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Integrating Digital Planning and Additive Manufacturing for Optimized Facial Prosthetic Rehabilitation: A Case Report

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1. Abstract

Facial mutilations encompass a wide range of defects affecting the head and neck, including critical anatomical structures such as the ears, nose, eyelids, chin, and oral tissues, including the hard and soft palate. Rehabilitation in these cases extends beyond technical prosthetic fabrication, addressing the significant psychosocial impact on affected individuals. The integration of digital technologies and additive manufacturing in healthcare has advanced rapidly, enabling the segmentation of computed tomography (CT) scans to generate precise 3D models. This digital workflow enhances visualization and accuracy in the planning and production of facial prostheses. This paper presents clinical examples demonstrating how the application of digital technologies and additive manufacturing optimizes the design and fabrication process. By streamlining the creation of prosthetic prototypes, these technologies improve efficiency during the sculpting phase and lead to more precise, natural-looking, and comfortable prostheses. Ultimately, these advancements contribute to better aesthetic and functional outcomes, improving patients' quality of life, restoring their sense of identity, and facilitating their reintegration into society. This study reports a clinical case of facial prosthetic rehabilitation in a patient with facial mutilations caused by malignant neoplasms, who received an adhesive-retained orbital prosthesis fabricated using a hybrid approach that combines digital workflow and 3D printing with conventional techniques.

2. Introduction

The rehabilitation of patients who have suffered facial mutilations due to malignant neoplasms represents one of the greatest challenges in dentistry and maxillofacial surgery. The loss of facial anatomical structures affects not only function but also identity, self-esteem, and quality of life. In addition to mechanical difficulties associated with speech, swallowing, and facial expression, these patients face significant psychosocial challenges, including social isolation and emotional disorders such as depression and anxiety [1-7].

Among the cancers responsible for extensive facial mutilations, squamous cell carcinoma (SCC), basal cell carcinoma (BCC), and melanoma are the most prominent. When located in areas such as the lips, nose, ear, or orbit, SCC may require extensive resections to ensure complete tumour removal, resulting in severe deformities. Malignant melanoma, one of the most aggressive skin tumours, arises from the uncontrolled proliferation of melanocytes and has a high metastatic potential. Although less common than SCC and BCC, melanoma can affect the face, particularly the periorbital region, potentially leading to ocular enucleation and extensive loss of orbital-palpebral tissue. Tumour excision in advanced stages may necessitate complete orbital removal, drastically affecting both aesthetics and functionality, as exemplified in the clinical case of Patient B in this study [8].

Facial reconstruction in oncologically mutilated patients may involve surgical approaches such as skin grafts, microvascular flaps, and osseointegrated implants. However, in many cases, prosthetic rehabilitation emerges as the most viable alternative, especially for patients who are not candidates for extensive surgery or who present medical contraindications to invasive interventions. In this context, the combination of virtual planning and additive manufacturing has revolutionized facial prosthesis fabrication, enabling more precise and personalized outcomes [9].

The growing use of additive manufacturing in healthcare is largely due to its ability to segment computed tomography (CT) images and generate accurate 3D models, which facilitate visualization and improve the precision of facial prosthesis fabrication. This technological advancement is particularly relevant for patients who have undergone facial or auricular mutilations due to malignant neoplasms and require prosthetic rehabilitation. Digital workflows enhance prosthesis accuracy and quality while optimizing production time [10].

Three-dimensional (3D) image reconstruction provides a comprehensive overview of complex pathologies, supporting patient education and clinical demonstrations. The conventional volume rendering technique (VRT) remains the most widely used imaging method, offering significant advantages in detection, interpretation, diagnosis, and treatment planning for dental and maxillofacial lesions [5]. VRT assigns a range of opacity values to CT numbers, yielding a clearer definition of object contours and allowing for a semi-transparent display of structures [6].

Additive manufacturing, or 3D printing, involves creating a three-dimensional solid object of any shape from a digital model. Its application in healthcare is expanding rapidly, as the ability to segment CT scans and produce 3D models enhances visualization and improves the accuracy of facial prosthesis production [1].

The advancement of 3D printing in dentistry has been further accelerated by cone beam computed tomography (CBCT), which ensures more accurate diagnosis and treatment planning, particularly for maxillofacial prostheses. [4]. This technology is especially beneficial for patients with facial disfigurements affecting areas such as the ear or scalp due to cancer, trauma, or congenital conditions. Digital workflows improve prosthesis precision and quality while also optimizing manufacturing time [1].

3. Case Report

3.1. Adhesive-Retained Orbital Prosthesis

A 67-year-old woman presented with an orbital defect following orbital exenteration for malignant melanoma of the left eyelid with orbital involvement. After surgery, the patient underwent adjuvant radiotherapy. Clinical examination revealed exposed bone and excessive cavity moisture, which limited the use of conventional impression techniques. To address these challenges, a computed tomography (CT) scan was performed, generating DICOM files for biomechanical analysis and enabling a more precise and personalized outcome.

The imaging data were segmented using In Vesalius software (CTI Renato Archer Information Technology Centre, Brazil), allowing the creation of three-dimensional (3D) anatomical models based on tissue density selection. The resulting models were exported in STL format and imported into Mesh mixer software (Autodesk Inc., USA) for digital planning. Virtual cavity cleaning and anatomical refinement were performed, followed by the generation of bio models and a prosthetic prototype. This digital workflow allowed the creation of a prototype that bypassed conventional impression techniques, accommodating the exposed bone and excessive cavity moisture. The bio models and prototypes were fabricated using additive manufacturing techniques and used as guides during the sculpting and fabrication of the adhesive-retained orbital prosthesis (Figure 1).

The chosen method for prosthesis fabrication was the hybrid approach, combining digital workflow and 3D printing with conventional techniques [7]. The first step was to paint the iris according to the colour of the right eye. The ocular prosthesis was fabricated using conventional manual techniques, with natural pigments, monopoly solution, and heat-polymerized methyl methacrylate (Classico, Brazil). The 3D-printed prototype was duplicated using irreversible hydrocolloid (Alginato Hydrogum, Zhermack S.p.A., Italy), and the wax pattern was manually finalized (Figure 2).

After completion of the wax pattern, the conventional method was followed, with a stone mold and silicone processing for the final prosthesis. The final facial prosthesis was fabricated using biocompatible, soft material, such as medical-grade silicone (VST30, Factor II, Inc., USA). With the use of the prosthesis, the patient demonstrated improvement in aesthetics, social life, self-esteem, and quality of life. She remains under follow-up, and even after one year of prosthesis use, it continues to be well-adapted and suitable for daily use (Figure 3).

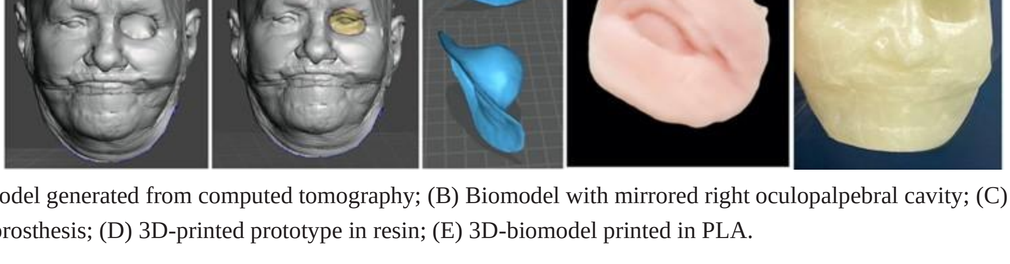

Figure 1: (A) Biomodel generated from computed tomography; (B) Biomodel with mirrored right oculopalpebral cavity; (C) Virtual planning of the oculopalpebral prosthesis; (D) 3D-printed prototype in resin; (E) 3D-biomodel printed in PLA.

Figure 2: Clinical sequence of adhesive-retained orbital prosthesis fabrication: (A) Initial clinical appearance with dressing; (B) Clinical features of the left orbital defect; (C) 3D-printed prototype try-in; (D) Final ocular prosthesis fabricated by conventional manual techniques; (E) Positioning of the ocular prosthesis in the wax sculpture; (F) Final wax sculpture try-in.

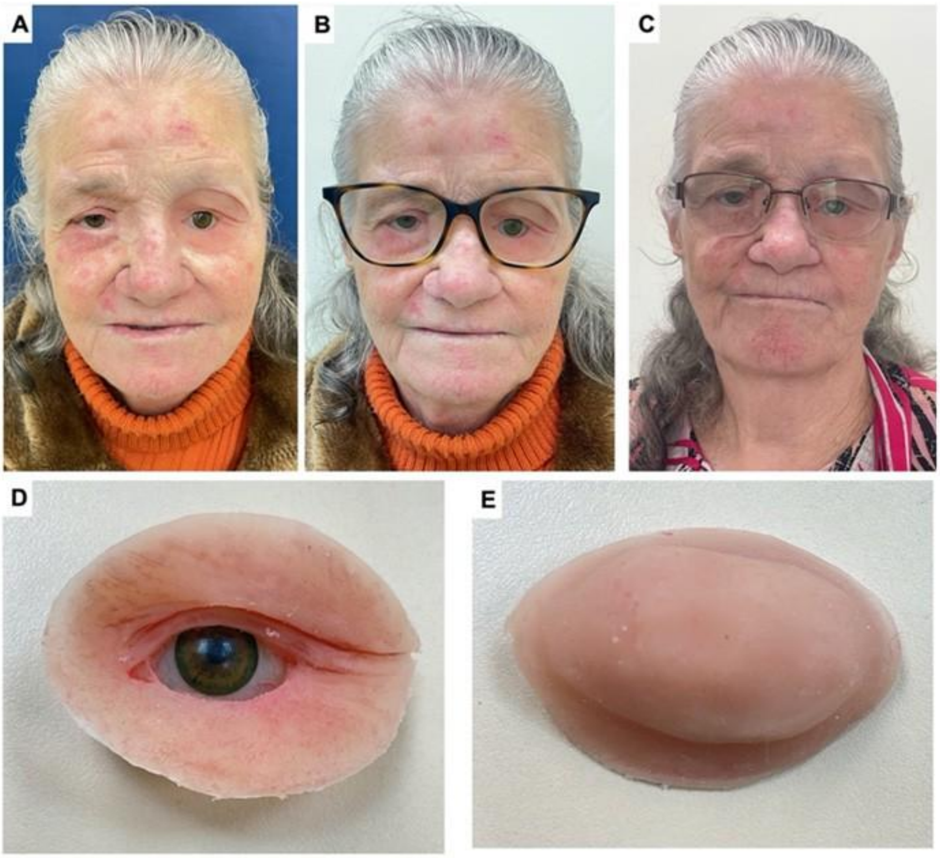

Figure 3: (A) Frontal view of the patient with the adhesive-retained orbital prosthesis; (B) Clinical view of the prosthesis with eyeglasses; (C) Clinical view after one year of follow-up; (D) External view of the final silicone prosthesis; (E) Internal view of the prosthesis.

4. Discussion

4.1. Integration of Additive Manufacturing in Facial Prosthetics

The integration of additive manufacturing (AM) into facial prosthetics represents a significant advancement in the rehabilitation of patients with facial mutilations. This case demonstrates the transformative potential of 3D printing technologies in creating customized prostheses, providing not only functional restoration but also improved psychosocial well-being [1,2]. Digital workflows enhance the precision, efficiency, and aesthetic outcomes of prostheses, ultimately contributing to improved quality of life [3].

4.2. Technological Advancements

The use of CT scans and 3D modelling software, such as In Vesalius and Mesh mixer, has revolutionized prosthetic fabrication. Segmenting CT scans to generate 3D models provides an accurate representation of patient anatomy, critical for designing prostheses that fit seamlessly with surrounding tissues [4]. Mirroring healthy anatomical structures ensures symmetry and natural aesthetics, essential for patient satisfaction and social reintegration. Digital tools also streamline workflow, reducing manual labour and potential errors during sculpting [5].

4.3. Clinical and Psychosocial Implications

Facial mutilations-whether due to malignancy, trauma, or congenital conditions-can cause significant psychological and social challenges, including low self-esteem, social isolation, and depression [1,3]. Providing patients with prostheses that closely resemble their natural appearance is therefore not merely technical, but a profound psychosocial intervention [2]. Adhesive auricular and orbital prostheses, as demonstrated in this case, highlight the adaptability of AM technologies. Digital workflows accommodate challenges such as residual fibrous tissue and orbital cavity moisture, ensuring comfortable, functional, and aesthetically acceptable prostheses [6]. Such customization is difficult to achieve with traditional methods, which rely on manual sculpting and impressions that are prone to inaccuracies [5].

4.4. Efficiency and Precision

A major advantage of AM in maxillofacial prosthetics is reduced production time [4,6]. Traditional prosthesis fabrication is time-consuming, requiring multiple appointments and extensive manual labour. The digital workflow allows rapid prototyping and iterative adjustments, shortening the time from diagnosis to delivery [2]. This efficiency benefits patients requiring urgent rehabilitation, such as post-surgical or post-radiotherapy cases [1,3]. Precision is also improved, as bio models provide tangible references during sculpting and fitting, minimizing errors and ensuring better fit, comfort, and long-term usability [2,4].

4.5. Limitations and Future Directions

Despite promising results, some limitations exist. High costs of 3D printing technologies and software may limit accessibility [3,5]. The learning curve associated with digital workflows and modelling software can challenge clinicians accustomed to traditional methods [6]. Additionally, current 3D printing cannot yet perfectly replicate all skin characteristics, including colour nuances, textures, and wrinkles. Ongoing innovations in materials aim to improve realism, but these solutions remain financially inaccessible for most professionals. Nevertheless, hybrid digital workflows combined with additive manufacturing are gradually optimizing prosthesis outcomes [1].

5. Conclusion

The application of digital planning and additive manufacturing enabled accurate anatomical reproduction and improved prosthetic adaptation in the clinical case. The clinical case presented in this study highlight the transformative role of digital workflows in achieving anatomically accurate and aesthetically pleasing prostheses. By leveraging CT scans, 3D modelling software, and rapid prototyping, clinicians can create customized solutions that enhance patient comfort and quality of life while reducing production time. The digital workflow reduced fabrication time, improved predictability, and minimized manual adjustments during the sculpting phase. The final prosthesis demonstrated satisfactory functional performance and aesthetic outcomes, contributing to improved patient comfort and rehabilitation. Digital planning based on CT allowed the fabrication of a bio model and prototype, facilitating accurate prosthesis design. The resulting oculopalpebral prosthesis showed adequate adaptation, comfort, and natural appearance.

As these technologies continue to evolve, they hold the promise of further enhancing the quality of life for patients with facial disfigurements, enabling them to reintegrate into society with confidence and dignity. Despite the notable advantages of additive manufacturing, challenges such as cost, accessibility, and the learning curve associated with digital tools remain barriers to widespread adoption. Future research should focus on making these technologies more affordable and integrating user-friendly training programs to facilitate their implementation in clinical practice. As advancements in 3D printing and digital modeling continue, the potential for improved patient outcomes in maxillofacial rehabilitation will only expand, reinforcing the importance of innovation in personalized healthcare solutions.

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