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Image-Guided Implantology and Bone Assessment

CAD CAM drilling guides for transferring CT-based digital planning to flapless placement of oral implants in complex cases

A. Francesco Valente[a] · B. Andrea Sbrenna[b]· C. Claudio Buoni[c]
[a]Rome, Italy
[b]Perugia, Italy
[c]Campus Biomedico University, Rome, Italy

Abstract The medical field is experiencing a robust trend toward minimally invasive surgical procedures This is made possible by the improvement of both diagnostic and operating equipment.
In oral implantology this trend is now mainstream thanks to the integration of CT scans, digital treatment planning software and smart oral appliances that exactly transfer the computerized planning to the surgical field. The present prospective clinical study shows how this approach may be useful also in complex, multi-implant cases. Fifty-six Brånemark System MKIV Tiunite^{TM} implants have been inserted 14 patients with minimally invasive computer-aided implant surgery and followed for 1 year. The implant success rate was 98.3% demonstrating that this approach is a predictable procedure. At the same time intraoperative and postoperative morbidity proved to be minimal leading to a greater patient satisfaction.

Keywords Prospective clinical study · Flapless surgery · Dental implant · Computer-aided implantology · Computed tomography

1 Introduction

Two of the most notable trends in modern surgical specialties are *minimally invasive surgery* [1] and the integration of computerized diagnostics and *computer-aided surgery*, in its different forms.

In oral implantology these two trends are now mainstream in the form on one side of the so called flapless surgery or minimally invasive implant surgery (MIIS) and on the other side of the computer-aided implant surgery (CAIS). Even tough MIIS and CAIS are independent techniques and indeed flapless surgery can be performed in some cases without the aid of the computer and on the other hand a computer-aided approach not always allows a flapless procedure, these two approaches can be very often combined with great advantage.

2 Minimally invasive implant surgery

In oral implantology MIIS is not new indeed and was practiced long before the advent of the osseointegration era in the 1960s [2]. Then the technique was abandoned because in contrast to the principles of osseointegration that advocated a submerged healing as a prerequisite for oral implant integration to the bone. When this principle proved to be partially incorrect the flapless approach reappeared in the literature. However in spite of the recent revival studies focusing on the efficacy of MIIS approach are scarce and none of them is a randomized controlled study; nonetheless the results are encouraging [3–5]. The most important raison d'être of MIIS is the reduction of patient morbidity through the mini-invasive approach. The advantages of flapless oral implant surgery compared to the open flap approach parallel those of a laparoscopic abdominal surgery compared to a laparotomy. The advantages for the patient are: reduction of surgical time; significant reduction or elimination of postoperative pain, bleeding, edema and ecchymosis; reduction of postoperative functional limitations; optimal esthetics because of absence of scars produced by incisions and respect of papilla integrity [6]. Furthermore the prosthetic phase of an immediate implant loading protocol, when indicated, is accomplished in a much easier and cleaner manner. Disadvantages of MIIS are the risk of partially inserting the implant outside of the bone envelope producing bone dehiscences or fenestrations and the greater surgical difficulty: being a blind surgical procedure MIIS requires a great deal of experience and dexterity. Indications for MIIS are those cases where the following criteria are fulfilled:

1. A bone crest of adequate dimensions to minimize the risk of fenestrations.
2. Possibility of inserting implants with good primary stability. A great caution should be therefore used with MIIS in type IV quality bone, implants associated with sinus lift and short implants.
3. Adequate dimensions of attached gingiva: even though the presence of attached gingiva is not necessary for the long-term success of oral implants [7], it is certainly desirable [8].
4. No need for bone augmentation.
5. No need for soft tissue augmentation. In the presurgical soft tissue evaluation it should be taken into account the recession that usually occurs after implant therapy [9]. Therefore MIIS should be used with caution in the esthetic zone.
6. One specific indication to MIIS is the immediate post extraction case, where the buccal bone is maintained and there is no need for regenerative procedures.

In conclusion it seems that there are several indications for MIIS, but the traditional open flap approach will continue to have a place in contemporary implant dentistry.

3 Computer-aided implant surgery

The advantages of CAIS are significant and can be summarized in: possibility of operating with a minimally invasive approach, greater accuracy and safety, reduction of surgical time, greater prosthetic success, possibility of manufacturing the prosthesis before the surgery. Main disadvantages of CAIS are the cost and the high dose of radiation with spiral CT. Cost and radiation dose can be significantly reduced with cone bean CT [10]. Today CAIS can be performed with three different methods:

1. Passive system: navigating with an optical tracking system [11] or a magnetic tracking system [12]. Navigation gives more freedom and flexibility to the surgeon that can modify the planned position of the implants. However navigation is more prone to human error and less accurate than semi-active systems.
2. Semi-active system: high precision technologic tools (surgical guides) with which to transfer the planned surgery to the surgical field are fabricated with computer-aided manufacturing (CAM) robotic technique.
3. Active system [13]: at least part of the surgery is directly performed by a robot equipped with sensors and a mechanical arm controlled by the surgeon. Active systems in implantology are still in a preclinical pioneering phase of development.

We believe that CAIS can be used with great advantage not only in simple cases, but also in the so-called complex cases, as those with limited amount of bone, those involving the completely edentulous patient, implants in the esthetic zone and tilted implants. The purpose of this study is to present the association of Minimally Invasive and CAIS in complex cases.

4 Materials and methods

Fourteen patients ranging in age from 30 to 72 years were consecutively treated in two clinical centers with mini-invasive flapless and computer-aided surgery using CAD–CAM stereolithographic surgical guides.

Entry criteria include absence of general contraindications to implant surgery and presence of partial or full edentulism such to define the case as complex according to the aforementioned criteria.

Nine patients were males and 5 were females; 3 were smokers and 4 were bruxists; 11 patients suffered from periodontal disease treated prior to implant therapy.

4.1 Treatment planning

The system we used in this clinical study is a semi-active one and consists in a integrated treatment sequence, that generally involves the following steps:

1. Fabrication of a radiopaque diagnostic appliance (Scanprosthesis©), exact replica of the final prosthesis (acceptance prosthesis) (Fig. 1a, b)

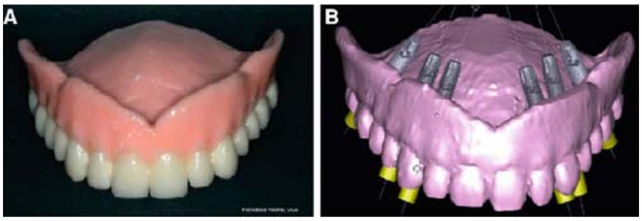

Fig. 1 **a** Scanprosthesis. **b** The same Scanprosthesis during the digital surgical planning

2. Computed tomography generally performed by spiral CT. It is essential to include in the scan the radiopaque template so to integrate the anatomical with the functional and aesthetic determinants.
3. Digital 3D CT-based surgical planning
4. CAM fabrication of stereolithographic oral appliances that exactly transfer the computerized planning to the surgical field
5. Computer-aided surgery

There are now numerous CT-based software available for 3D implant planning. The one shown in the present case series is the SimPlant© software (Materialise n.v., Leuven, Belgium) that uses the original DICOM CT data to produce axial, 3D, panoramic and cross-sectional images, all visible at the same time in four interactive windows in the computer screen (Fig. 2). With this software the jaws can be seen from any viewpoint and the implants virtually placed according to the bone anatomy and prosthesis design. The bone quality of the planned sites can be evaluated in Hounsfield units.

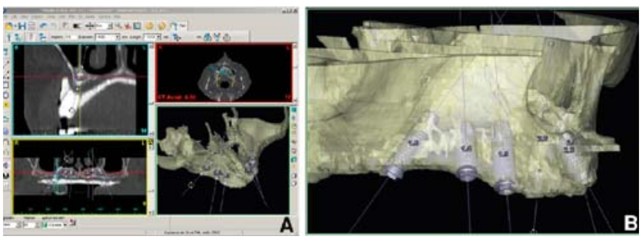

Fig. 2 **a** The new Beta version of SimPlant© 10 software with four interactive panes: axial, 3D, panoramic and cross-sectional images; **b** 3D image of a severely atrophic maxilla with two distal implants tilted to bypass the maxillary sinus

Once the planning was completed it was sent via the Internet to the production centre where by using CAM technology custom drill guides (SurgiGuides©) have been produced by a laser that polymerize liquid acrylic resin in layers (stereolithography). After resin polymerization, stainless steel drill guide cylinders of different diameters are positioned along the planned implant axis. The SurgiGuides© provide a link between the digital plan and the actual surgery (Fig. 3). Such drill guides render obsolete the traditional mental transfer of the planning to the surgery and the mental

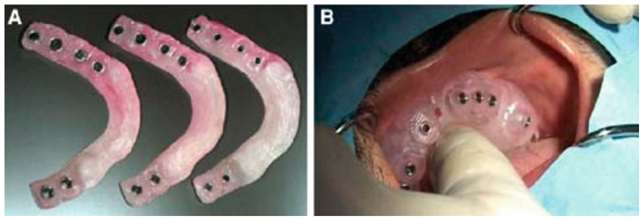

Fig. 3 **a** Three SurgiGuides© with combined mucosa and tooth support in a partially edentulous mandible. Notice the metal cylinders of increasing diameter. **b** Checking the fit of the SurgiGuides© in a fully edentulous maxilla

navigation process that while giving a great deal of freedom to the surgeon increases variability and errors compared to the planning.

4.2 Surgical procedure

Patients took amoxicillin 2 g 1 h before the start of the procedure and 1 g b.i.d. for the following 3 days. Anesthesia was administered with articaine with 2% adrenaline (Ultracain, ESPE, Seefeld, Germany). After checking the fit of the surgiguides the osteotomy were performed with burs of increasing diameter under copious irrigation. After the 2 mm drill a mucotomy was performed exactly concentric to the osteotomy using a dedicated flapless kit (Nobel Biocare italiana, Milano, Italia). Care must be taken to avoid movement of the surgiguides during the procedure (Fig. 4a). Nobel Biocare Brånemark Implants of different lengths (range 8.5–15 mm) and diameters (4 and 5 mm) were finally inserted (Fig. 4b). Eleven implants in four patients were subjected to an immediate occlusal loading protocol. For each implant site the bone quality [14], the final insertion torque (Fig. 5a), the resonance frequency analysis (RFA) in implant stability quotient (ISQ) and the implant dimensions have been registered. Bone level has been measured at the surgery and at the 6 months follow-up. Probing pocket depth and bleeding on probing were also recorded at follow-up. Patient satisfaction was evaluated using a 100 mm visual analog scale questionnaires. For nine patients follow-up CT have been prescribed.

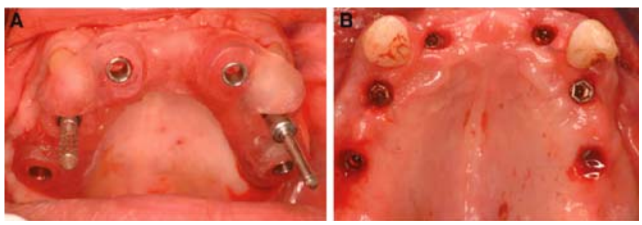

Fig. 4 **a** stabilizing the surgiguide with direction indicators and burs. **b** the implants flaplessly inserted with no incisions, no sutures and very little bleeding

3.3 Results

Fifty-six implants have been inserted with this protocol and followed for at least 6 months and for a maximum of 24 months. The mean insertion torque was 35 Ncm. The mean ISQ was 71.2 at insertion and at 75.6 at 6 months follow-up. All implants but one were integrated and functional at the 6 months follow-up, giving an implant survival rate of 98.3%. Regarding general satisfaction with the treatment the mean score on the VAS was 90 (range 62–100) and the mean score for pain and bleeding after the surgery were, respectively, 17 and 5. The analysis of the follow-up CT have shown good correspondence between the planned and the final fixtures position.

5 Conclusion

The reduction of iatrogenic morbidity has always been a cornerstone of medical ethics. MIIS reducing patient experience of pain and discomfort almost to zero strictly complies with the golden medical rule of ''Primum Non Nocere'' and should be utilized whenever possible. The computer-aided approach can afford a Minimally invasive surgical access in the majority of implant cases otherwise bounded to receive an open surgical procedure and for this reason has the potential of dramatically changing the oral implant scenario.

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Is the course of the inferior alveolar nerve deducible from the shape of the mandible?

S. Zachow[a] · H. Lamecker[a] · B. Elsholtz[b] · M. Stiller[b]

[a]Zuse-Institute Berlin (ZIB), Medical Planning Systems, Germany

[b]Universitätsmedizin Berlin, Charité, Campus Benjamin Franklin, Germany

Abstract In a predominant amount of cases in orthodontics and orthognathic surgery, from the removal of wisdom teeth or cysts up to osteotomies, two-dimensional imaging is the first, and often the only method of the diagnostic process However, without knowing the exact course of the mandibular nerve, the risk of an unintended lesion during an intervention is considerably high. This becomes even more relevant with an increasing number of cases, *and complications*, in dental implantology and orthognathic surgery. Hence, three-dimensional (3D) imaging such as cone beam tomography or DVT is increasingly employed. Within this study we are going to analyze the 3D courses of the mandibular nerves statistically, aiming to provide knowledge about the *potential* course of the mandibular canal for two-dimensional imaging, thus extending diagnostics and therapy planning in dento-maxillofacial surgery or dental implantology.

Keywords Orthognathic surgery · Dental implantology · OPG · Mandibular nerve · Statistical shape model

1 Introduction

In dental implantology a primary concern is an optimal and stable placement of implants within the jaw-bone without any impairment of the facial nerves. Typically implant planning is performed on the basis of panoramic X-ray images (so-called orthopantomograms, OPG). However, such OPGs do not provide information on the thickness or width of the mandibular corpus and the lateral position of the inferior alveolar nerve (IAN), which is located between the mandibular and mental foramina. The only information that can be perceived from such two-dimensiomal (2D) images is the height in cranial-caudal direction and the vertical position of the nerve. A decision, whether or not an implant could pass a nerve, which might be beneficial for an increased stability, cannot be made. With dental CT scanners one can overcome this problem, thus a more reliable three-dimensional (3D) planning with regard to the mandibular nerve becomes possible. But, not in all cases a 3D scan is indicated, and time and effort acquiring a DVT is currently higher than that of an OPG. In this study we develop a statistical 3D shape model of a human mandible *including* the IAN, aiming to evaluate the variations in the courses of the mandibular canals, and whether or not these courses are deducible from the shape of the mandible.

2 Previous works

An early classification of the vertical positions of the course of the alveolar nerve was reported by Carter and Keen [1]. Three main courses were identified on basis of eight dissected mandibles (Fig. 1, left). In a study of Nortje et al. [2] the course of the IAN was evaluated with the help of 3,612 panoramic radiographs. In conclusion three distinct variations between the apices of the roots of the teeth and the lower border of the mandible were described, predominantly being bilaterally symmetrical. In about 3% of the mandibles duplication or division of the canal, partial or complete absence, or lack of symmetry was found.

Multiple mandibular canals, characterized by a single mandibular foramen and two nearly equal canals are rather unusual. Duplication or division of the canal was found in 0.9% (33/3,612) of all cases. This observation was confirmed in an evaluation of 6,000 panoramic radiographs, with 57 (0.95%) cases of so called *bifid mandibular canals* [4]. In a review by Anderson et al. [5] was stated, that the buccal–lingual and superior–inferior positions of the IAN were not consistent among mandibles. The IAN frequently ran a concave

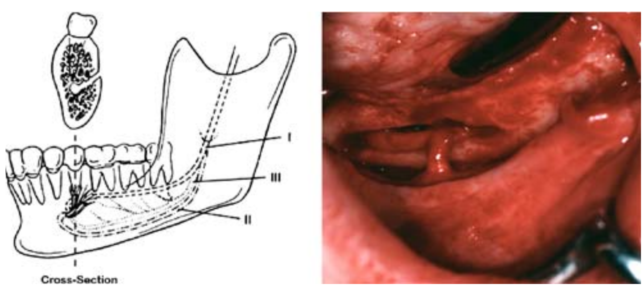

Fig. 1 *Left* variation of the vertical position of the inferior alveolar nerve according to [1] (reproduced from [3]); *right* mental foramen view, preparation of an inferior alveolar nerve for transposition