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Tilted Implants: A Review of Rationale, Biomechanics and Applications

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Abstract

Rehabilitation of partial or complete edentulism with dental implants is a well-documented treatment plan with a predictable outcome up to date. The use of tilted implants for rehabilitation of full or partial edentulous patients has been suggested by many authors with several advantages, including immediate loading, avoiding the anatomic limitations (maxillary sinus and mental foramen), and as an alternative for complex surgical procedures (sinus augmentation, and repositioning of inferior dental canal, and others). Other advantages of this approach include increasing implant length, engaging more cortical bone, increasing bone-implant contact, and thus increasing primary stability; in total arch cases, this technique reduces the size of the anteroposterior spread of the prosthesis and, therefore, better load distribution. The use of tilted implants has gained popularity recently, so this review aims to clarify the rationale, biomechanics, and applications of tilted implants. In conclusion, in this review article, the application of tilted implants in rehabilitation of partial or complete edentulism provides a viable alternative to more complex procedures, with the advantage of immediate loading and a better survival rate, with no difference in bone loss, compared to axial implants. Although the biomechanics of tilted implants are different from that of axial implants in that there will be greater stress concentration on the bone around implants; there is more excellent distribution of the loads to the peri-implant bone with tilted implants compared with vertical ones because of increased implant length and thus "making the best use of available bone".

Keywords:
Tilted implants, angled implants, graft-less full arch implantation.

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Introduction:

Elderly population prevalence and life expectancy have increased remarkably in the past decades; this probably results from social and economic progress, the successfulness of public health plans, upgrades in the prevention of diseases, and ease of access to and increased quality of care [(1)]. Although there is development in dental care, edentulism is still very prevalent on a global level [(2)]. Edentulism hurts the quality of life and oral health. Elderly people wearing complete dentures for many years (in the mandible especially) are often unsatisfied; lack of prosthesis stability during eating and speaking is the main reason. Treating partial or complete edentulism with dental implants is predictable and well-documented to date [(3,4)].

Patients treated with implant-supported prostheses reported improved masticatory function (chewing efficiency and biting force). However, it is well established that patients seeking implant treatment but receiving removable prostheses aren't satisfied. Conversely, atrophied edentulous arches rehabilitation in the posterior area with dental implants is frequently contradicted by poor quality of bone, bone resorption, mental foramen location, inferior dental canal, and maxillary sinus [(5-7)].

Several alternative procedures have been suggested to override these anatomic limitations, such as using short implants, which are considered the least invasive [(8)]. Short implants can't be used when the available bone height is insufficient; other reconstructive procedures were suggested, such as grafting with autogenous bone [(9)] and sinus lifting [(10)]. Different techniques, such as pterygoid implants [(11)] and zygomatic implants [(12)], can be used. However, these procedures are associated with several disadvantages, including graft morbidity, uncertain predictability, and complexity of the surgery [(13-15)].

A tilted implant is defined as an implant placed with an angle of 15 degrees or more from perpendicular to the occlusal plane [(18)]. Tilting the posterior implants along the anterior wall of the maxillary sinus or avoiding the mental foramen (inferior alveolar nerve) was suggested as a conservative technique for treating atrophied edentulous arches. The first to describe the successful application of tilted implants in the rehabilitation of atrophied edentulous arches were Mattson et al. (1999), Krekmanof et al. (2000), Aparicio et al. (2001), Fortin et al. (2002), and Malo et al., (2003) [(16-20)].

So, this review aims to emphasize the "tilted implant concept", rationale, biomechanics, and applications.

The rationale for tilted implants

The rehabilitation of the atrophied edentulous mandible is limited posteriorly by the mental foramina and the inferior dental canal. This limited bone volume could be restored by regenerative procedures such as bone grafting or inferior alveolar nerve repositioning. However, these interventions are demanding and need longer periods for rehabilitation. The original Brånemark protocol was the treatment of choice many years ago, with a survival rate of 80% to 90%. This technique involves placing 4 to 6 parallel implants between the mental foramina and distal cantilever [(21)]. The pitfall of this procedure was the bilateral distal cantilever, which can reach 20mm, which results in increased bending moments and stress concentration at implants and neighboring bone, leading to crystal bone resorption and compromised survival of the implants [(22)].

Similarly, bone volume in the anterior area may be sufficient in the case of atrophied maxillary implant rehabilitation. Still, severe bone resorption in premolars and molars as a consequence of tooth loss worsened by maxillary sinus pneumatization can present a challenge for implant placement in this area [(9,22)]. Alternative techniques, including crystal and lateral maxillary sinus lifting procedures, were described to facilitate implant placement. Although these techniques have excellent outcomes, several complications were associated with them, including fistula, sinusitis, loss of implant or graft, and osteomyelitis. Also, these procedures are demanding for both patients and clinicians, in addition to increased financial costs and surgical risks [(24,25)]. Tilted implants have been adopted for the rehabilitation of atrophied maxillae and mandibles. Tilting the distal implants in the mandible prevents mandibular nerve damage; similarly, tilting distal implants in the maxilla eliminates the need for complex sinus augmentation procedures.

The advantages of using tilted implants include:

Increased implant length, thus, engagement of more cortical bone, leading to increased primary stability [18].

In rehabilitating the entire arch, distal implant tilting reduces the cantilever length to increase the anteroposterior spread (the distance measured from the most anterior to the most posterior implant). Thus, better distribution of load can be accomplished [26]. Immediate loading of tilted implants in treating wholly or partially edentulous patients is becoming increasingly popular among clinicians. Systematic reviews pointed out that implant treatment success isn't impaired by immediate loading and emphasized the significance of the micromorphology of implants and patients' selection on the treatment outcome [27-29].

Biomechanics of tilted implants

When forces of mastication load implant-supported prostheses, the forces are transmitted to the implants and the surrounding bone. These forces, according to mechanical principles, will result in resistance forces in the involved material, which are stress-related. Stress acts in the same manner as it causes strain or deformation. A general rule states, "The greater the stress and strain in any material, the greater the risk of failure" [30,31]. Determining how much strain and stress bones can withstand is difficult, if possible, to accomplish. The reason for this is the different properties of bone around implants (which may be cortical dense bone, trabecular bone, and immature bone; similarly, humans and other species have different bone properties) [32]. Nevertheless, possible bone failure fatigue should be kept in mind, which is a failure of material caused by cyclic loading. This fatigue is subtle because the magnitude of strain or stress causing it is significantly lower than those causing single-cycle failure. An example of this fatigue is pure titanium, which has a tensile strength of about 760 MPa. In comparison, 300 MPa can cause fatigue of the material if it exceeds the limit of 10 million cycles [33]. A similar situation occurs in bone. For example, the peak strain of peri-implant bone around a 25° tilted implant is significantly greater than that of peri-implant bone around an axially loaded implant. In some situations, bone fatigue is possible under cyclic loading; humans routinely exert about 100 movements of chewing per day, which means that in one year, many thousands of cycles can be accumulated [34].

A question that comes into mind is, what are the differences between vertical and tilted implants concerning the peri-implant bone? A proper way to compare vertical and tilted implants is to load these implants with the same amount of vertical force and in identical bone so that the cofounding factors (properties of bone, geometry of the implant, and implant loading) are controlled systematically to allow fair comparison. One study in particular used finite element analysis to perform this comparison; Brunski and Aparicio performed this study to observe stress distribution around osseointegrated implants placed in three orientations (straight, 15°, and 25°) about the occlusal plane and loaded by the same amount of vertical force (0.34 N) as shown in figure 1. This study concluded that when all confounding factors are equal (quality and quantity of surrounding bone, force loaded, implant's shape and size), increased implant angulation increases stress in the peri-implant bone compared to a vertically placed implant [35].

The pioneer of tilted implants (Aparicio et al., 2001) stated that using tilted implants provides the advantage of "maximum use of available bone and result in a simpler, more predictable, less costly and less time-consuming treatment compared to bone grafting procedures in the maxillary sinus or augmentation techniques" [18]. This statement explains that when there is, for example, 10mm available bone height, a 10mm vertical implant can be placed, while if the implant is placed inclined at 25° the length of the implant would increase to 11mm (10% increase with an inclination of 25°); similarly, when the implant is placed inclined 35°, the length would increase 15% compared to vertical implant [35]. As shown in figure 2.

Therefore, in terms of "making the best use of available bone," a tilted implant is superior arguably because it has more excellent bone-implant contact than a vertically placed implant [(36)].

Discussion

Rehabilitation of atrophied edentulous arches by dental implants in the posterior area is often impaired by many factors, including poor quality of bone, advanced resorption of bone, maxillary sinuses pneumatization, and relative inferior dental canal surfacing in the mandible, making implant placement in these areas difficult. These anatomic limitations can be avoided by using tilted implants to increase bone-implant contact (engaging maximum bone amount) and using longer distal implants simultaneously [(37)].

Many researchers have studied the performance of tilted implants; **Mattson et al. (1999)** were among the first to use tilted implants. They installed 86 implants in 15 atrophied maxillae; the observation period ranged from 36 to 54 months. During the observation period, one tilted implant was lost; it was removed after 6 months of installation (at the 2nd stage of surgery) because it was not osseointegrated (running on the anterior wall of the maxillary sinus with minimal bone contact). 98.8% of the implants survived through the observation period without primary bone resorption on follow-up radiographs [(16)].

Krekmanof et al. (2000) inserted 206 implants (36 tilted in mandibles and 40 tilted in maxillae) in 25 mandibles and 22 maxillae (47 patients), and the follow-up period ranged from 35 to 54 months and 35 to 60 months, respectively. They reported a 100% cumulative implant success rate in mandibular implants (whether tilted or not), and 95.7% for tilted implants and 92.5% for non-tilted implants in the maxilla [(17)].

Aparicio et al. (2001) were the first to use tilted implants in partially edentulous maxillae. They inserted 101 implants (42 were tilted) in 25 patients. The explanation for using tilted implants in partially edentulous maxillae, as stated, was "because the residual bone quantity was less than 8mm under the maxillary sinus". All patients were followed up at 1, 3, and 12 months after prosthesis delivery then once annually for a range period of 21 to 87 months after loading. The cumulative implant success rate after 5 years was 95.2% for tilted implants and 91.3% for axial implants, and the conclusion was that tilted implants are safe alternatives for sinus augmentation techniques [(18)].

Fortin et al. (2002) inserted 245 implants (90 tilted) to treat completely edentulous maxillae of 45 patients with Marius prosthesis (metal bar fixed on implants and an overlying removable overdenture). The cumulated survival rate was 97% at 5 years [(19)].

Maló et al. (2003) are the first to use the "all on four" concept with immediate loading. They inserted 176 implants in 44 patients with edentulous mandibles (4 implants pre-patient); in each patient, the 2 anterior implants were placed vertically, and the 2 posterior implants were placed 30° distally angulated. The cumulative implant survival rate was 97.2% demonstrating the viability of the "all on 4" concept with immediate loading (within 2 hours postoperatively) [(20)].

Del Fabbro et al. (2012) in their systematic review, which included 10 studies, 1992 implants were inserted in 462 patients (12 partial and 458 complete fixed prostheses), rehabilitating 213 mandibles and 257 maxillae. Tilted implants were 966 (48.5%), and 1026 (51.5%) were upright. This study concluded that the prognosis using this therapeutic technique was superb with a loss of only 1.25% of implants in the first year and 2 failures then after, without any significance in implant success between tilted and axial implants; in addition to no significant bone loss difference was observed between tilted and axial implants [(38)].

Another systematic review by **(Lin and Eckert, 2018)**, which included 42 studies, revealed that the implant survival rate in the included studies was variant with the lowest of 89.4% (during 1 year) and the highest of 100% (5 years follow-up), and 97.5% (during 7 years follow-up). There was no statistical difference in the survival rate and marginal bone loss between tilted and axial implants [(39)]. **Apaza Alccayhuaman et al. (2018)** published a systematic review revealing the same evidence as Lin and Eckert (2018); this study included 17 researchers and showed that there wasn't any statistical significance in implant survival rate and marginal bone loss between tilted and straight implants in 3-5 years of function [40]. The latest systematic review published by **Mehta et al. (2021)**, which included 11 studies (total implant number 1148), also revealed that there wasn't a difference in marginal bone loss and implant survivance between axial and tilted implants, which is in agreement with the previous systematic reviews [41].

Conclusion

Using tilted implants provides a viable option for immediate rehabilitation of partial or completely edentulous arches with a reasonable survival rate and no difference in bone loss compared to vertical implants.

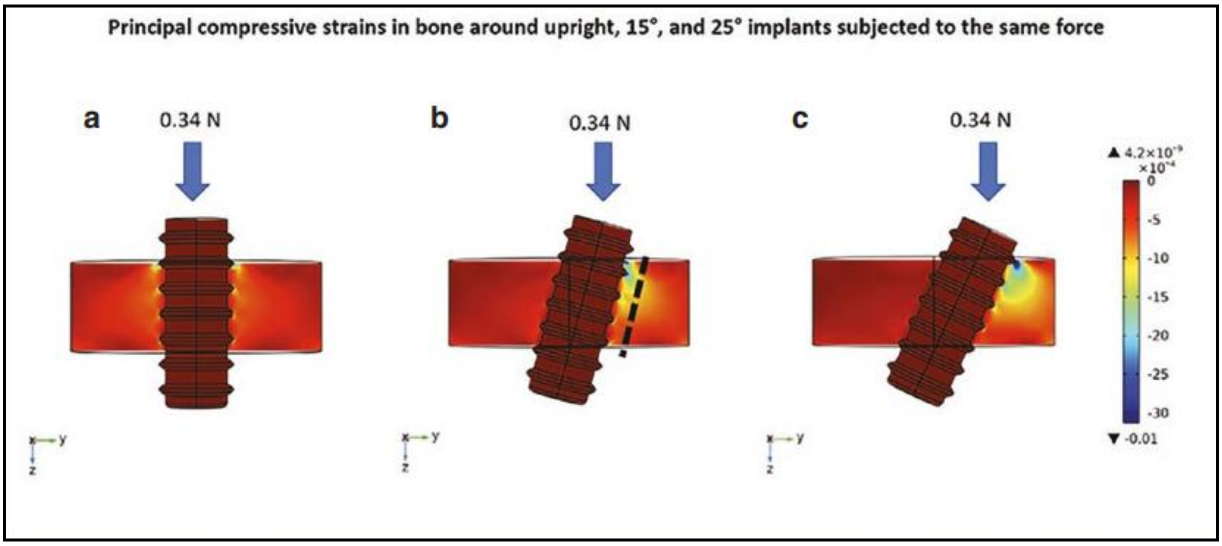

Figure 1: (a–c) peri-implant stress distribution with different angulations loaded by the same force [35].

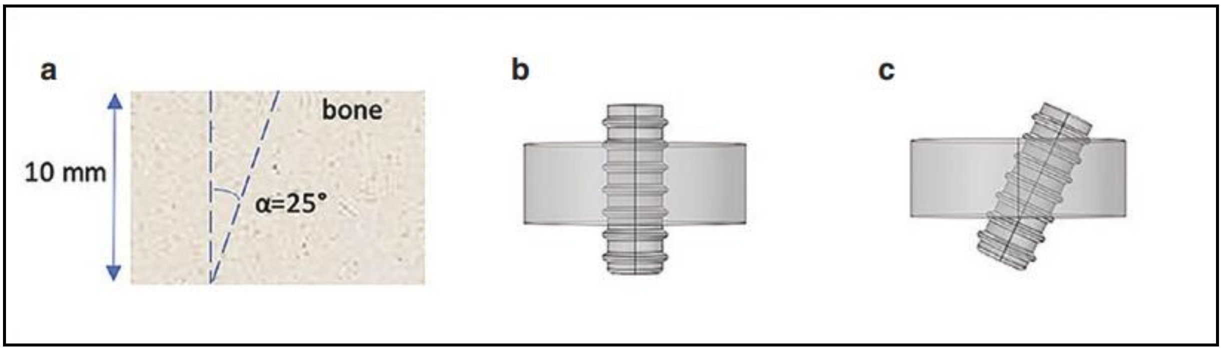

Figure 2: (a) 10 mm available bone height. If the implant is placed vertically (b), the length of the implant is 10mm, if the implant is tilted 25° the length would increase to 11mm (c) [35].

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