Malignant Tumors of the Maxilla: Virtual Planning and Real-Time Rehabilitation with Custom-Made R-zygoma Fixtures and Carbon–Graphite Fiber-Reinforced Polymer Prosthesis

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ABSTRACT

Background: Oral cancer is a mutilating disease. Because of the expanding application of computer technology in medicine, new methods are constantly evolving. This project leads into a new technology in maxillofacial reconstructive therapy using a redesigned zygoma fixture.

Purpose: Previous development experiences showed that the procedure was time-consuming and painful for the patients. Frequent episodes of sedation or general anesthetics were required and the rehabilitation is costly. The aim of our new treatment goal was to allow the patients to wake up after tumor surgery with a functional rehabilitation in place.

Materials and Methods: Stereolithographic models were introduced to produce a model from the three-dimensional computed tomography (CT). A guide with the proposed resection was fabricated, and the real-time maxillectomy was performed. From the postoperative CT, a second stereolithographic model was manufactured and in addition, a stent for the optimal position of the implants. Customized zygoma implants were installed (R-zygoma, Integration AB, Göteborg, Sweden). A fixed construction was fabricated by using a new material based on poly(methylacrylate) reinforced with carbon/graphite fibers and attached to the implants. On the same master cast, a separate obturator was fabricated in permanent soft silicon.

Results: The result of this project showed that it was possible to create a virtual plan preoperatively to apply during surgery in order for the patient to wake up functionally rehabilitated.

Conclusion: From a quality-of-life perspective, it is an advantage to be rehabilitated fast. By using new computer technology, pain and discomfort are less and the total rehabilitation is faster, which in turn reduces days in hospital and thereby total costs.

KEY WORDS: maxillectomy, oral epithesis, zygoma fixtures, zygoma implant-supported prosthesis

Oral cancer is a mutilating disease. The priorities of tumor surgery are to save life, achieve normal function, and aesthetics.

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Options after tumor resection in the maxilla are conventional obturator prosthesis, an obturator prosthesis retained on osseointegrated implants, or reconstructive surgery with free microvascular flaps with or without osseointegrated implants that allow for a bone-anchored prosthesis.

Reconstructive microvascular techniques together with development in dental implant technology can today reconstruct intraoral defects and restore chewing and speech functions,[1,2] but it is time-consuming and difficult (Figure 1). Because of the expanding application of computer technology in medicine, new methods are constantly evolving, allowing faster and better results.[3,4]

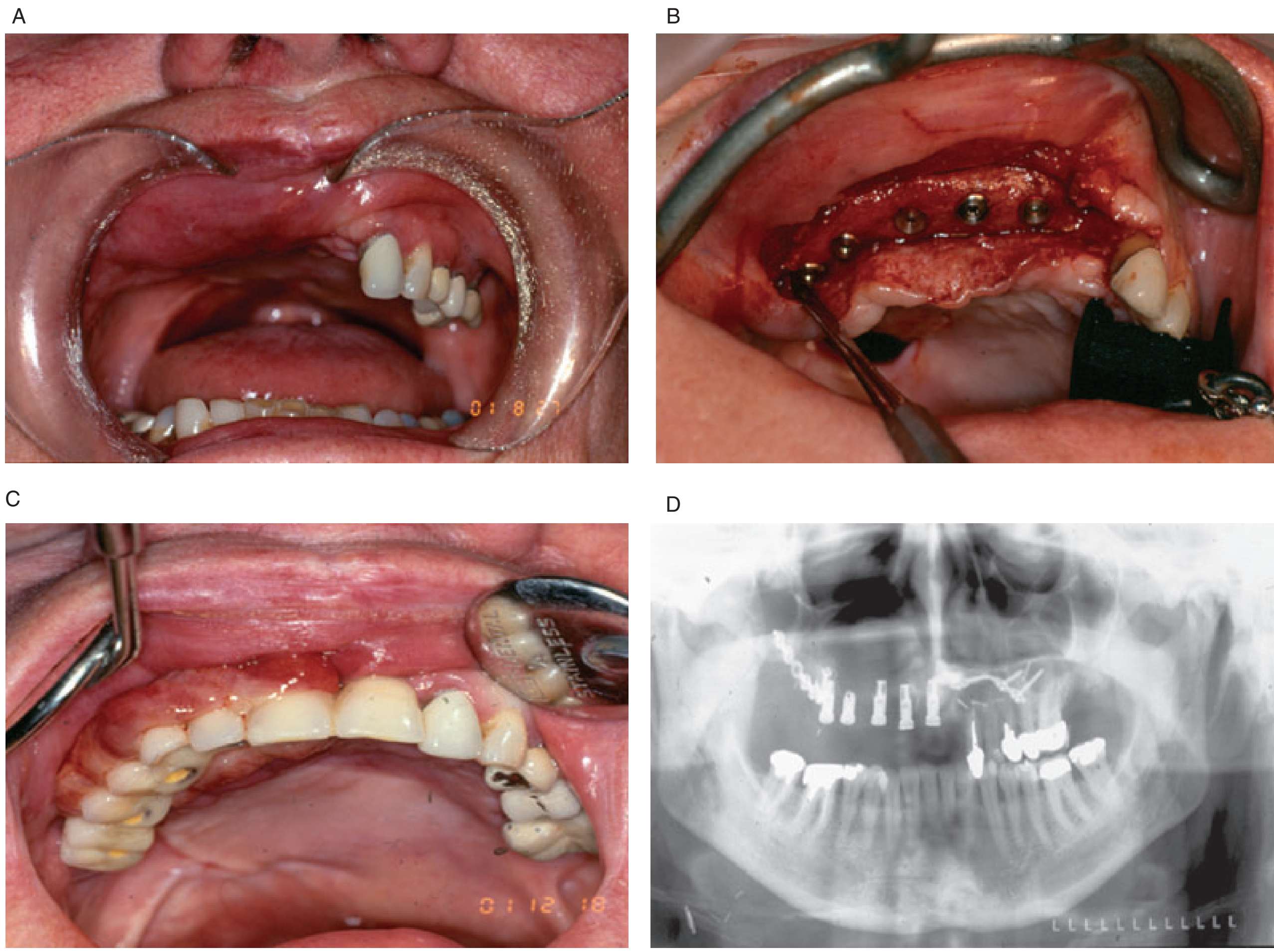


Figure 1 *A*, Ameloblastoma after hemimaxillectomy and a microvascular free scapula flap with muscle transfer. *B*, After 3 months of healing, five implants were installed. *C*, A fixed six-unit porcelain-fused-to-metal bridge was attached to implants after 6 months of healing. *D*, Orthopantomogram after implant installation.

This project leads gradually into new technology in planning and performing maxillofacial reconstructions using reliable computerized models of the human anatomy and newly designed zygoma fixtures (Hirsch and Ekstrand) customized (Brånemark Integration, Göteborg, Sweden) for retention of obturators.

The ultimate goal of this project was to develop a reproducible, reliable, and useful clinical method to accurately simulate surgical interventions on virtual patient models in view of better preparation, improved surgical outcome, shorter operating time, and faster functional rehabilitation with obturators. The specific aim was that the patient should be reconstructed with a functional prosthetic reconstruction at the time of ablative tumor surgery. This article presents previous development experiences and the actual status as of today.

MATERIALS AND METHODS

The early development phase consisted of treating complicated situations with extended defects after ablative tumor surgery using available implants and a standard protocol for prosthetic procedures. This can be exemplified with two types of specific situations. The first patient presented an extended maxillary right-sided defect after tumor resection, and in addition osteoradionecrosis on the left side. Two regular 20 mm fixtures were installed in the zygoma on the right side and fitted with 10 mm standard abutments. After 4 months of healing, a bar construction was connected to the abutments retaining an obturator.

The second patient presented an extradural skull base chordoma invading in the maxilla causing massive bone destruction. The maxilla was eventually totally dislodged because of the extensive bone loss (Figure 2, A and B).

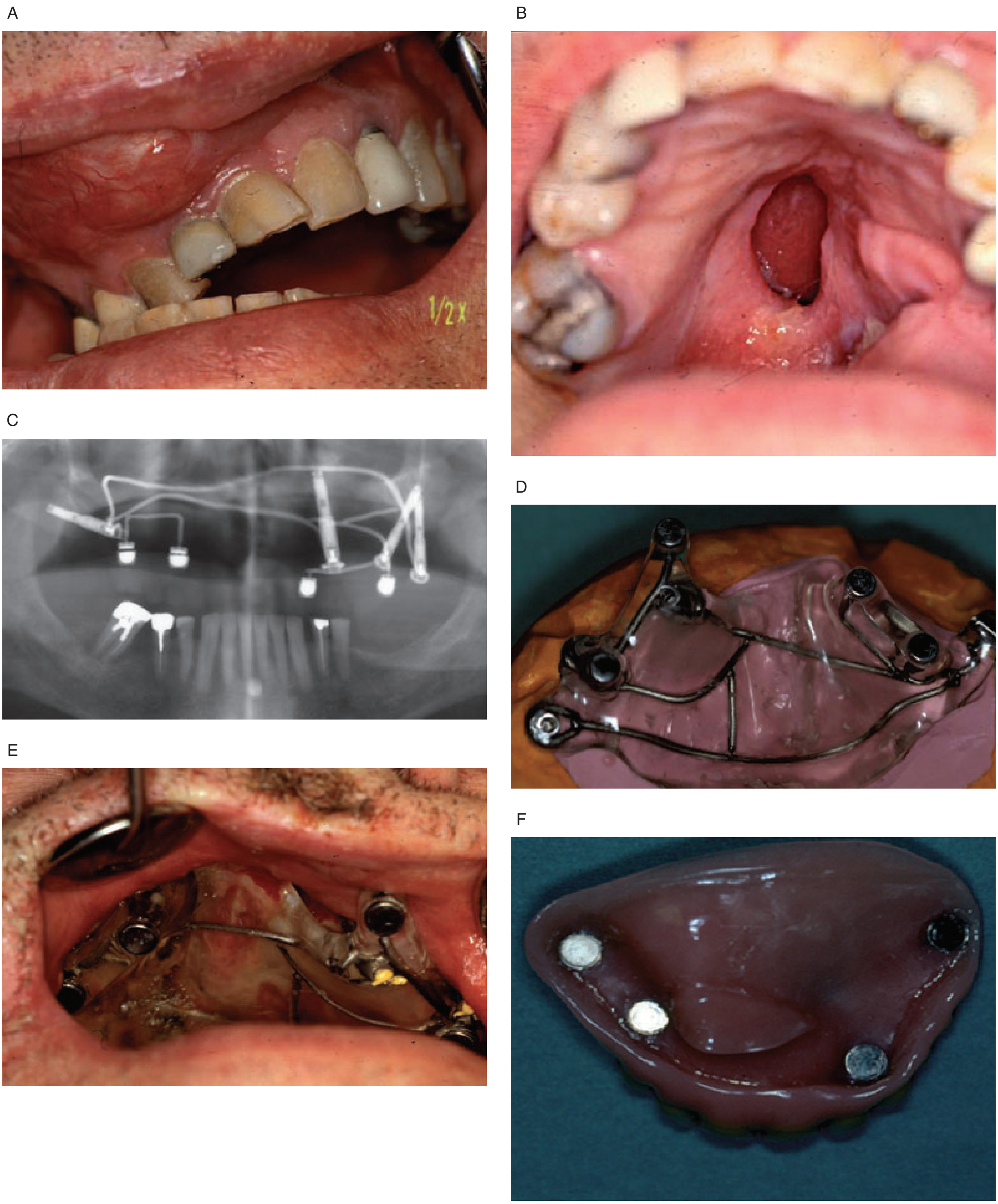


Figure 2 *A* and *B*, Extradural skull base chordoma invading in the maxilla causing massive bone destruction. *C* and *D*, Standard fixtures, abutments, and an acrylic plate reinforced with a titanium framework with embedded four magnets. *E*, Acrylic plate reinforced with a titanium framework in situ with embedded magnets. *F*, The prosthesis with magnets.

A

B

Figure 3 *A* and *B*, Lateral and axial views of the stereolithographic model with proposed resection outlined.

At the time of a complete maxillectomy, dental implants were installed according to our pretreatment plan. One 15-mm implant was installed in the right zygoma, two 15 mm in the left, and one 15 mm in the remaining part of the frontal process of the maxilla on the left side. After connection of standard millimeter abutments and impression, an acrylic plate (Ivoclar, Schaan, Liechtenstein) reinforced with a titanium framework was fabricated. Embedded in the acrylic plate were four magnets (Magnacap, Technovent, Sheffield, UK) (see Figure 2C). The plate fitted on to the abutments sealed off the oral environment from the nasal cavity and maxillary sinuses (see Figure 2D). A conventional removable denture retained by the magnets finalized the construction (see Figure 2, E and F). Follow-up visits showed no leakage of fluid or air.

The following conclusions were drawn from our development experiences. The procedure was too time-consuming from the start, after sufficient healing following tumor surgery, to the finalization of the permanent prosthetic device. Based on the mentioned experiences, the treatment concept was discussed and redesigned.

Stereolithographic models were introduced to produce a physical model from the three-dimensional computed tomography (CT). The model that gives an accurate picture of the situation except for loss of thin, nonsignificant delicate bony structures[5] was used to outline the extension of the tumor to produce a guide for the actual resection. Using the guide, the proposed resection was performed on the stereolithographic model (Figure 3). The model produced was the instruction for the dental technician to fabricate an obturator to fit the defect. The real-time maxillectomy was performed using the guide, and the sinus cavity lined with a split skin graft followed by a silicon obliteration of the cavity (Provil NOVO Putti, Heraeus/Kulzer, Germany). The prefabricated partial provisional denture was secured with ordinary fracture screws 10 to 15 mm in length (Synthes, Oberdorf, Switzerland) (Figure 4).

From the postoperative CT, a second stereolithographic model was manufactured. On this model, the start and end point sites for installation of osseointegrated implants were decided with due respect to available bone volume and quality and biomechanical requirements.[6]

With a stent, the optimal position for the implants was clarified from an occlusal and functional point of view (Figure 5). Customized zygoma implants (R-zygoma, Integration AB, Göteborg, Sweden) were installed in order to get anterior as well as posterior

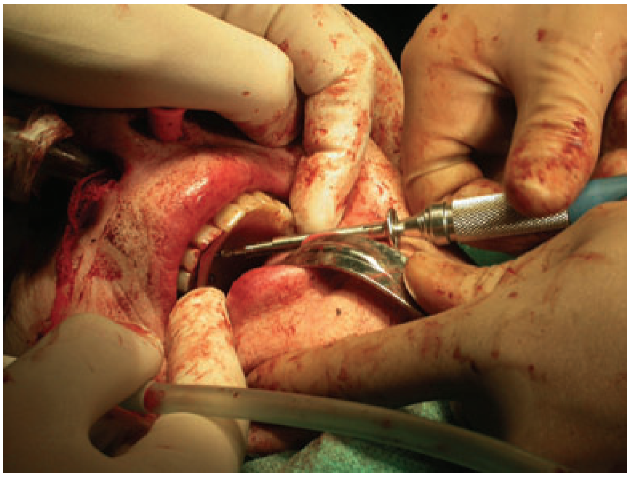


Figure 4 The prefabricated partial provisional denture secured with fracture screws.

Figure 5 The stent guiding the optimal position for the implants.

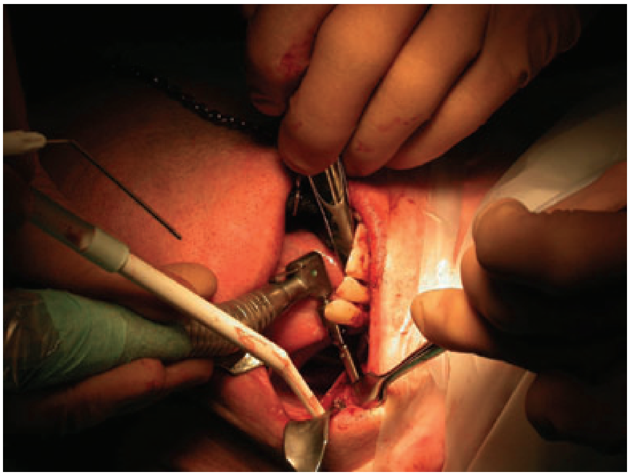
support. The implant has a threaded part and a nonthreaded part (Figure 6). The length of the threaded part is based on measurements on the CT and stereolithographic model of remaining bone at the site of installation. The length of the nonthreaded part is measured from the site of entrance into the bone to a point where the 45-degree angle of the zygoma aims at the occlusal surface of the most superior part of the teeth replacement allowing for an abutment if required.

The idea was to place one R-zygoma implant horizontally superior of the apices of the remaining front teeth, and one or two R-zygoma implants in the remaining part of the zygomatical bone as previously suggested in the conventional procedure (Figure 7).[7]

Abutment connection has been performed after 6 months of healing. The prosthetic procedure followed a standard protocol.[8] A fixed construction was fabricated by using a specially developed material based on poly-(methylmethacrylate) reinforced with carbon/graphite fibers[9,10] and attached to the implants. On the same master cast, a separate obturator was fabricated in permanent soft silicon (GC Reline, GC Corporation, Tokyo, Japan)[11] (Figure 8).

Figure 6 The R-zygoma implant with a threaded part and a nonthreaded part.

A



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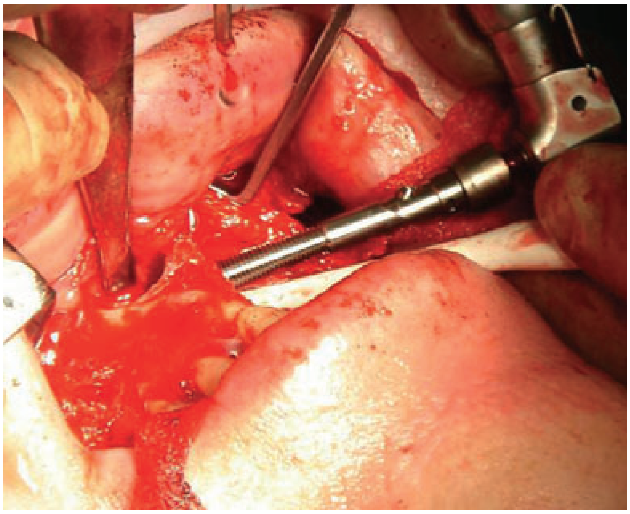

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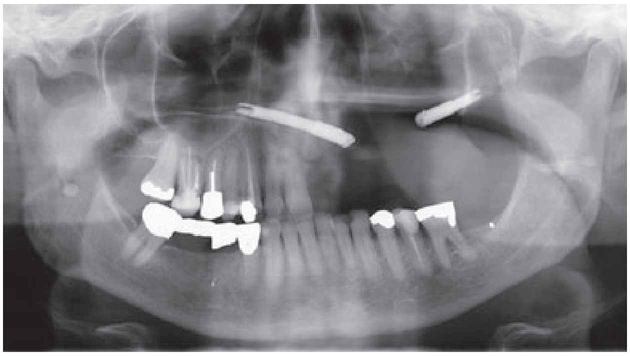

Figure 7 *A*, The installation of the R-zygoma in the remaining part of the zygomatic body and *B*, over the remaining front teeth. *C*, Postoperative orthopantomogram.

Figure 8 The fixed construction with poly(methylmethacrylate) reinforced with carbon/graphite fibers attached to the implants and the soft silicon obturator in place.

RESULTS AND DISCUSSION

Early reconstruction is important according to our clinical experiences, because it counteracts contraction of the tissue and scar formation, thereby ensuring adequate mouth opening and jaw function. From a quality-of-life perspective, it is an advantage for the patient to be functionally rehabilitated fast, and it reduces discomfort and pain significantly. There are a number of health economic aspects to be further evaluated, but it is clear that the number of hospital days are reduced. Customized R-zygoma fixture has been used up to now. Standardizing the R-zygoma implants would shorten the preoperative planning phase which from time to time is of importance especially in patients with malignant disease. Accordingly, the future implants to be used will have a 14-mm threaded part, and the nonthreaded coronal section will be available in three different lengths. This decision is based on our present cumulative experience.

The future development includes fusion of CT, magnetic resonance imaging, and possibly CT/positron emission tomography (PET Imaging) which increase the reliability for detecting bone invasion.[12]

This enables a more precise marking of the tumor on the images on the radiological workstation, and a precise virtual tumor resection and a fabrication of a surgical stent for the operation. The virtual tumor resection will be followed by planning of the fixture installation using a software (Mimics, Materialise, Leuven, Belgium) that will also supply a stent for the fixture placement. The software also allows for mirroring non-affected anatomical structures to an affected, destructed side. This allows for an exact reconstruction of severely damaged areas.

A stereolithographic master cast based on the mentioned planning will be supplied to the dental technician on which a provisional fixed bridge plus the removable silicon obturator will be completed. At this stage, the real-time surgery can proceed followed by an immediate rehabilitation with the prosthesis.[13]

From a surgical technical point of view, installation of osseointegrated implants is best performed in connection with the tumor resection. Also, no additional surgical procedures are needed. In cases where postoperative radiation is planned, there is usually a lag phase before radiation therapy is initiated, which leaves enough time for primary fixture healing.[14] The titanium implants do not emit significant backscatter radiation. In situations with postoperative radiation therapy exposing areas where titanium implants have been placed, it is recommended that all prostheses, frameworks, and abutments are removed before irradiation; the fixtures should be allowed to remain intact but should be covered with skin or mucosa[15]. However, in our protocol, the suprastructure contains no metal and is constructed by a carbon fiber-reinforced polymer (for review,[9]) and there is no need for removal of the construction. Survival after cancer therapy is so high and outcome from osseointegrated implant therapy is so favorable that the treatment can be recommended even in the irradiated patient.[16]

Regardless of the size or location of the defect, and regardless of the number and position of the remaining teeth, our basic principle has been to obtain maximum support for the obturator. The obturator is supported by the surrounding soft tissues and the fixed construction. Satisfactory obturation of the defect is evaluated by speech production and absence of nasal leakage during swallowing. Post-insertion instructions should include recommendations for the frequency of removal and cleaning of the removable device.

It should be assumed that the patient will wear the obturator 24 hours a day and for that reason, hygiene procedures of the fixed construction and the obturator must be reemphasized at every follow-up visit to avoid soft tissue complications and dental disease.

To avoid bacterial and fungal growth, the soft obturator should be immersed in boiling water for 10 minutes every week.[17]

For the construction attached to the implants, a carbon-graphite fiber-reinforced polymer material was used. This material is an alternative to conventional metal framework. The core material is carbon-graphite reinforced polymer surrounded by a denture base material. The advantages of this material include ease of production, reduced production time, and a reduced cost of materials.[10,18]

One main disadvantage of the fiber-reinforced material is the black color. This is mastered by covering the framework composite with an opaquer in the similar manner as metallic frameworks are covered. For coating of framework and attachment of synthetic teeth, denture base polymers with improved impact resistance are used, thus providing a tougher suprastructure.

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