Prosthetically Driven, Computer-Guided Implant Planning for the Edentulous Maxilla: A Model Study

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ABSTRACT

Objectives: To analyze computer-assisted diagnostics and virtual implant planning and to evaluate the indication for template-guided flapless surgery and immediate loading in the rehabilitation of the edentulous maxilla.

Materials and Methods: Forty patients with an edentulous maxilla were selected for this study. The three-dimensional analysis and virtual implant planning was performed with the NobelGuide™ software program (Nobel Biocare, Göteborg, Sweden). Prior to the computer tomography aesthetics and functional aspects were checked clinically. Either a well-fitting denture or an optimized prosthetic setup was used and then converted to a radiographic template. This allowed for a computer-guided analysis of the jaw together with the prosthesis. Accordingly, the best implant position was determined in relation to the bone structure and prospective tooth position. For all jaws, the hypothetical indication for (1) four implants with a bar overdenture and (2) six implants with a simple fixed prosthesis were planned. The planning of the optimized implant position was then analyzed as follows: the number of implants was calculated that could be placed in sufficient quantity of bone. Additional surgical procedures (guided bone regeneration, sinus floor elevation) that would be necessary due the reduced bone quality and quantity were identified. The indication of template-guided, flapless surgery or an immediate loaded protocol was evaluated.

Results: Model (a) – bar overdentures: for 28 patients (70%), all four implants could be placed in sufficient bone (total 112 implants). Thus, a full, flapless procedure could be suggested. For six patients (15%), sufficient bone was not available for any of their planned implants. The remaining six patients had exhibited a combination of sufficient or insufficient bone. Model (b) – simple fixed prosthesis: for 12 patients (30%), all six implants could be placed in sufficient bone (total 72 implants). Thus, a full, flapless procedure could be suggested. For seven patients (17%), sufficient bone was not available for any of their planned implants. The remaining 21 patients had exhibited a combination of sufficient or insufficient bone.

Discussion: In the maxilla, advanced atrophy is often observed, and implant placement becomes difficult or impossible. Thus, flapless surgery or an immediate loading protocol can be performed just in a selected number of patients. Nevertheless, the use of a computer program for prosthetically driven implant planning is highly efficient and safe. The three-dimensional view of the maxilla allows the determination of the best implant position, the optimization of the implant axis, and the definition of the best surgical and prosthetic solution for the patient. Thus, a protocol that combines a computer-guided technique with conventional surgical procedures becomes a promising option, which needs to be further evaluated and improved.

KEY WORDS: computer-guided planning, prosthetically driven implant placement, three-dimensional

INTRODUCTION

Development in computer technology has changed diagnostic and interventional possibilities not only in general medicine, but also in implant dentistry. The

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goal is not only to improve the precision and predictability of implant placement, but also to change an invasive surgical protocol to a flapless procedure[1] and eventual immediate loading. Dynamic and static systems are proposed. The first one is navigation surgery, a real-time surgical procedure,[2,3] and the latter one is based on a surgical template,[4,5] either model based or computer based. Navigation surgery requires a complex infrastructure with regard to space and costs and, therefore, has not really been introduced in daily practice for the placement of dental implants. Measurements that compared planned and effective implant position have shown differences between static and dynamic methods. The navigation system provides optimum precision,[2] while static systems show greater variations. One study using a stereolithographically produced template found differences up to 3 mm between planned and effective position and up to 7° deviation of the implant axis.[6] Optimized planning software of static systems today, for example, like NobelGuide™ (Nobel Biocare, Göteborg, Sweden) or Materialize (Materialise Dental NV, Leuven, Belgium), allows virtual implant placement with analysis of the jaw in all three dimensions resulting in higher precision.[4,5] Differences of a maximum 1.1 mm and 2.8° in implant axis were measured, which is acceptable in implant dentistry.[5] Other measurements of planned and installed implant position resulted in up to 2.4 mm of linear deviation and up to 4° angular deviation.[7]

The electronic data obtained by the planning process can be directly transferred into the fabrication of surgical guides (stereolithography).[8] By means of this procedure, the surgical installation of the implants can be performed without raising a flap. Such methods also suggest the immediate loading of the implants, at least in well-selected cases. A high precision in implant placement, combined with a fast surgical technique, reduces the impact on the patient and patient's morbidity.[9] Reduction of invasive surgical procedures, of postoperative pain or swelling, and of healing time meets the patients' demands and wishes.[10] As of today, only case reports and few data were published in clinical studies, but so far, the results seem to be promising.[11,12]

A direct comparison of different computer systems by a well-designed study (randomized controlled trial) is not available. Computer-assisted planning is particularly suggested in complex situations when computer tomography (CT) scans and volume tomography are applied anyway. For various reasons, objections against such technology are listed. Surgeons often doubt that the technology provides sufficient precision and still prefer to raise a flap and to use standard procedures with conventional surgical guides. They also mentioned that the computer technology with flapless surgery can be applied only in few patients, namely in those with sufficient bone and without the need for adjunctive surgical procedures like the local guided bone regeneration (GBR) or sinus floor elevation (SFE) in the maxilla. Such surgical procedures broaden the indication for implant rehabilitation and are frequently applied, but they also increase the risk of complications. Therefore, here as well three-dimensional computer-guided planning would be advantageous even in cases when flapless procedures cannot be fully practiced. There are many opinions and disputes on this issue but little objective data. The prosthetically driven placement of implants in the edentulous maxilla is demanding; profound insight in the maxillary anatomy and individualized analysis is advantageous. The edentulous maxilla is considered to be the indication of first priority for computer-guided planning.

The aim of this study was to use computer-assisted diagnostics of maxillary CT, to perform virtual implant planning, and to evaluate the application and limitations of the three-dimensional computer technology in hypothetical indications.

MATERIALS AND METHODS

Patients

The data of 40 patients, 16 men and 24 women with a mean age of 59 ± 10 years, were used for this study. They all had an edentulous maxilla, wearing complete dentures, and asked for implant-supported prosthesis. The time of maxillary edentulousness varied from 4 months to 23 years. On the basis of their orthopantomogram, it was decided to continue the planning of these patients with a CT of the maxilla. These radiographic data were stored electronically.

Prior to the CT records, esthetics, fit of the denture base, functional aspects, occlusion, and vertical dimension of the complete dentures were checked clinically. If the patients did not have a properly designed and well-fitting denture, an optimized prosthetic setup was produced. Either the original denture or the setup was then converted into a denture-like radiographic template, which was used for the CT. This denture template

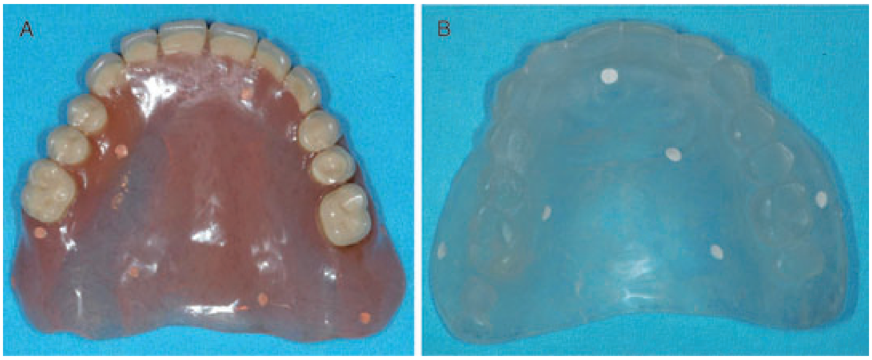

Figure 1 *A* and *B*, Denture-like radiographic templates. *A*, Denture with gutta percha markers; *B*, acrylic duplication of denture or setup with gutta percha markers.

exhibited 7 to 10 radio-opaque markers from gutta percha, scattered all over the denture (Figure 1, A and B).

Computer Technology

First, a CT had to be taken from the patients with the denture-like template in situ. Mostly spiral CTs (Somatom, Siemens, Erlangen, Germany) and a few cone-beam CTs (New Tom 9000, Quantitative Radiology, Verona, Italy) were obtained. In the context of the present study, it was found that the spiral CT had a slightly better image quality with clearer visibility of structures of interest.

During the CT records, the patients had to bite strongly on an occlusal index from a hard silicon material. Second, the CT records were taken just from the template. The electronic data of both radiographic records were processed by the computer software and combined. This allowed for a computer-assisted three-dimensional analysis of the jaw in relation of the jawbone and individual denture. In the present study, the CT analysis and virtual implant planning was performed with the NobelGuide™ software program. Accordingly, the best implant position was determined in relation to the bone structure and prospective tooth position. Replace® tapered implants (Nobel Biocare) were used for the virtual planning of the implant position.

Hypothetical Indications

In the context of the present study for all maxillary jaws of the 40 patients, two hypothetical treatment plans were performed and evaluated as follows, irrespective of the effective treatment that was carried out for the patients. The number of patients whose implants could all be placed in sufficient bone was identified. The number of implants was calculated that could be placed in sufficient quantity of bone for each hypothetical indication. Additional surgical procedures (GBR, SFE) that would become necessary as a result of the reduced bone quality and quantity were specified. As a prerequisite of immediate loading, the protocol defined that all four respectively six implants had a minimum length of 10 mm and at least two respectively three implants had a standard diameter of 4.3 mm.

Bar Overdenture. The first hypothetical indication was a bar overdenture supported by four implants. The implant location was planned in the anterior position within the area of the first premolars, well distributed to provide for an adequate length and space of the bar segments (Figure 2, A and B).

Simple Fixed Prosthesis. The second hypothetical indication was a fixed prosthesis supported by six implants. The location of the implants had to consider a distribution of three implants per jaw side, extending into the area of the second premolar or first molars and in a favorable position to the denture teeth. A full symmetry of the implant position was not required. The implant axis had to be planned for a framework that was connected on the implant level by direct screw retention without angled abutments (see Figure 2, C and D).

In order to increase the validity of the virtual analysis, two examiners completed the computer-assisted planning and their results were compared. If differences in the results were observed, the cases were reevaluated, and consensus was sought by both examiners.

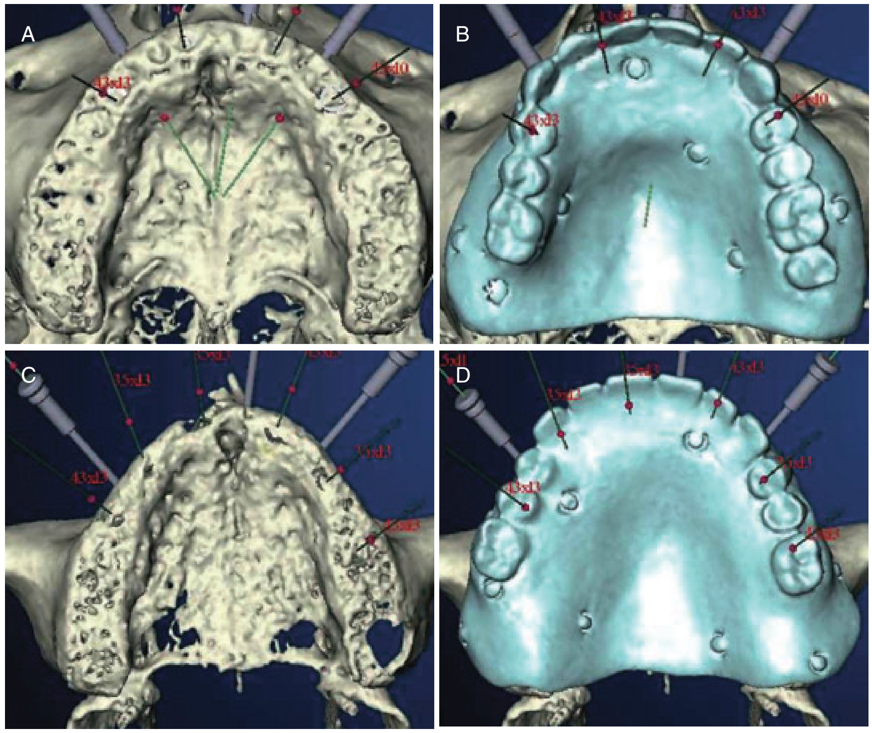

Figure 2 *A–D,* Computer analysis and virtual implant placement for the following hypothetical planning. *A,* Four implants virtually placed for a bar overdenture; *B,* in relation to the prosthesis; *C,* six implants virtually placed for a simple fixed prosthesis; *D,* in relation to the prosthesis.

RESULTS

The dentures of exactly 20 patients (50%) were of sufficient quality and were directly converted into the radiographic templates with gutta percha markers. For the remaining 20 patients, a new setup was fabricated and converted into radiographic template. Some radiographs exhibited minor artifacts but not to an extent that they could not be analyzed. In one case, the CT scan volume was insufficient and hindered an accurate virtual implant placement. Therefore, the planning of 39 patients is reported.

Computer-Guided Virtual Planning: Bar Overdenture with Four Implants

In 70% of the patients ($n = 28$), all four implants (total 112) could be placed in bone of adequate width and height without the need of adjunctive surgical procedures. Thus, a flapless procedure was suggested. In 15% of the patients ($n = 6$), the bone was insufficient in height and width, and all 24 implants of those patients could not be virtually placed. The remaining six patients (15%) had exhibited a combination of sufficient or insufficient bone. Altogether, for a total of 123 implants (79%), sufficient bone was available in height and width, while for 33 implants (21%), the width of the bone in the anterior segment was not available, and GBR would become necessary due to thin bone. There was no need for SFE as the implants were planned in a more anterior location. Figure 3A shows the number of patients and their respective number of implants in the sufficient/insufficient bone.

Computer-Guided Virtual Planning: Simple Fixed Prosthesis with Six Implants

In 30% of the patients ($n = 12$), all six implants (total 72) could be placed in the bone of adequate width and height without the need of adjunctive surgical procedures (see Figure 3B). Thus, a flapless procedure was suggested. In 18% of the patients ($n = 7$), the bone was insufficient in height and width, and all 42 implants of those patients could not be virtually placed. The remaining 21 patients (52%) exhibited a combination of sufficient or insufficient bone. Altogether, for a total of 146 implants (62%), sufficient bone was available, while for 88 implants (38%), the bone height and width in the anterior or posterior segment were not available, and

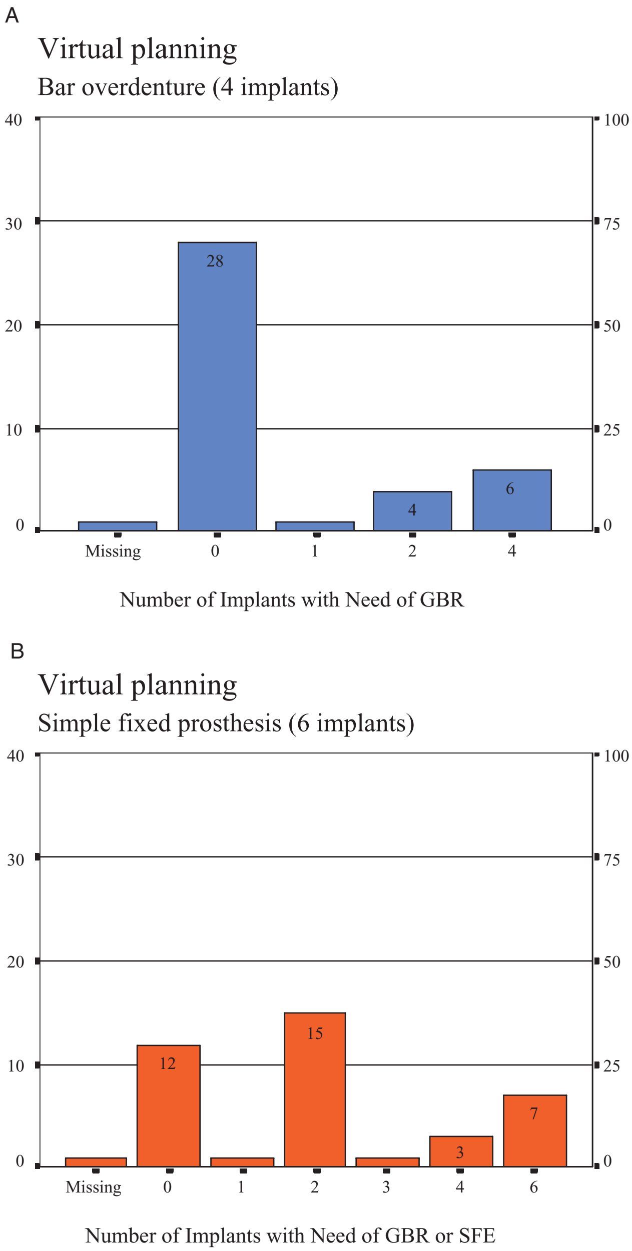

Figure 3 *A* and *B*, Columns showing the number of patients with respective number of implants that can be placed in sufficient/insufficient bone for *A*, a bar overdenture, and *B*, a simple fixed prosthesis. GBR = guided bone regeneration; SFE = sinus floor elevation.

SFE/GBR would be necessary (Figure 4, A–C). Sinus lift procedures became necessary for a total of 51 implants in 17 patients in one or both sides.

DISCUSSION

Computer-guided systems available in the market appear to offer clear benefits, although precision of the systems, investment, and cost–benefit ratio of such treatment strategies are still controversially discussed and need further evaluation.[13] The computer-guided system (NobelGuide) consists of three steps: (1) analysis of radiographs including virtual implant planning; (2) fabrication of surgical guides followed by a surgical flapless procedure; and (3) immediate loading by a provisional prosthesis, within "1 hour" as promoted by current marketing. The prosthesis has to be fabricated before the surgical intervention takes place. The advertisement of computer-guided flapless solution with the NobelGuide system is euphoric, focuses much on immediate loading, and tends to overlook patients' individual oral and anatomic conditions. Otherwise, the high value of three-dimensional planning is not sufficiently underscored. In order to better understand the advantages and limitations of the computer-guided system, this present study was conducted with the most demanding anatomic site. The edentulous maxilla was selected for prosthetically driven three-dimensional implant planning. The virtual planning cannot fully control the primary stability of the implants, and immediate loading was not the important outcome of the present study. The study, first of all, intended to focus on optimized planning and, subsequently, on the facilitation and safety of surgical procedures. It is well known from various studies that atrophy, and loose and osteoporotic bone are often encountered in the edentulous maxilla, and implant placement becomes difficult or not feasible at all.[14,15] In certain patients, complete grafting of the entire maxilla would be necessary. In the present analysis of 40 patients, it was observed that four implants for overdenture support could be located in the sufficient bone and adequate position in 70% of the patients and 79% of the implants. Reduced implant diameter and the need for GBR were regarded necessary for another 21% of the implants. This demonstrates that often a thin bone wall in the anterior region is present. Otherwise, if implants for an overdenture are planned, an SFE could be avoided. On the basis of the hypothetical treatment option, only a few patients had to be excluded completely from implant placement for planned bar overdentures.

With an increasing number of implants – as necessary for fixed prosthesis – their placement in a more posterior zone becomes critical and is conflicted with reduced bone height and deep sinus floor. The need for transcrestal or lateral SFE is obvious. The prerequisite for the installation of all six implants by means of a

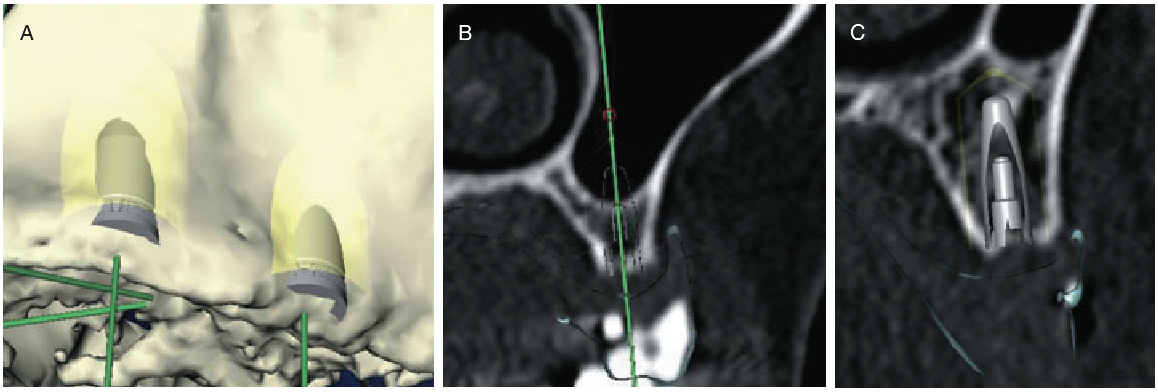

Figure 4 *A–C*, Virtual implant placement in optimized prosthetic position. *A*, with need of buccal guided bone regeneration; *B*, with need of sinus floor elevation; *C*, compared with an implant in sufficient bone.

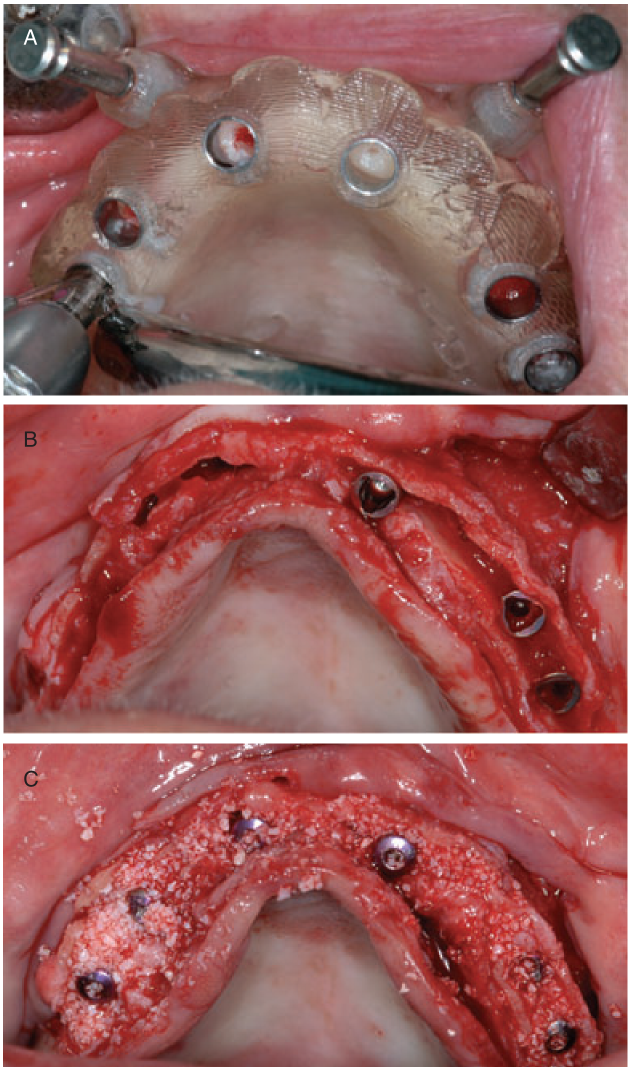

Figure 5 *A–C*, Maxillary jaw with insufficient bone width. *A*, pilot drilling is performed in the best position according to virtual planning with stereolithographic surgical splint; *B*, flap is raised and implants are placed according to the pilot drill with the bone split technique; *C*, situation after the space is filled with Bio-Oss® (Geistlich Söhne AG, Wolhusen, Switzerland) material.

guided flapless procedure fulfilled only 30% of the patients. But still, 62% of the implants might be placed in the sufficient bone, while in 38% of the implants, either transcrestal or lateral SFE[16,17] would be necessary or a reduced diameter and local GBR with membrane technique.[18]

From the present data, it is confirmed that a full flapless is not available for many patients. But it is also concluded that computer technology and conventional surgery can be applied in the same patients in a one- or two-stage procedure. Dentists have to learn and become aware that a combination of guided flapless technique and conventional surgery is feasible and may be advantageous. The splint is used for the pilot drilling of all implants. Eventually, the respective implants are placed in a flapless way where sufficient bone is present. Then, the surgical splint is removed and surgery is completed by raising a flap, followed by selective additional

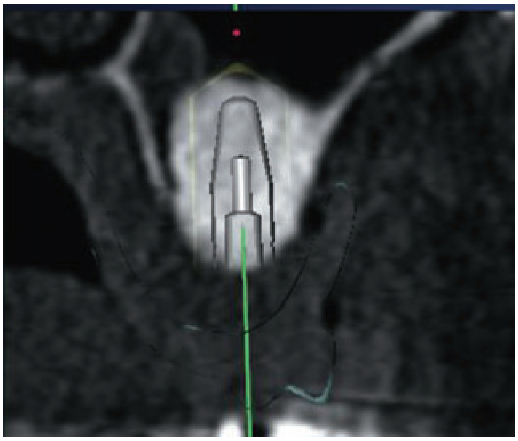

Figure 6 Computer-guided implant placement in the augmented sinus.

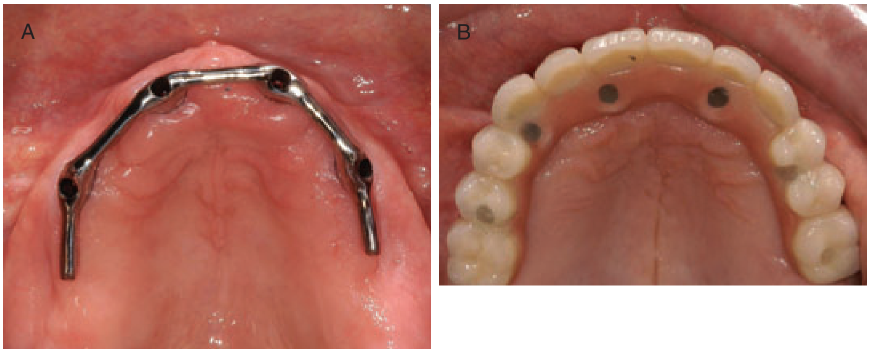

Figure 7 *A*, Clinical view of a bar overdenture; *B*, clinical view of a simple fixed prosthesis.

procedures (transcrestal implant placement, lateral SFE, local GBR, or bone splitting) for the remaining implants (Figure 5). If a lateral SFE is performed in a two-stage way, again the best position of the implant in the augmented site can be carefully determined by subsequent computer-guided planning (Figure 6).

Advantages of a computer-guided technology in implant dentistry would be more safety in planning and better control of the prospective implant axis in relation to the prosthetic tooth position. This leads to a higher predictability of the treatment outcome with subsequent better patient information about the implant prosthodontic treatment. One important prerequisite of the technology is not sufficiently underscored so far. It is the expertise and experience in prosthodontics, particularly full complete dentures, that is strongly needed if the planning tool is to be successfully applied. Figure 7, A and B shows the final reconstructions in situ with optimal implant axis for both the bar and the simple fixed prosthesis.

Critical objections against such computer technology are increased costs, for purchasing the software, for the training of the dentists, and for the stereolithographically produced surgical templates. Time investment for the planning process also means an increase in costs.

However, three-dimensional analysis of computer tomograms and virtual implant placement, once the doctor is familiar with the software, are fast. A compensation of costs results from reduced chairside time when doing surgery and a reduction of follow-up visits of the patients. Reduced patient morbidity is further an important aspect that cannot be calculated directly in money, but is beneficial for the patients.

CONCLUSIONS

An efficient planning tool based on new computer technology facilitates final decision making in implant prosthodontic treatment. In compromised situations with some bone available, the best position of the implant placement is evaluated, and the need for additional surgical interventions can be exactly determined. This improves the predictability of treatment goal, allows for a better risk management, and provides more individual information for the patient. These are the most important aspects of this technology, which may contribute to establish higher-quality standards in implantology.

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