthetics. Foundational works demonstrated that digital workflows could significantly improve prosthesis precision by enabling three-dimensional visualization and virtual modeling of facial anatomy. Early experimental studies integrating laser surface digitizing with CAD/CAM systems confirmed the feasibility of digitally designing facial prostheses with anatomically accurate contours and consistent symmetry, particularly through the use of mirrored contralateral structures.

Subsequent investigations expanded on these findings by comparing digital and conventional fabrication techniques. Multiple authors reported that CAD/CAM-based prostheses exhibited superior marginal adaptation and surface accuracy compared to those produced through traditional wax modeling and silicone molding. Non-contact optical scanning was shown to eliminate tissue deformation caused by impression materials, which is especially relevant in anatomically mobile regions such as the cheeks, nasal tip, and periorbital area. These advantages were consistently associated with improved aesthetic outcomes and reduced need for prosthesis adjustment.

The use of computed tomography (CT) and magnetic resonance imaging (MRI) has been extensively discussed in the literature as a critical component of digital ectoprosthetic workflows. Unlike surface scanning methods, CT and MRI provide comprehensive information on both soft and hard tissues, enabling precise planning of implant-supported prosthetic fixation. Studies focusing on extraoral implant-retained prostheses highlighted that preoperative tomographic analysis significantly improves implant positioning accuracy and long-term prosthetic stability. As a result, implant-supported ectoprostheses are widely regarded as the most reliable fixation method in contemporary practice.

Advancements in rapid prototyping and additive manufacturing further accelerated the adoption of digital technologies in ectoprosthetics. Selective laser sintering and related techniques enabled the fabrication of highly customized molds and substructures with reduced production time. Several clinical reports demonstrated that digitally manufactured prostheses could be produced within hours rather than days, while maintaining high mechanical and aesthetic quality. Moreover, digital workflows allow prosthetic data to be archived indefinitely, facilitating exact reproduction or modification of prostheses without cumulative inaccuracies.

Patient-centered outcomes have also been a major focus of recent research. Numerous studies emphasized that digital impression techniques significantly reduce patient discomfort by eliminating the need for extensive facial impressions, which often require airway management and can be particularly challenging for pediatric patients or individuals with psychological or neurological impairments. The absence of radiation in three-dimensional photographic systems was additionally identified as a notable advantage, although these methods remain less extensively studied compared to CT- and laser-based approaches.

Despite the clear benefits, several authors have noted that CAD/CAM technologies do not entirely replace clinical expertise. Accurate digital modeling requires a high level of anatomical knowledge and proficiency in specialized software. Furthermore, the literature stresses that successful outcomes depend on the correct selection of scanning methods based on clinical indications, defect size, and fixation strategy.

In summary, the reviewed literature consistently supports the conclusion that CAD/CAM technologies represent a significant advancement in dental ectoprosthetics. Digital workflows enhance accuracy,

predictability, efficiency, and patient comfort while enabling long-term data preservation and reproducibility. Nevertheless, their effective implementation requires careful methodological planning and interdisciplinary collaboration, positioning CAD/CAM not as a replacement for clinical judgment, but as a powerful tool that augments contemporary maxillofacial prosthetic practice.

RESEARCH METHODOLOGY

This study is based on the application and analytical evaluation of digital CAD/CAM technologies for the fabrication of facial ectoprostheses in orthopedic dental rehabilitation. The research adopts a technology-oriented methodological approach, focusing on contemporary digital workflows used in clinical and laboratory practice. The primary objective is to assess the methodological advantages of computerized prosthetic fabrication compared with conventional techniques.

The methodological framework includes a structured analysis of two fabrication approaches: traditional impression-based methods and computerized CAD/CAM-based methods. Particular emphasis is placed on the digital approach due to its growing clinical relevance and reproducibility. The CAD/CAM workflow is analyzed as a multistage process consisting of data acquisition, digital data processing and three-dimensional design, template or mold modeling, and direct manufacturing of the prosthesis.

At the first stage, three-dimensional anatomical data are obtained using advanced imaging techniques, including computed tomography (CT), magnetic resonance imaging (MRI), laser surface scanning, and three-dimensional photographic systems. Tomographic data acquired through CT and MRI are processed in DICOM format and converted into STL files using specialized medical modeling software, enabling accurate integration into CAD environments. Laser scanning is used to capture surface geometry through non-contact optical measurement, generating high-resolution point-cloud models suitable for prosthetic design. Three-dimensional photography is additionally considered as a non-invasive data acquisition method, offering patient comfort and the absence of ionizing radiation.

The subsequent stages involve digital processing and virtual modeling of the prosthesis, allowing precise anatomical reconstruction, symmetry correction, and preclinical visualization. Digital datasets are archived to ensure repeatability and facilitate future reproduction or modification of prostheses without loss of accuracy. Particular attention is given to implant-oriented planning, as CT and MRI data provide critical information on underlying bone structures, which is essential for selecting fixation strategies. Overall, the applied methodology enables improved accuracy, reduced treatment time, enhanced patient safety, and predictable clinical outcomes in facial ectoprosthetic rehabilitation.

ANALYSIS AND RESULTS

However, authors also point to the disadvantages of these methods. CT involves harmful radiation, while MRI has several contraindications, such as the presence of pacemakers, aneurysm clips, or other elements that are dangerous when exposed to magnetic waves. Furthermore, converting DICOM files to STL format is time-consuming and requires trained personnel and additional software.

Unlike CT and MRI, laser scanning provides only a surface image, making this method applicable only for the 3D design of prostheses. A significant advantage, however, is the short time required to analyze the entire surface, making the process more comfortable for the patient. In contrast, MRI requires staying still in a confined space for a long period, which can be problematic for obese individuals or those with claustrophobia. Laser scanning does not require data conversion, as these scanners support the STL format. A major downside, however, is a technical limitation: the laser beam travels in a straight line and cannot “bend” around complex anatomical shapes or scan undercuts, which can negatively affect the quality of the virtual facial model. Currently, several laser scanners exist, such as the Facia Laser Surface Scanner, ATOS, Polhemus FastScan, and VIVID 700.

To begin the 3D design stage, medical personnel must have a virtual 3D model of the head and prosthetic bed in STL format. Regardless of the acquisition method, the model may contain defects, irregularities, or unscanned areas displayed as “shadowed” points or gaps in information. This can affect the accuracy of the prosthesis model and the quality of its marginal fit, necessitating primary processing and defect correction. Some authors refer to this process as “computer remodeling,” performed on CAD devices. There are approximately seven types of CAD software on the market today, each allowing for the manipulation of STL files: reading, converting, and editing.

Once a high-quality 3D model is obtained, the technician proceeds to the 3D design of the prosthesis. The design can be borrowed from a database, mirrored from the opposite side of the patient’s face, or adapted from a scanned and remodeled “donor” organ.

In scientific literature, the stage of manufacturing a prototype or its negative mold is described using the terms Computer-Aided Design and Rapid Prototyping. This involves the rapid creation of either a trial specimen—which is then fitted to the patient and adjusted with wax—or a negative mold for pouring silicone. Currently, there are five technical methods used to achieve this: Stereolithography (SLA/STL), Selective Laser Sintering (SLS), Solid Ground Curing (SGC), Fused Deposition Modeling (FDM), and Laminated Object Manufacturing (LOM). Many authors believe that Selective Laser Sintering is the fastest and most accurate method.

Rapid prototyping allows the technician to obtain either a trial blank or a negative mold. The latter offers a significant speed advantage; for example, producing a mold and vulcanizing the silicone took only 8.5 hours from the moment the virtual model was created. However, the first method (trial blank) allows for a physical fitting to ensure correct positioning and that the anatomical and aesthetic parameters meet the expectations of both the doctor and the patient. This fitted sample then serves as the substrate for creating the final negative mold out of gypsum or silicone.

CONCLUSIONS AND SUGGESTIONS

Regardless of whether traditional or computerized methods are chosen, facial ectoprosthetics is a labor-intensive process requiring extensive knowledge of maxillofacial anatomy, technical skills, and software proficiency. Given the uniqueness of every individual, the success of psychological and social rehabilitation depends on the medical staff's ability to analyze the clinical picture as a whole. While the increased production speed and potential independence from traditional medical education make CAD/CAM highly promising, some authors still question its utility. Ultimately, it is not the method itself, but the result for the patient that serves as the primary measure of success. To date, there is insufficient comparative research regarding the accuracy of prostheses made by different methods, as existing studies show nearly identical results.

Patients with facial defects experience significant hardships related to both impaired function of specific maxillofacial organs and an unsatisfactory physical appearance [1,3]. The loss of an auricle (outer ear), the external part of the nose, the orbit and its contents, lips, cheeks, or cheekbones leads not only to aesthetic deficiency but also to a range of psychological and social problems. Because the human face is the primary "communication tool" and the center of attention during interaction, a defect creates psychological barriers due to the intense emotional tension caused by dissatisfaction with one's appearance [4,6,7,8]. This significantly reduces the patient's quality of life.

The goal of treatment for these patients is to restore tissue volume and organ function while creating satisfactory aesthetics for psychological and social rehabilitation [10,11,12]. While the level of modern surgical techniques and equipment often allows for the restoration of tissue volume and function, recreating the former aesthetics of the face can be a complex task or even impossible due to the extent of the defect or complex anatomical shapes, such as the ear. Furthermore, surgery may be contraindicated for medical reasons. Such treatment is also lengthy (1–1.5 years), and a patient's personal refusal or fear of numerous operations (often requiring 15–20 procedures) may lead them to choose an alternative method [12,16,17,18].

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