Management of Maxillofacial Deformities: Surgical and Non-Surgical Solutions

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Preface

The maxillofacial region stands as the epicenter of human identity, communication, and vital biological functions. Deformities in this area transcend mere aesthetic concerns; they leave profound imprints on an individual’s life, ranging from the basic mechanics of breathing and mastication to social integration and self-worth. This comprehensive work aims to explore both surgical and non-surgical solutions by synthesizing the most advanced approaches offered by modern medicine and technology. From the nose—the face’s most prominent feature—to the ears, which play a critical role in social interaction, and into the revolution of digital prosthetics for tissue replacement, this journey serves as a holistic guide for clinicians and specialists alike.

The opening pillar of this book, authored by Dr. Huseyin ISIK, titled *"The Crooked Nose: Surgical Planning and Implementation Principles,"* sheds light on perhaps the most demanding discipline within the world of rhinoplasty. A crooked nose is far more than a simple axial deviation; it represents a complex disharmony of cartilage, bone, and soft tissue. This section emphasizes that a surgeon must think not only as an operator but also as an engineer and an artist. Every step—from the mechanics of septal deviations to the precise geometry of osteotomies—aims to restore aesthetic balance while preserving the patient’s respiratory quality. In modern surgery, alignment alone is no longer sufficient; the key to success lies in ensuring long-term stability, overcoming "cartilage memory," and designing an architectural plan unique to each case.

Another vital, yet sometimes overlooked, element of facial aesthetics is the ear. Dr. Ergin BILGIN’s chapter, *"Management of Prominent Ear Deformity: Surgical and Non-Surgical Approaches,"* offers a multi-dimensional perspective on this condition. While surgical intervention remains the gold standard, this work details the power of non-surgical molding techniques and early intervention, particularly in infancy. The evolution of surgical methods has shifted toward less invasive routes, where tissue-respecting suture techniques and cartilage-shaping methods converge. This section provides a framework for clinical decision-making based on the patient’s age and the severity of the deformity.

The most visionary segment of this work, bridging the gap between current practice and future medicine, is Dr. Ergin BILGIN’s second contribution: *"The Use of Digital Technologies in Maxillofacial Prosthetics: Current Applications, Challenges, and Future Perspectives."* Maxillofacial prostheses have moved beyond simply filling voids that surgery cannot repair. Through 3D scanning, computer-aided design (CAD), and additive manufacturing (3D Printing), it is now possible to produce prostheses with micron-level precision that integrate seamlessly with the patient’s anatomy. However, this technological leap introduces new hurdles, such as the learning curve of digital workflows, material science limitations, and economic accessibility. This chapter examines how digitalization is transforming the collaboration between surgeons and anaplastologists and looks toward a future where artificial intelligence is fully integrated into these processes.

This book is not a static collection of data but a dynamic learning process. Each case is unique, and every solution is a form of art that touches a patient’s life. Beyond teaching technical procedures, our goal is to convey the biological depth behind these complex deformities. Within these pages, where technological speed meets surgical mastery, you will witness how boundary-pushing scientific approaches translate into tangible improvements in human lives.

The face is the mirror of the soul; repairing the fractures in that mirror is not just a treatment, but a restoration of dignity. We hope this work serves as a beacon for the medical community and all healthcare professionals dedicated to this challenging yet deeply rewarding field.

The Use of Digital Technologies in Maxillofacial Prosthetics: Current Applications, Challenges, and Future Perspectives

Ergin Bilgin

Introduction

Maxillofacial deformities can arise due to trauma, cancer, or congenital anomalies, severely impacting patients' quality of life. These defects not only impair aesthetic appearance but also disrupt fundamental functions such as speech, mastication, and social adaptation, leading to significant challenges at both individual and societal levels. Research has highlighted the burden of these conditions on public health with striking figures: “It is estimated that 69 million (95% CI 64–74 million) individuals experience traumatic brain injury (TBI) from all causes each year, with the Southeast Asian and Western Pacific regions experiencing the greatest total disease burden” (Dewan et al., 2018, p. 1080). This is reported to cost the global economy approximately 400 billion USD annually (Maas et al., 2017, p. 989). These data demonstrate that the management of maxillofacial defects is not merely a clinical necessity but also a serious and persistent socio-economic issue.

Given this extensive burden, it is essential to clarify the objectives of maxillofacial prosthetics. “Maxillofacial prosthetics refers to the discipline that combines art and science in reconstructing anatomical, functional, or cosmetic defects of the maxilla, mandible, and facial regions through artificial substitutes when these areas are lost or impaired due to surgical procedures, trauma, pathology, or congenital and developmental anomalies” (Chalian, 1974). Maxillofacial prostheses aim not only to anatomically mimic lost tissue but also to reconstruct the patient's functional capacity and psychosocial well-being. Indeed, it has been reported that such rehabilitation contributes to improving appearance, facilitating early healing, reducing surgical and hospitalization time, lowering treatment costs, and supporting an early return to psychosocial life (Goiato, 2009; Hatamleh, 2010).

Maxillofacial prosthetic rehabilitation performed with traditional methods involves highly laborious, invasive procedures with low reproducibility. Materials used during impression-taking may escape into defect cavities, cause immunological reactions, and even necessitate hospitalization due to secondary infections (Ravikumar et al., 2015; Datta et al., 2017). Furthermore, there are practical limitations such as prolonged laboratory stages, multiple clinical visits, and high costs. In line with these requirements, the first step toward modernization in maxillofacial rehabilitation prior to digitalization was taken with implant-supported systems. The development of osseointegrated implants provided greater stability and retention in prosthetic devices compared to adhesive systems, offering patients increased comfort and security while positively impacting self-confidence (Goiato, 2007).

However, even implant-supported systems did not completely eliminate the limitations of the traditional workflow; therefore, the field experienced its true transformation with the rise of digital technologies. Traditional prosthesis fabrication processes still involved intensive labor, numerous clinical visits, and a high dependency on the individual skills of the prosthodontist. In recent years, the integration of digital technologies has fundamentally altered this landscape.

The background of this digital transformation is not limited to advancements in medical technologies alone; the Third Industrial Revolution, where computer technologies and the internet transformed production processes (Greenwood, 1997), and the Fourth Industrial Revolution, characterized by the integration of physical-digital systems (Schwab, 2016), have laid the groundwork for fundamental paradigm shifts in healthcare. The proliferation of cyber-physical systems has accelerated the transition of clinical imaging, measurement, and modeling methods toward digital foundations; consequently, a faster, more precise, and standardized workflow has been adopted in dentistry and maxillofacial surgery (Hultin et al., 2012; Kamio et al., 2018; Revilla-Leon et al., 2018).

The integration of digital methods into clinical applications ensures that treatments are more predictable and completed in shorter timeframes. This trend has become prominent in restorative dental procedures, implant planning and placement processes, as well as major surgical interventions (Hultin et al., 2012; Revilla-Leon et al., 2018; van Baar et al., 2018). The common denominator of these methods is the requirement for accurate digitization of anatomical structures. While traditional radiological methods remain effective in bone reconstruction (van Baar et al., 2018), it is noteworthy that 3D scanners offer radiation-free alternatives providing high accuracy (Revilla-Leon et al., 2018; Nedelcu et al., 2018). Nevertheless, high hardware costs prevent the adoption of digitalization at the same pace in every clinical setting.

In this context, photogrammetry stands out as a low-cost and accessible digital modeling method (Stuani et al., 2019). Photogrammetry is a mathematical technique that extracts three-dimensional positional information based on identifying common points in images of an object obtained from different angles (Kraus, 1998; Rivara et al., 2016; Sanchez-Monescillo et al., 2016). A particularly remarkable aspect of the method is its ability to offer accuracy comparable to high-cost scanners while being applicable with relatively simple equipment. Photogrammetry has a wide range of applications, from growth analysis of biological specimens (Syngelaki et al., 2018) and modeling plant geometries (Biskup et al., 2007; Clark et al., 2011) to obtaining various medical parameters from clinical patients (Mitchell & Newton, 2002; McKay et al., 2010; Hernandez & Lemaire, 2017; Mertens et al., 2017). In dentistry, it has been utilized to create digital models using both intraoral and extraoral images; it has been shown to be effective in planning maxillofacial surgeries and evaluating outcomes, thanks to the accurate recording of soft tissues (Sanchez-Monescillo et al., 2016; Ravasini et al., 2016; Almuzian et al., 2015; Kulczynski et al., 2018).

One of the examples embodying the clinical impact of digital transformation is auricular prosthesis applications. Tanveer et al. (2023) define auricular defects as "morphological deformity of the external ear due to surgery following tumor resection, trauma, or congenital malformations" (p. 1). There are two primary treatment options for such defects: surgical reconstruction or auricular prosthesis. The fact that surgical methods often fail to yield satisfactory results (Tanveer et al.,

2023) makes digital-based prosthesis production processes even more critical. The ability of CAD/CAM-based systems to provide predictable results in the planning and production of auricular prostheses has reduced patient visits and laboratory time; however, high costs and the need for trained personnel continue to be limiting factors on a global scale (Tanveer et al., 2023, p. 33).

All these developments indicate that digital technologies in the field of maxillofacial prosthetics have not only overcome existing clinical and technical limitations but have also become fundamental components defining future standards. The integration of digital workflows into imaging, modeling, design, and manufacturing processes is transforming through tools such as CAD/CAM systems, 3D printers, photogrammetry, and cyber-physical technologies, thereby reshaping the boundaries of the field. This review aims to systematically present current applications of digital technologies in maxillofacial prosthetics, discuss the clinical, technical, and economic challenges encountered in their utilization, and evaluate prominent future perspectives in the literature within a holistic framework.

The Evolution of Digital Technologies in Maxillofacial Prosthetics: Limitations of Traditional Methods and Advantages of Digital Workflows

Limitations of the Traditional Method

Although traditional methods in maxillofacial prosthesis fabrication have been used as the standard approach for many years, current literature indicates that these practices harbor significant limitations from various perspectives. Revealing the structural differences between traditional facial prosthesis design and manufacturing methods and experimental new digital approaches is critical to understanding the direction in which modern maxillofacial rehabilitation is evolving. As noted in the comparative analysis by Sharma et al. (2023, p. 1190), many stages of the production process, from the requirement for patient visits to cost-effectiveness, diverge significantly between conventional and digital methods. In this context, the following table is presented to systematically compare the advantages and limitations offered by traditional techniques versus CAD/CAM-based digital workflows.

Table 1. Differentiating the benefits of traditional face prosthesis design and manufacture techniques from those of more experimental approaches

Conventional Method	CAD/CAM-Based Digital Method
Multiple patient visits are required.	A single visit or no patient visits may be required.
The process is labor-intensive and highly dependent on the clinician's experience.	The design and manufacturing process is easier.
Results may not always meet the patient's expectations.	Outcomes mostly meet expectations thanks to virtual planning.
Planning and production time is long.	The total duration is significantly shorter due to the digital process.
The manufacturing process is costly.	It is more cost-effective; in most cases, it is about half the cost of the traditional method.

Source: (Sharma et al., 2023, 1190).

In the traditional workflow, the stages of impression-taking, model preparation, and try-ins are both time-consuming and largely dependent on the clinician's manual skill. This multi-stage process can pose additional risks for the patient, particularly in cases of extensive palatal or facial defects; complications such as the escape of impression material into defect cavities, foreign body reactions, and secondary infections are among the most frequently debated disadvantages of the conventional method. Furthermore, the chain of procedures in this method, which necessitates multiple clinical visits, both increases the patient's treatment burden and reduces the time efficiency of the process.

The retention methods used in traditional facial prostheses—specifically chemical adhesives and mechanical systems—often fail to provide the durability and ease of use required by patients (Hatamleh et al., 2023, p. 232). Such limitations can make it difficult for prostheses to fully meet aesthetic and functional expectations, thereby negatively impacting patient satisfaction. Determining factors in whether patients accept a prosthesis include the level of comfort, color, harmony with the face, maintenance requirements, aesthetic appearance, cost, and the success of retention. Additionally, patients' perceptions of the prosthesis are influenced by the rehabilitation process they undergo, the stages through which the prosthesis is manufactured, the clinician's attitude and trustworthiness, and the level of available clinical facilities. The preparation process for traditional facial prostheses is defined as a clinically exhausting and technically complex process that requires significant time and labor; this creates a lasting burden on both patients and the clinical services provided (Atay et al., 2013; Nemli et al., 2013; Adisman, 1990; Chang et al., 2005; Hooper et al., 2005; Markt & Lemon, 2001; Nuseir et al., 2019).

Against this background, the transition to digital technologies represents not only a technical innovation but also a structural redefinition of the workflow. Recent research reveals that the utilization rate of digital technologies in maxillofacial prosthetic applications has increased significantly (Elbashti et al., 2019). These technologies are used as complementary tools supporting traditional production steps; in some cases, they even allow for certain stages of facial prosthesis preparation to be completely substituted with digital methods (Peng et al., 2015). However, although various digital techniques regarding the computer-aided production of maxillofacial prostheses are detailed in the literature, it is understood that a universally accepted, standard production protocol specific to digitally designed facial prostheses has not yet been established. From a theoretical perspective, each digital technique utilized possesses its own unique strengths and weaknesses. Therefore, it is essential to systematically compare these methods, identify potential problems, and develop evidence-based recommendations regarding workflows that can provide the clinician with the most effective results (Farook et al., 2019).

Digital CAD/CAM-based approaches have the potential to mitigate a significant portion of these limitations. While the digital impression-taking process reduces the biological and technical complications seen in conventional methods, it simplifies the workflow by moving most of the design and production stages to a virtual environment. The digital processing of data obtained after scanning allows for the virtual planning of prostheses and their production via 3D printers at any desired time. Consequently, the process is markedly accelerated for both the clinician and the patient; in some cases, a single clinical visit may suffice for the final production of the prosthesis. Since digital design performed in a 3D environment enables the modeling of the prosthesis to be more compatible with anatomical structures and more predictable, it offers superiority over the conventional method in terms of reducing unsatisfactory outcomes.

From a cost perspective, there is a striking difference between the two methods. While the materials used in the conventional method, laboratory time, and multiple clinical visits increase the total cost, digital workflows can offer a more cost-effective solution thanks to reproducible design, automated manufacturing processes, and shorter clinical duration. Findings reported by Sharma et al. (2023, p. 1190) reveal that, in some cases, the total cost of the digital method can drop to approximately half that of the conventional approach. The inclusion of photogrammetry-based systems into the digital workflow further accelerates this transformation. The ability to create high-accuracy digital models with simple and relatively low-cost equipment has expanded the use of CAD/CAM infrastructure and increased the accessibility of digital methods. This feature strengthens the feasibility of digitalization, particularly in clinics where high-cost intraoral scanners are unavailable (Stuani et al., 2019).

However, despite the significant gains provided by digital workflows, current literature also indicates that the widespread applicability of these technologies is limited by several structural barriers. Notwithstanding the advantages offered by digital technologies, there are some major challenges in this field. First, high costs represent one of the greatest obstacles limiting the proliferation of these technologies. Certain types of modern 3D printers are quite expensive, and researchers often have to customize simple 3D printers to suit their specific purposes (Apresyan et al., 2023, p. 25). Furthermore, the use of these technologies generally requires a high level of technical knowledge and skill. This constitutes a significant barrier, especially for small-scale clinics.

At this point, the literature emphasizes that socio-economic factors particularly determine the pace of digital transformation. It is stated that financial inadequacies are among the biggest obstacles to implementing digital workflows in rural areas and developing countries. Notably, it is expressed that most patients requiring prosthetic rehabilitation in these regions come from middle- and low-socioeconomic groups.

The use of digital technologies in the design and production of maxillofacial prostheses offers significant advantages compared to traditional methods. While these technologies allow for the development of individualized treatment plans, they also hold the potential to improve aesthetic and functional outcomes. Nevertheless, considering factors such as cost, the requirement for technical expertise, and infrastructural differences, it is clear that digital workflows are not equally applicable in all clinical settings. Therefore, interpreting the current evidence within a critical framework that evaluates both technical gains and structural constraints together appears to be a fundamental necessity for determining the future directions of digital maxillofacial prosthetic applications.

Advantages of Digital Workflows

Digital workflows in maxillofacial prosthetics appear not merely as a "faster version" of the traditional technique, but as a holistic paradigm shift that redefines the steps of measurement, design, production, and application. Amalraj et al., studying nasal prosthesis fabrication, express this transformation as follows: “The use of digital technologies into the fabrication process has transformed the production of nasal prosthesis, providing more precision, customisation, and efficiency” (Amalraj et al., 2024). This statement indicates that the primary advantage of digital workflows is the high accuracy and standardization that make the prosthesis not just an "approximation" for the patient, but "perfectly compatible" from anatomical and functional perspectives.

In order to comprehend the advantages of digital workflows, it is necessary to jointly evaluate both the technological transformation in the diagnostic/planning phase and the new approaches that replace traditional impression and modeling processes.

Rehabilitation of maxillofacial defects has relied on traditional methods for many years; particularly in palatal defects, the impression-taking process has been both technically challenging and risky for the patient. As Farook et al. (2021) stated in their study on dental prosthetics, conventional impression methods can lead to serious complications. These risks include the displacement of impression material into the defect cavity, immune responses to foreign bodies in the healing cavity, and secondary infections necessitating hospitalization (Ravikumar et al., 2015; Datta et al., 2017). When such risks are combined with the transfer of impressions to plaster models and the possibility of models deteriorating, being lost, or requiring a retake over time, the process is prolonged and clinical success can be negatively impacted.

In response to these issues, digital technologies—specifically CAD/CAM systems, 3D scanning, digital recording, virtual design, and 3D printing—have been increasingly adopted in maxillofacial prosthetic practice (Farook et al., 2020). Technologies used in prosthetic dentistry in recent years, particularly CAD-CAM and rapid prototyping methods, have provided significant progress in this field by offering solutions to the challenges encountered in traditional processes. These innovations can be considered a significant step toward both increasing patient safety and making clinical workflows more efficient for clinicians. Specifically, digital record-keeping and the use of 3D scanners offer a more precise and sustainable approach to prosthesis design and production, minimizing issues such as the damage or loss of physical models (Farook et al., 2021, p. 2).

Digital design environments place the personalization of the prosthesis at the center of clinical practice. At this point, Amalraj et al. emphasize that aesthetic and functional harmony has become an inherent feature of digital planning, stating, “Digital technologies offer high precision and personalisation, producing prosthetics that closely mirror the patient’s original anatomy” (Amalraj et al., 2024). This level of personalization makes the reconstruction of a natural appearance possible, especially in structures like the nose and ears that are central to facial aesthetics, creating a decisive impact on the patient's body perception and social visibility.

Another fundamental advantage of the digital workflow is that the prostheses do not merely "look better" but are also more functional. In the case of nasal prostheses, the same study makes the following observation: “Digital technology allows for more realistic prostheses, including correct skin textures and colours. Furthermore, the precision of 3D printing allows a superior fit, improving the prosthesis’s functional characteristics, such as nasal airflow” (Amalraj et al., 2024). This finding demonstrates that digital workflows do not offer just a cosmetic improvement; they are also aimed at optimizing fundamental functions such as respiration, phonation, and prosthetic stability.

In terms of patient experience and satisfaction, significant advantages of digital technologies have also been put forward. In the cross-sectional study conducted by Hatamleh et al. with maxillofacial prosthesis patients, the digital 3D process is described as follows: “Digital 3D technologies of defect capture, data designing, and 3D modeling were used and perceived as helpful and comfortable” (Hatamleh et al., 2023). In the same study, the subjective experience of patients regarding the prosthesis is conveyed with these words: “Patients perceived their prosthesis as easy to handle, suited them, and they felt confident with it” (Hatamleh et al., 2023). These findings indicate that the digital workflow directly improves not only clinical parameters but also the patient's daily life practices—such as the duration the prosthesis remains attached, its visibility in social environments, and the sense of comfort and security.

The literature also emphasizes the dimension of digital planning specifically regarding time and labor savings. Thanks to digital facial scanning, photogrammetry, and CAD/CAM-based processes, prosthesis design is largely completed in a virtual environment, while production is automated through 3D printers. Consequently, there is less need for the multiple try-on sessions required in the classical method; in some cases, a single clinical visit may suffice for the delivery of the prosthesis (Sharma et al., 2023; Stuani et al., 2019). Particularly for patients with extensive defects and systemic diseases, the reduction in the number of clinical visits significantly alleviates both physical burden and psychological stress.

Another structural superiority of digital workflows is the dimension of reproducibility and archivability. Face and defect data obtained via 3D scanners or photogrammetry can be permanently stored in a digital environment; in the event of the prosthesis breaking, getting lost, or requiring revision, a new prosthesis can be rapidly produced using the same data set (Farook et al., 2020; Stuani et al., 2019). This situation provides strategic flexibility to clinics in terms of both cost and time; it also offers a significant advantage for treatment continuity and long-term follow-up.

The cross-sectional study by Hatamleh et al., which examines the use of digital technologies in maxillofacial prosthesis patients, reveals in detail the impact of digital workflows on both clinical outcomes and patient experience. The authors summarize the position of digital integration in rehabilitation with the following statement: “Integration of 3D technologies plays a vital role in their rehabilitation” (Hatamleh et al., 2023, p. 6). This emphasis demonstrates that digital workflows have not only provided time and cost savings in the production of facial prostheses but have also become a central component of rehabilitation.

In the aforementioned study, digital technologies were integrated into multiple stages of the prosthesis production process. The researchers describe the methods used as follows: “Digital 3D technologies of defect capture, data designing, and 3D modeling were used and perceived as helpful and comfortable” (Hatamleh et al., 2023, p. 1). Within this scope, it was reported that various digital tools, such as CBCT/CT scans, soft tissue simulations, 3D modeling, indirect 3D scanning, and skin spectrometry, were utilized across different patient groups. For instance, in auricular prosthesis cases, the application of CBCT/CT scans and soft tissue simulations in 22 patients, 3D modeling in 12 patients, and skin spectrometry in 17 patients demonstrates that digital technologies have become a routine and systematic part of the clinical workflow (Hatamleh et al., 2023).

The impact of digital planning and visualization on the patient experience is also particularly emphasized among the study's findings. The authors describe the patients' process of evaluating their prostheses post-treatment with the aid of digital technologies as follows: “Patients find it very helpful to visualize their prosthesis in-situ post-treatment with the aid of 3D technologies” (Hatamleh et al., 2023, p. 2). This visualization opportunity facilitates the patient's understanding of the extent of the defect, the planned prosthesis design, and the expected aesthetic outcomes, thereby strengthening treatment consent and compliance.

The study also indicates that digital planning is effective not only on perceptual levels but also on objective clinical outcomes and health system-level outputs. The researchers summarize this with the following sentence: “Such planning improved results and reduced the subjectivity of the operator which leads to reduced cost and enhanced service provision in resource-limited countries such as the country of the study" (Hatamleh et al., 2023, p. 6). This statement makes the advantages of digital workflows visible on three levels: improvement in the quality of clinical results, reduction of operator dependency in decision-making processes, and increased cost-effectiveness, particularly in resource-limited healthcare systems.

The findings of Hatamleh et al. (2023) demonstrate that digital technologies used in the design and production of implant-supported maxillofacial prostheses contribute to patients perceiving their prostheses as "helpful and comfortable," while also increasing prosthetic stability and overall satisfaction. Thus, digital workflows offer a multi-layered set of advantages at both the clinical and systemic levels, enabling the production of complex and aesthetically satisfying prostheses while requiring less clinical effort compared to traditional methods (Hatamleh et al., 2023).

Lastly, it is crucial to highlight that digital workflows play a facilitative role in multidisciplinary collaboration. The same digital dataset can be utilized simultaneously by the surgeon, prosthodontist, radiologist, and biomedical engineer; thus, design decisions can be discussed through a shared virtual platform. This type of collaborative planning—particularly in complex nasal, auricular, or maxillary defects-contributes to conducting both surgical reconstruction and prosthetic rehabilitation in a more harmonious and predictable manner.

When evaluated within this integrity, the advantages of digital workflows are not limited to technical improvements alone; they signify a multi-layered transformation encompassing patient comfort, psychosocial well-being, clinical efficiency, cost-effectiveness, and interdisciplinary coordination. Therefore, digitalization in the field of maxillofacial prosthetics should be viewed not merely as an auxiliary tool, but as a paradigm that forms the fundamental backbone of contemporary clinical practice.

Digital Workflows and Technologies: Face Scanning and Imaging Techniques, CAD, CAM, and 3D Printing

The adoption of digital workflows in maxillofacial prosthetic rehabilitation has gained momentum as a result of requirements arising from both the clinical risks and operational challenges of classical methods. Digital technologies have led to a significant paradigm shift in dentistry by overcoming the limitations of traditional methods. For instance, tools such as cone-beam computed tomography (CBCT) have transformed dental practices by providing critical information for diagnosis and treatment planning (Stuani et al., 2019, p. 46). However, CBCT has certain limitations in the three-dimensional reconstruction of intraoral tissues. Factors such as metal restorations in the mouth, patient movement, and the low definition of occlusal surfaces can negatively affect the quality of reconstruction. Furthermore, the use of CBCT exposes the patient to radiation, which limits its routine use solely for scanning the dental arch (Stuani et al., 2019, p. 46). Digital workflows hold the potential to offer faster and more accurate results by reducing such limitations.

Within this framework, it can be said that digital workflows do not merely transform specific technical steps but represent a structural change spreading throughout the entirety of maxillofacial prosthetic rehabilitation. Farook et al. express this transformation with the following words: "The rapid integration of digital technologies into maxillofacial prosthetics has transformed both the technical workflow and patient outcomes. Traditionally, prosthetic rehabilitation of facial defects required labor-intensive manual sculpting, multiple clinical visits, and was highly dependent on the skills of the prosthetist. However, advances in computer-aided design (CAD), computer-aided manufacturing (CAM), three-dimensional (3D) printing, and digital imaging have introduced new levels of precision, reproducibility, and efficiency into the field" (Farook et al., 2020, p. 2). This statement indicates that digital workflows are not merely a technical innovation replacing classical methods, but a methodological leap that reorganizes the entirety of diagnosis, planning, and treatment.

The first and fundamental step of digital workflows is the accurate digitization of the defect and surrounding anatomical structures. For this purpose, various imaging technologies such as cone-beam CT (CBCT), multi-slice CT, extraoral 3D face scanners, and photogrammetry-based systems are utilized. These tools, while imaging bone structures and implant placement sites with high spatial resolution, also enhance the anatomical accuracy of the prosthetic design by enabling the three-dimensional recording of soft tissue contours (Stuani et al., 2019). Considering the limitations and radiation burden of CBCT, optical 3D scanners and photogrammetry become a more rational option, particularly in cases where only the dental arch or a limited facial region needs evaluation (Stuani et al., 2019, pp. 45–46).

At this point, photogrammetry stands out as one of the digital data collection methods prominent for both cost and accessibility. According to the classic definition referenced by Stuani et al.: "Photogrammetry is a mathematical technique based on the generation of three-dimensional coordinates to define the spatial arrangement of an object by identifying repeated points in multiple images acquired at different angles of the same object" (Kraus, 1998; Rivara et al., 2016; Sanchez-Monescillo et al., 2016, as cited in Stuani et al., 2019, p. 43). In the context of dentistry and maxillofacial surgery, this definition points to photogrammetry's capacity to digitize complex facial anatomy with high accuracy without imposing an additional radiation burden on the patient. Indeed, Stuani et al. summarize the clinical spectrum of this method as follows: "In the field of dentistry, photogrammetry has already been used to obtain digital models by taking intraoral and extraoral images, and is also a very useful tool in the planning and evaluation of results of maxillofacial surgeries by providing a good registry of soft tissues" (Almuzian et al., 2015; Kulczynski et al., 2018, as cited in Stuani et al., 2019, p. 44).

These findings demonstrate that photogrammetry is a strategic tool for the realistic recording of soft tissue, not only in dental implant planning but also in nasal, auricular, and orbital prosthesis design. Especially in extensive facial defects, the combination of optical scanning and photogrammetry makes it possible to reliably create the symmetry and contours of the prosthesis in harmony with the face in a virtual environment.

Following the digital data collection stage, the Computer-Aided Design (CAD) process continues with the processing of the acquired three-dimensional data, the virtual reconstruction of the defect, and the generation of the prosthetic design. This phase involves steps such as clearing artifacts from the raw 3D scan data, reconstructing the defective area through mirroring of the unaffected side of the face, aligning the mirrored section to fully cover the defect, segmenting overlapping areas, and finally merging it with the actual facial region. At the conclusion of these procedures, a consolidated digital prosthesis model ready for production is obtained (Sharma et al., 2023). Such a CAD workflow provides more precise control of anatomical symmetry compared to classical wax modeling and allows for rapid revision of the design when necessary.

The final stage, Computer-Aided Manufacturing (CAM), involves exporting this model in STL format and importing it into 3D printer software. Subsequently, the physical model of the prosthesis is printed using either biocompatible materials or non-biocompatible materials to be used in mold preparation. Rapid prototyping techniques enable the replication of complex facial contours with a high level of detail, thereby minimizing the adjustments required during the clinical stage.

To visually summarize the digital workflow discussed in this section, a flow diagram schematically illustrating the typical CAD/CAM-based process used in maxillofacial prosthesis production can be utilized. This schema demonstrates the integrated digital process at a single glance, extending from the acquisition of patient data to the creation of the three-dimensional virtual face model, the correction and reconstruction of the defect area during CAD stages, and the transfer of STL data to 3D printing in the CAM process (Sharma et al., 2023).

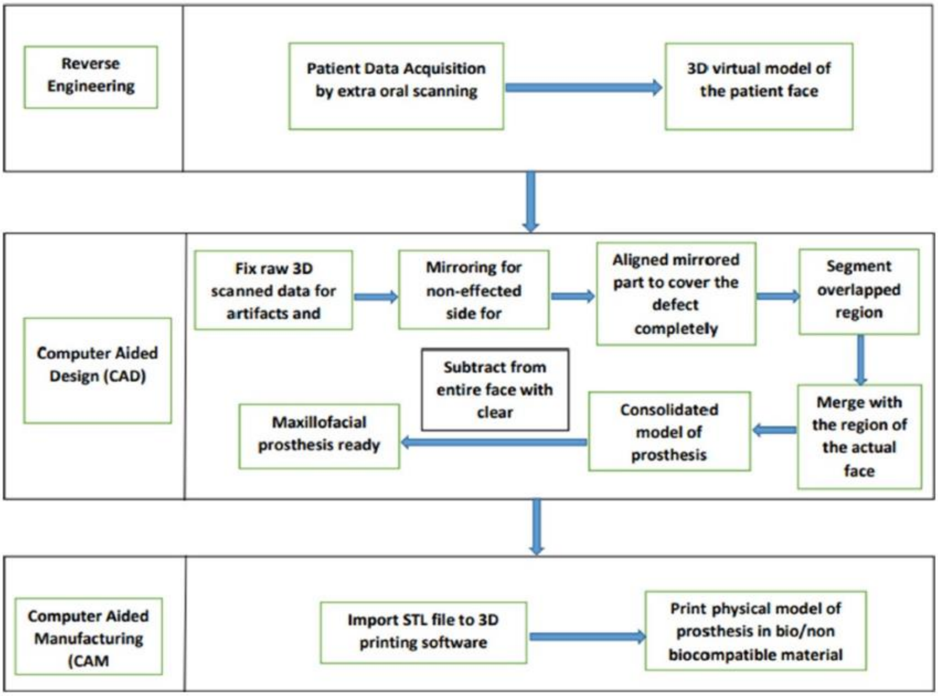

Figure 1. Schematic digital workflow for maxillofacial prosthesis fabrication, including reverse engineering (patient data acquisition and 3D virtual face model generation), computer-aided design (data cleaning, mirroring of the unaffected side, defect coverage, segmentation, merging, and generation of a consolidated prosthesis model), and computer-aided manufacturing (STL export and 3D printing of the physical prosthesis in bio or non-biocompatible materials) (adapted from Sharma et al., 2023).

Clinical Applications of Digital Technologies: Nasal, Auricular, Palatal, and Maxillary Prostheses

The integration of digital technologies into aesthetic and reconstructive surgery has ushered in a new era, particularly in the rehabilitation of nasal, auricular, and maxillofacial defects of the facial region. These approaches, replacing traditional surgical methods, offer the opportunity for flawless preoperative planning by transforming the patient's anatomical data into digital twins.

Nasal Prostheses

The weight of materials such as alginate used in traditional impression methods can compress the soft tissue in the nasal region, leading to anatomical deformation. In current clinical applications, as emphasized by Unkovskiy et al. (2018), this risk has been completely eliminated through the use of laser scanners and photogrammetry methods. This digital data acquisition process records the patient's facial topography with millimetric precision while allowing the surgeon to virtually determine the prosthesis boundaries on the tissue before the operation. This stage is of critical importance for the aesthetic success of the prosthesis's marginal fit with the surrounding tissues (Unkovskiy et al., 2018).

The greatest challenge in designing nasal prostheses is the central position of the nose on the midline of the face. While the mirroring technique used in unilateral defects is successful for ears, it requires a different approach for organs like the nose that lack a symmetrical partner. Tanveer et al. (2021), in their systematic review, state that digital libraries are utilized through CAD (Computer-Aided Design) software. With this method, the nasal form most suitable for the patient's face type is selected from a database and modified in a digital environment. This reduces dependency on the technician's manual skills, ensuring more predictable and natural results (Tanveer et al., 2021).

The retention of the prosthesis in place is a fundamental requirement, especially for patients leading an active life. The digital workflow minimizes the surgical margin of error in the placement of implant-supported prostheses. Almufarrij et al. (2025) reported that virtual surgical planning (VSP) and 3D-printed surgical guides ensure that implants are placed in the ideal bone volume. These guides allow the surgeon to place implants at pre-determined angles and depths during the operation, perfecting the mechanical connection of the prosthesis with retentive systems such as magnets or bars (Almufarrij et al., 2025).

Once the design is complete, rapid prototyping technologies come into play for prosthesis production. The study by Nuseir et al. (2019) shows that 3D printers reduce clinical time by 40-60% by producing not only the prosthesis mold but also temporary models that the patient can use during the trial phase. This method allows the patient's aesthetic expectations to be met even before the final silicone is cast. Furthermore, thanks to digital archiving, in the event of the prosthesis being lost or deformed, the same prosthesis can be reproduced in a short time without the need for a new impression (Nuseir et al., 2019).

In the study by Amalraj et al. (2024), it is noted that nasal anomalies generally occur as a result of surgical excision due to skin cancer, trauma, or other medical conditions. Such situations create serious challenges aesthetically and functionally. Traditional nasal repair methods may not always yield the desired results and may require complex surgical procedures. In this context, prosthetic rehabilitation stands out as an alternative that offers better aesthetic results and involves fewer complications (Amalraj et al., 2024, p. 1). However, traditional prosthesis production processes are labor-intensive methods dependent on manual skills. This can lead to variations in quality and fit. The integration of digital technologies into prosthesis production processes has revolutionized this field by providing greater precision, personalization, and efficiency.

The characteristics of the case addressed by Amalraj et al. (2024) are as follows: A 53-year-old male patient presented with a growth in the nasal region and was diagnosed with Grade 2 squamous cell carcinoma (Amalraj et al., 2024, p. 1). The patient underwent a total rhinectomy, and the area was closed with a forehead rotation flap. The bridge of the nose, including the nasal bones, was resected, and post-operative 6MV X-ray therapy was applied to the tumor bed. Using the patient's pre-operative photographs, the digital design process was initiated, and the obtained data were converted into DICOM format (Amalraj et al., 2024, p. 2). Subsequently, CT datasets were converted into STL files using Mimics software, and the prosthetic design was realized.

Digital approaches in nasal prosthesis production proceed through a workflow that integrates design and manufacturing processes. In the clinical example reported by Amalraj et al. (2024), this workflow is defined by the following steps: 3D Imaging and Scanning: Modern imaging techniques were used to create a precise digital image of the patient's facial anatomy (Amalraj et al., 2024, p. 1). In this process, a detailed scan of the nasal defect was achieved using 3D facial scanning technology (Amalraj et al., 2024, p. 3). Digital images were transferred to specialized CAD software, and a prosthesis compatible with the patient's anatomy was designed (Amalraj et al., 2024, p. 3). The software allowed for personalized adjustments such as skin tone, texture, and functional factors.

The final design was transferred to a 3D printer using biocompatible materials, and the prosthesis was produced using stereolithography (SLA) or selective laser sintering (SLS) technologies. Post-printing, the prosthesis was processed to enhance its appearance and durability. Painting matching the skin tone, the addition of hair or eyelashes, and protective coatings were applied. Finally, the prosthesis was fitted to the patient, and due to the high precision of the digital workflow, additional adjustments were generally not required. The prosthesis was secured using adhesives or implants (Amalraj et al., 2024, p. 3).

Auricular Prostheses

The use of digital technologies in the rehabilitation of auricular prostheses has eliminated asymmetry, one of the most challenging aesthetic problems in reconstructive surgery. While manually modeling an ear form in traditional methods is strictly dependent on the clinician's artistic ability, today's CAD/CAM systems provide a flawless fit by transforming the patient's healthy ear into a digital template.

In traditional anaplastology methods, the production of auricular epitheses relies on physical impressions taken from the patient and manual wax modeling. However, today, computer-aided design and three-dimensional modeling technologies have elevated this process to a much more precise and patient-oriented dimension. Especially in unilateral deformities such as microtia, transferring the patient's intact ear to a digital environment using high-resolution optical scanners or computed tomography data allows for perfect morphological symmetry. These digital datasets are adapted to the defective area using the mirroring technique, creating digital models that are anatomically closest to reality. Advanced software used during the modeling phase not only copies the external ear form but also optimizes the edge transitions of the epithesis and its contact surfaces with the soft tissue. Problems such as edge thickness and tissue incompatibility encountered in traditional methods are minimized through precise digital adjustments. During the design process, implant positions or magnetic attachment housings that will provide retention for the epithesis are also integrated into the model, allowing surgical and prosthetic planning to be carried out simultaneously. This integration directly contributes to the patient's quality of life by increasing both the aesthetic and functional stability of the prosthesis (Federspil, 2015).

The clinical process begins with the digital transfer of complex convolutions in the ear region (helix, tragus, concha). Unkovskiy et al. (2019) state that optical surface scanners do not deform the tissue at all compared to traditional plaster impression methods and increase patient comfort by 80%. Particularly in pediatric cases or patients with post-traumatic sensitivity, non-contact scanning methods reduce pressure on the tissue to zero, ensuring anatomical details are recorded in their purest form (Unkovskiy et al., 2019).

The mirroring technique is applied to the acquired digital data. In this technique, the patient's existing healthy ear is flipped horizontally in the computer software and placed on the missing side. Ciocca et al. (2009) presented in their clinical reports that this digital symmetry method reduces projection and angle errors frequently encountered in manual modeling by 95%. On the software, the edge thicknesses and tissue transition lines of the prosthesis are thinned millimetrically, which maximizes aesthetic visibility by ensuring the prosthesis integrates seamlessly with the skin (Ciocca et al., 2009).

The retention of ear prostheses is generally provided by endosseous implants placed in the mastoid bone. Virtual surgical planning (VSP), emphasized by Almufarrij et al. (2025), allows the bone volume where the implants will be placed to be analyzed before the operation using CT/CBCT data. Thanks to surgical guides obtained from 3D printers, implants are placed with the most ideal vector to perfectly match the magnet or bar systems of the prosthesis. This shortens the operation time while increasing surgical success (Almufarrij et al., 2025).

Additive manufacturing is used in the transition of the finalized design to physical production. Rather than printing the prosthesis directly, as suggested by Jamayet et al. (2019), producing negative molds for silicone casting with 3D printers has become the clinical standard. This method enables the use of biocompatible medical-grade silicones. 3D-printed molds offer much smoother surfaces and sharper edge details compared to traditional handmade molds, minimizing post-operative prosthetic finishing procedures (Jamayet et al., 2019).

Palatal and Maxillary Rehabilitation

The rehabilitation of palatal and maxillary defects is one of the most complex disciplines of aesthetic surgery in terms of preserving orofacial aesthetics and function. These defects, which generally occur as a result of oncological resections or congenital malformations, not only impair the ability to chew and speak but also cause serious aesthetic deformities by leading to the loss of soft tissue support in the midface. In these cases, digital workflows aim to compensate for the volumetric deficiency created by tissue loss with millimetric accuracy through VSP and personalized prosthesis design.

The most prominent aesthetic problem developing after maxillary resection is the inward collapse of the upper lip and cheek area. Restoring this volume with traditional obturator prostheses frequently results in failure due to the weight of the prosthesis. Soltanzadeh et al. (2019) revealed that pre-operative facial scans of the patient are analyzed with digital planning software, and the ideal prosthesis volume to provide lip support is calculated using this data. With this method, the outer contour of the prosthesis is shaped according to the patient's pre-operative soft tissue profile, thereby preserving facial symmetry (Soltanzadeh et al., 2019).

Success in clinical application relies on the merging of hard tissue data (CBCT/DICOM) with soft tissue surface data (STL). Ciocca et al. (2009) reported that this hybrid data integration is much more reliable than conventional impression methods in determining the boundaries of the palatal defect. Obturators designed in a digital environment fit perfectly into the anatomical recesses of the resection cavity. This precise fit not only increases the seal but also optimizes the center of gravity of the prosthesis, allowing the patient to use their facial muscles more naturally (Ciocca et al., 2009).

The weight of maxillary prostheses is a critical obstacle for both patient comfort and prosthetic retention. Digital production technologies enable "hollow" designs, which are quite difficult to achieve in a traditional laboratory setting. Tasopoulos et al. (2020) proved that hollow obturators produced with CAD/CAM systems are 40-55% lighter than traditional acrylic prostheses. This lightness prevents the prosthesis from sagging due to gravity, avoids deformation of the nasolabial fold, and ensures the long-term success of orofacial aesthetics (Tasopoulos et al., 2020).

The durability of aesthetic results depends on how well the prosthesis is stabilized by endosseous implants or existing tooth support. Zoabi et al. (2022) emphasize that the use of virtual surgical guides allows for implant placement at the most appropriate angle into the limited bone tissue surrounding the maxillary resection cavity. This guided surgical approach ensures that implants are positioned not only functionally but also in a way that supports the aesthetic finish line of the prosthesis. Thus, the patient's smile line and tooth arrangement are made compatible with the overall aesthetic proportions of the face (Zoabi et al., 2022).

Advantages, Challenges, and Limitations

The study by Hatamleh et al. demonstrates that digital technologies in implant-supported facial prostheses significantly increase patient satisfaction and prosthetic stability (Hatamleh et al., 2023). However, it is also emphasized that these positive effects are not absolute but sensitive to biological and anatomical conditions. In the study, while the success rate of implants in the auricular region was 97%, the success rate of implants in the orbital region was reported as 25% (Hatamleh et al., 2023). This finding shows that no matter how advanced digital planning and production processes are, the anatomical region where the implant is placed, bone quality, and the patient's maintenance habits continue to be decisive in the final success of the treatment.

Digital technologies are providing a significant transformation in the design and production of maxillofacial prostheses; while offering aesthetically and functionally satisfying results, they accelerate production processes and reduce costs. However, factors such as implant success, regional anatomical differences, and patient maintenance behaviors can partially limit the effectiveness of these technologies (Hatamleh et al., 2023). Therefore, as much as further development of digital workflows is needed in the future, progress must also be achieved in the fields of implant biology and patient education.

Additionally, it is emphasized that financial inadequacies are among the biggest obstacles to implementing digital workflows in rural areas and developing countries. Notably, it is stated that most patients requiring prosthetic rehabilitation in these regions come from middle- and low-socioeconomic groups. Moreover, it is expressed that the purchase and maintenance of specialized scanning and CAD technologies are high-cost, making it difficult to justify these technologies economically. This stands out as a significant factor hindering the widespread adoption of digitalization (Farook et al., 2021, p. 2).

Discussion

Photogrammetry stands out as a low-cost and accessible alternative for obtaining digital models in the field of dentistry. In the study by Stuani et al., the accuracy and precision of digital models obtained using the photogrammetry technique were evaluated, emphasizing that this method can be applied at a lower cost compared to traditional scanning techniques. In the study, measurements of digital models obtained via photogrammetry showed a limit of agreement between -0.433 and 0.611 mm when compared with plaster models (Stuani et al., 2019, 43). These results reveal that photogrammetry could be a potential area of use in applications requiring millimetric precision, such as the preparation of surgical guides. However, as noted in the study, the photogrammetry method offers lower precision compared to traditional intraoral and extraoral scanning techniques. This indicates that further research and optimization are required for photogrammetry to be widely used in clinical applications (Stuani et al., 2019, 43). Specifically, improvement methods such as lens calibration, integration of target references, and the use of alternative software could increase the accuracy of this technology in clinical settings.

In this context, while photogrammetry holds significant potential in areas such as archiving digital models, diagnosis, and planning, it should be carefully evaluated in applications requiring higher precision, such as prosthetic fit and adaptation of periodontal tissues.

The study by Amalraj et al. (2024) demonstrates that fully digitally produced nasal prostheses provide a significant advancement in facial reconstruction. By offering precision, personalization, and efficiency, digital technologies provide new hope and a higher quality of life for individuals who have undergone rhinectomy. With continued technical advancements, greater benefits are expected in digital prosthesis production, expanding the possibilities in this field. This digital transformation allows prostheses to be designed in a way that is more compatible with facial anatomy while standardizing the production process, thereby increasing the predictability of treatment outcomes and significantly raising patient satisfaction.

The advantages provided by digital workflows in nasal prosthesis production stand out significantly compared to traditional methods. In the study by Amalraj et al. (2024), it was stated that digital technologies allow prostheses to better harmonize with the patient's facial anatomy, ensuring that details such as skin texture and color are accurately reflected. Furthermore, thanks to 3D printing technology, the functional characteristics of prostheses, such as nasal airflow, can be better optimized. Digital processes reduce production time from weeks to a few days, thereby lowering costs and making prostheses more accessible. However, the high cost of digital technologies and the training required for their integration into clinical practice may limit access in certain regions. In the future, the quality and accessibility of prostheses are expected to increase further with more advanced 3D printing materials and CAD software.

Recent research reveals that the utilization rate of digital technologies in maxillofacial prosthetic applications has increased markedly (Elbashti et al., 2019). These technologies are being used as tools to support traditional production steps; in some cases, they even allow for certain stages of facial prosthesis preparation to be completely replaced by digital methods (Peng et al., 2015). Nevertheless, although different techniques regarding the computer-aided production of maxillofacial prostheses have been reported in detail in the literature, it is observed that a standard and universal production protocol specific to digitally designed facial prostheses has not yet emerged. From a theoretical perspective, each digital technique used possesses its own unique challenges and limitations. Therefore, it is of great importance to evaluate existing methods comparatively, identify potential problems, and develop recommendations regarding which procedures can provide the most effective results for the clinician (Farook et al., 2019).

Conclusion

The digitalization of maxillofacial rehabilitation is not merely a change in technical tools; it is a profound transformation that redefines the interaction between clinician and patient, as well as the overall treatment outcomes. The manual margin of error inherent in traditional methods, combined with impression processes that are physically taxing for the patient, is being replaced by data-driven, predictable, and high-precision protocols. The data discussed in this review confirm that digital workflows provide an indisputable superiority over conventional approaches, particularly in the reconstruction of anatomical symmetry and the enhancement of prosthetic stability.

Despite this, the requirement for high-cost hardware the greatest obstacle to digitalization—is beginning to be overcome through innovative and accessible solutions such as photogrammetry. The integration of low-cost optical data collection methods with high-precision CAD software strengthens the applicability of these technologies not only in advanced centers but also in resource-limited regions. The millimetric error margins of photogrammetry remain within acceptable limits for surgical guide production and diagnostic phases, allowing for the democratization of the digital transformation.

The study by Stuani et al. (2019) demonstrates that photogrammetry can be a low-cost and accessible alternative for obtaining digital models in dentistry. The study indicated that digital models created with photogrammetry are compatible with plaster models and provide millimetric precision in measurements. Photogrammetry stands out as a promising technology, particularly in fields such as the preparation of surgical guides, digital model archiving, and diagnosis. Nevertheless, further research and technical improvements to increase accuracy are necessary for the method to be widely used in clinical applications. The low-cost and accessibility advantages offered by photogrammetry may contribute to the proliferation of digital workflows in dentistry. However, the necessity for further evaluation and development regarding the clinical usability of this technology remains.

However, the opportunities provided by technology should not be considered independently of biological realities. Regional variations in implant success and tissue compatibility indicate that even the most advanced CAD/CAM systems remain dependent on the patient's individual biological response and self-care discipline. This necessitates evaluating the success of digital workflows not only through software accuracy but also in conjunction with a multidisciplinary surgical planning approach and a comprehensive patient education process.

In the future, with the inclusion of artificial intelligence-supported design algorithms and a broader spectrum of biocompatible 3D printing materials, prostheses are expected to evolve from being mere aesthetic masks into functional organ simulations that provide dynamic tissue responses. In particular, the lightness provided by "hollow" designs and the microscopic surface details offered by 3D printers will facilitate somatic integration, allowing patients to perceive the prosthesis as a natural part of their body.

In conclusion, the field of maxillofacial prosthetics is evolving from a craft-oriented approach into an engineering and biology-based discipline. Despite current challenges, the standardization and reproducibility offered by digitalization will not only compensate for the functional losses of patients with facial defects but will also maximize their social rehabilitation and self-confidence. While this technological leap pushes the boundaries of clinical success, it establishes patient satisfaction as the ultimate and most important criterion of rehabilitation.

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Surgical Planning and Implementation Principles in The Crooked Nose

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Introduction

Rhinoplasty represents a complex surgical approach that establishes a fine bridge between facial aesthetics and functional harmony. In particular, the correction of crooked or irregular nasal shapes not only enhances the acceptability of aesthetic outcomes but also improves nasal airflow and functional respiratory functions. Therefore, the critical determinants of surgical success should not be limited solely to the efficacy of surgical techniques but should be addressed as a harmonious integration of comprehensive preoperative planning and operational implementation processes.

The planning phase requires a detailed evaluation of individual anatomical structures and functional goals. Variations in maxillofacial, nasal septal, and nasal tip structures guide the determination of surgical objectives, while also encompassing multidisciplinary communication and a long-term follow-up plan to balance patient expectations with clinical reality. In modern rhinoplasty, simulation-based design has become a critical tool for personalizing the surgical approach; thereby minimizing the discrepancies between the planned outcome and operative reality. Furthermore, preoperative assessment strengthens the capacity to foresee and manage potential complications by identifying risks at the skeletal and connective tissue levels.

The implementation phase refers to the operational execution of the plan. In crooked noses, the selection of surgical techniques and the calculation of secondary correction possibilities must be performed in alignment with objective goals. The implementation process requires the coordinated and complementary execution of interventions such as appropriate osteotomic techniques, cartilage formation, and tip surgery.

Successful results are achieved through the surgeon's fine manual dexterity, combined with the stabilization of intraoperative relationships, the preservation of the fragile balance between tissues, and the minimization of deviation from the target. In this context, the tight integration between planning and implementation not only strengthens aesthetic complementarity but also provides significant improvements in functional outcomes.

This study aims to present all principles in detail by examining the fundamental planning parameters and operational implementation dynamics that influence the success of crooked nose surgery.

Definition of Crooked Nose Deformity as a Surgical Problem and Morphodynamic Analysis

The crooked nose is defined as a significant deviation of the nasal pyramid from the facial midline and is considered one of the most challenging topics in rhinoplasty surgery. This condition is not merely an aesthetic concern but also a functional pathology leading to severe airway obstruction (Rohrich et al., 2002). In the literature, the term "crooked nose" is used to describe the deviation of both bony and cartilaginous structures from the midline.

As a surgical problem, the crooked nose is the result of asymmetric relationships between the septum, upper lateral cartilages, nasal bones, and sometimes the lower lateral cartilages. Guyuron (1998) classified these deformities morphologically as C-shaped, S-shaped, and linear (axis-dependent) deviations. However, from a surgical perspective, a "morphodynamic" evaluation is mandatory beyond this classification.

The "Crooked Nose" Paradox in Surgery

The primary challenge in crooked nose surgery is the memory of the cartilaginous and bony structures, along with the fact that the surrounding soft tissues have shaped themselves according to this curvature. As emphasized by Byrd et al. (2007), although correcting the septum is the gold standard for straightening the nasal axis, it is not sufficient on its own.

The septum is the main supporting column of the nose. Deviations in the septal cartilage structure, referred to as the "L-strut," cause direct displacement of the nasal dorsum (bridge) and the tip. Constantian (1994) stated that in the vast majority of patients with a crooked nose, the amount of septal cartilage is insufficient or the cartilage is deformed under tractional forces.

In a crooked nose, the nasal bones are usually of different lengths and angles. While the nasal bone on one side is longer and more vertical, the bone on the other side is short and depressed. This asymmetry is not just a simple fracture healing issue but is often a reflection of traumas sustained during childhood on facial development (Gunter & Rohrich, 1987).

Morphodynamic Analysis

Morphodynamic analysis is an approach that examines the tension, torque, and support mechanisms that create the nasal image, beyond its static appearance.

Biomechanically, cartilage possesses an internal tension called "interlocking stresses." Fry (1966) experimentally demonstrated that damage to the perichondrium or a layer of cartilage on one surface causes the tissue to bend toward the opposite side. In morphodynamic analysis, the surgeon must calculate these intrinsic forces. In a crooked nose, the cartilage has adapted under the tension of the existing curvature for years. If these stresses are not released during surgery (via scoring, morselization, or grafting), the cartilage may return to its original form over time.

A dynamic often neglected in crooked nose analysis is the soft tissue envelope. Toriumi (2006) noted that in long-term asymmetries, the nasal skin and subcutaneous tissues (SMAS) are tighter on the curved side and looser on the other. Even if the bone and cartilage are corrected, this asymmetric memory of the soft tissue tends to pull the nasal axis back to its original side. Therefore, morphodynamic analysis must also include "soft tissue adaptation."

The morphodynamic characteristics according to crooked nose types are provided in Table 1.

Table 1. Morphodynamic Characteristics According to Crooked Nose Types

Deformity Type	Basic Pathology	Morphodynamic Challenge
Linear Deviation	Total axial shift of the septum	Risk of dislodgement from the maxillary crest
C-Type Curvature	Cartilage excess on one side	High tension on the convex side
S-Type Curvature	Multiple fractures and rotation	Risk of middle vault collapse

Diagnostic Methods and Surgical Strategies

Before surgical planning, the patient's analysis must be conducted in the following three planes:

- Static Analysis: Determination of the midline (the line from the nasion to the philtrum) using standard photographs.
- Dynamic Analysis: Observation of whether the deviation increases during smiling due to the influence of the depressor septi muscle.
- Functional Analysis: Evaluation of the internal and external nasal valves using the Cottle maneuver.

Various techniques have been proposed to achieve morphodynamic balance in the treatment of the crooked nose. Spreader Grafts are the most widely used method to stabilize the middle vault and maintain the septum in the midline (Sheen, 1984). This revolutionary technique by Sheen is a result of morphodynamic analysis; because in a crooked nose, the angle between the upper lateral cartilages and the septum is narrowed, and this angle must be mechanically supported.

On the other hand, "Cross-bar" grafting or asymmetric osteotomies are applied to break the cartilage memory. Rohrich et al. (2002) emphasize that for a "finesse" result, not only the bones but also the ligaments connecting the nose to the face (e.g., Pitanguy's ligament) must be balanced.

The correction of the crooked nose deformity is an "engineering" problem that requires the reconstruction of nasal anatomy. The forces preventing the nose from staying in the midline stem not only from cartilage curvature but also from the dynamic loads placed upon these structures.

Structural Stabilization: The L-Strut and Grafts

In the surgical management of crooked noses, leaving the septal cartilage as an "L"-shaped frame (L-strut) is a fundamental rule. However, in cases of severe deviation, this frame is inherently unstable. Studies by Byrd et al. (2007) have revealed that the ideal L-strut structure should have both caudal (front) and dorsal (top) margins at least 10-15 mm wide. In crooked noses, the cartilage is often weakened or traumatized. Toriumi (2006) advocates that the use of an "Extended Spreader Graft" is essential to increase the stability of this structure. These grafts not only open the airway but also align the crooked dorsal septum like a rail.

The deviation of the caudal septum (the lower support near the tip) causes tip deviation. Gunter and Rohrich (1987) proposed re-fixing the caudal septum onto the maxillary crest using the "septal swing door" technique. If the caudal cartilage is too weak, this support mechanism should be mechanically reinforced using a "Caudal Septal Extension Graft."

Extracorporeal Septoplasty

In some complex crooked noses with "S" types or multiple fractures, it may not be possible to correct the septum in situ. In such cases, the "Extracorporeal Septoplasti" method, popularized by Gubisch (1995), comes into play. In this method, the septal cartilage is first removed entirely. The septum is corrected outside (ex vivo), reinforced with cartilage patches (batten grafts) if necessary, and transformed into a straight plate. Finally, the corrected cartilage is re-inserted into the nose and sutured to the upper lateral cartilages and the bony structure.

Gubisch's long-term follow-ups (2005) showed that this method reduced the recurrence rate to below 10%, especially in severely traumatic crooked noses. However, this technique requires high surgical precision as it carries the risk of total loss of dorsal nasal support.

Bony Vault and Asymmetric Osteotomies

The upper bony vault is rarely symmetric in a crooked nose. Osteotomies (bone incisions) performed to reposition the bones require asymmetric planning rather than a standard procedure. Tardy and Denneny (1984) proposed incisions at different levels for the wide and narrow sides of the bony pyramid:

- Wide Side (Convex): Since the bone is longer, an "intermediate osteotomy" or the removal of a bone wedge may be required to shorten the bone.
- Narrow Side (Concave): The bone is shorter and depressed; the goal here is only to mobilize the bone and perform an "out-fracture."

Rohrich et al. (2002) stated that in severe axial shifts, a wedge resection (removing a small piece of bone) from the base of the deviated side facilitates the seating of the bony pyramid in the midline. This is mechanically similar to changing the position of a hinge.

Soft Tissue Memory and the "Recoil Phenomenon"

Even if the bone and cartilage are surgically corrected, the soft tissue and skin envelope over the nose tend to return to the crooked position they have been accustomed to for years. This is called the "Recoil Phenomenon."

Daniel (1992), in his fundamental works on rhinoplasty, emphasizes that subcutaneous scar tissue and asymmetric muscle pulls (e.g., m. nasalis) can distort the nasal axis. To minimize this risk:

- Wide Subperichondrial Dissection: Complete separation of the soft tissue from the cartilage and release of stress.
- Over-correction: Some surgeons hyper-correct the nose slightly toward the opposite side, anticipating the pull during the healing period.

The surgical success of crooked nose deformity depends on balancing the vectorial forces acting on the nasal skeleton rather than achieving a static symmetry. The literature teaches that from Sheen's spreader grafts to Gubisch's extracorporeal approach, the "mechanical memory" underlying the problem must be broken. Asymmetric osteotomies and rigid L-strut support are indispensable elements in solving this complex biomechanical equation.

Surgical Importance of the Facial Midline and Reference Points

The most common cause of failure in crooked nose surgery is treating the nose as an isolated unit, independent of the rest of the face. Successful surgical planning relies on an approach that considers the nose a central component of the face and accurately analyzes its geometric relationship with adjacent anatomical structures.

The "True" vs. "Perceived" Midline

The greatest pitfall in surgical planning is ignoring the distinction between the "true" (geometric) midline and the "perceived" (aesthetic) midline.

- True Midline: This is a theoretical plane determined by the skeletal structure of the skull, passing through fixed bony landmarks such as the nasion and the anterior nasal spine. However, in most patients, the facial skeleton is asymmetric, and this line may not represent the visual center of the face (Rohrich et al., 2002).
- Perceived Midline: This is the line that an observer perceives as the "center of balance" when looking at a face. This line is influenced not only by bony structures but also by soft tissue distribution, the level of the eyes, and the position of the oral commissures. If a surgeon focuses solely on bringing the nose to the "true" midline on an asymmetric face, the nose may appear discordant or "alien" to the rest of the face. Therefore, the goal is to position the nose at the "optical midline," where it appears most balanced within the patient's own facial asymmetrics (Daniel, 2018).

Primary Reference Points

The severity of nasal deviation should be evaluated through the relationship between three fundamental reference points: Glabella (between the eyebrows), Subnasale (the nose-lip junction), and Menton (the tip of the chin).

- Superior Reference (Glabella): Determines the starting point of the nose. In crooked noses, the nasion (nasal root) is frequently displaced to the right or left of the glabella center.
- Middle Reference (Subnasale): Indicates the position of the caudal end of the septum and the anterior nasal spine. Deviation of this point from the midline is the primary cause of curvature in the lower third of the nose (Guyuron et al., 2015).
- Inferior Reference (Menton): The position of the chin tip can either mask or emphasize nasal deviation. For example, if a patient's chin is deviated to the right and the nasal tip is also inclined to the right, the crookedness is less noticeable; however, if the nasal tip is inclined to the left, the asymmetry becomes dramatic.

The line formed by connecting these three points (Facial Midline) serves as the primary guide in determining how much the nose needs to be repositioned.

Hemifacial Asymmetry and the "Ceiling Effect"

In more than 90% of crooked nose cases, varying degrees of hemifacial asymmetry are present. One side of the face (usually the left) may be narrower, shorter, or more retruded than the other. This asymmetry acts as a "ceiling effect," limiting the surgical outcome.

- Maxillary Height Difference: If one side of the upper jawbone is higher than the other, it causes the nasal base to be tilted. If the foundation is not level, it is technically impossible to build the "building" (the nose) perfectly straight.
- Orbital Asymmetry: A difference in the horizontal level of the eyes can distort the surgeon's perception of "straightness." If the surgeon uses the eyes as a reference during surgery, the nose may remain crooked relative to the vertical axis of the face (Jang et al., 2016).

- Soft Tissue Constraints: On the narrower side of the face, the skin and soft tissue envelope are tighter, while they are looser on the wider side. Even if the skeleton is corrected, the tissues on the tight side have the potential to pull the nose back toward its old position (rebound) (Cerkes, 2016).

Optical Correction and Camouflage

In modern rhinoplasty, the goal is not always to correct anatomical flaws 100%, but to create optical illusions by manipulating the perspective. This is called "optical correction" or "camouflage surgery."

- Asymmetric Grafting: If the nasal pyramid cannot be brought completely to the midline, a thick spreader or onlay graft placed on the concave side creates the perception that the nose is straight (Vuyk, 2015).
- Manipulation of Dorsal Aesthetic Lines (DAL): When the width and parallelism of light reflections descending from the eyebrows to the nasal tip are made surgically symmetrical, the nose is perceived as "straight" even if the underlying skeleton is slightly crooked.
- Osteotomy Strategies: Breaking the bones at asymmetric levels (asymmetric osteotomy) is used to provide balance between the narrow and wide sides of the face (Gerbault et al., 2016).

The surgeon must demonstrate these facial asymmetries to the patient in front of a mirror before the operation and emphasize that surgery is an "art of balancing," and that absolute geometric symmetry has biological and aesthetic limits.

Nasal Tip Asymmetries and Their Dynamic Relationship with the Axis

One of the greatest frustrations in rhinoplasty surgery is seeing a nasal tip that either shifts off-axis during the healing process or retains its initial curvature, despite a perfectly straightened nasal dorsum (bridge) on the operating table. This phenomenon proves that the nasal tip is not an isolated aesthetic unit but part of a dynamic mechanism formed by septal support and the lower lateral cartilages (LLC).

The "Tent Pole" Analogy and Septal Support

In rhinoplasty literature, the "caudal septum" is depicted as a "tent pole" upon which the nasal tip rests. If this pole is crooked, it is impossible for the peak of the tent to be symmetrical. Byrd and Hobar (1993) noted that the projection and rotation of the nasal tip are heavily dependent on septal integrity.

Deviation of the caudal septum not only causes airway obstruction but also results in asymmetric pressure applied to the lower lateral cartilages on both sides. Toriumi (2006), in his seminal work on "Structure Rhinoplasty," emphasizes that preserving the L-strut support of the caudal septum—or reconstructing it if weak (using techniques such as septal extension grafts)—is indispensable for the long-term stability of the tip. Tip sutures (domal sutures) performed without correcting the caudal septal curvature trigger the "recoil" phenomenon by increasing tension on the cartilage, leading the tip to return to its original crooked axis.

The Tripod Theory

The "Tripod Theory," introduced by Jack Anderson (1969), remains the most valid model for understanding tip mechanics. According to this model, the nasal tip is like a three-legged stool: two legs are formed by the lateral crura (alar cartilages), and the third leg is formed by the junction of the medial crura from both sides (the columella).

- Asymmetric Legs: If one lateral crus is longer or weaker than the other, the tripod tilts toward that side.
- Relationship with the Axis: A deviation in the nasal axis is usually a disruption of the relationship between these tripod legs and the ground (the maxillary base and septal angle). As Toriumi (2006) stated, to correct the axis, it is not enough to simply cut the cartilages; the differences in length and resistance between the tripod legs must be equalized.

Cartilage Memory and Interlocking Stresses

The domal region defines the "tip defining points," the highest points of the nasal tip. Asymmetry in the domes usually stems from congenital differences in cartilage morphology or post-traumatic scar tissue. However, the hidden danger here is the principle of "interlocking stresses" defined by Fry (1966).

Fry proved that the protein matrix within cartilage is under a specific tension. Aggressive suturing or unilateral resections performed to achieve domal symmetry disrupt the internal balance of the cartilage. If the surgeon does not account for cartilage memory while correcting an asymmetric dome structure, the cartilage will bend (warping) during the healing process, pulling the tip off-axis again. Daniel (1992) advocates the philosophy of "strengthening the weak" to prevent this; rather than excising excess cartilage, balance should be established by supporting the deficient side with grafts.

Lateral Crural Steal and Asymmetric Maneuvers

The lateral crural steal technique involves "stealing" a portion of the cartilage from the lateral crus and adding it to the medial crus by moving the dome. While this is generally used to increase projection and rotate the tip (lift it), it can also serve as a symmetry tool in complex crooked noses.

In complex asymmetries, the surgeon does not apply an equal amount of "steal" to both sides. Depending on the direction of the curvature, more cartilage is shifted from one side to equalize the lengths of the lateral crura. Toriumi warns that if this technique is performed uncontrollably, it may lead to external valve collapse. Therefore, it is essential to use supporting structures to fill the space of the stolen cartilage and stabilize the alar wing.

The Gold Standard: Lateral Crural Strut Graft (LCSG)

One of the most powerful tools Toriumi (2006) introduced to rhinoplasty literature is the Lateral Crural Strut Graft, which is the gold standard in treating tip asymmetries. This technique aims to completely change the form of the cartilage via rigid cartilage bars (usually septal cartilage) placed underneath the lateral crus.

- Mechanical Correction: The LCSG straightens a bent or weak lateral crus like a "splint."
- Axis Control: If the nasal tip is tilted toward one side, the LCSG on that side acts as a lever, pushing the tip toward the midline.
- Combatting Recoil: Cartilage memory (Fry's principle) becomes ineffective in the presence of a strong strut graft. The graft physically prevents the cartilage from returning to its old crooked form.

Toriumi (2006) states that these grafts are not just aesthetic fillers but structural engineering marvels; when placed correctly, they "reduce tip bulbosity, prevent alar collapse, and permanently correct axial deviations."

Soft Tissue Envelope and Scar Contraction

In rhinoplasty, one does not only work with cartilage; the "soft tissue envelope" is a critical part of the equation. Daniel (1992) emphasizes that in thick-skinned patients, micro-asymmetries in the cartilages may be masked by the skin, but in thin-skinned patients, even the slightest axial deviation will come to light.

Scar contraction (shrinkage of the wound), which begins around the 6th postoperative month, is a dynamic force that exacerbates asymmetries. If the cartilaginous framework is not strong enough, contraction forces bend the tip at its weakest point. This is the most common late-term cause of the "straight bridge but crooked tip" scenario. Foreseeing this process, the surgeon may need to perform "over-correction" on the asymmetric side or "armor" that area with extra support (onlay grafts or struts).

Nasal tip asymmetries and their relationship with the axis are a matter of dynamic balance rather than a static image. Interventions performed without providing the fundamental support of the caudal septum, breaking the cartilage memory (Fry's principle), and establishing the force balance between the legs of the tripod are destined to recur. Toriumi's structural approach and Daniel's aesthetic analyses teach the surgeon not just to "fix the curve," but to "build an architecture that ensures the maintenance of straightness." Success in the relationship between the tip and the axis is directly related to how well the surgeon manages cartilage biomechanics and the vectorial forces during the healing process.

Camouflage Techniques: Grafting and Soft Tissue Adaptation

In rhinoplasty, mechanical correction and structural stabilization form the skeleton of the operation; however, the element that determines the final aesthetic outcome is the soft tissue envelope covering this skeleton and its interaction with the underlying structure. In complex cases, no matter how perfectly the cartilaginous and bony structures are aligned, asymmetric skin thickness, cicatricial (scar) tissues, or cartilage irregularities can distort light reflections, causing the nose to appear crooked. As Rollin Daniel (1992) emphasized in his classic work, rhinoplasty is not just a surgical procedure but also an art of "light and shadow management."

Light Reflexes and the Illusion of Straightness

For a nose to be perceived as "straight," the pair of light reflections passing over the nasal bridge (dorsal aesthetic lines) must extend continuously and symmetrically from the inner edge of the eyebrows to the tip defining points. Daniel (1992) stated that the key to success in rhinoplasty lies in the manipulation of these lines.

In complex crooked noses, even if the infrastructure is corrected, microscopic depressions under the skin cause shadowing. These shadows are interpreted by the human brain as "curvature" or "depression." The primary goal of camouflage techniques is to fill these shadow areas with strategic grafts to ensure uniform light reflection and create an illusion of symmetry.

Soft Tissue Adaptation and Skin Type

Soft tissue adaptation is a double-edged sword depending on the patient's skin type:

- Thin Skin: Reflects even the smallest cartilage irregularity to the surface like a "fault." In thin-skinned patients, camouflage is not a luxury but a necessity for the success of the operation. Sheen

(1987) advocated that graft edges must be beveled to prevent their visibility.

- Thick Skin: Can assist the illusion of symmetry by masking underlying corrections, but it is a source of asymmetry in its own right. In thick-skinned patients, soft tissue adaptation may require aggressive supratip sutures or subcutaneous excisions to ensure the skin "sets" onto the new skeleton (dead space management) (Daniel, 1992).

Crushed Cartilage: Biological Putty

Crushed cartilage is one of the oldest and most effective camouflage materials in rhinoplasty. Eliminating the biomechanical memory of the cartilage with a masher or hammer turns it into a kind of "biological putty."

- Application Areas: Dorsal irregularities, stepping at the junction of the upper lateral cartilage and bone (keystone area), and transition lines between the tip and supratip.
- Interaction with Fry’s Principles: As Fry (1966) noted, when cartilage is crushed, it loses its internal tensions. This prevents the cartilage from warping in the area where it is placed. However, Daniel (1992) warns that excessive crushing (turning it into a paste) can lead to chondrocyte death and unpredictable resorption (melting) in the long term. The ideal is to increase flexibility while preserving the integrity of the cartilage.

Onlay Grafts and Shield/Cap Grafts

Onlay grafts are grafts placed freely over the cartilaginous or bony structure to directly address volumetric deficiencies rather than providing structural support.

- Camouflage Role of Spreader Grafts: While primarily structural, spreader grafts can sometimes be used unilaterally or with asymmetric thickness for "camouflage" purposes to erase asymmetric shadows in the mid-vault (Gunter & Rohrich, 1997).

- Shield and Cap Grafts: Used to increase nasal tip projection while also highlighting light reflexes in the tip region. Toriumi (2006) suggests "sheathing" shield grafts with crushed cartilage or perichondrium to ensure their edges are not visible through the soft tissue.

Diced Cartilage in Fascia (DCF)

In complex revision cases and severe dorsal irregularities, the combination of diced cartilage with fascia (DCF) has created a revolution in the art of camouflage. This technique is a modification by Daniel (2003) of the "Turkish Delight" technique, popularized especially by the Turkish surgeon Onur Erol (2000).

Technique: Cartilage is diced into 0.5–1.0 mm cubes and usually wrapped in temporal fascia to form a "sausage."

Advantages:

- Perfect Fit: The cartilage pieces confined within the fascia adapt perfectly to the natural slope of the nasal bridge.
- Zero Edge Visibility: Unlike solid cartilage blocks, the edges of DCF are soft and do not reveal the graft's presence even in thin-skinned patients.
- Vascularization: Daniel (2003) argued that the fascia provides a nutritional bed for the cartilage pieces, resulting in a lower resorption rate compared to solid grafts.

Fascial Enveloping and Dermal Strategies

Not only cartilage, but soft tissue grafts alone (temporal fascia, perichondrium, or allogenic dermis) also play a critical role in camouflage.

- SMAS Management: Preserving the nasal SMAS layer during surgery and performing dissection in the sub-perichondrial plane ensures the preservation of natural camouflage.
- Fascial Onlay: A layer of temporal fascia draped over the entire cartilaginous skeleton in thin-skinned patients acts as a "tissue transplant," thickening the skin and covering the flaws of the underlying skeleton like a blanket (Daniel, 1992). This is used as a

"dermal rescue" strategy, particularly in revision surgery where skin nutrition is compromised.

Camouflage techniques are not a "curtain" that hides mechanical flaws in rhinoplasty, but an adaptation process that allows structural correction to integrate with aesthetics. As Daniel emphasized, a surgeon's success is measured not by how much they straightened the skeleton, but by how symmetrical the light reflecting off that skeleton appears. This spectrum of techniques, ranging from onlay grafts to DCF and from crushed cartilage to fascial enveloping, provides the surgeon with maneuverability in complex cases. It should be remembered that while fighting against cartilage memory (Fry's principle) is vital, predicting how the soft tissue will adapt to this cartilage is equally essential.

Postoperative Recurrence: Cartilage Memory and the "Recoil" Phenomenon

The paradox of rhinoplasty surgery is that the static success achieved at the end of the operation can dissolve over time when faced with biological processes and tissue biomechanics. Many cases exhibit a perfect axis and symmetry in the early postoperative period (1–3 months), yet show a tendency to return to their initial curvature or asymmetry by the 12th month. In literature, this points to the "recoil" phenomenon and the "molecular memory" of the cartilage.

Fry’s Principles and Interlocking Stresses

The fundamental reference point for understanding cartilage memory is the experimental work published by H.J. Fry in 1966 and 1967. Fry proved that septal cartilage is not just a homogeneous mass but contains an internal balance of tension (interlocking stresses).

- Internal Tension Balance: Mucopolysaccharides and collagen fibers within the cartilage matrix are under tension in the outer layers (near the perichondrium). When this tension is equal on both surfaces, the cartilage remains straight.
- The Breakdown of Balance (Warping): Fry (1966) demonstrated that if the superficial layer on one side of the cartilage is cut or

damaged, the intact tension on the opposite side prevails, forcing the cartilage to bend. This "warping" occurs away from the damaged side.

In surgical practice, this reveals that simply bringing a crooked septum to the midline is insufficient; these asymmetric stresses within the cartilage must be mechanically released through scoring/etching techniques (Fry, 1966).

Recoil and Tissue Memory

"Recoil" stems not only from the cartilage's own memory but also from the vectorial forces exerted by the surrounding soft tissues and the scar tissue formed during the healing process.

- Tissue Memory: If the nasal skin and soft tissue envelope have been stretched over a crooked skeleton for years, the tissue seeks to return to its "old mold" even after the skeleton is corrected.
- Contraction Forces: Scar tissue, formed by fibroblast activity during healing, shrinks over time. Daniel (1992) states that this shrinkage occurs along the "path of least resistance." If the surgeon has not supported the skeleton strongly enough, scar contraction bends the cartilages and pulls the nose back to its old axis.

Consequently, success in complex crooked noses lies not just in correction, but in creating a "counter-force" capable of resisting healing forces (Toriumi, 2006).

Strategies Against Recurrence: Weakening vs. Splinting

To prevent recurrence, surgeons have historically developed two main approaches: weakening the cartilage or imprisoning it.

- Scoring and Morselization: Based on the "conjoint cartilage" principles defined by Gibson and Davis (1958), non-full-thickness incisions (scoring) made on the convex side of the cartilage release the tension on that side. However, this technique is risky; excessively scored cartilage may lose stability over time, leading to a "saddle nose" deformity.

- Spreader Grafts and the Sandwich Technique: One of the most reliable methods for combatting recurrence is to "sandwich" the crooked septal cartilage between two straight and rigid cartilage grafts (spreader grafts). Gunter and Rohrich (1997) emphasized that this technique physically blocks cartilage memory and permanently stabilizes the axis of the mid-vault.

Over-correction and Internal Splinting

In complex cases, "over-correction" is a strategic maneuver used to defeat cartilage memory.

- Vectorial Compensation: If the nasal tip is deviated to the left, the surgeon fixes the tip with sutures or grafts in a slight hyper-correction to the right (slightly beyond the midline). This leaves a margin of tolerance to neutralize the "recoil" effect in the postoperative period.
- Internal Splinting: Byrd and Hobar (1993) noted the importance of internal silicone splints and suturing techniques to keep the cartilage fixed in its new position during the first 10–14 days, when cartilage memory is most active.

Revision Surgery and "Fibrotic Memory"

The risk of recurrence in revision surgery is much higher than in primary cases due to the addition of "fibrotic memory" to cartilage memory. Scar tissue from previous surgeries impairs blood circulation, preventing the nutrition of grafts and leading to asymmetric shrinkage. Toriumi (2006) suggests using more resistant costal (rib) cartilage instead of septal cartilage in revision cases and "armoring" the structural support (L-strut) with substantial grafts.

Postoperative recurrence is a result of the biomechanical laws of cartilage rather than mere technical failure by the surgeon. The internal stresses defined by Fry (1966) and the scar contraction emphasized by Daniel (1992) are the "invisible rivals" of rhinoplasty. The key to fighting recurrence is not just breaking cartilage memory by scoring, but permanently suppressing this memory with structural elements such as spreader grafts, lateral crural strut grafts, and septal extension grafts. A successful surgeon focuses not on the image on the operating table, but on the biomechanical balance one year later.

Conclusion

In rhinoplasty, the "outcome" is measured not by the final symmetry achieved by the surgeon on the operating table, but by the axial accuracy the patient sees in the mirror during the first year of healing (and beyond). The techniques and philosophical approaches detailed throughout this text have demonstrated that success in crooked nose surgery is possible not by dominating the tissue, but by understanding its nature and physical limitations.

The most critical element for the surgeon to keep in mind is the concept of "structural stabilization and long-term resistance." The "extracorporeal approaches" and "asymmetric osteotomies" we have examined are the surgeon's most powerful weapons against the recoil forces generated by cartilage memory. However, the dynamic relationship between even a mechanically perfectly constructed skeleton and the soft tissue envelope and scar contraction will continue to be the ultimate determinant of the result.

Camouflage techniques represent the point where surgical perfectionism meets "realism." The fact that light and shadow management can sometimes completely eliminate a microscopic asymmetry represents the artistic side of modern rhinoplasty. On the other hand, the section on revision strategies should be a source of humility for every surgeon; we must not forget that lessons learned from failures are the brightest lanterns illuminating the path to success.

This study is built upon the reality that the septal approach is the foundation, the dorsal vault reconstruction is the skeleton, and soft tissue management is the aesthetic veil. In this context, the most valuable gain to be achieved is for the uncertainty felt in the face of a complex case to be replaced by a strategic plan to be implemented step-by-step.

In conclusion, a surgeon who breaks the cartilage memory, repositions bony asymmetries according to the facial axis, and utilizes the adaptive power of soft tissue can create results that withstand the effects of time and biology. It should be remembered that rhinoplasty is an art where the surgeon's analytical intelligence and aesthetic vision merge at the same scalpel tip.

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Management of Prominent Ear Deformity: Surgical and Non-Surgical Approaches

Ergin Bilgin

Introduction

Facial aesthetics represent one of the most critical components of an individual's interaction with the outside world. Situated on the lateral projection of the face, the ears play a silent yet decisive role in balancing this aesthetic integrity. The human ear contributes to facial symmetry not only through its function of collecting sound waves but also through its proportion and angulation relative to cranial morphology. Prominent ear deformity is characterized by an excessive protrusion of the auricle from the mastoid bone and the underdevelopment of its anatomical folds. Although this phenomenon is considered an anatomical variation rather than a medical pathology, it has become a focal point of aesthetic surgery and anaplastology due to its profound psychosocial implications (Siegert et al., 1994).

From an anthropological and anatomical perspective, a standard ear structure maintains an auriculo-cephalic angle of approximately 20° to 30° with the skull base. The distance between the helical rim and the mastoid bone typically ranges from 15 to 20 mm (Schendel, 1995). In prominent ear deformity, these parameters deviate significantly. The aesthetic definition generally relies on two primary morphological deficiencies: first, the failure of the antihelical fold to form completely, and second, the excessive depth or width of the concha (Yang et al., 2015). When these two factors combine, the ear projects excessively outward from the sides of the head, disrupting the overall facial balance. Ideally, an aesthetic ear is inconspicuous, symmetric, and harmonious with facial features; however, in cases of prominence, the auricle becomes the dominant element of the face (Jonas & Janis, 2015).

The origins of prominent ear formation extend back to embryological development. The auricle begins to take shape starting from the sixth week of intrauterine life through the fusion of the first and second branchial arches. Any interruption during this process leads to deformations in the cartilaginous framework. Genetic factors are the most common cause of this deformity; studies indicate that approximately 60% of individuals with prominent ears have a family history, suggesting an autosomal dominant inheritance pattern (Gantous et al., 2018).

At the anatomical level, the primary factors causing the deformity are the stiffness and moldability of the fibrocartilaginous tissue. The absence of the antihelical fold may stem from localized weaknesses in the cartilage or differences in calcification (Thorne, 2013). In some instances, the attachment angle of the conchal cartilage to the skull base or volumetric excess of the concha causes the ear to be pushed forward. These congenital developmental variations may be noticeable immediately after birth or become more pronounced during the growth years (Vella, 2024).

The impact of prominent ear deformity on the individual extends far beyond physical appearance, reaching deep psychological layers. Childhood, in particular, is the phase where the social consequences of this deformity are most devastating. During school years, when children are most vulnerable to peer bullying, they face the risk of ridicule due to their ear shape. This can undermine a child's self-esteem, leading to social isolation, academic underachievement, and even depressive symptoms (MacGreggor, 1951).

In adolescents and adults, the condition may manifest as body image distortion or social phobia. Individuals may constantly alter their hairstyles or avoid specific social settings to conceal their ears, which they perceive as a defect. At this juncture, modern surgery and anaplastology offer more than just a physical correction; they initiate a process of psychological rehabilitation that reconstructs the individual's social life. Indeed, significant improvements in quality of life, self-esteem scores, and social engagement are observed following otoplasty or digital prosthetic solutions (Sadhra et al., 2017).

Ultimately, prominent ear deformity is not merely an anatomical deviation but a multidimensional phenomenon that shapes an individual’s quality of life and social identity. Thanks to digital workflows and advanced surgical techniques, the management of this deformity is now achieved with high success rates in both aesthetic and functional terms.

The core objective of this study is to bridge the gap between theoretical anatomical knowledge and the practical realities of managing prominent ear deformities. While the condition is frequently categorized as a minor aesthetic concern, its impact on a patient's psychological development necessitates a more nuanced, clinical approach. This study aims to provide a comprehensive roadmap that navigates the transition from early neonatal prevention to sophisticated adult surgical reconstruction. By synthesizing traditional gold standards with modern innovations, the research seeks to offer a balanced perspective on how to achieve long-term morphological stability and patient satisfaction.

The structural flow of this paper is designed to mirror the clinical decision-making process. It initiates with an in depth exploration of auricular anatomy, identifying the specific cartilaginous deviations that characterize the deformity. Following this foundation, the discourse shifts to diagnostic protocols and clinical evaluation, where the emphasis is placed on precise measurement and the identification of patient expectations. A central focus of the study is the surgical methodology section; here, rather than merely listing techniques, the study provides a detailed, step by step breakdown of a representative operative procedure. This granular analysis aims to demystify intraoperative maneuvers and highlight the critical role of structural re-engineering in otoplasty.

Recognizing that the future of the field lies in less invasive interventions, the scope further extends to non-surgical management. This includes an evaluation of neonatal ear molding, a window of opportunity often missed in clinical practice. The final chapters of the research delve into future perspectives, considering the potential integration of digital modeling and bio-regenerative materials. Ultimately, this study is not just a technical review but a call for a more holistic treatment philosophy one that treats the ear as both a biological structure and a cornerstone of an individual's social identity.

Anatomy of Prominent Ear Deformity

The auricle possesses one of the most complex three-dimensional architectural structures in the craniofacial region. Its aesthetic and functional integrity relies on a thin, flexible, and convoluted fibrocartilaginous skeleton tightly enveloped by skin. To accurately analyze prominent ear deformity, one must first examine the auricular morphometry considered within normal limits and the cartilaginous units that constitute this morphology.

A standard ear structure is positioned with its vertical axis tilted posteriorly by approximately 15° to 20°. The superior margin of the auricle aligns with the level of the eyebrow, while the inferior margin is parallel to the nasal tip. Anatomically, the ear consists of several key components: the helix, antihelix, concha, tragus, antitragus, and lobule (Alisson, 1990).

In prominent ear deformity, the geometric relationship between these units is disrupted. The most prevalent anatomical deviation is the underdevelopment of the antihelical fold. The antihelix, which normally resembles a Y-shaped fork, serves as the primary mechanism that folds the upper portion of the ear toward the head (Yang et al., 2015). When this fold fails to form or becomes effaced, the helical rim extends outward, resulting in the characteristic prominent appearance.

The elastic cartilage, the cornerstone of the auricular skeleton, is resistant to deformation yet flexible due to its high concentration of elastin fibers. In individuals with prominent ear deformity, two primary variations in the cartilaginous tissue are observed:

- *Conchal Hypertrophy:* In some cases, even if the antihelical fold is normal, the conchal cartilage is significantly deeper or wider than average. This condition causes a mechanical displacement of the entire auricle away from the mastoid bone (Thorne, 2013).
- *Cartilage Flexibility and Memory:* Disruptions in the folding process of the cartilage during the embryological period force the tissue's "shape memory" to remain in a flat configuration. One of the greatest challenges in surgical intervention is overcoming this

cartilage memory to create a new and permanent fold (Lanz & Wood, 2005).

The deformity is not always confined to a single region. A combination of antihelical flattening in the superior pole, conchal hypertrophy in the middle pole, and a protruding lobule in the inferior pole may coexist (Benkler et al., 2023).

The most objective criteria in diagnosing prominent ear deformity are the angular values between the mastoid bone and the auricle. In clinical literature, this relationship is defined by two primary angles (Porter & Tan, 2005):

- *Auriculo-cephalic Angle:* The angle between the outer rim of the ear and the skull. In the normal population, this value ranges from 25° to 35°. In prominent ear deformity, this angle frequently exceeds 40° to 45°.
- *Concho-cephalic Angle:* The angle between the conchal cartilage and the mastoid surface. An increase in this angle directly enhances the lateral projection of the ear.

The deviation of the cartilaginous angle from the norm is not merely a visual concern; it can also lead to physical vulnerability. An ear with increased projection becomes more susceptible to external trauma (Lanz & Wood, 2005).

Furthermore, the cartilage structure undergoes significant biomechanical changes with age. In children, the cartilaginous tissue is softer and more amenable to manipulation, partly due to the influence of maternal estrogen. While this facilitates successful outcomes using suture-only techniques in pediatric otoplasty, the increased stiffness and calcification of cartilage in adults may necessitate the use of cartilage-weakening techniques (Songu & Adibelli, 2010).

A schematic representation of normal and prominent ear anatomy is provided in Figure 1.

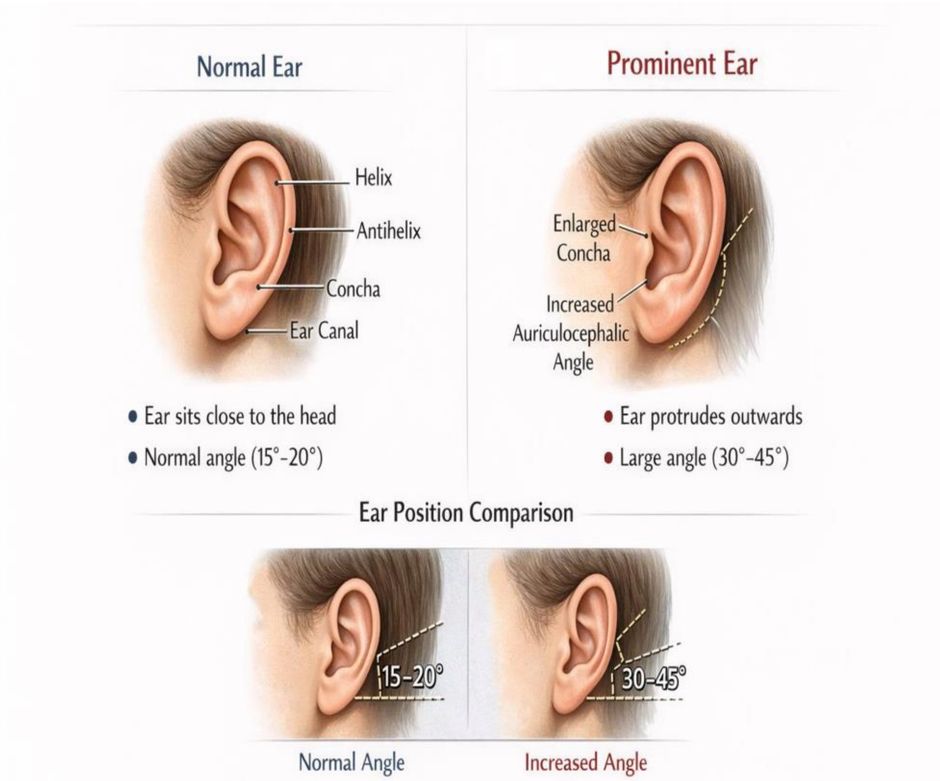

Figure 1. Normal Ear / Prominent Ear Deformity

Diagnosis and Clinical Evaluation

The management of prominent ear deformity is not merely a visual adjustment; it is a quest for symmetry that aligns with the overall proportions of the face. The first step toward a successful treatment process is a meticulous clinical evaluation that accurately identifies the anatomical components of the deformity and bridges the gap between patient expectations and medical reality. The diagnostic process relies on a multi-layered protocol consisting of physical examination, standardized photographic records, and anthropometric measurements (Ordon et al., 2019).

Clinical evaluation begins with the patient seated upright in a natural posture, with the head aligned such that the superior ear canal and the infraorbital rim are on the same level (the Frankfurt Horizontal Plane). The surgeon must manually examine all components of the auricle (Sommer & Mendelsohn, 2004).

The response of the cartilage to manual manipulation is a decisive factor in selecting the surgical technique. When the ear is pushed posteriorly with the finger, the ease with which the antihelical fold forms is assessed. If the cartilage is excessively stiff and resilient, it is anticipated that suture techniques alone may be insufficient and that cartilage-weakening techniques will be required (Songu & Adibelli, 2010).

Furthermore, the extent to which the deformity stems from an absent antihelix versus conchal depth must be differentiated. This distinction determines whether the sutures should be anchored to the mastoid bone or placed within the cartilage itself (Kelley et al., 2003).

To move beyond subjective observations in diagnosis, specific millimetric references are employed. These measurements are critical for establishing the preoperative baseline and documenting postoperative success (Kim et al., 2021). The distance between the helical rim and the skull (Helix-Mastoid Distance) is measured at three points. Measurements exceeding 10-12 mm at the superior pole, 16-20 mm at the midpoint, and 20-22 mm at the inferior pole support a diagnosis of prominence. Angles exceeding 30° are considered pathological and may constitute an indication for surgical correction (Kemaloğlu et al., 2016).

For standardization in academic and clinical records, photographs of the patient should be taken from six fundamental angles. The posterior view is particularly valuable for visualizing the width of the concha-mastoid angle and planning the incision. Photographic analysis is indispensable for helping the patient recognize existing asymmetries and for objectively comparing postoperative results (Becker et al., 2006).

The diagnostic process should not be limited to physical data alone. Especially in pediatric patients, the question of whether the decision for surgery stems from the family's desire or the child's own will is of vital importance. The social difficulties experienced by the child due to this deformity can be evaluated using standardized quality-of-life scales (Papadopoulos et al., 2015). In adult patients, identifying the source of motivation and ensuring the realism of postoperative expectations are key to postoperative satisfaction (Sclafani & Mashkevich, 2006).

Surgical Techniques

The surgical correction of prominent ear deformity (otoplasty) is predicated on the principles of reshaping the auricular cartilage and narrowing its angle relative to the cranial base. Although dozens of different modifications have been described in the literature, the cornerstones of modern otoplasty consist of the suture techniques developed by Mustarde and Furnas. These two approaches offer biomechanical solutions to the two primary components of the deformity: the absence of the antihelix and conchal hypertrophy (Horlock et al., 2001).

The Mustarde Technique

The Mustarde technique is considered the pioneer of "cartilage-sparing" approaches in otoplasty literature. Introduced to the medical world by Jack Mustarde in 1963, this method shifted the surgical philosophy toward reshaping through sutures without disrupting cartilaginous integrity a departure from the aggressive excision-based techniques prevalent at the time. The primary objective of the Mustarde technique is to address the insufficiency of the antihelical fold, which is the most common cause of prominent ear deformity. The technique is based on creating a natural-looking fold by bending the cartilage through the tension generated by permanent mattress sutures placed on the posterior surface (Mustarde, 1963).

The operation commences with an elliptical or hourglass-shaped skin incision made behind the ear. The surgeon meticulously dissects the subcutaneous tissues to preserve the perichondrium layer over the cartilage. During this stage, injecting solutions containing local anesthetics and epinephrine between the cartilage and skin helps control bleeding and define tissue planes, thereby minimizing trauma. The exact location of the intended fold is marked using guide needles passed from the anterior surface of the ear toward the posterior. These needles indicate the entry and exit points for the sutures on the posterior side. In Mustarde's original description, these points are strategically positioned between the scaphoid fossa and the concha (Mustarde, 1963).

The heart of the technique lies in the placement of horizontal mattress sutures. Typically, 3-0 or 4-0 non-absorbable transparent nylon or polypropylene sutures are preferred. Usually, 3 to 4 sutures are placed along the longitudinal axis of the ear. The superior-most suture shapes the projection of the upper pole, while the middle sutures define the body of the antihelix. The sutures must pass through the full thickness of the cartilage without piercing the anterior skin. If a suture only catches the perichondrium, it may loosen over time due to the resistance of cartilage memory, leading to recurrence (Bull & Mustarde, 1985).

In adult patients specifically, the cartilage may be thick and resilient. In such cases, sutures alone may not suffice to bend the cartilage, or the excessive load might cause the suture to cut through the cartilage a phenomenon known as the "cheese-cutter effect." The anterior scoring procedure, based on the Gibson principle, breaks the cartilaginous resistance through controlled superficial incisions on the anterior surface, facilitating a more natural fold under the tension of Mustarde sutures (Stewart & Lancerotto, 2018).

The stages of the Mustardé technique are shown schematically in Figure 2.

Figure 2. The Stages of Mustarde Technique

The Mustarde technique offers a natural aesthetic result as it avoids creating sharp, unnatural edges in the cartilage. However, it is not sufficient as a standalone procedure for patients with conchal hypertrophy. In these cases, it must be su pplemented with Furnas sutures to bring the ear closer to the cranial base (Adamson & Strecker, 1995). Additionally, technical limitations such as palpable sutures under the skin or late suture extrusion are occasionally encountered, particularly in patients with thin skin.

The Furnas Technique

The Furnas technique focuses on reducing the projection of the middle third of the ear. While the Mustarde technique involves intra-cartilaginous folding, the Furnas approach anchors the cartilage as a whole to the mastoid region of the skull (Furnas, 1968).

A significant component of prominent ear deformity is the excessive angulation of the conchal cartilage away from the mastoid bone. To narrow this angle, Furnas advocated for the creation of a permanent bridge between the cartilage on the posterior surface of the ear and the robust fibrous membrane covering the mastoid bone, known as the periosteum (Furnas, 1968).

Following the posterior auricular incision, the post-auricular muscles and fibrous connective tissue between the conchal cartilage and the mastoid bone are cleared. Evacuating this space provides the necessary mechanical room for the ear to set back. The surgeon passes permanent sutures (typically 4-0 nylon) through the full thickness of the conchal cartilage, including the perichondrium. The other end of the suture is anchored to the sturdy periosteal layer of the mastoid bone. The placement of these sutures dictates the degree of posterior setback. Usually, two or three sutures are placed; when tightened, the conchal bowl is "buried" toward the cranial base (Furnas, 1968). The stages of the Furnas technique are shown schematically in Figure 3.

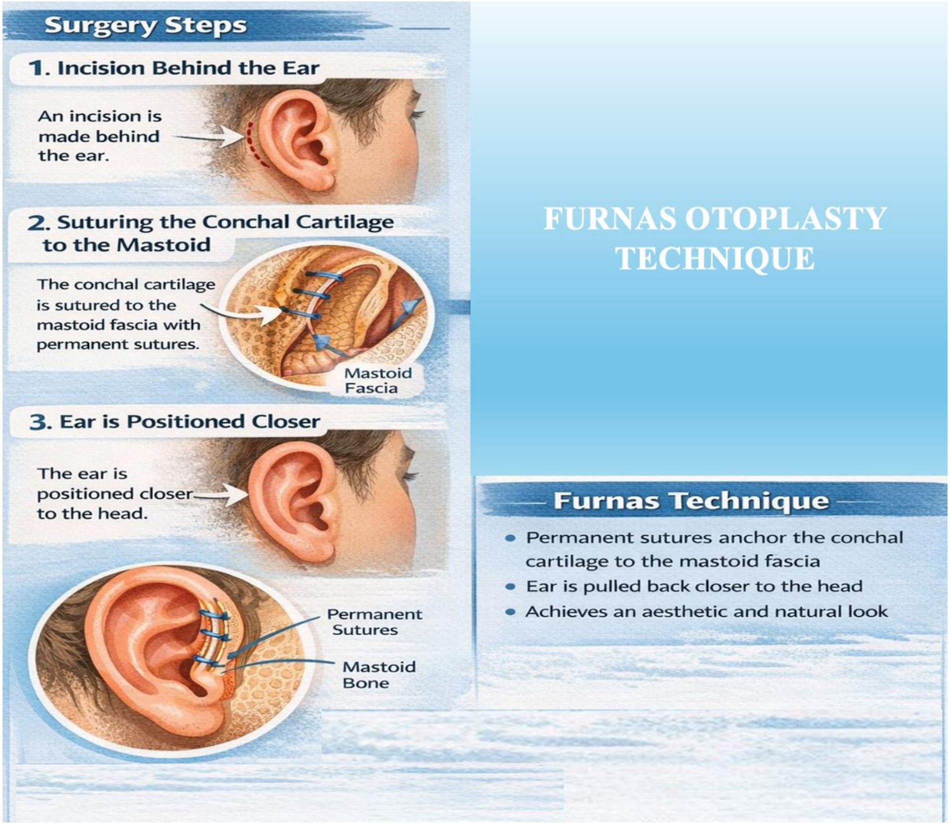

Figure 3. The Stages of Furnas Technique

In some cases, the concha is so enlarged that simply pulling it back with sutures may constrict the external auditory canal or cause buckling on the anterior surface of the ear. In such instances, a crescent-shaped piece of cartilage is excised from the conchal floor as an adjunct to the Furnas technique. This allows the ear to rest posteriorly without resistance (Thorne, 2013).

The most delicate aspect of the Furnas technique is the risk of over-tightening or incorrect suture angulation. If the sutures pull the ear too far forward, it can lead to a narrowing of the external auditory canal, known as iatrogenic stenosis. Consequently, the surgeon must continuously monitor the patency of the ear canal from the anterior view while tying the knots (Limandjaja et al., 2009).

In clinical practice, the Furnas technique is rarely performed in isolation. While Furnas sutures bring the middle and inferior portions of the ear closer to the cranial base, Mustarde sutures complete the natural fold of the superior pole. Combining these two techniques is the most reliable approach to prevent aesthetic errors such as the "telephone ear deformity," where the middle portion is overly recessed while the superior and inferior poles remain prominent (Deleito et al., 2014).

The Combined Approach

The simultaneous application of Mustarde and Furnas techniques in otoplasty is referred to as the combined approach. This methodology represents the most comprehensive surgical strategy to address the multidimensional nature of prominent ear deformity. In approximately 80% of clinical cases, the deformity arises from a combination of antihelical folding deficiency and conchal depth rather than a single anatomical flaw. The combined approach aims to correct these two issues within the same session in a way that balances one another.

The sequence of surgical steps is critical for maintaining final symmetry. Most surgeons adopt a "bottom-up" or "foundation-to-roof" principle. First, the conchal cartilage is sutured to the mastoid periosteum. This stage establishes the primary angle of the ear relative to the skull base; thus, Furnas sutures form the mechanical foundation (Furnas, 1968). Once the middle portion of the ear is repositioned, Mustarde sutures are placed to address the projection of the upper portion. These sutures create the antihelical fold, allowing the superior third of the ear to curve back naturally (Mustarde, 1963).

The primary aesthetic advantage of the combined approach is the prevention of the "telephone ear" complication. Relying solely on Furnas sutures can leave the ear looking overly flat in the center, whereas using only Mustarde sutures leaves the conchal prominence unaddressed. The coordinated use of both techniques ensures that the helical rim follows a smooth, soft curve parallel to the cranial base from top to bottom (Uysal et al., 2014).

In the combined approach, suture tension exists in a dynamic equilibrium. If Furnas sutures are over-tightened, the tissue mobility required for Mustarde sutures may be compromised. Therefore, surgeons often place all sutures first and tighten them incrementally while checking for symmetry from the anterior aspect before tying the final knots. For adult patients with strong cartilage memory, controlled anterior scoring along the antihelix prior to suturing allows for shaping with less tension. This hybrid approach minimizes the risk of recurrence while reducing the likelihood of sutures cutting through the cartilage (García-Purriños et al., 2019).

During the operation, the surgeon uses trial sutures to decide which technique should predominate. If the antihelical fold forms easily with light finger pressure, a Mustarde-heavy plan is preferred; however, if the entire ear projects as a single block, a Furnas-heavy strategy is chosen (Olgun & Dilber, 2022).

The stages of the combined technique are shown schematically in Figure 4.

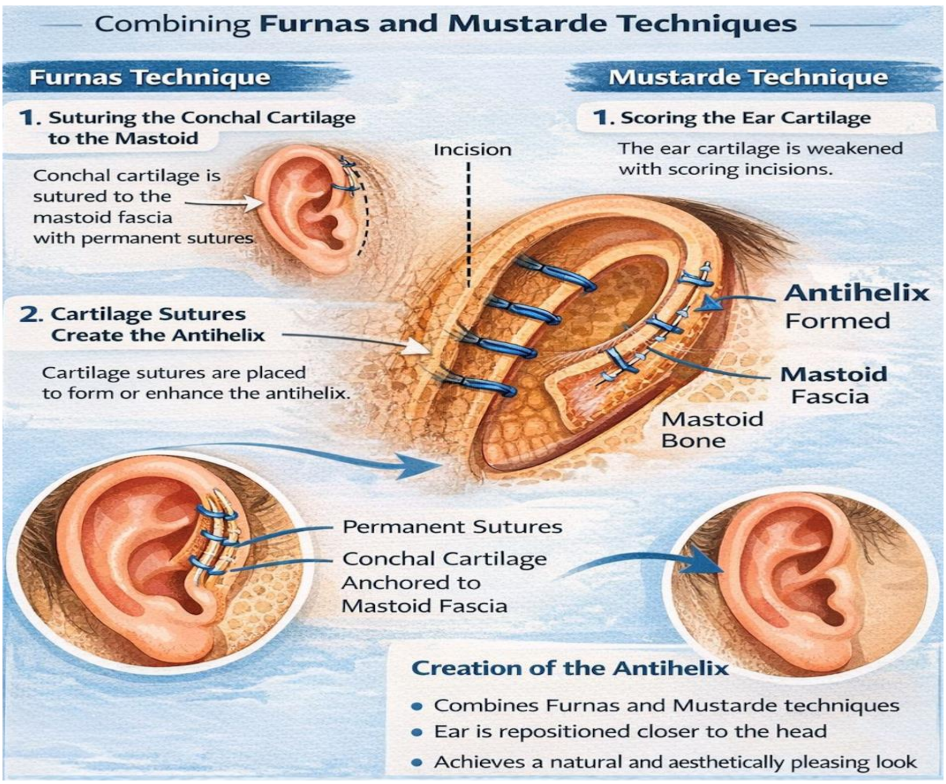

Figure 4. The Stages of Combined Technique

Post-Operative Care and Complication Management

The success of an otoplasty procedure depends as much on the quality of post-operative care and proactive management of complications as it does on the technical execution itself. Due to its thin skin envelope and relatively limited blood supply, auricular cartilage is highly susceptible to pressure sores and infections. Consequently, the post-surgical phase requires a rigorous follow-up protocol. The primary objectives following surgery are to preserve the newly established cartilaginous framework and to optimize tissue healing (Kotler et al., 1994).

Immediately following the operation, a bulky dressing is applied to support the ears and provide mild compression. This bandage prevents hematoma formation while shielding the ears from external trauma. The initial dressing is typically removed by the surgeon after 24–48 hours. Patients are advised to wear elastic headbands 24 hours a day for the first week, and only at night for the subsequent 4–6 weeks. The purpose of nocturnal use is to prevent the ear from inadvertently folding forward during sleep, which could rupture the Mustarde or Furnas sutures. Prophylactic antibiotics and analgesics are routinely prescribed. However, severe and unilateral pain is not considered a normal post-operative course and should be interpreted as a potential harbinger of a hematoma (Sclafani & Mashkevich, 2006).

Otoplasty complications are categorized into early and late-stage groups based on their timing of onset:

- *Early Complications:* Hematoma is the most critical early complication. Blood accumulating between the cartilage and the skin can impair the nutrition of the cartilage, leading to perichondritis or necrosis. In cases of severe pain, the bandage must be removed immediately, the hematoma drained, and the source of bleeding controlled. Although rare, chondritis (cartilage inflammation) can lead to permanent deformity, such as cauliflower ear. Aggressive antibiotic therapy against resistant bacteria, such as *Pseudomonas*, may be required. Skin necrosis typically occurs due to excessively tight bandaging or excessive trauma during cartilage weakening procedures.

- *Late Complications:* Recurrence the return of the deformity is the most common late complication. It occurs when the cartilage memory is not sufficiently broken or when sutures cut through the cartilaginous tissue. Recurrence rates in the literature are reported between 5% and 15%. Another common issue is suture spitting, where permanent sutures erode through the thin ear skin. This is generally resolved by removing the suture under local anesthesia; if tissue healing is complete, removal does not usually lead to recurrence. Aesthetic errors such as telephone ear or hidden helix result from faulty technical planning. Revision surgery is typically deferred until tissue edema has fully subsided, usually at least 6 to 12 months post-operatively. Furthermore, the risk of hypertrophic scarring or keloid formation along the posterior incision line is higher in dark-skinned individuals and is managed with steroid injections (Limandjaja et al., 2009).

The final outcome of otoplasty generally becomes definitive by the sixth month. In academic evaluations, success is assessed through millimetric measurements of whether the auriculo-cephalic angle has been maintained. Ultimately, the improvement in patients' psychosocial well-being remains the most significant subjective indicator of surgical success (Aliyeva et al., 2024).

A Clinical Case Study

The surgical correction of prominent ear deformity in the pediatric population necessitates a nuanced approach that addresses both the aesthetic projection and the cartilaginous structural integrity. In this clinical case, a seven-year-old patient presented with bilateral prominence characterized by a combination of conchal hypertrophy and a poorly defined antihelical fold. Prior to the intervention, comprehensive informed consent was obtained from the legal guardians, covering the procedural risks and the potential outcomes. Furthermore, explicit written authorization was secured for the utilization of clinical photography for academic dissemination, ensuring strict adherence to bioethical standards.

The surgical sequence commenced with a strategic fish-mouth elliptical incision marked on the posterior auricular surface. This specific excision pattern is designed not only to remove the redundant post-auricular skin but also to facilitate a tension-free closure that conceals the eventual scar within the cephaloconchal sulcus. By meticulously preserving the perichondrium during this initial phase, the vascularity of the underlying cartilage was maintained, which is a critical factor for preventing chondritis and ensuring long-term viability in pediatric tissues. The aforementioned stage is shown in Figure 5.

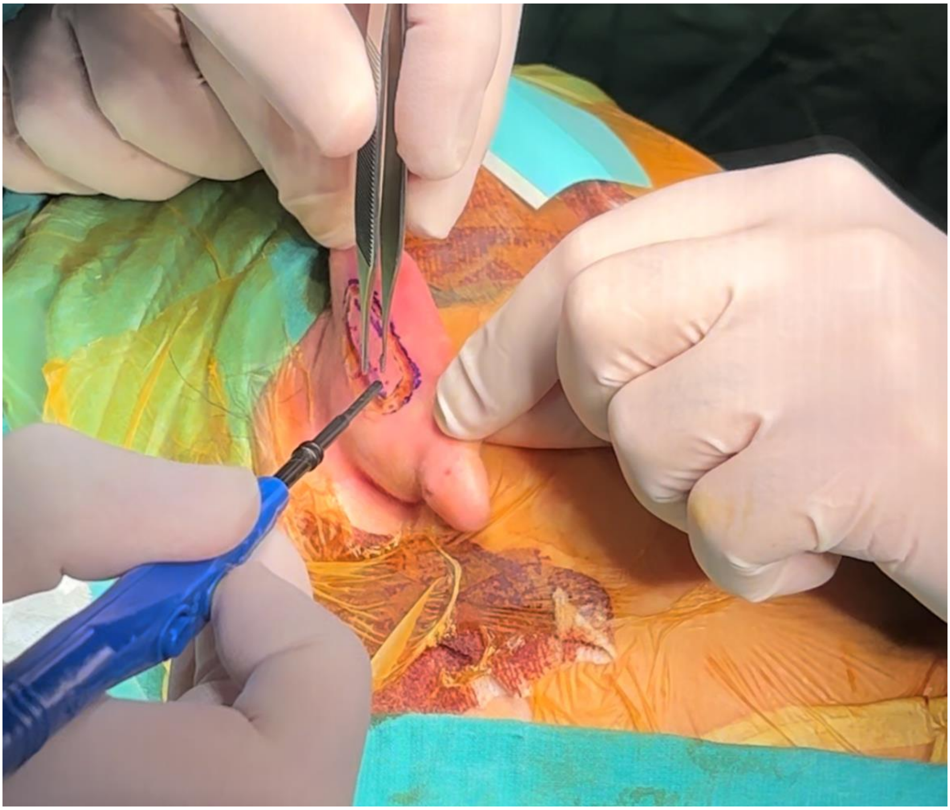

Figure 5. Preoperative Marking and the Fish-Mouth Elliptical Incision on the Posterior Auricular Surface

Once the posterior cartilaginous surface was exposed, the focus shifted to the precise definition of the antihelical fold. Using 4.0 silk sutures as percutaneous markers, the desired fold line was projected from the anterior skin to the posterior surface. This step is vital for ensuring symmetry, acting as a definitive guide for the placement of Mustardé sutures. In this specific sequence, the reconstruction began distally; horizontal mattress sutures (Mustardé) were placed first to create the antihelical curvature. By establishing the fold before addressing the conchal position, the surgeon can more accurately judge the remaining degree of prominence and ensure the helix remains visible from a frontal view. Percutaneous mapping of the antihelical fold using 4.0 silk sutures and subsequent placement of Mustardé sutures is shown in Figure 6.

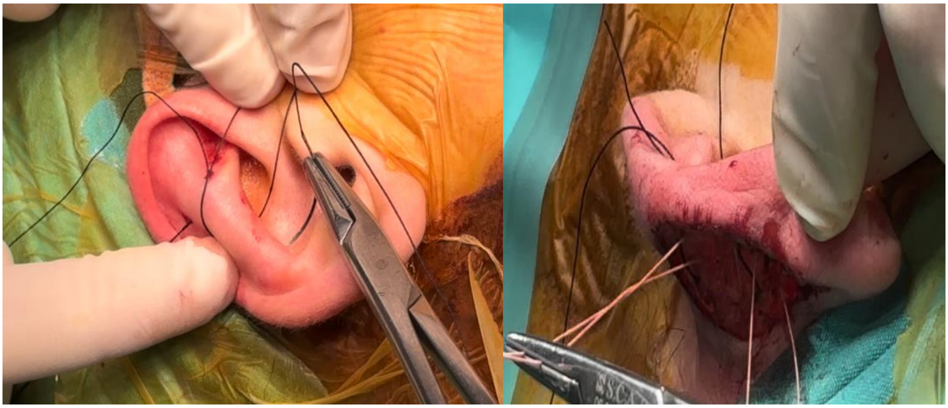

Figure 6. Percutaneous Mapping of the Antihelical Fold Utilizing 4.0 Silk Sutures and the Subsequent Placement of Mustardé Sutures

Following the successful creation of the antihelical fold, the secondary phase of structural stabilization was performed using Furnas-type sutures. These concha-mastoid sutures were anchored to the mastoid periosteum to rotate the entire auricular complex medially. By applying the Furnas sutures after the Mustardé sutures, the tension on the conchal bowl is titrated against a now-structured antihelix, preventing the telephone ear deformity and allowing for a more harmonious setback of the auricle. This sequential approach ensures that the ear's projection is reduced without over-compressing the newly formed antihelical anatomy. The application of Furnas concha-mastoid sutures is shown in Figure 7.

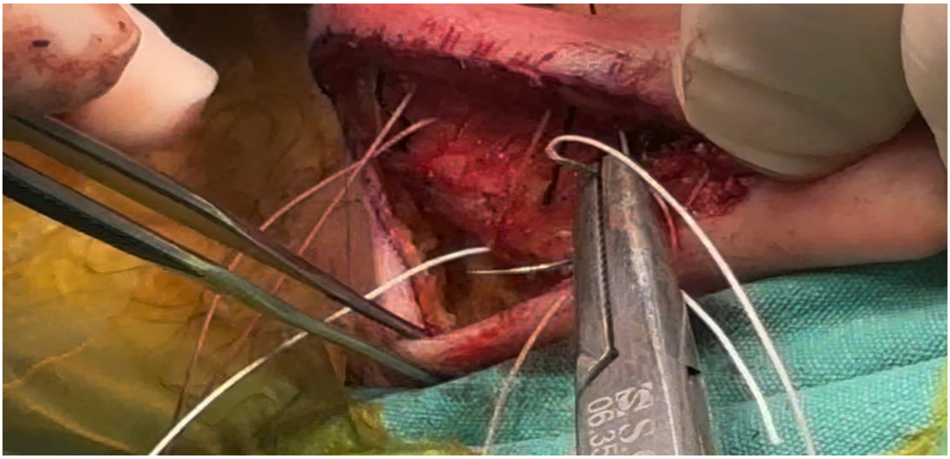

Figure 7. The Application of Furnas Concha-Mastoid Sutures

The final stage involved the meticulous adaptation of the soft tissue. For the skin closure, 5.0 Rapid Vicryl (irradiated polyglactin 910) was selected. The choice of a rapidly absorbable synthetic suture is particularly advantageous in pediatric otoplasty, as it eliminates the need for suture removal a process that can be distressing for young patients while minimizing the risk of suture-related granulomas. This material ensures adequate tensile strength during the initial healing phase before undergoing rapid hydrolysis. Skin closure with 5.0 Rapid Vicryl sutures is shown in Figure 8.

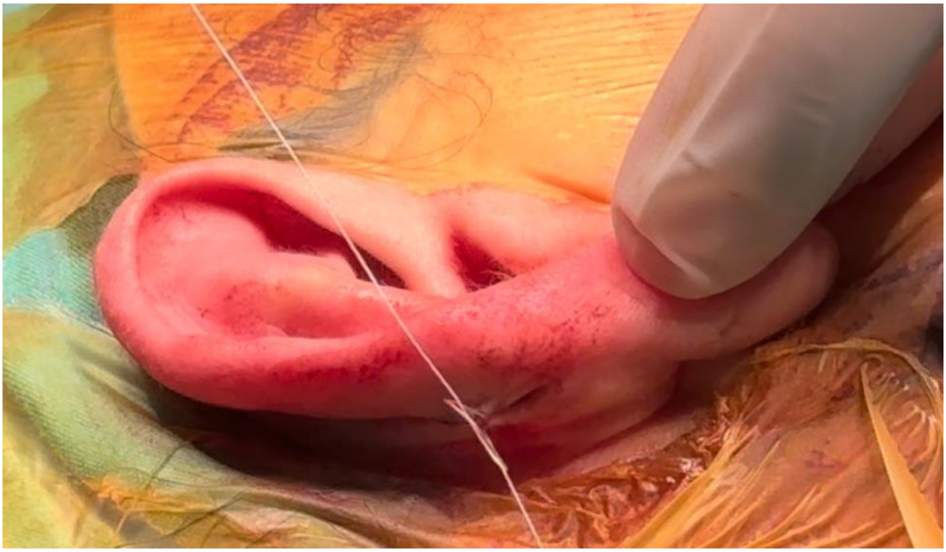

Figure 8. Skin Closure with 5.0 Rapid Vicryl Sutures

This case highlights that the systematic application of fish-mouth excision, silk-guided marking, and the combination of Furnas and Mustardé sutures provides a reliable framework for pediatric otoplasty. The methodology focuses on achieving a natural anatomical contour while prioritizing patient comfort and surgical longevity. The documented clinical photographs, for which all legal permissions have been obtained, demonstrate the effectiveness of this multi-layered reconstructive approach in Figure 9.

Figure 9. Preoperative and Postoperative Clinical Photographs

Non-Surgical Techniques

Although the management of prominent ear deformity has traditionally been synonymous with surgical intervention, modern medical technologies have brought non-surgical alternatives to the forefront. These approaches are primarily categorized into two groups: ear molding systems that exploit cartilage flexibility during the neonatal period, and minimally invasive/percutaneous methods aimed at achieving results comparable to surgery (Van Wijk et al., 2009).

In newborn infants, cartilaginous tissue is exceptionally soft and malleable due to elevated levels of circulating maternal estrogen. Molding therapy initiated within the first few weeks of life can impart a permanent and natural form to the cartilage without the need for surgical maneuvers (Schultz et al., 2017).

Maternal estrogen maximizes tissue flexibility by increasing the concentration of hyaluronic acid within the cartilage. After the first six weeks of life, estrogen levels decline, and the cartilage begins to stiffen as it acquires shape memory. Consequently, the success of molding techniques is directly time-dependent. These molding systems consist of an external framework that repositions the ear into an ideal anatomical orientation and internal molds that reconstruct the antihelical fold. Studies report complete success and permanence rates exceeding 90% in cases where treatment is initiated early. The primary advantages of these systems include the elimination of anesthesia, the removal of surgical risks, and the prevention of future psychosocial trauma (Feijen et al., 2020).

Developed as an alternative to traditional surgery and also known as minimally invasive otoplasty, the stitch otoplasty or incisionless otoplasty method aims to reshape the cartilage solely through needle punctures without skin incisions. Instead of making a formal cut, non-absorbable sutures are passed subcutaneously and through the cartilage using specialized guide needles to create Mustarde-like plications. This method is popular due to shortened recovery times and the lack of a requirement for hospitalization. However, because cartilage memory is not surgically weakened, long-term recurrence rates are significantly higher compared to traditional techniques. Furthermore, there is a risk of sutures becoming visible on the skin surface in patients with a thin dermal envelope (Mohammadi et al., 2016).

A relatively recent approach, the EarFold system, involves the subcutaneous placement of gold-plated nitinol clips through a minimal incision. Nitinol is a metal with a predetermined shape memory; once the clip is deployed, it automatically bends the cartilage to create an antihelical fold. While effective, this method is limited to cases characterized by antihelical deficiency; it does not provide an adequate solution for patients with concomitant conchal hypertrophy (Honeyman et al., 2020).

Laser technology, which is still largely in the experimental phase, is based on the principle of thermally heating the cartilage using laser energy to relax internal stress points. This aims to alter the shape memory of the cartilage, allowing for "sutureless" reshaping. However, due to challenges regarding tissue necrosis and precise temperature control, its widespread clinical utility remains restricted (Susaman & Karlıdağ, 2022).

Future Perspectives

The management of prominent ear deformity is witnessing a paradigm shift, transitioning from the mechanical principles of surgical techniques to a focus on biotechnology, regenerative medicine, and digitalization. While traditional otoplasty remains a suture-oriented craft built upon the foundations laid by Jack Mustardé and David Furnas, future perspectives redefine this process as molecular-level shaping and personalized biometric engineering. The most compelling focal point of this transformation is the ability to reprogram the biomechanical memory of cartilaginous tissue through cellular intervention. In the future, invasive procedures such as cartilage weakening may be replaced by biochemical agents or enzymatic injections that temporarily soften the tissue. Such an approach promises to relax intra-tissue stresses at a molecular level, making the cartilage more compliant with the tension created by sutures rather than physically incising the tissue with surgical instruments.

Digital planning and artificial intelligence (AI) integration have the potential to radically enhance the predictability of otoplasty. Symmetry analysis, which currently relies on the surgeon’s aesthetic judgment, is being superseded by 3D facial scanning technologies with millimetric precision. AI algorithms can compare a patient's craniofacial structure against thousands of normative datasets to automatically calculate the most anthropometrically ideal ear angle and projection for that specific individual. This is not merely a visualization tool; it could evolve into a navigation system that determines the exact coordinates for Mustardé suture placement during surgery. Furthermore, 3D printing technology enables the creation of 100% personalized, biocompatible templates to be placed on the cartilage intraoperatively, minimizing surgical margins of error and giving tangible form to the concept of personalized surgery (Witsberger et al., 2023).

Regenerative medicine and tissue engineering are poised to offer permanent solutions to recurrence and tissue loss—some of the most challenging aspects of otoplasty. In the future, particularly in cases of severe asymmetry or concomitant deformities like microtia, cartilage scaffolds produced via bioprinters using the patient's own stem cells will be utilized. These living scaffolds will not only provide structural correction but will also ensure full integration with the patient's biological tissue, effectively eliminating complications such as foreign body reactions or suture erosion. As the role of biomaterials and shape-memory polymers in surgery expands, permanent sutures used to secure the cartilage may be replaced by smart implants that are absorbed by the body once tissue healing is complete, having taught the cartilage its new form during the interim.

On the psychosocial dimension, virtual reality (VR) and augmented reality (AR) technologies will optimize the decision-making process by allowing patients to experience their post-operative appearance beforehand. This will reduce surgical anxiety, particularly in pediatric patients, while establishing a more transparent framework for expectation management. However, the ethical boundaries of this technological leap and the risk that the pursuit of the perfect ear might erase individual diversity will become broader areas of discussion in future medical literature. Ultimately, prominent ear management is evolving from a mechanical repair into a bio-aesthetic engineering discipline where biology and digital intelligence dance in perfect harmony. This evolution will fundamentally change not only the angle of the ears but the very nature of surgery itself.

Conclusion and Recommendations

The management of prominent ear deformity represents a meticulous process that extends beyond surgical intervention, bridging the patient's craniofacial morphology with a profound psychosocial equilibrium. As evidenced throughout this comprehensive review, a successful treatment strategy cannot be reduced solely to the millimetric narrowing of the auricular angle. True success is achievable only through a tailor-made planning approach, customized to each patient's cartilaginous elasticity, conchal depth, and antihelical structure. While modern otoplasty literature stands on the foundations laid by giants such as Mustardé and Furnas, it is clear that today these techniques should be utilized not as static formulas, but as a dynamic toolkit. The surgeon's greatest skill lies in sensing the tissue memory of the cartilage at the operating table and deciding where to rely on the strength of a suture and where to employ cartilage-weakening techniques.

From a clinical perspective, otoplasty is evolving from a mere shape-correction surgery into a discipline of tissue management. The most valuable takeaway from this evolution is the absolute superiority of cartilage-sparing approaches. The aggressive methods of the past, which involved excising cartilage and leaving behind sharp, unnatural edges, have now been superseded by techniques that respect tissue integrity. For a surgeon, the ultimate aesthetic goal is not just to bring the ears closer to the head, but to reconstruct an auricle that integrated seamlessly with the overall harmony of the face, bearing no surgical scars or signs of manipulation to the casual observer. In this context, the definition of the ideal ear rests upon an aesthetic balance that varies from individual to individual.

In terms of clinical practice, the most vital recommendation is that surgical success lies not only in the operating room but also in transparent communication with the patient and their family. Especially in interventions performed during childhood, the decision for surgery should be based not just on anatomical necessity, but on the child's well-being and self-esteem within their social environment. Proper timing, the right technique, and realistic expectations are the invisible pillars that determine the success of an otoplasty. Parents and patients must be clearly informed about the limitations of surgery, the importance of patience during the healing process, and the direct impact of post-operative diligence particularly regarding headband use and protection from trauma—on the permanence of the result.

On the threshold of a technological transformation, the integration of 3D modeling, augmented reality, and biocompatible materials into the world of otoplasty holds great promise for minimizing surgical margins of error. Our recommendation to surgeons is to view these digital tools not merely as accessories, but as essential adjuncts that enhance surgical predictability. Pre-operative digital simulations facilitate the patient's adaptation to their new appearance and allow the surgeon to analyze potential asymmetries beforehand. However, it must be remembered that no technology can replace the sensitivity of a surgeon's touch or their aesthetic judgment over the cartilage.

In conclusion, prominent ear surgery is a perfect synthesis of scientific technical precision and artistic aesthetic foresight. A surgeon's wealth of anatomical knowledge, mastery of cartilage biomechanics, and adaptation to innovative approaches will rebuild not only the patient's physical appearance but also their confidence and standing in social life. While non-surgical methods and tissue engineering will undoubtedly gain more ground in the future, the greatest guides for today's surgeon must remain respect for tissue, empathy for the patient, and aesthetic integrity. This roadmap transforms otoplasty from a mere technical procedure into a holistic rehabilitation process that elevates an individual's quality of life.

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The three chapters compiled in this book addressing the surgical management of crooked nose deformity, digital technologies in maxillofacial prosthetic rehabilitation, and the treatment of prominent ear deformity provide a holistic overview demonstrating that the facial region is not merely a morphological structure. Rather, it represents a dynamic intersection of functional, psychosocial, and technological dimensions. Although each text focuses on distinct anatomical structures, they converge on a common ground: the correction of form alone is insufficient for success. The true decisive plane is the reconstruction of a broad life-space, ranging from everyday functions like respiration and mastication to social visibility, eye contact, and self esteem.

In the section on the crooked nose, the nose is treated not just as a bone cartilage structure positioned on the midline, but as a dynamic organ that simultaneously determines facial symmetry, respiratory function, and the patient’s self perception. It is emphasized that deviations in the nasal axis are often intertwined with underlying hemifacial asymmetry; therefore, the pursuit of absolute symmetry remains a limited goal both biomechanically and aesthetically. Rather than a linear midline that appears ideal on paper, surgical planning must be conceptualized as a search for balance that accounts for the patient’s actual facial asymmetry and the memory of the tissues.

Similarly, the chapter on maxillofacial prosthetics demonstrates that defects following trauma, tumor resection, or congenital anomalies are complex conditions with lasting impacts on fundamental functions such as speech, chewing, swallowing, and social participation not just simple tissue loss. Here, the prosthesis is positioned not as an aesthetic mask filling a void, but as a biotechnological interface striving to restore the patient's functional capacity and psychosocial integrity. The emphasis on how rehabilitation facilitates early healing, shortens surgical and hospital stay durations, and accelerates the individual's return to social life reinforces this integrated perspective.

The otoplasty section frames prominent ear deformity as a condition associated with peer bullying, decreased self esteem, and social withdrawal starting from childhood. It shows that even minor changes in ear angulation and contour can profoundly affect a person's willingness to show themselves in society. Consequently, the objective of ear surgery is not merely to correct the helix concha angle, but to transform the relationship the patient maintains with both the mirror and their social environment. When read together, these three perspectives reveal that the ultimate metric for any intervention in the facial region be it septorhinoplasty, implant-supported facial prosthetics, or otoplasty is not millimetric angles or distances, but the patient's body image, social comfort, and long-term quality of life.

Perhaps the most significant commonality across these three chapters is the insistence that surgical or prosthetic interventions should be designed to harmonize with biomechanical limits rather than attempting to dominate the tissues. In the crooked nose chapter, it is clearly stated that cartilage memory and scar contractions can disrupt the nasal axis over time; thus, a flawless alignment on the operating table is not a reliable indicator of success in isolation. Principles such as structural stabilization, preservation of L-strut integrity, reconstruction of the dorsal skeleton, and performing osteotomies in harmony with facial asymmetry reflect an approach that prioritizes long-term equilibrium over short-term correction.

A similar principle of respect for tissue governs the section on otoplasty. Modern trends have moved away from aggressive cartilage resections, favoring cartilage sparing techniques rooted in weakening and reshaping the tissue instead. Achieving lasting and natural looking results is now understood to depend on evaluating the elastic properties of cartilage in tandem with suture placement and tension distribution. This approach requires anticipating how the ear's contour will be perceived under natural light from both frontal and lateral perspectives.

In the realm of maxillofacial prosthetics, biomechanical reality manifests across multiple layers ranging from implant angulation and prosthetic weight to hollow designs and soft tissue support. Digital planning and virtual surgical guides allow for the precise placement of implants to manage functional loads while maintaining an aesthetic finish line, particularly in regions with limited bone volume. However, the striking disparity in success rates between auricular and orbital implants, as noted in these studies, serves as a clear reminder: even the most sophisticated digital systems remain constrained by biological responses and patient maintenance habits. Consequently, every procedure described in this book converges on a single necessity: an approach that values technical mastery as much as it respects tissue boundaries and the long-term interaction between tissue, prosthesis, and scarring.

The second part of the book treats digital technologies not merely as technical add ons to speed up specific steps, but as a paradigm shift that reconfigures the entire cycle of diagnosis, planning, design, and production in maxillofacial rehabilitation. Tools such as Cone Beam Computed Tomography (CBCT), extraoral 3D facial scanners, and photogrammetry based systems enable the recording and integration of hard and soft tissue data within a single digital environment at high spatial resolution.

CAD/CAM based design environments allow for the virtual filling of defects, ensuring symmetry through mirror-imaging from the healthy side, and optimizing the prosthesis's center of gravity and internal voids with millimetric precision. Furthermore, 3D printing facilitates the standardization of lightweight, hollow, and functional forms that would be difficult to achieve manually in a traditional laboratory setting. Digital archiving also grants clinics strategic flexibility; in the event of a damaged or lost prosthesis, rapid reproduction is possible using the existing dataset, saving both time and cost.

This transformation extends beyond facial prostheses alone. In nasal prosthesis cases, digital workflows allow for more realistic reflections of skin texture and color while enabling designs that optimize nasal airflow. For auricular prostheses, the use of preoperative facial scans and hybrid datasets (CBCT + facial scanning) allows for volume analyses that reconstruct lip, cheek, and ear contours much closer to the patient’s preoperative profile.

In the otoplasty section, digitalization is identified as a groundbreaking potential for surgical planning and education rather than direct production. 3D modeling and virtual planning tools allow surgeons to simulate suture placement, cartilage weakening lines, and expected contour changes before the first incision. This not only sharpens the surgeon’s visual mechanical foresight but also fosters more transparent communication with the patient.

Nevertheless, all three sections candidly acknowledge that digitalization is not a boundless or universally accessible solution. The requirement for high-cost hardware, the need for advanced technical expertise, and infrastructural disparities limit the prevalence of digital workflows, particularly in low to middle income countries or rural areas. While low-cost optical data collection methods like photogrammetry hold the potential to partially bridge these gaps, further research is required to optimize their measurement precision and software integration.

When these three chapters are evaluated in unison, a common principle emerges that transcends technical tools: surgical and prosthetic decisions must rely neither solely on the surgeon’s intuition nor exclusively on digital outputs. The section on the crooked nose emphasizes that success should be measured not by a photograph taken on the operating table, but by a nasal axis that remains balanced years later and the patient's enduring satisfaction. The assertion that lessons learned from revision surgeries serve as the clearest guide for surgical decisions encapsulates the epistemological stance of this field.

In the maxillofacial prosthetics chapter, the multifaceted gains provided by digital workflows regarding clinical outcomes, patient satisfaction, and healthcare costs are detailed. However, a warning is issued: these gains may paint an overly optimistic picture unless they are integrated with an understanding of implant biology, regional anatomy, and patient maintenance habits. The text underscores the need for comparative, long-term, and methodologically rigorous studies to determine which patient groups, defect types, and economic conditions render digital methodologies the most rational choice.

A similar framework exists in the otoplasty section: the choice between neonatal ear molding and surgical otoplasty should be made based on the type of deformity, the child’s age, family expectations, and long-term psychosocial impacts, rather than mere technical availability. Here, objective metrics (such as ear to head angles and projection distances) and subjective indicators (patient and family satisfaction, peer relationships, and self-esteem) are treated as complementary dimensions that must be evaluated together.

Considered collectively, the three sections of this book illustrate that the fields of facial surgery and maxillofacial prosthetics are evolving from traditional crafts into disciplines rooted in engineering and biology. It is anticipated that digital workflows especially when combined with AI-supported design algorithms and a broader range of biocompatible or bioregenerative materials will elevate prostheses from being simple aesthetic covers to functional organ simulations. Similarly, low cost photogrammetry solutions and desktop 3D printers offer a promising democratization potential, allowing these advanced technologies to be implemented across wider geographies rather than remaining confined to elite centers.

On the other hand, as emphasized in the crooked nose and otoplasty chapters, regardless of the degree of digitalization, facial surgery remains fundamentally the art of managing the relationship between human tissue, light, shadow, and the observing eye. A minor optical correction on the nasal bridge or a subtle curve in the helical contour can produce a greater aesthetic impact than any millimetric measurement. Therefore, future clinical practice will likely require a hybrid expertise where bioengineering, digital design, and surgical intuition intersect.

In conclusion, through three distinct sections focusing on nasal, maxillofacial, and ear deformities, this book clarifies a fundamental message:

- Every intervention in the facial region must be conceived within the triangle of morphology, function, and psychosocial integrity.
- When utilized correctly, digital technologies are powerful tools that expand both diagnostic and therapeutic horizons; however, they cannot replace biological realities, socioeconomic constraints, or patient subjectivities.
- Long-term success depends less on a single perfect technique and more on the capacity to maintain a perspective that integrates respect for tissues, data driven planning, interdisciplinary collaboration, and patient centered ethics.

This afterword seeks to complement the multilayered information presented in the book’s three chapters with a framework for the future: the ultimate goal of facial surgery and maxillofacial rehabilitation is to write a story of resilient and meaningful reintegration one that is supported by technology but anchored in human experience.