

# Digital Applications of Maxillofacial Reconstruction – A systematic review

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## Abstract

**Objectives:** Many patients with maxillofacial defects require maxillofacial prosthetic rehabilitation due to cancer, trauma, or congenital diseases. Adequate surgical and prosthetic treatment planning is required to achieve satisfactory morphological and functional results. Before computer-aided design/computer-assisted manufacture (CAD/CAM) technology was introduced, conventional methods have been used to reconstruct the facial form, which involved making impressions, obtaining models and fabricating the prosthesis all of which is time consuming and requires multiple visits. A rapid progress has been made with advances in digital technology, such as milling systems, rapid prototyping, three-dimensional (3D) scanning and 3D printing, which has improved the patients' expectations, the functional and esthetic treatment outcomes.

**Materials and methods:** An electronic search was conducted in the Cochrane, PubMed (MEDLINE), and ScienceDirect databases between July 2000 and October

2020. A manual search was also performed to cover all digital aspects of the maxillofacial prosthesis. The inclusion criteria were randomized clinical trials, prospective or retrospective cohort, and cross-sectional studies performed on humans with at least 1 year of follow-up and published within the last 20 years.

**Results:** The results showed that the used technologies in a digital workflow of auricular, orbital and nasal prosthesis reduce the manufacturing time and allow the manufacture of high-quality prostheses for missing facial parts. The methodology provides a good position for further development issues and is usable for clinical practice.

**Conclusion:** Utilization of digital technologies in the facial prosthesis manufacturing process can be a good contribution for higher patient comfort and production efficiency but also comes with a higher initial investment and greater demands for experience with software tools.

**Keywords:** Maxillofacial Prosthesis, CAD/CAM, Rapid Prototype, Digital Workflow

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## Introduction

Many patients with maxillofacial defects require maxillofacial prosthetic rehabilitation due to cancer, trauma, or congenital diseases. [1] These defects often require adequate and high-quality surgical and prosthetic treatment planning to overcome the associated esthetic and psychological problems in order to achieve satisfactorily morphological and functional results. [2] Before computer-aided design / computer-assisted manufacture (CAD/CAM) technology was introduced, conventional methods have been used to reconstruct the facial form using extraoral prostheses, which involved making impressions, obtaining models that accurately represent the

defect, then fabricating and fitting the prosthesis; this is usually time consuming and requires multiple visits. [3] However, rapid progress has been made in maxillofacial prosthetics with advances in digital technology [4], such as milling systems, rapid prototyping, three-dimensional (3D) scanning, and 3D printing. Several studies have shown a dramatic increase in the reported usage of digital technologies in maxillofacial prosthetics. [5] The process of fabrication of the extraoral prosthesis using the digital workflow has four key elements: 1- data acquisition, 2- design, 3- manufacture, and 4- evaluation. [6,7]

Data acquisition can be accomplished using laser scanning, 3D photogrammetry, ultrasound

along with computed tomography (CT) and magnetic resonance imaging (MRI). [8] All of these methods have their advantages and disadvantages. [9] The data acquired by CT or MRI are initially processed into Data Imaging and Communication in Medicine (DICOM) format. Thereafter, it is then converted into Standard Tessellation Language (STL) format which allows it to become editable using CAD software. The STL model of the prosthesis can then be printed using 3D printing techniques such as Selective Laser Sintering (SLS) and fused deposition modeling (FDM). [75]

Facial morphology and analysis are integral parts of designing an extraoral prosthesis. [10] Two-dimensional (2D) photographic, Vernier caliper, and bevel protractor measurements are all conventional methods for facial analysis, which are used to measure 2D projection distances and angles. [11,12] However, recent dramatic evolution in optical scanning and designing technology has shifted the treatment modality from 2D to 3D approach [13-15]. Clinicians can use 3D facial scanning to record landmarks, capturing emotions for surgical planning and maxillofacial rehabilitation. [15,16]

One of the main applications of digital technology in maxillofacial prosthodontics is implant planning, in which the surgeon can visualize the desired extraoral implant locations preoperatively, then digitally design and fabricate a surgical guide using rapid prototyping (RP) technology. This improvement in technology has the benefit of providing an accurate implant position and avoiding the vital anatomical structure better than ever before. [17]

The purposes of this article are to systematically review and highlight the rapidly growing field of digital technology, and how it has specifically impacted the way clinicians and anaplastologists approach maxillofacial reconstruction. The focus within this review is on digital applications of nasal, auricular, and orbital prostheses, specifically on rapid prototyping (RP) and 3D technology. A breakdown of each digital workflow is discussed, with focusing on the software programs that were used to build each prostheses and the advantages and disadvantages of each system.

## Materials and Methods

An electronic search was conducted in the Cochrane, PubMed (MEDLINE), and ScienceDirect databases between July 2000 and March 2021. A manual search was also performed using key words (maxillofacial prosthesis, digital workflow, CAD/CAM, rapid prototyping and

facial scanner) to cover all possible digital aspects of the maxillofacial prosthesis and the related topics that were chosen. The inclusion criteria were randomized clinical trials, prospective or retrospective cohort studies, and cross-sectional studies performed on humans with at least 1 year of follow-up and published within the last 20 years. The researcher independently screened the title and abstract of every article, also analyzed the manuscripts in order to establish its eligibility. The literature search included only English-language articles in the field of dentistry and ones published in peer-reviewed dental journals. The exclusion criteria were studies based on surveys or expert opinions. The selected articles were classified into different levels of evidence by means of the Strength of Recommendation from the Taxonomy criteria. The characteristics collected from the studies in order to perform a qualitative analysis were based on the type of intervention, outcome (success, survival, and failure rates), assessment criteria, and follow-up time.

## Results

### *Study selection:*

The search yielded a total of 360 articles. The articles were screened by reading titles, and 279 were removed as unrelated and excluded, leaving 105 articles. These articles were further scrutinized by abstract reading and 77 were selected. Finally, after applying all inclusion and exclusion criteria, the authors were left with 39 articles focusing on clinical examination and treatment planning of different levels of digital applications pertaining to the orbital, auricular and nasal prosthesis. The review included original research, randomized controlled trials, and articles published from 2000 to 2021.

### *Assessment of study quality:*

Two reviewers independently and in duplicate evaluated the quality of the included studies as part of the data extraction process. Any disagreements were resolved by consensus or by consulting the last signing author of the present study.

### *Description of the studies*

21 cross-sectional study, 14 vitro pilot study, 13 retrospective, 4 prospective and 25 review studies were included in the systematic review.

## Discussion

### *Data acquisition*

Recently, with the advent of contemporary facial scanners has increased the use of facial morphology capture and optical scanning

technology which has raised images from 2D to 3D. [4, 18] A 3D facial scanner is the non-contact optical measurement tool that can obtain 3D facial models with skin texture and color in open data format; albeit with the scanning process usually short. Face scanners promise wide applications in medicine and dentistry, including facial recognition, capturing facial emotions, facial cosmetic planning and surgery, and maxillofacial rehabilitation. [10]

Higher accuracy of the scanner improves the quality of the data recorded, which ultimately benefits the outcome. Facial scanner has a nominal accuracy that is obtained by measuring standard geometric entities at the factory [10]; However, because the scanned object (a real person's face) has a more complicated shape and texture than a standard model, several recent investigations have found differences between nominal accuracy and practical accuracy of facial scanners. [19,20] Zhao et al. [20] evaluated the practical accuracy of optical facial scanners for facial deformed patients in oral clinics. They found no significant difference in accuracy among different scanning systems like FaceScan (structured light-based system) and 3dMD (stereophotography technology). Furthermore, optical facial deformity was approximately 0.6-0.7 mm with deformed area and 0.5-0.6 mm with global face. They also showed that the 3D accuracy of different facial partitions was inconsistent, with better performance at the middle face.

The emergence of three-dimensional visualization of human anatomy in computerized tomography (CT) and magnetic resonance imaging (MRI) has opened new possibilities for design of maxillofacial prosthesis. [25] [26]. Bohner et al. in 2019 [22] reviewed the estimated mean accuracy of facial scan. Included studies reported deviation values less than 2 mm for 1.5T Avanto MRI (Siemens), M4D Scan (Rodin4D), and Structure Sensor (Occipital Inc), which Knoops et al. found out that they were all considered clinically acceptable [23]. However, magnetic resonance imaging and infrared scanners do not present the comparable accuracy as stereophotogrammetry and white light scanners. [24]

### *Design and Manufacture*

Computer data manipulation allows the exact measurements to be replicated or modified. [27] The mirror image approach was frequently utilized when designing a prosthesis. This approach differentiated the defected and healthy sides along the midline of the model. Thereafter, reflected the healthy side to the opposite side and the difference between mirrored data and defected

data were presented along the contour of the prosthesis. [31-34]

A blueprint for the final prosthesis can be created by computer numeric controlled (CNC) milling machine [28], but the applications of CNC milling is limited when trying to replicate the internal features of a complex anatomy [29,30]. Therefore, the advancement of RP systems has contributed to the output of customized anatomical 3D models with internal complexity. [35,36] Because RP methodologies build an object by a digital model that has been virtually sliced [37], it allows complex shapes to be produced with internal detail and undercut areas. [38] Stereolithography is an example for this technique, which creates 3D objects under a computer-guided laser by curing a liquid resin. [39] Thermojet Printer (3D Systems) is a more recent system that is able to use wax as the building material, which offers the benefit of direct casting from a wax model [4].

However, the high cost of the equipment, complex machinery, and the requirement on special skills to operate the machinery during production are all limitations of using RP technology. The initial capital necessary to configure the system, nevertheless, may be lessened by launching a centralized service in state-, country-, or even continent-level. [40]

### *Digital Workflow for Nasal Prostheses*

#### *Data acquisition*

Several authors had used CT scans as a common methods of data acquisition [41-44], while others had used photogrammetry [45-48], and laser scanners [49-52]. In order to improve the accuracy and reduce risk of missed parts, combination of multiple methods might be applied [53,54,77]. The softwares such as Mimics and Simplant by Materialise (Leuven, Belgium) had been used when data were initially acquired by CT scans. The transformation of the DICOM files of CT [39,42,53] to STL format can be achieved in a CAD software; however, this process was not generally necessary when using laser/light scanning and photogrammetry.

#### *Design and Manufacture*

A nasal prosthesis can be printed directly [44,45,48,54], but Unkovskiy et al. [54] considered the marginal adoption poor even though it might avoid a try-on appointment. Eggbeer et al. [45] used a printed material (TangoPlus, Stratasys) that was an acrylate- base material but with flexibility. However, its physical properties were not strong enough even though being close to benchmark silicone, and might be further affected by ultraviolet light, which caused premature breakdown of thin wall sections after daily usage.

A nasal prosthesis can also be manufactured indirectly by converting the virtual model of a prosthesis to be a negative volume in a block, which than an empty mold for further silicone processing can be designed. [41,45,46,49,55,56] Utilizing CAD softwares such as Pro-E software and Makerware (Makerbot, USA) for designing the molds was illustrated by different articles. [39,44] Because printing a mold would take more material than the actual prosthesis. However, reducing the mold's thickness by 2.5 mm might be considered to lower the manufacturing cost. [43] Moreover, because the generated resin mold was durable and allowed for multiple pourings, future remanufacturing might be done in the same mold when discoloration or deterioration of the silicone elastomer happens over time. [41]

### *Digital Workflow for Auricular Prosthesis*

#### Data acquisition

It was similar to the data acquisition method for nasal prostheses. Laser scanning was the preferential method for auricular prostheses [59]. This is even though there is no significant difference on clinical implications among CT, MRI, and laser scanning [7]; However, anterior edge misfit was the main drawback described by Unkovskiy et al. [59] This inaccuracy was the result of the movement of patients during scanning. For accurate data representations, the patient should avoid moving for the duration of the scan. Softwares like 3Ddoctor (Able Software Corp, Lexington, MA) [60], Mimics (Materialise, Leuven, Belgium) [37] and Polygon Editing Tool (Konica Minolta) [61,62] were used to process the data which was acquired from scanning. Afterwards, the data are exported to STL file format and imported into CAD software.

#### Design and Manufacture

Several authors mentioned the use of different software like CAD tools such as Meshmixer (Autodesk Inc.) [63], Rapidform [65], and Magic & RSM (Materialise) [41]. Making auricular prostheses using CAD/CAM technology was considered favorable because an ear sculpture using wax can be avoided by mirroring the healthy ear to the defect side [57], integrating the edges with the tissue surface, and then utilizing negative volume of the prosthesis to construct a prosthetic segmented mold. [64-66] The process can be done on a computer and the patient can visualize the results on the monitor before the fabrication process. On the other hand, some authors stressed the necessity of a digital library for the selection of prostheses when absence of healthy ears happened on both sides which represent a challenge for the clinician

[60,64], Overall, the computer aided method could help the auricular prosthesis fabrication in terms of shape, size, position of the prostheses, as well as shorten the processing time in comparison to conventional techniques. [58]

Unkovskiy et al. [59] showed that an additional prototype try-on stage before indirectly fabricating the prosthesis by creating a mold for the silicone processing could lead to the better result in fitting. In addition, Tam et al. [68] discovered that four of six auricular prostheses fabricated by indirect technique had good marginal accuracy and retention, while all six had symmetry and good location.

### *Digital Workflow for Orbital Prosthesis*

#### Data acquisition

In most circumstances, proper digital manufacture of an ocular prosthesis remains a hurdle. The eye is confined within a socket surrounded by hard and soft tissue, unlike auricular or nasal abnormalities which are protrusion on the face. 3D scanning methods like using 3DSS-STD-II structured-light facial scanner (Digital Manu, Shanghai) [70], and even the combination of images from facial scanner by 3dMDface System (3dMD) and intraoral scanner by Trios (3Shape) [71] had been used in the fabrication of orbital prostheses. Ciocca and Scotti [72] used MRI combined with laser scanning imaging for the rehabilitation process to capture the soft tissue and its skin textures; However, laser would be absorbed by dark areas that are essential for the fabrication of orbital prostheses, such as eyebrows, eyelashes, and undercut areas. 3D photography had also been discovered as a choice for data acquisition [73,74]. Moreover, Bi et al. [70] recommended taking two 45-degree scans from the left and right and merging them in a CAD software when using a facial scanner to avoid undercut misrepresentations.

Different technologies and techniques had also been applied to the data acquisition of orbital defects. Yoshioka, et al. [76] used a 3D non-contact digitizer (VIVID 910; Konica Minolta, Japan) utilizing laser-beam light sectioning technology, which was less harmful than CT scans; However, low repeatability may be its drawbacks. On the other hand, Jaesang et al. [69] chose to scan the cast made from the physical impression of the socket using a light intensity 3D scanner, since the ocular images on CT were difficult to be identified and did not represent the true volume of the eye.

Yoshioka et al. [76] described the photo-mapping technique using Mimics (Materialise, Leuven, Belgium) to three-dimensionally place a digital photograph on the CAD model. This

allowed the confirmation of the pupil's external profile and position on the model, considering the correct location of the pupil cannot be acquired via CT or face impressions since the patient's eyes must be closed. Moreover, patients' motivation may be further improved by presenting the proposed final prosthesis image via the CAD software.

### Design and Manufacture

Examples of the CAD software used in orbital prosthesis fabrication are Geomagic (Geomagic Studio; Geomagic Inc) [70,71], SURFACER (alphacam; GmbH) [73] and ClayTools system (Freeform Modeling Plus; Wilmington) [72], these software could mirror the unaffected side onto the affected side and merge the margins after determination of the midline to achieve bilateral symmetry [70-72].

To apply a prefabricated ocular prosthesis in digital workflow, the stock ocular prostheses could be scanned for establishing a digital ocular prosthesis database; by printing out the corresponding resin ocular duplicated model after virtual selection of the ocular mold based on iris and pupil position, it could be used for preserving internal space within silicone prosthesis for the matched prefabricated ocular prosthesis to fit in [70].

Moreover, the orbital prosthesis prototype could be printed for the try-on purpose. [73,74] As for the definitive prosthesis, the silicone part surrounds the ocular prosthesis could be fabricated by creating a mold for silicone packing, which would require extra staining after processing. [70-72].

### Conclusions

Utilization of digital technologies in the facial prosthesis manufacturing process can increase patient comfort and production efficiency. However also it comes with higher initial investments and demands longer experience with software tools.

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