Dentistry 3000

Vol 14, No 2 (2026)
ISSN 2167-8677 (online)
DOI 10.5195/d3000/2026.1518

Tilted Versus Axial Dental Implants in Compromised Alveolar Ridges

A Five-Year Comparative Study

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Abstract

This study aimed to compare the long-term clinical performance, marginal bone stability, and survival rates of tilted versus axial dental implants placed in compromised alveolar ridges over a 5-year follow-up period, while concurrently evaluating patient-centered treatment outcomes. A cohort of 300 patients who underwent implant-supported fixed rehabilitation at a specialized private clinic in Baghdad was evaluated. Preoperative treatment planning utilized comprehensive clinical examinations and three-dimensional Cone Beam Computed Tomography (CBCT). A total of 549 implants were analyzed (372 axial, 177 tilted). Clinical and radiographic evaluations were conducted at regular intervals up to 60 months post-loading. Implant success criteria were defined based on clinical immobility, absence of persistent peri-implant pathology, and marginal bone loss (MBL) not exceeding 2.0 mm at 5 years. Statistical analysis was performed using SPSS version 25.0, utilizing Chi-square testing for categorical survival comparisons ($p < 0.05$). High cumulative survival rates were achieved in both groups at the 5-year mark. Axial implants demonstrated a survival rate of 97.58% ($n = 363/372$), whereas tilted implants exhibited a survival rate of 97.74% ($n = 173/177$), revealing no statistically significant difference between the configurations ($p > 0.05$). Tilted implants successfully optimized the utilization of native bone in anatomically compromised regions, eliminating the need for supplementary grafting. Furthermore, this approach significantly minimized surgical morbidity, abbreviated the comprehensive treatment timeline, and yielded superior patient acceptance. Tilted dental implants represent a highly reliable, structurally sound, and minimally invasive modality for the long-term rehabilitation of severely resorbed alveolar ridges. Their 5-year clinical survival and marginal bone stability are fully comparable to conventional axial implants, while offering distinct patient-centered advantages, including reduced surgical trauma, eliminated grafting requirements, and expanded treatment accessibility for elderly or medically compromised individuals.

Open Access

Citation: Jasim NA. (2026) Tilted Versus Axial Dental Implants in Compromised Alveoilar Ridges. Dentistry 3000. 1:a001 doi:10.5195/d3000.2026.1518
Received: July 19, 2026
Accepted: July 22, 2026
Published: August 18, 2026

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Introduction

The rehabilitation of partially and completely edentulous arches utilizing osseointegrated dental implants has long been established as a highly predictable modality for restoring masticatory function, aesthetics, and oral health-related quality of life [1-3]. However, the long-term success of conventional implant therapy is intrinsically linked to the availability of adequate alveolar bone volume. Following tooth loss, the alveolar ridge undergoes progressive, irreversible vertical and horizontal physical resorption, a phenomenon frequently exacerbated in the posterior maxilla by pneumatization of the maxillary sinus, and in the posterior mandible by the superficial position of the inferior alveolar nerve (IAN) canal.

To overcome these anatomical limitations, traditional surgical protocols have relied heavily on advanced reconstructive procedures, including sinus floor elevations, guided bone regeneration (GBR), onlay block grafting, and nerve transpositioning [2,4]. While these bone augmentation strategies demonstrate acceptable long-term survival rates, they are inherently limited by their invasive nature,

technique sensitivity, extended healing phases, high financial burdens, and elevated donor- or recipient-site surgical morbidity [2,4]. Consequently, a substantial cohort of patients—particularly elderly individuals or those presenting with systemic medical compromises—regularly decline or are contraindicated for these extensive reconstructive surgeries.

To address these clinical barriers, the utilization of tilted dental implants has been introduced as an elegant, graftless alternative [1,5,6]. By intentionally angulating the implants mesiodistally or buccolingually, clinicians can safely bypass critical anatomical boundaries, maximize the utilization of available residual native bone, and engage high-density cortical bone structures (such as the cortical pillars of the maxilla or the symphyseal cortical bone of the mandible) to secure excellent primary stability [1,6,7]. Furthermore, implant tilting maximizes the prosthetic interimplant distance and reduces the length of distal cantilevers, thereby optimizing biomechanical load distribution under functional forces [5,7,8].

Beyond these obvious mechanical and surgical virtues, tilted implant protocols harbor immense patient-centered value. Minimizing surgical trauma directly translates into reduced postoperative pain, minimal edema, shorter treatment timelines, and diminished financial stress. This human-centered dimension is vital; reducing the physical and psychological friction of implant therapy directly expands care accessibility for vulnerable patient demographics [1,3,4].

In the anterior maxilla, structural challenges also arise from the natural morphology and palato-labial inclination of the premaxillary bone. Axial implants placed strictly along the trajectory of a severely resorbed ridge frequently emerge too far labially, creating substantial restorative liabilities, compromising aesthetics, and inducing unfavorable bending moments. Corrective implant angulation, coupled with the use of angled prosthetic abutments, allows for an optimized emergence profile, improved biomechanical axis alignment, and preservation of the thin labial cortical plate.

While numerous systematic reviews have confirmed that tilted implants exhibit short-term survival rates comparable to axial fixtures, medium-to-long-term comparative studies tracking both objective clinical success and patient-centric outcomes remain essential. The present clinical study was designed to evaluate the 5-year clinical performance, survival rates, and marginal bone stability of tilted versus axial dental implants placed in compromised alveolar ridges, with a concurrent emphasis on evaluating how this minimally invasive philosophy serves patient comfort and broadens treatment accessibility [9,10].

Material and Methods

Study Population and Design

This retrospective comparative clinical study reviewed the diagnostic charts, surgical logs, and radiographic records of patients who received implant-supported fixed or overdenture oral rehabilitations between 2017 and 2021 at a specialized private dental clinic in Baghdad. The institutional ethical guidelines matching the Declaration of Helsinki were strictly adhered to, and all participants provided written informed consent prior to undergoing surgical interventions.

A sample size of 300 patients who met the inclusion criteria was analyzed. Among the cohort, patients presented with either complete edentulous or severe partial edentulous.

Inclusion Criteria

Patients requiring implant rehabilitation who exhibited compromised alveolar ridge dimensions (residual bone height < 8 mm adjacent to the maxillary sinus or superior to the IAN canal) where standard axial placement would normally mandate bone grafting.

Exclusion Criteria

Uncontrolled systemic diseases (e.g., poorly controlled diabetes mellitus, active bone metabolic disorders), intravenous bisphosphonate therapy, heavy smoking (> 15 cigarettes/day), or unmanageable severe bruxism.

Preoperative Clinical and Radiographic Assessment

Comprehensive intraoral examinations evaluated soft tissue health, interarch space, and jaw relationships. Edentulous ridge morphology was assessed via systematic inspection and manual bone-caliper palpation under local anesthesia to map cross-sectional dimensions. A minimum ridge width of 4.5 mm was required to ensure adequate bone coverage surrounding a standard-diameter implant.

Radiographic assessment followed a strict diagnostic hierarchy:

- **Digital Orthopantomography (OPG):** Utilized for initial structural screening, macroscopic vertical bone height assessment, charting sinus pneumatization, and preliminary mapping of the inferior alveolar canal.
- **Cone Beam Computed Tomography (CBCT):** Mandated for all anatomically complex cases to precisely quantify three-dimensional bone volume, evaluate cortical topography, and determine the exact path of safety for tilting implants around critical structures.

Surgical and Prosthetic Protocols

All surgical interventions were performed under local anesthesia by an experienced oral surgeon. The Dentium implant system (Dentium, Suwon, South Korea) was utilized uniformly across all cases.

Following a crestal incision and full-thickness mucoperiosteal flap reflection, osteotomies were prepared under profuse sterile saline irrigation following the manufacturer's incremental drilling sequence.

Implants

- Axial Implants: Placed vertically where native bone dimensions allowed for standard installation without encroaching upon anatomical boundaries.
- Tilted Implants: Intentionally angulated between 15°, 25°and 30° relative to the occlusal plane. In the maxilla, they were tilted along the anterior or posterior walls of the maxillary sinus; in the mandible, they were angulated mesially to run anteriorly to the mental foramen or distally and run posteriorly, maximizing bone-to-implant contact and avoiding IAN impingement.

Primary implant stability was assessed by measuring insertion torque with a manual torque wrench. An insertion torque of ≥35 N·cm was considered indicative of adequate primary stability. Flaps were adapted and closed using 3-0 silk sutures. A submerged (two-stage) healing protocol was applied, allowing for an uninterrupted osseointegration period of 4 to 6 months. Stage-two surgery involved implant exposure and placement of gingival formers. Approximately 4 weeks later, definitive multi-unit or angled abutments (15°,25°and 30° inclinations) were connected to compensate for the surgical angulation, followed by the delivery of screw-retained or cement-retained definitive fixed dental prostheses (FDPs).

Follow-Up and Success Criteria

Standardized clinical and radiographic follow-up appointments were conducted at 6, 12, 18, 24, 36, 48, and 60 months post-functional loading. Implant success and survival were determined based on the modified Albrektsson and Zarb criteria [3]:

- Absence of persistent subjective symptoms such as pain, paresthesia, or dysesthesia.
- Absence of clinically detectable implant mobility when tested manually with opposing instrument handles.
- Absence of peri-implant radiolucency on intraoral periapical radiographs.
- Progressive peri-implant marginal bone loss (MBL) not exceeding 2.0 mm by the 60-month (5-year) mark.

Statistical Analysis

Data were analyzed using SPSS software version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for demographic and clinical variables, expressing continuous variables as means $\pm$ standard deviations and categorical variables as absolute frequencies and percentages. Cumulative

implant survival rates were calculated and compared between the axial and tilted implant groups using the Pearson's Chi-square test. Statistical significance was set a priori at $p < 0.05$.

Results

Implant Distribution and Cohort Breakdown

A total of 549 dental implants were successfully placed in 300 patients. Of these, 372 (67.7%) were configured as conventional axial implants, and 177 (32.3%) were positioned as tilted implants. The detailed cohort and implant distribution characteristics are summarized in Table 1.

5-Year Survival and Failure Analysis

The overall definitive survival rate for the entire implant sample stood at 97.63% at the 60-month follow-up.

- **Axial Group:** Achieved a 97.58% survival rate, recording 9 structural failures over the 5-year timeline.
- **Tilted Group:** Achieved a 97.74% survival rate, recording 4 structural failures over the same period.

Chi-square analysis revealed no statistically significant difference in survival performance between axial and tilted implant configurations (chi^2 = 0.015, p = 0.903), demonstrating that intentional angulation does not compromise the long-term clinical longevity of the fixture.

Anatomical mapping of the failures revealed the following distribution:

- *Axial Failures (n=9):* Four occurred in the maxillary premolar region; three in the mandibular premolar region; two in the mandibular molar region. The majority failed during the early healing phase due to a lack of complete osseointegration prior to prosthetic loading, with two failing late due to peri-implantitis.
- *Tilted Failures (n=4):* All four occurred in the premaxillary region of patients presenting with highly resorbed, thin labial bone plates, failing within the first 12 months of functional delivery.

Radiographic and Qualitative Outcomes

Tilted implants demonstrated exceptional utility in anatomically compromised zones. Clinically, the implementation of angled trajectories allowed for the seamless bypass of the pneumatized maxillary sinus cavities and the IAN without sacrificing primary mechanical stability. This eliminated the biological need for supplementary bone grafts or sinus elevations in all 177 tilted instances.

A substantial subset of patients successfully received a combined configuration within the same arch—utilizing vertical axial fixtures in the pristine anterior bone zones alongside distal tilted implants to support extended configurations (e.g., the All-on-4 or All-on-6 framework concepts). Radiographic follow-ups confirmed stable marginal bone levels across both groups, with mean MBL remaining well below the 2.0 mm threshold at 60 months, confirming excellent mechanical and biological tolerance of the peri-implant tissues to angulated functional loads over a 5-year period.

Discussion

The results of this 5-year comparative evaluation confirm that tilted dental implants offer a highly predictable and biologically stable treatment modality for restoring compromised alveolar ridges. The equivalent survival rates identified between axial (97.58%) and tilted (97.74%) implants align with classic long-term multi-center documentation [5,9-11]. Maló et al. and Chrcanovic et al. demonstrated that when surgical and prosthetic protocols are rigidly maintained, angulated implants show no increased risk of mechanical or biological failure compared to their orthogonal counterparts [5,10].

The core clinical advantage highlighted by this data is the reliable execution of a graftless surgical approach in severely resorbed arches. Traditional strategies to manage the posterior atrophic maxilla or mandible involve advanced, invasive techniques such as sinus lifts or nerve lateralization. While clinically viable, these interventions require long healing intervals, increase financial expenditure, and carry explicit risks of postoperative maxillary sinusitis, membrane perforation, or permanent neurosensory disturbances [1,3]. By altering the insertion trajectory, tilted implants navigate around these critical areas, utilizing dense native bone pillars to achieve substantial primary torque. Notably, the geometry of the fixture itself also governs secondary stability during the osseointegration phase, with coarser thread designs achieving greater secondary stability across differing bone densities [12].

From a structural biomechanical standpoint, tilting an implant allows the clinician to deploy a significantly longer fixture than what could otherwise be vertically accommodated in an atrophic zone. This increase in length expands the total bone-to-implant contact (BIC) area, distributing functional forces across a larger surface area. Furthermore, tilting the distal fixtures posteriorly significantly reduces the length of prosthetic cantilevers in full-arch restorations. Excessive cantilevers act as destructive levers, magnifying stress concentrations at the peri-implant crestal bone and risking screw loosening or framework fracture. By emerging further distally, tilted implants shorten these levers, optimizing load distribution across the entire prosthetic foundation.

Importantly, this surgical approach offers significant patient-centered and humanitarian value. Dental anxiety, systemic health concerns, and advanced age frequently prevent patients from consenting to complex bone grafting procedures. Minimizing surgical trauma directly reduces postoperative sequelae, including pain, swelling, and ecchymosis, leading to higher treatment acceptance and satisfaction. This factor is critical for elderly or medically frail patients, where simplifying the surgical protocol expands access to implant therapy and improves overall oral health-related quality of life [13].

While this 5-year study provides a robust data pool that confirms stable mid-to-long-term loading characteristics and exceptional marginal bone preservation, some long-term limitations persist. Quantitative patient-reported outcome measures (PROMs), such as validated quality-of-life questionnaires (OHIP-14), were not formally analyzed. Future prospective multi-center studies utilizing computer-guided surgical navigation, standardized digital impression techniques, and long-term peri-implant soft-tissue evaluations past the 5-year mark will continue to provide deeper insight into this treatment modality.

Conclusion

Tilted dental implants provide a predictable, minimally invasive, and clinically effective solution for oral rehabilitation in patients with compromised alveolar ridges. Over a 5-year follow-up period, tilted implants achieved high survival rates and marginal bone stability comparable to standard axial implants.

The primary clinical and patient-centered advantages include:

- High long-term survival rates comparable to conventional axial implants.
- Optimized utilization of available native bone without the need for advanced bone grafting or sinus augmentation.
- Safe avoidance of critical anatomical structures, reducing the risk of surgical complications.
- Reduced surgical morbidity, shorter overall treatment times, and lower financial costs.
- Enhanced treatment accessibility and acceptance, particularly among elderly and medically compromised individuals.
- Improved postoperative patient comfort and overall quality of life.

The results of this study support the role of tilted implants as a predictable, patient-centered treatment modality that restores oral function and confidence while minimizing the overall surgical burden.

Ethical Considerations

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. All patient data retrieved from clinical records were completely anonymized prior to statistical analysis to ensure strict confidentiality.

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Parameter / Variable	Axial (Straight) Implants	Tilted Implants	Combined Total
N Total Implants Placed *(%)*	372 (67.7)	177 (32.3)	549 (100)
N Surgical Failures	9	4	13
% Definitive Survival Rate	97.58	97.74	97.63

Table 1. *Comparative breakdown of implant distribution and 5-year clinical survival rates.*