

RATIONALE FOR TILTED IMPLANTS: FEA CONSIDERATIONS AND CLINICAL REPORTS

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SUMMARY

Rationale for tilted implants: FEA considerations and clinical reports.

The prevalence of the elderly population, as well as life expectancy, increased in the final decades of the 20th century, as described in the World Health Organization 2004 Annual Report. The edentulous condition therefore has a negative impact on the oral health-related quality of life. Patients wearing complete dentures for many years intact, and especially in the mandible, are often unsatisfied because of the instability of the prosthesis during speaking and eating. To date dental implant treatment is well documented as a predictable treatment for partial or complete edentulism. On the other hand the rehabilitation of atrophied edentulous arches with endosseous implants (> 10 mm) in the posterior regions is often associated with anatomic problems such as bone resorption, poor bone quality, mandibular canal, and the presence of maxillary sinuses. Different procedures have been proposed to overcome these anatomic limitations. The use of tilted implants parallel to the anterior wall of the maxillary sinus or the mental foramen/inferior alveolar nerve has been proposed as a conservative solution for the treatment of the atrophic edentulous maxilla. Aim of this study was to describe, through a detailed literature review, the clinical and biomechanical rationale for tilting implants and to evaluate the long-term prognosis of immediately loaded full fixed prostheses for the treatment of edentulous patients (#35) with extreme bone atrophy rehabilitated with both axial (#70) and tilted (#70) implants from 2008 to 2010. The results of the present study would suggest that this new surgical technique may reduce patient morbidity and extend the indications for immediate loading full fixed rehabilitations. 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.

Key words: tilted implants, FEA, immediate loading, full fixed rehabilitation.

RIASSUNTO

Razionale per impianti inclinati: considerazioni FEA e relazioni cliniche.

La prevalenza della popolazione anziana, così come l'aspettativa di vita, è aumentata negli ultimi decenni del XX secolo, così come descritto dal Rapporto Annuale 2004 della Organizzazione Mondiale della Sanità. La condizione di edentulia correlata ha quindi un impatto negativo sulla salute orale in relazione alla qualità della vita. Infatti i pazienti portatori di protesi totali da molti anni, soprattutto quelle mandibolari, sono spesso insoddisfatti a causa della instabilità della protesi durante importanti funzioni quali la fonazione e la masticazione. A tuttoggi la riabilitazione implantare per il trattamento dell'edentulia parziale o totale è stata chiaramente documentata come predicibile. D'altra parte la riabilitazione delle arcate edentule atrofiche mediante impianti endossei (> 10 mm) nelle regioni posteriori è spesso associata a problemi anatomici come appunto: il riassorbimento osseo, la scarsa qualità dell'osso, il canale mandibolare, e la presenza di seni mascellari. Diverse procedure sono state proposte per superare questi limiti anatomici. L'uso di impianti paralleli inclinati alla parete anteriore del seno mascellare o ai forame mentoniero/nervo alveolare inferiore è stata proposta come una soluzione conservativa per il trattamento del mascellare edentulo atrofico. Scopo di questo studio è stato quello di descrivere, attraverso una revisione dettagliata della letteratura, le ragioni cliniche e biomeccaniche per l'inclinazione degli impianti e di valutare la prognosi a lungo termine di protesi a carico immediato per il trattamento di pazienti edentuli (#35) con atrofia ossea estrema riabilitati con impianti sia assiali (#70) che inclinati (#70) dal 2008 al 2010. I risultati del presente studio suggeriscono che questa nuova tecnica chirurgica è in grado di ridurre la morbilità del paziente e di estendere le indicazioni al carico immediato nelle riabilitazioni protesiche fisse totali. Tutto questo migliora la prevedibilità dell'obiettivo terapeutico, permette una migliore gestione del rischio, e fornisce informazioni più individuali per il paziente. Questi sono gli aspetti più importanti di questa tecnologia, che può contribuire a stabilire standard di più alta qualità in implantologia.

Parole chiave: impianti inclinati, FEA, carico immediato, riabilitazione fissa totale.

Introduction

The prevalence of the elderly population, as well as life expectancy, increased in the final decades of the 20th century, as described in the World Health Organization 2004 Annual Report. The edentulous condition therefore has a negative impact on the oral health-related quality of life. Patients wearing complete dentures for many years in fact, and especially in the mandible, are often unsatisfied because of the instability of the prosthesis during speaking and eating. To date dental implant treatment is well documented as a predictable treatment for partial or complete edentulism (1). Edentulous patients treated with prostheses supported by osseointegrated implants can realize improved masticatory function in terms of chewing efficiency and bite force. However, it is reported that patients who asked for implant therapy but received conventional dentures are not fully satisfied showing only a marginal improvement in their quality of life. On the other hand the rehabilitation of atrophied edentulous arches with endosseous implants (> 10 mm) in the posterior regions is often associated with anatomic problems such as bone resorption, poor bone quality, jaw shape and location of the mental foramen or loop of the alveolar nerve, mandibular canal, and the presence of maxillary sinuses (2-4). Therefore in the past, according to the original concept for the placement of Brånemark System implants in atrophied completely edentulous arches, the implants were placed in a fairly upright position. With such implant position it was often necessary to fabricate a bilateral cantilever (Fig. 1) that was up to 20 mm in length so as to provide the patient with good chewing capacity in molar regions, increasing the risk of implant failure (5-8). Different procedures have been proposed to overcome these anatomic limitations. The least invasive is the use of short implants (9); however, when bone height is insufficient even for short implants, reconstructive alternatives, such as autogenous bone grafting (10) and sinus lift augmentation (11) may be indicated. Other techniques may also be used, such as implants placed in the pterygomaxillary region (12) and zygomatic implants (13). Nevertheless, each of these techniques presents disadvantages, such as morbidity in graft



Figure 1

When the implants are placed in a fairly upright position is often necessary to fabricate a bilateral cantilever to provide the patient with good chewing capacity.

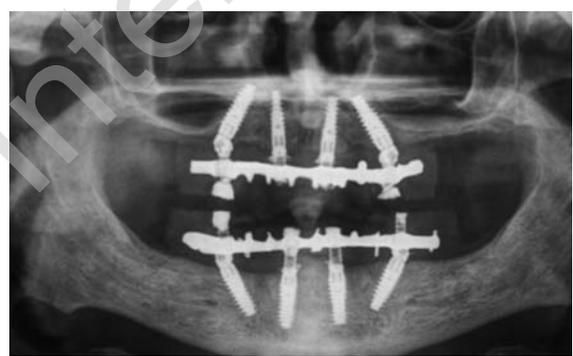


Figure 2

The use of tilted implants parallel to the anterior wall of the maxillary sinus or the mental foramen/inferior alveolar nerve has been proposed as a conservative solution for the treatment of the atrophic edentulous maxillae.

donor sites, postoperative discomfort, questionable predictability, and surgical complexity (14-16).

The use of tilted implants parallel to the anterior wall of the maxillary sinus or the mental foramen/inferior alveolar nerve (Fig. 2) has been proposed as a conservative solution for the treatment of the atrophic edentulous maxillae (17-22).

Rationale for tilted implants: feasibility considerations

The biomechanical rationale for using inclination of distal implants is based on the reduction of can-

tilt length and as a consequence give rise to better load distribution of the prosthesis support. Additionally, tilting implants can optimize the anterior/posterior spread of the implants along the alveolar crest increasing the polygonal area to provide satisfactory molar support for a full fixed prosthesis (FFP) of 12 masticatory units. Krekmanov et al. (17) reported a gained mean distance of 6.5 mm of prosthesis support in the mandible and 9.3 mm in the maxilla, as a result of implant tilting.

The tilting may also allow for improved cortical anchorage and primary stability as well as the use of a longer implant. By tilting the implant in fact, a more posterior implant position can be reached, and improved implant anchorage can be achieved by benefiting from the cortical bone of the wall of the sinus and the nasal fossa.

Clinically the inclination of posterior implants is usually performed with distalization of the implant emergency sites.

In the maxilla, the presence of large sinuses may require the installation of implants parallel to the anterior sinus walls with distal inclination.

In the mandible, the further the mental foramen are from the alveolar crest, the greater the distal implant inclination can be, and, consequently, the implant platform is located more distally. The ‘apex’ of these implants and the rotation fulcrum are located in the canine region, and the implant platform emerges in the first or second premolar region.

Several clinical studies have reported high survival rates (Table 1) for tilted implants (23-26). However,

questions remain relative to the amount of stress generated at the bone surrounding tilted implants.

In 2008 Bevilacqua et al. (27) performed a 3-dimensional finite element analysis to study the stress values surrounding tilted versus vertical implants both singularly or splinted in a full fixed prosthesis (FFP).

They found that single tilted implant, submitted to a vertical load, demonstrated higher peri-implant bone stress than the single vertical implant submitted to the same vertical load. The stresses increased as the tilt of the single implants increased. When the implants were splinted in a rigid FFP, however the use of tilted distal implants, with reduced cantilever lengths, resulted in lower mechanical stresses on the peri-implant bone with respect to the vertical implants with longer cantilevers.

Moreover a reduction of stress around anterior implants was observed with the tilted distal implants compared to the vertical implant FFP design.

Multi-unit prostheses may demonstrate greater inaccuracies compared with single implant restorations in fact, but due to the absence of moment loading, the multi-implant configuration appears to compensate for the higher strain development. With regard to the FFP framework stress finally, lower von Mises values were observed with tilted implants than with vertical implants.

These and other (17-19,21) encouraging results have done so as that the last frontier in implant dentistry is represented by reducing the number of implants supporting a prosthetic rehabilitation as well as the

Table 1 - Results of the tilted implants main clinical studies.

Adhesive	Test	Samples	Mean (MPa)	SD	
Author (year)	Observation period (average months M)	Number of implants: axial and (tilted)	Implant survival rate: axial and (tilted)	Marginal bone loss: axial and (tilted)	Degree
Krekmanov (2000)	5 years (37 M)	59 (42)	91,3% (95,2%)	0,92 mm (1,21 mm)	30
Aparicio(2001)	5 years (46,5 M)	66	93% (98%)		25/35
Fortin(2002)	5 Y	245	97%		30/35
Malò(2003)	1Y	58 (58)	96,7%		30
Malò(2005)	1Y	64 (64)	97,6%	0,9 mm	30
Malò(2007)	21 M (13 M)	46 (46)	97,8%	1,9 mm	30
Testori(2008)	1Y	164 (82)	98,8%	0,9±0,4 (0,8±0,5)	30/35
Agliardi(2010)	30 months	48 (48)	100%	0,9 mm(0,8 mm)	

time that elapses between implant placement and prosthetic loading.

Such recent studies infact have reported good clinical outcomes when a combination of axial and tilted implants is used to support a fixed full-arch rehabilitation in either arched.

From this point of view the success of the protocols in which four implants were placed to support a full-arch prosthesis indicate that the placement of larger numbers of implants may not be necessary for successful implant treatment of edentulous arched.

Biomechanical analyses indicate infact that the most anterior and posterior implants supporting a reconstruction take the major load share at cantilever loading, irrespective of the number of intermediate implants. For a given distance between the anterior and the posterior implant, the load supported by the most heavily loaded implant (the distal implant) is virtually independent of the total number of implants that support the restoration (28).

The larger the ratio cantilever/potency arm, the larger the compressive forces on the abutments. With the increase of cantilever distance there is an increase of axial force and saggital bending moments and the largest effects occur in the abutment adiacent to the cantilever itself. From this point of view the results from the study of Geremia et al. in 2009 (29) showed that ***the force on abutment adjacent to cantilever of the tilted model with loading at the maximum cantilever distance (20 mm) was even lower than the straight counterpart with loading at 10 mm.***

Clinical guidelines usually recommend that the cantilever should not be longer than 2.5 times the anteroposterior distance, and other variables should be considered to determine cantilever length, such as bone quality, number and diameter of implants, and opposing arch conditions.

However if a cantilever is inevitable, short distal implants may be an alternative to restrain the vertical movement of the cantilever end. Furthermore, when good anchorage to the prosthesis is mandatory and here are anatomical restrictions to place implants more distally, tilting distal implants has been recommended. The inclination of distal implants infact does not have any deleterious biomechanical effect on abutments of the tested models and may re-

duce the absolute value of compressive stress compared with the nontilted, indicating a possible biomechanical advantage in reducing stresses at the bone-implant interface (30,31).

High survival rates have been frequently reported in the literature for immediate function of fixed mandibular complete-arch prostheses supported by three or four implants. However, when immediate loading is applied in the maxilla, a larger number of implants is generally used, although documented experience on delayed loading has shown equivalent outcomes when comparing the use of four or six maxillary implants as support for fixed full-arch prostheses.

An interesting contribution in this way came in 2010 from the study of Carvalho Silva et al. (32). The authors, using the three-dimensional finite element method (FEM), compared the biomechanical behavior of the "All-on-Four®" system with that of a six-implant-supported maxillary prosthesis with tilted distal implants. The models were subjected to four different loading simulations (1-full mouth biting, 2-canine disclusion, 3-load on a cantilever, 4-load in the absence of a cantilever). The results of the mathematic solutions were converted into visual results and expressed in color gradients, ranging from red to blue, with red representing the highest stress values. ***In both models, in all loading simulations, the peak stress points were always located on the neck of the distal tilted implant.*** The von Mises stress values were slightly higher in the "All-on-Four" model (7% to 29%, higher, depending on the simulation) and in the presence of a cantilever, the maximum von Mises stress values increased by about 100% in both models. In conclusion the stress locations and distribution patterns were similar in the different models, however the addition of implants resulted in a reduction of the maximum von Mises stress values mainly obvious during canine disclusion. Within the limitations of this study, it could be concluded that the stress location and distribution patterns were very similar in the two models. The addition of implants in the six-implant model, increasing the prosthesis support, resulted in a decrease in the maximum von Mises stress values. The cantilever should be avoided or minimized, as its presence greatly increases stress on the distal implant,

regardless of whether or not the prosthesis is supported by four or six implants. Cantilevered FDPs also reveal a higher incidence of technical complications, such as screw loosening or fracture (33-35). The clinical implication of these studies is that more patients can be successfully treated with dental implants without more complex techniques, such as nerve transposition in the mandible or grafting of the maxilla. Treatment of some patients would not have been possible with conventional placement without grafting or other more demanding procedures. Tilting per se is not considered to be more complicated than conventional implant placement, as experienced by many authors. The method of tilting implants described for treatment of edentulous arches represents an alternative or complementary technique to others mentioned in the literature. It leads to an improved position of the support and allows for placement of longer implants and/or improved anchorage in dense bone.

Biomechanical measurements show that the tilting does not have a negative effect on the load distribution when it is a part of prosthesis support.

The advantages are further extension of the prosthesis in a posterior direction, possible use of longer posterior implants, and improved bone anchorage. The technique is relatively easy to perform in any outpatient setting by a surgeon who is not familiar with transpositioning of the mandibular nerve or bone grafting of the maxillary sinus. Furthermore, it eliminates the need for such advanced techniques for some patients.

Material and methods

A prospective three-year clinical study on 35 consecutive patients (140 implants), aged between 38 and 77 years (average: 54,18) with severely atrophy maxilla and/or mandible was carried out (36,37). Inclusion criteria were as follows: inclusion criteria were patients of any race and sex at least 18 years of age in good systemic condition without contraindications to surgical and restorative procedures; completely edentulous mandible/maxilla or periodontally compromised teeth with poor long-term pro-



Figure 3
Periodontally compromised teeth with poor long-term prognosis.

gnosis (Fig. 3); sufficient bone height and width in the intraforaminal zone or in the pre-maxilla for the insertion of at least 10-mm-long and 4-mm-wide implants; presence of extremely atrophic posterior mandible or maxilla that would require bone augmentation prior to implant placement; and patients who had rejected any type of bone-grafting procedure. Exclusion criteria were acute infection at the intended implant site, hematologic diseases, coagulation problems, presence of immunological diseases, uncontrolled diabetes, metabolic bone disease, pregnancy or lactation, bruxism or clenching, irradiation of the head or neck region or chemotherapy within the past 12 months; poor oral hygiene; and poor motivation to return to scheduled control visits.

All patients were informed of the purpose of the study, as well as possible alternative treatments, and provided their written consent.

Starting 2 days before surgery and then for each day for the first week afterward, patients rinsed twice daily with chlorhexidine digluconate 0.2% mouthwash. Surgery was performed under local anesthesia with articaine chlorhydrate with adrenaline 1:100,000 and intravenous sedation with diazepam (Valium 5 mg, Roche). Patients were premedicated with 2 g of amoxicillin and clavulanic acid (Augmentin, Roche) 1 hour prior to surgery and continued with 1 g twice a day for 1 week postoperatively. Cortisone (Seldesam 4 mm), anti-inflammatory (Lixidol 30 mg), and antacid medication (Zantac 50 mg) were given during the surgery. Analgesics (Naprossene Sodico [Synflex Forte], Recordati) were prescribed in case of pain. All patients received four implants (Nobel

Active®, Nobel Biocare AB, Göteborg, Sweden). A flapless or miniflap approach were used. All patients were treated by guided surgery (NobelGuide™, Nobel Biocare AB, Göteborg, Sweden), with axial (70) and tilted (70) implants and fixed partial prostheses immediately loaded.

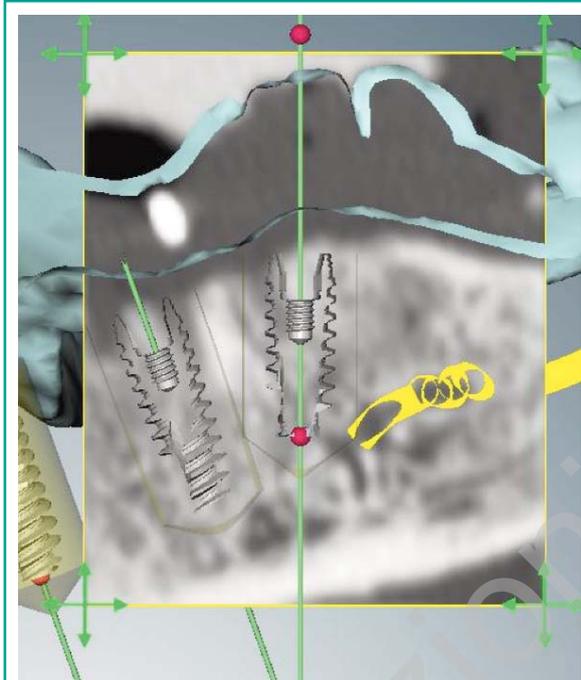


Figure 4
The insertion axis and the depth of the implants was carefully studied with a special guided implant software (Nobel Guide, Nobel Biocare AB, Göteborg, Sweden) so as to avoid violation of the mandibular canal or sinus antrum.

The two distal tilted implants were placed near the emergence of the nerve or parallel to the anterior sinus wall with 30 degrees angulation relative to the occlusal plane (Fig. 5). While the two mesial sites were prepared at the level of the lateral incisors. The insertion axis and the depth of the implants was carefully studied with a special guided implant software (Nobel Guide, Nobel Biocare AB, Göteborg, Sweden) so as to avoid violation of the mandibular canal or sinus antrum (Fig. 4). Because of the angulation of the distal implants distal abutments could emerge in the second premolar/first molar zone with a great reduction of distal cantilever. Bone density was assessed during the early phase of drilling by the surgeon, and a subjective evaluation was performed using a 2.0-mm drill. The implant site was usually underprepared by avoiding countersink so as to maximize implant stability. A torque controller with a torque limit of 50 Ncm was used during implant placement, and a manual wrench was used in case of incomplete seating of the implant. Every implant was placed with a primary stability ranged between 35 and 70 N/cm. Multiunit abutments (MUA, Nobel Biocare) (Fig. 6) or standard straight temporary abutments were connected to the distal implants to allow for an optimal prosthetic screw access, while straight abutments (Fig. 7) were placed over the mesial implants. After surgery an acrylic resin provisional prosthesis with 10 teeth was delivered (Fig. 8). Centric and lateral contacts were limited to the intercanine zone. Healing in all cases was uneventful, as expected. A panoramic radiograph was taken to check implant position and the coupling

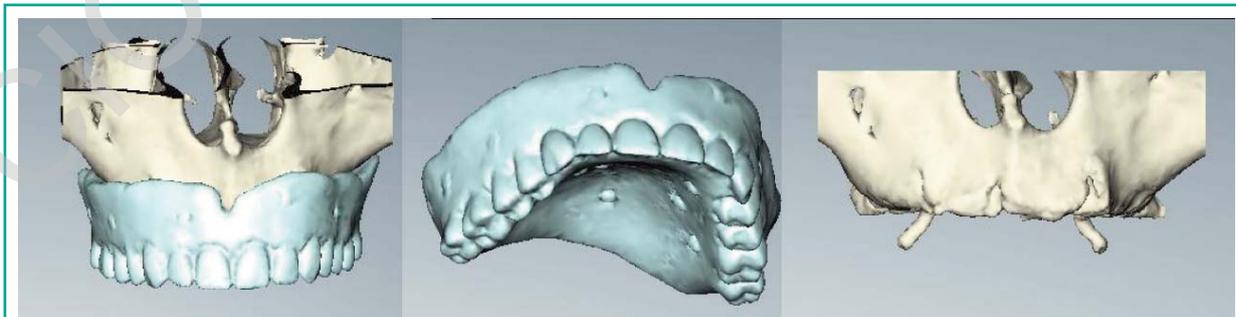


Figure 5
The two distal tilted implants were placed near the emergence of the nerve or parallel to the anterior sinus wall with 30 degrees angulation relative to the occlusal plane.



Figure 6
Multiunit abutments (MUA, Nobel Biocare) or standard straight temporary abutments were connected to the distal implants to allow for an optimal prosthetic screw access.



Figure 8
After surgery an acrylic resin provisional prosthesis with 10 teeth was delivered.



Figure 7
Straight abutments were placed over the mesial implants.

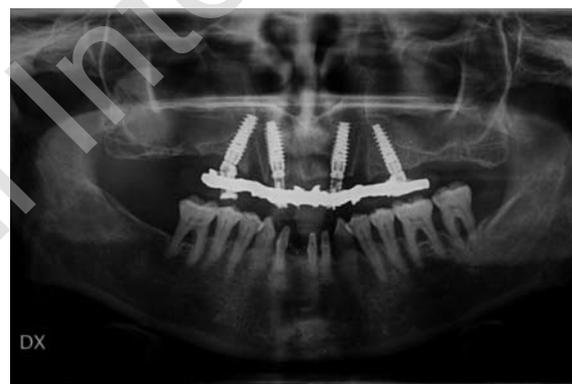


Figure 9
A panoramic radiograph was taken to check implant position and the coupling between prosthetic components.

gbetween prosthetic components (Fig. 9). After surgery, patients were instructed to avoid brushing and any trauma to the surgical site. Cold food was suggested for the first day and a soft diet for the first week thereafter. After 4 to 6 months of function, the patients underwent the prosthetic phase. The final prosthesis was fabricated using the CAD-CAM Pro-cera system. The titanium prosthesis consisted of a milled commercially pure titanium framework (Pro-cera, Nobel Biocare) veneered with acrylic resin teeth and a polymethyl methacrylate (PMMA) base.

Panoramic radiographs and, when possible, peria-pical radiographs using the parallel projection technique, were taken at 6 and 12 months and once yearly thereafter for up to 5 years. Marginal bone loss and overall bone level throughout the study were assessed using these radiographs. Stability of the prosthesis and proper occlusion were also checked. At the 1-year control visit, the stability of individual implants was manually tested after unscrewing the prosthesis by using the metallic handles of two opposing instruments. Finally, patient satisfaction was assessed after 1 year of function by means of a questionnaire.

Results

Overall 140 implants were placed with a flapless or mini-flap approach. The average follow-up period was 25 months. The implant cumulative survival rate was 100% for all the implants. No other implants as so far failed. As regards radiological follow-up when compared with baseline the behaviour of axial and tilted implants was similar. The mean (SD) marginal bone remodeling (mesial +distal values average) from immediate loading to the 1-year time-point follow-up (81 implants) was 0.66 mm (± 0.14) for the axial implants and 0.77 (± 0.42) for the tilted ones. No failure of abutments and prostheses occurred. No other biological complications were recorded. Esthetics, phonetics, and mastication were considered as excellent by 100% of the patients.

Conclusions

The prevalence of the elderly population, as well as life expectancy, increased in the final decades of the 20th century, as described in the World Health Organization 2004 Annual Report. The edentulous condition therefore has a negative impact on the oral health-related quality of life. On the other hand the rehabilitation of atrophied edentulous arches with endosseous implants (> 10 mm) in the posterior regions is often associated with anatomic problems such as bone resorption, poor bone quality, jaw shape and location of the mental foramen or loop of the alveolar nerve, mandibular canal, and the presence of maxillary sinuses. Different procedures have been proposed to overcome these anatomic limitations. The use of tilted implants parallel to the anterior wall of the maxillary sinus or the mental foramen/inferior alveolar nerve has been proposed as a conservative solution for the treatment of the atrophic edentulous maxilla. The biomechanical rationale for using inclination of distal implants is based on the reduction of cantilever length and as a consequence give rise to better load distribution of the prosthesis support. Additionally, tilting implants can optimize the an-

terior/posterior spread of the implants along the alveolar crest increasing the polygonal area to provide satisfactory molar support for a full fixed prosthesis (FFP) of 12 masticatory units. Several clinical studies have reported high survival rates for tilted implants.

However, questions remain relative to the amount of stress generated at the bone surrounding tilted implants. The single tilted implant infact, submitted to a vertical load, demonstrate higher peri-implant bone stress than the single vertical implant submitted to the same vertical load. The stresses increases as the tilt of the single implants increases. However when the implants are splinted in a rigid FFP, the use of tilted distal implants, with reduced cantilever lengths, results in lower mechanical stresses on the peri-implant bone with respect to the vertical implants with longer cantilevers.

Moreover a reduction of stress around anterior implants is observed with the tilted distal implants compared to the vertical implant FFP design.

Multi-unit prostheses may demonstrate greater inaccuracies compared with single implant restorations infact, but due to the absence of moment loading, the multi-implant configuration appears to compensate for the higher strain development.

These results have done so as that the last frontier in implant dentistry is represented by reducing the number of implants supporting a prosthetic rehabilitation as well as the time that elapses between implant placement and prosthetic loading.

From this point of view the protocols in which four implants were placed to support a full-arch prosthesis indicate that the placement of larger numbers of implants may not be necessary for successful implant treatment of edentulous arched. In 2003 Malò et al. proposed a special guide designed from himself for the assisted placement of the distal tilted implants. This guide was placed into to a 2 mm hole made at the midline of the mandible or the maxilla, and its titanium band was bent so that the occlusal centerline of the opposite jaw was followed. In this way it was possible the implants to be placed in the center of the opposite prosthesis and cuncurrently to find the optimal position and inclination for the best implant anchorage and prosthetic support. Nowadays computer-guided flapless surgery for implant placement using

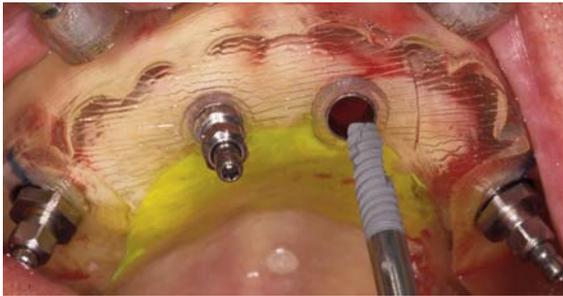


Figure 10
Nowadays computer-guided flapless surgery for implant placement using stereolithographic templates.



Figure 11
The advantages of this surgical protocol are its minimally invasive nature, accuracy of implant placement, predictability, less post-surgical discomfort and reduced time required for definitive rehabilitation.

stereolithographic templates (Fig. 10) is gaining popularity among clinicians and patients. The advantages of this surgical protocol are its minimally invasive nature (Fig. 11), accuracy of implant placement, predictability, less post-surgical discomfort and reduced time required for definitive rehabilitation. The introduction of digital systems into the diagnostic routine, and their application using three dimensional data sets of the bone topography, have made it possible to reconcile the two central aspects of planning an ideal prosthetic solution with the given anatomic situation prior to implant surgery. There is no intrinsic limitation of this technique if the initial bone height is severely reduced and the risk of perforations of the sinus membrane or alveolar nerve and loop during the drilling procedure are no likely to occur because of the accuracy of the safety distance calculated during the computer planification (Fig. 12).

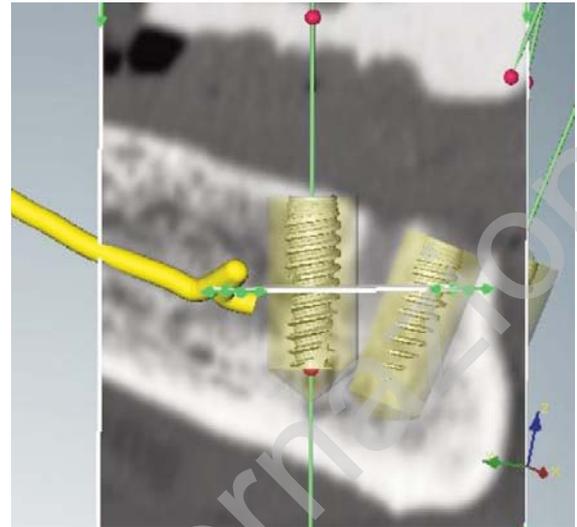


Figure 12
There is no intrinsic limitation of this technique if the initial bone height is severely reduced and the risk of perforations of the sinus membrane or alveolar nerve and loop during the drilling procedure are no likely to occur because of the accuracy of the safety distance calculated during the computer planification.

The results of the present study would suggest that this new surgical technique may reduce patient morbidity and extend the indications for immediate loading full fixed rehabilitations. 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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