Current State of Craniofacial Prosthetic Rehabilitation

Nina Ariani, DDS[a]/Anita Visser, DDS, PhD[b]/Robert P. van Oort, DDS, PhD[b]/
Lindawati Kusdhany, DDS, PhD[c]/Tri Budi W. Rahardjo, DDS, PhD[c]/Bastiaan P. Krom, PhD[d]/
Henny C. van der Mei, PhD[d]/Arjan Vissink, DDS, MD, PhD[b]

Purpose: This study aimed to review the current state of the techniques and materials used to rehabilitate maxillofacial defects. ***Materials and Methods:*** The MEDLINE and EMBASE databases were searched for articles pertinent to maxillofacial prostheses published from January 1990 to July 2011. The main clinical stages were the subject of analysis. ***Results:*** A multidisciplinary approach is preferred when rehabilitating maxillofacial defects. Surgical reconstruction can be used for smaller defects, but larger defects require a prosthesis to achieve an esthetic rehabilitation. Implant-retained prostheses are preferred over adhesive prostheses. Silicone elastomer is currently the best material available for maxillofacial prostheses; however, longevity and discoloration, which are greatly influenced by ultraviolet radiation, microorganisms, and environmental factors, remain significant problems. In the near future, the widespread availability and cost effectiveness of digital systems may improve the workflow and outcomes of facial prostheses. Patients report high satisfaction with their prostheses despite some areas that still need improvement. ***Conclusions:*** Maxillofacial prostheses are a reliable treatment option to restore maxillofacial defects and improve quality of life. Significant progress has been made in the application of implants for retention and digital technology for designing surgical guides, suprastructures, and craniofacial prostheses. Further improvements are necessary to enhance longevity of prostheses. *Int J Prosthodont 2013;26:57–67. doi: 10.11607/ijp.3220*

Patients acquire maxillofacial defects due to cancer, trauma, or congenital diseases. Such defects often require high-quality prosthetic treatment[1] because of the associated esthetic and psychologic problems (Fig 1a).[2]

[a]*PhD Student, Department of Biomedical Engineering, W.J. Kolff Institute, University Medical Center Groningen and the University of Groningen, Groningen, The Netherlands; Department of Prosthodontics, Faculty of Dentistry University of Indonesia, Jakarta, Indonesia.*
[b]*Associate Professor, Department of Oral Maxillofacial Surgery and Maxillofacial Prosthetics, University Medical Center Groningen and the University of Groningen, Groningen, The Netherlands.*
[c]*Professor, Department of Prosthodontics, Faculty of Dentistry, University of Indonesia, Jakarta, Indonesia.*
[d]*Associate Professor, Department of Biomedical Engineering, W.J. Kolff Institute, University Medical Center Groningen and the University of Groningen, Groningen, The Netherlands.*
[e]*Professor, Department of Biomedical Engineering, W.J. Kolff Institute, University Medical Center Groningen and the University of Groningen, Groningen, The Netherlands.*
[f]*Professor, Department of Oral Maxillofacial Surgery and Maxillofacial Prosthetics, University Medical Center Groningen and the University of Groningen, Groningen, The Netherlands.*

Correspondence to: *Dr Anita Visser, Department of Oral and Maxillofacial Surgery and Maxillofacial Prosthodontics, University Medical Center Groningen, PO Box 30.001, 9700 RB Groningen, The Netherlands. Email: a.visser@umcg.nl*

In many cases, it is challenging to reconstruct maxillofacial defects, and satisfactory esthetic outcomes can be difficult to achieve. Maxillofacial defects can be treated by surgical reconstruction or prosthetic rehabilitation (Fig 1b).[3–5] Surgical reconstruction is particularly difficult from a technical perspective, and this approach has a high risk of complications and seldom leads to patient satisfaction.[4] Further, the esthetic results are often disappointing, especially for oncologic surgical ear reconstructions. With regard to reconstruction of nose defects resulting from tumor surgery, it has been reported that reconstruction with an expanded forehead flap may be a good alternative to maxillofacial prostheses.[6]

Maxillofacial prosthodontists have a number of options available to rehabilitate patients using prosthetic restorations to achieve improved function and esthetics.[5] An esthetic and comfortable maxillofacial prosthesis alleviates patients' concerns and improves their quality of life[7,8] without the risks associated with surgery.

Maxillofacial prostheses can provide a natural-looking cosmetic situation. In many cases, the esthetic outcomes of maxillofacial prostheses are superior to those of surgical reconstruction.[3,9] In the past, maxillofacial prostheses were retained by mechanical tools (eg, eyeglasses), skin adhesives, or undercuts.[10] Since 1979,

Figs 1a and 1b Patient treated for a basal cell carcinoma of the nose. **(a)** A bar suprastructure was placed on two implants in the floor of the nose. **(b)** The nasal prosthesis was positioned on the bar suprastructure.

however, there has been a shift toward implant-retained maxillofacial prostheses,[11,12] which are preferred by many patients over conventional prostheses.[13,14]

This narrative review addresses the current state of the treatment options and materials involved in the rehabilitation of maxillofacial defects (ear, nose, and orbital defects). Possible treatment outcomes are reviewed, as is the impact of various treatments on the coping ability and quality of life of patients. To the best of the authors' knowledge, no such review exists in the literature despite continuing progress in maxillofacial prosthodontics. Additionally, the current literature does not allow for a systematic approach.

Literature Search

A search of the MEDLINE and EMBASE databases was conducted using a combination of the following search terms: "facial defect," "maxillofacial prosthesis," "silicone facial prosthesis," "facial prosthodontics," "adhesive facial prosthesis," "extra-oral implants," "nasal defect," "orbital defect," "sculpturing," "digital planning," "stereolithography," and "color matching." A manual search of the reference lists of identified articles was also undertaken. Title and abstracts identified through electronic searches were reviewed by two authors independently. The references spanned the period from January 1990 to July 2011. Only papers written in English, German, or Dutch that were relevant to maxillofacial prosthodontics were incorporated in this review.

The Multidisciplinary Approach

Treatment of maxillofacial defects has evolved to incorporate a multidisciplinary approach with a combination of invasive and noninvasive treatment options. The treatment plan results from discussions between various members of the treatment team, including ablative surgeons, reconstructive surgeons, maxillofacial prosthodontists, and maxillofacial technicians. The following factors must be taken into account with regard to the prosthodontic rehabilitation: *(1)* amount of remaining supportive tissue; *(2)* number, position, and condition of remaining teeth; *(3)* age and medical condition of the patient; *(4)* pathologic findings; *(5)* patient preferences regarding surgical versus prosthetic reconstruction; *(6)* technical skills of the reconstructive surgeon and prosthodontist; *(7)* mental status and manual skills of the patient to deal with a maxillofacial prosthesis; and *(8)* availability of adequate supportive care in case the patient is not able to take care of the prosthesis. Next, the treatment plan is discussed with the patient and his or her family. In other words, maxillofacial rehabilitation is an integral part of patient management, which is composed, at least in high- and middle-income countries, of a combination of implantology, technology, advanced surgical and prosthetic procedures, and proper instruction and education of the patient/family/caregivers.[15–17] The latter is especially important for elderly patients since they may face difficulties in handling and cleaning of the prosthesis.[18]

The multidisciplinary team can comprise a wide variety of ablative, reconstructive, and prosthodontic fields, including otolaryngology, maxillofacial surgery, plastic/reconstructive surgery, maxillofacial prosthetics, radiology, medical oncology, pathology, psychology, social work, speech and physiotherapy, and dietetics.[19,20] All disciplines must cooperate to provide the patient with an optimal, individualized treatment plan. This way, patients receive not only medical care but also comprehensive follow-up therapy to help patients cope with their defects and improve their quality of life.[5,15,21]

Surgical Reconstruction

This review focuses on craniofacial prosthetic rehabilitation; therefore, surgical reconstruction will only be discussed briefly. Advances in imaging modalities (eg, high-resolution computed tomography [CT] scanners, magnetic resonance imaging [MRI]), alloplastic materials, and surgical techniques and instruments have led to greatly improved approaches to surgical reconstruction of the maxillofacial area using either autologous and/or alloplastic materials.[22,23] In extensive ablative procedures, a combination of free tissue transfer, local flaps, and implant-retained prosthesis rehabilitation is performed. The successful outcome of these approaches is apparent when psychosocial outcomes are taken into account.[24] While smaller defects can often be successfully reconstructed with surgery in local hospitals,[25,26] larger and more complex defects call for medical centers with greater expertise.[27,28] Complex cases may require several operations over a prolonged period of time. For example, surgical reconstruction of a nose requires 3 to 15 operations over 4 to 49 months to achieve reasonable esthetics.[29] Even then, a suboptimal esthetic outcome may be obtained. Further, the extensive and time-consuming surgical treatments place a significant strain on patients.

Maxillofacial Prostheses

Conventionally and Adhesively Retained Prostheses

Retentive methods for maxillofacial prostheses include adhesives, undercuts, eyeglasses, and implants.[30–35] Conventionally retained prostheses using adhesives are often rated as unsatisfactory by patients because of the difficulties associated with properly placing the prosthesis and with prosthesis movement or dislodgement during daily activities.[36,37] Further, adhesives can cause irritation of the skin.[17,31,38,39] Retentive problems may occur due to loss of adhesive strength,[40] but this can be solved in part by using a combination of adhesives. Layering of two adhesives was shown to produce the highest adhesive properties.[31] Unfortunately, no superior combination of prosthetic materials/adhesives has been developed in recent decades.[38,41–43]

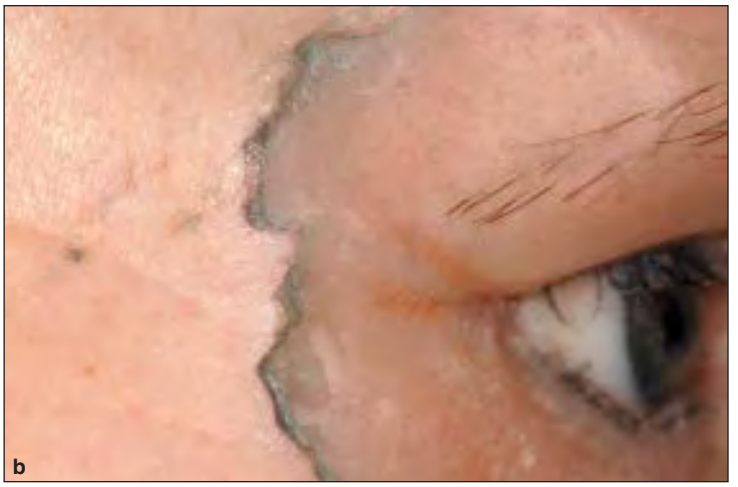
Implant-Retained Prostheses

Implant-retained maxillofacial prostheses have become an excellent treatment option and are usually preferred by patients over adhesive prostheses. The surgical technique to insert osseointegrated implants is relatively simple and associated with a low rate of perioperative or long-term complications.[14,44] Several retention systems for implant suprastructures are currently available, including bar-clip retention, ball attachment, magnetic retention, locator abutment attachment, and the slant lock system.[36,45–48] Implant-retained prostheses are easier to put in place, more comfortable to wear, and easier to clean.[11,16,17,30,32,34,49–54]

For maxillofacial prostheses, the bar-clip and magnetic systems are the most commonly used.[55] Recent in vitro studies show that the bar-clip system has the highest retention and should be the method of choice for retaining auricular and nasal prostheses.[56] The disadvantage of this system is that sufficient space is needed inside the prosthesis to accommodate the acrylic resin clip carrier and bar. Magnetic systems have lower shear strength[57] but are more suitable when there is insufficient space for a bar-clip system and when horizontal forces can be avoided. Magnets can also be useful in cases involving nonparallel implants; therefore, they are particularly well suited for orbital prostheses or patients with low manual strength or dexterity.

Some disadvantages of implant-retained prostheses have been reported. By definition, percutaneous implants impair the function of the first line of defense, the skin, and thus are prone to microbial infection.[58] It should be noted that reduced peri-implant skin reactions are observed in irradiated skin compared to nonirradiated skin.[14] Furthermore, when placed in irradiated bone, the risk of implant failure is 3 to 12 times higher than in nonirradiated bone.[13,14,59,60] Implants placed in the mastoid area show higher overall success rates than implants placed in the nasal and orbital area.[14,58]

Despite these disadvantages, implant-retained prostheses are clearly preferred by patients over conventional prostheses and have been shown to improve patients' daily activities and quality of life.[13,61–66]



Figs 2a to 2d Main disadvantages of the materials used in maxillofacial prosthodontics. **(a)** Implant-retained ear prosthesis with proper shape, color, and margins directly following placement. **(b)** Discoloration at the edges of an adhesively retained orbital prosthesis after 1 year. **(c)** Rupture of the silicone material of an ear prosthesis due to repeated placement and removal. **(d)** Discolored orbital prosthesis after 18 months.

Prosthetic Materials

During the last five decades, silicone elastomers have been the material of choice for fabricating a maxillofacial prosthesis.[41,67–72] The introduction of room-temperature vulcanizing polymers (eg, MDX-4-4210, Dow Corning; VST-50, Factor 2) has been an improvement over polymethyl methacrylate, polyvinyl chloride, and polyurethane for fabricating maxillofacial prostheses.[19,73–77] A recent trial examined a new material: chlorinated polyethylene.[41] The study found that current wearers of silicone-based maxillofacial prostheses preferred silicone elastomers to chlorinated polyethylene elastomers, while new users had no preference for either material.[41]

In the 1990s, Andres et al[78] and Beumer et al[19] reported the ideal properties of maxillofacial prosthetic materials. These lists contain a total of 68 criteria divided into three sections (physical and mechanical properties, processing characteristics, and biologic properties). The criteria include color stability, margin integrity, edge strength, durability, ease of use, adjustments without remake, cost of production, nontoxicity, and short fabrication time. The most commonly reported disadvantages include limited longevity of the elastomers, discoloration, nonrepairability, and degradation (Fig 2).[14,42,79,80] Despite recent advances in material technology, a 2010 survey in North America, Europe, Asia, and Australia revealed that the same criteria still apply and the same disadvantages still exist.[42]

Longevity

Longevity is an important feature of maxillofacial prostheses.[81] Degradation and discoloration will require a remake of the prosthesis. Discolored prostheses can cause esthetic problems and have a negative impact on quality of life. Factors associated with the longevity of silicone elastomer prostheses include the use of skin adhesives, ultraviolet radiation, discoloration, loosening of the acrylic resin clip carrier from the silicone, aging by environmental influences such as pollution, and degradation by microorganisms.[5,14,82] On average, maxillofacial prostheses need to be (re)made every 1.5 to 2 years, which can be a considerable burden on the patient.[14,83,84] This topic requires additional investigation in future research.

Color Matching

Achieving color match to the skin for a maxillofacial prosthesis is a difficult procedure that has generally been based on the clinician's expertise and experience. Color match can be achieved by adding suitable pigments to translucent silicone elastomers until an acceptable color match (preferably under daylight) is attained. Rayon fibers can also be incorporated into the polymer network before curing. This method is called intrinsic coloration. For this method to be successful, the pigments must be dispersible in the polymer and must not have any significant adverse effects on the physical properties of the base material.[85] An already acceptable color match can be further improved by applying pigments dispersed into a solvent on the surface of the prosthesis (ie, extrinsic coloration).[42] It should be noted, however, that pigments used with silicone elastomers do exhibit color changes over time.[79,86]

Several studies have indicated that the human eye is less sensitive to color differences in dark shades than in light shades.[87,88] A discrepancy can emerge between the color perceptions of the patient and clinician, particularly under different lighting conditions. Therefore, Cheng et al[89] suggested making three prostheses with slightly different colors to match the skin color under natural light. The best match from these three prostheses is then chosen after custom external coloration. This method provides patients with a range of options (eg, related to the season) and may reduce the need for remakes due to clinically unacceptable color match as perceived by observers. However, this method is very costly and rarely used.

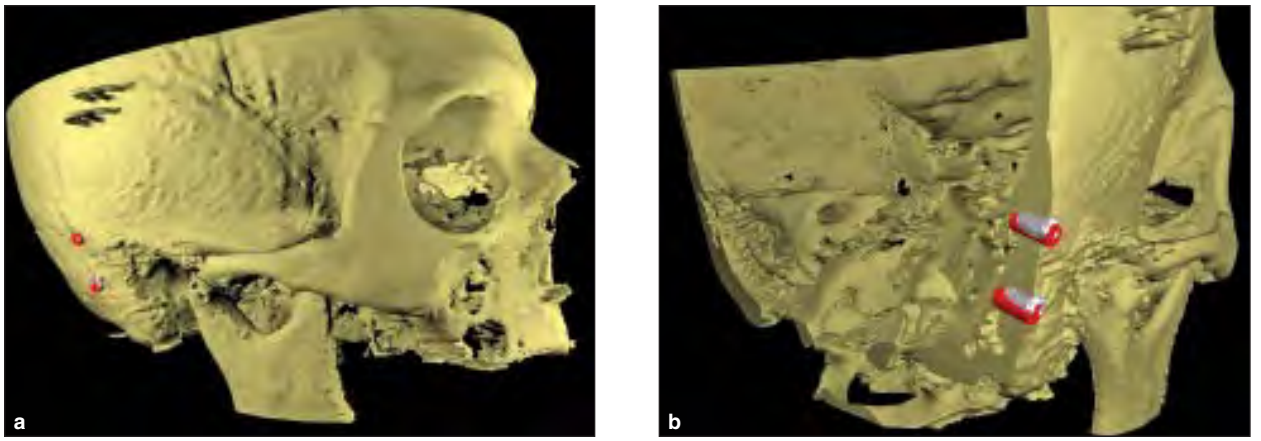
The use of a spectrophotometer and computerized color formulations may assist the clinician in obtaining a certain degree of objectivity in color matching.[90] Several color measurement systems are available: spectrophotometers, fiber-optic devices, and imaging color analyzer modules. Of these, the imaging color analyzer module has been shown to provide the best clinical results.[91] The major disadvantages of the other two systems include the large minimum size of the measurement area, contact measurement, poor accuracy, poor functionality, poor repeatability, and unsuitable acquisition protocol.[91] Comparison of the results between studies is difficult due to nonstandardized use of spectral instrumentation and illuminants.[90]

Color matching using quantitative color measurement for maxillofacial structures is still far from perfect.[92–94] Important questions that remain to be answered include whether a particular instrument records the color correctly (eg, black read as black by the instrument, thereby also assessing the degree of translucency) and whether these measurements result in a color formula that matches the recorded shade. A new measurement tool in objective color matching, the volume reflection meter, may overcome many of the disadvantages discussed above. This highly sensitive tool can detect small differences in the scattering properties of translucent materials and account for the translucent characteristics of the skin at three different distances from a light source with a single measurement.[95]

Microbiologic Challenges

A study of the surface characteristics of maxillofacial prosthetic elastomers identified the role of surface texture in harboring microorganisms.[96] Another study identified a possible link between incorrect elastomer formulation and the susceptibility of a maxillofacial silicone elastomer to deterioration by ingrowth of fungi.[97] A recent study showed that the adherence of *Candida albicans* differs between materials and was found in room-temperature polymerized silicone elastomers processed for at least 12 hours.[98]

A cross-sectional study on microflora associated with extraoral endosseous maxillofacial implants showed that no single organism emerged as a predominant cause of peri-abutment skin infection.[99] *Staphylococcus aureus*, Gram-negative bacilli, and yeasts were all present on pericutaneous implants as potential pathogens in a biofilm-mode of growth. Hygiene was an important factor in maintaining healthy peri-implant tissue. Culture and sensitivity results should guide treatment of peri-implant infections.[99,100] In a recently published study by the current authors,[101] a mixture of microorganisms including yeast and bacteria (ie, a multispecies biofilm) was observed on silicone facial prostheses. These



Figs 3a and 3b Accuracy of digitally planned implants in the mastoid region. **(a)** By superposing the preoperative and postoperative cone beam CT data, an impression of the preoperative implant plan *(red)* compared to the actual implant placement can be obtained. The implants *(gray)* were placed in close proximity to the planned locations. **(b)** Sectional plane of the mastoid area with the actual implant positions. The implants were fully surrounded by bone and in close proximity to the planned locations.

microorganisms were also present on the margin area not directly adjacent to the implants. However, opportunistic *Candida* spp were only isolated from silicone prostheses and prosthesis-covered skin, not from healthy skin.

Discoloration of maxillofacial prostheses has been described as fungal driven.[102] An in vitro study aimed to determined the association of fungal growth with discoloration, the effect of antifungal agents incorporated into the silicone on fungal growth, and the longevity of antifungal action.[102] It was concluded that fungi from the genus *Penicillium* were associated with discolored areas of a nasal prosthesis. Addition of clotrimazole to silicone samples was shown to be effective in inhibiting fungal growth, while nystatin was shown to be ineffective. The inhibition of fungal growth indicated a degree of stability and longevity when samples were stored dry or in water at room temperature.

It has been postulated that biofilm on implant surfaces may complicate the management of periimplant skin infections and the relative effects of antimicrobial agents, which can play a role in the failure of endosseous maxillofacial implants and prostheses.[100,103] Recombinant human Beta Defensin 3 exhibited antibacterial activity against some oral pathogenic strains on elastomers, but no information was provided regarding its activity toward strains isolated from the skin.[104]

As is clear from the studies discussed above, maxillofacial endosseous implants and prostheses face multifactorial infection problems due to the unnatural situation created by the prosthesis. The chronic interruption of the skin surface by the suprastructure fixed on the implants causes poor air circulation, accumulation of moisture, and compromised hygiene.[58,103] Therefore, adequate hygiene instruction regarding cleaning the prosthesis, implants, and superstructure is crucial.[48,61–63,105,106] If the patient fails to practice proper hygiene, the use of local antibiotics, antimycotics, and steroids may be needed in addition to reinstruction and remotivation of meticulous hygiene.[32] Occasionally, surgical thinning and debridement of the skin is needed to restore tissue health.[34,103]

Computer-Guided Implant Placement and Prosthesis Fabrication

With the aid of digital technology, it is possible to digitally plan and place extraoral implants and design and fabricate maxillofacial prostheses. A major advantage of digital planning is that clinicians can preoperatively visualize the desired implant locations and positions on the computer screen, after which a surgical guide can be digitally designed and fabricated via rapid prototyping (RP) technology (Fig 3). The surgical guide leads the surgeon during implant placement, thereby avoiding damage to vital anatomical structures, safeguarding a sufficient bone volume at the implant site,[107,108] and limiting the burden of the surgical procedure on the patient. This technique is rarely described in the literature for extraoral areas. Van der Meer et al[109] showed that extraoral implants can be placed in the preoperatively planned and prosthetically preferred position when applying digital technology (Fig 3). Slight variations were seen between the planned and actual implant positions, but these differences were minor, and the implant positions were more than satisfactory from a surgical and prosthodontic point of view.

Before computer-aided design/computer-assisted manufacture (CAD/CAM) technology became available, the method used to reconstruct a facial form using maxillofacial prostheses involved skillful hand-carving of a wax cast. In 2003, Wolfaardt et al[16] suggested that RP technology, stereolithography, and fused deposition modeling showed promise as tools for head and neck reconstructions. Recent advances in computer technology allow for the digital design of maxillofacial prostheses.[110–112] Various techniques involving CAD/CAM methods have now been published and evaluated. When applying CAD/CAM technology for the fabrication of maxillofacial prostheses, a common treatment sequence begins by capturing the patient's soft and hard tissues using imaging techniques (eg, CT, MRI). Next, this information is converted into an RP model using computer software (eg, Mimics, Materialise). RP models can be either directly printed in wax or printed in acrylic resin and then transferred into a wax cast via duplication techniques. The wax cast is fitted to the patient, and final small details must be hand carved because RP techniques cannot exactly mimic the skin curvature. Subsequently, the silicone elastomer prostheses are conventionally fabricated after fitting on the cast.[113–119] CAD/CAM systems can also be used to make immediate maxillofacial prostheses with a form selected from a digital library when the original facial structure (eg, the nose) is deformed. This process takes less time compared to the conventional technique.[120] The potential for technologic advances to transform an artistically driven process into a process based on reconstructive biotechnology cannot be overlooked.[121]

A comparison of conventional impression procedures and RP technology in terms of quality, accuracy, required time, and ease of production for making and duplicating prostheses showed that RP has many advantages. However, the RP equipment must become more cost effective, user friendly, and compact.[122,123] Compared with conventional procedures, the cost of CAD/CAM fabrication seems high at the initial investment, but on a daily basis, the costs are probably lower than those of manual fabrication by technicians.[113] There is no information in the literature regarding the availability of CAD/CAM technology in low- and middle-income countries. Increased availability of CAD/CAM centers, digital transmission of files, and shipment of stereolithography casts via postal service may further reduce costs in the future.

Patient Satisfaction

The ideal prosthesis mimics the missing facial contours as precisely as possible (see Fig 1). A successful rehabilitation allows patients to appear in public without fear of attracting unwanted attention.[124–127] This applies not only to the final prosthesis but also to provisional prostheses.[128] A comprehensive and high-quality provisional can increase patients' daily activities and quality of life.[129] However, patients may also benefit from social counseling following restoration with a maxillofacial prosthesis to further improve their quality of life and coping ability.[130]

Patients' attitudes and opinions regarding maxillofacial prostheses have been assessed using surveys. The responses revealed that although patients express a high degree of satisfaction with their prostheses,[13] they also wish that their prostheses could last longer and be more color stable.[14,80] In addition, patients reported concerns about the fit of their prostheses.[81] Social acceptance was found to improve when a maxillofacial defect was adequately covered by a prosthesis, and patient satisfaction was shown to be directly related to patients' confidence in their prosthodontist.[64]

Some patients have reported a desire to eliminate the use of adhesives, which they found to be awkward and irritating.[81] Implant-retained maxillofacial prostheses are better accepted by patients compared to adhesive prostheses and offer improved daily activities and quality of life.[11,13,16,17,61–66]

Discussion and Conclusion: Current Limitations and Hopes for the Future

Currently, the literature does not allow for robust recommendations based on high-quality evidence. Prosthodontic rehabilitation of craniofacial defects remains the skilled manual work of anaplastologists and maxillofacial prosthodontists. Therefore, the literature on prosthodontic craniofacial rehabilitation predominantly consists of cases and case series in which the authors share their expertise, whereas sound clinical trials comparing different treatments are lacking. With the introduction of digital techniques, which may make craniofacial prosthodontics less reliant on the artistic skills of the specialist, more standardized work and thus more rigorous clinical trials may soon become possible.

To the present authors' knowledge, there are no published papers describing a fully digital workflow for scanning, designing, and fabricating maxillofacial prostheses that can then be placed directly onto the patient without the use of plaster casts, wax casts, etc. Nonetheless, the authors expect that a 100% digital workflow will become available within the next decade. Such advancements may also allow for minimally invasive implant surgery.

However, issues related to the longevity and color stability of maxillofacial prostheses need to be addressed as well. To overcome material degradation related to microbial biofilm formation and provide accurate and repeatable color matching, industrial designers must work closely with clinicians. Developing new techniques and materials is costly, and the group of patients who are in need of this technology is rather small. For this reason, the industry is often uninterested in cooperating with clinicians. Maxillofacial prosthodontists must convince technicians and manufacturers that such developments will greatly improve patients' quality of life.

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Literature Abstract

Prevalence of oral HPV infection in the United States, 2009–2010

Oral human papillomavirus (HPV) infection is associated with a subset of oropharyngeal squamous cell carcinomas (OSCCs). HPV positive OSCCs are associated with sexual behavior, in contrast with HPV negative OSCCs, which are associated with chronic tobacco and alcohol use. The incidence of OSCCs has significantly increased in the last three decades and HPV has been implicated as the underlying cause. Little is known about the epidemiology of oral HPV infection and the purpose of this study was to determine the prevalence of HPV infection in the United States. A cross-sectional study was conducted by NHANES from 2009 to 2010. The subjects were a representative sample of the civilian noninstitutionalized US population, aged between 14 and 69 years. An in-home interviewer administered survey was used to obtain sociodemographic and sexual behavior data. DNA was collected from oral exfoliated cells and HPV detection was performed by multiplex polymerase chain reaction. Statistical analyses used NHANES sample weights to provide weighted estimates for the US population. The overall prevalence of HPV infection was 6.9%. The prevalence of high-risk HPV infection was 3.7% and for low-risk infections was 3.1%. The most prevalent HPV type detected was HPV-16. The peak prevalence of HPV infection was in the 30- to 34-years age group. Men had a slightly higher prevalence than women for any HPV infection. Infection was more common in individuals who reported engagement in sexual activity and increased with lifetime and the number of recent partners. Smokers also showed a higher infection rate. The presence of oral HPV infection was substantially lower than the reported prevalence of genital HPV infection. It was found that oral HPV infection is predominantly sexually transmitted. From this study, it seems that sexual behavior and current smoking status can be potentially modifiable risk.

Gillison ML, Broutian T, Pickard RK, et al. *JAMA* 2012;307:639–703. **References:** 40. **Reprints:** Maura Gillison, MD, PhD, Ohio State University, 420 W 12th Ave, Room 620, Columbus, OH 43210. Email: maura.gillison@osumc.edu—*Clarisse Ng, Singapore*