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REVIEW ARTICLE

WILEY CLINICAL ORAL IMPLANTS RESEARCH

Clinical performance of intentionally tilted implants versus axially positioned implants: A systematic review

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Abstract

Objectives: The aim of this review was to determine the clinical performance of dental implants that are intentionally tilted when compared with implants that are placed following the long axis of the residual alveolar ridge.

Materials and methods: A systematic review of the scientific literature using a predefined research question (PICO) and search strategy was undertaken. This search included five electronic databases. Two independent reviewers examined electronic databases and performed a manual review following search strategy to accomplish the item generation and reduction. Included articles were evaluated to determine the level of evidence. Data were extracted only from level I and level II studies, based on the Oxford Centre for Evidence-based Medicine—Levels of Evidence (March 2009). If included studies were homogeneous in nature, data were to be accumulated. However, if included studies were heterogeneous in nature, only descriptive data would be reviewed and analyzed.

Results: A total of 811 articles were identified through the PICO question and search strategy. Detailed review of the abstracts and articles resulted in further item reduction, and 46 articles were included for full-text review. A total of 42 articles were then selected for inclusion in the systematic review. The identified articles included two level I and 20 level II studies. In addition, 15 level IV, one gray literature, and four previous systematic reviews with meta-analyses were also used in the study. The extracted data from the included studies demonstrated heterogeneity that prevented quantitative assessment, and only one level II study directly compared tilted and axially placed implants. Assessment of the descriptive data demonstrated no differences in implant survival, marginal bone loss, prosthesis survival, or patient-reported outcome measures (PROMs) whether implants are placed axially or with intentional inclination of the coronal aspect of the implant toward the distal aspect of edentulous jaws.

Conclusions: Based upon the systematic review of the literature, an analysis of the descriptive data suggested no differences in clinical performance between implants that are placed in an axial position relative to the residual alveolar ridge when compared with implants that are intentionally tilted toward the distal aspect of edentulous jaws.

KEYWORDS

clinical assessment, clinical research, clinical trials, diagnosis, prosthodontics tilted, axial

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1 | INTRODUCTION

Natural teeth are supported in alveolar bone by the periodontal ligament. Most descriptions of the periodontal ligament identify the different supporting fiber groups that maintain the natural tooth in its position within the jaw. Force application to the tooth will create different types of forces within the ligament itself. A vertical force on a natural tooth will cause some of the periodontal ligament fibers to stretch, creating tensile force between the ligament and the surrounding bone while forces applied in an angular fashion will create compressive forces in some areas and tensile forces in other areas within the ligament space (Alhashimi, Frithiof, Brudvik, & Bakhiet, 2001; Feller et al., 2015; Lv et al., 2009).

Dental implants are maintained in bone by direct deposition of mineralized bone on the surface of the dental implant. (Albrektsson & Zarb, 1993; Albrektsson, Zarb, Worthington, & Eriksson, 1986; Branemark, 1983) Although there are areas of fibrous connective tissue that also contact the implant, the predominant structure at the interface of implant and bone is calcified material. As a tissue, bone is far more than simply mineralized structure as it is dependent upon connective tissue, vascular supply and cells that are responsive to the need for osseous remodeling. Without constant bone remodeling, the survival of bone at the surface of an alloplastic device, the dental implant, would be very short-lived.

Dental implants, like natural teeth, also experience complex force applications. It may be reasonable to suggest that the unique configuration of a dental implant, often exhibiting a screw shaped macrostructure and a highly complex microstructure with a series of peaks and valleys related to the manufacturing process and surface treatment of the implant, creates a more complex set of forces than those that are seen on the natural tooth.(Brunski, 1988) Compressive, tensile, and shear forces represent the major categories of force that need to be maintained in a relative equilibrium to achieve and maintain osseointegration (Brånemark, Ohrnell, Skalak, Carlsson, & Brånemark, 1998; Brånemark & Skalak, 1998).

Biomechanical descriptions of stress distribution at the interface of implant and bone demonstrate a different pattern regarding force application to natural teeth. With natural teeth, the goal is to place forces down the long axis of the teeth. With implants, this force application may be somewhat irrelevant because the complex forces of compression, tension, and shear exist macroscopically at each thread of the implant and microscopically at every undulation of the microscopic surface of the implant. Early descriptions of implant placement in such a way as to create axial loading of the implant were derived from theories that were applicable to natural teeth. Over time, some clinicians recognized that efforts to create a vertical osteotomy to house the implant in a similar way to that of the natural teeth were frequently a futile effort. Discussions of slight angulations grew as the recognition that off axis loading of implants was not associated with chronic implant failure. In fact, the form of the residual alveolar ridge, particularly in the anterior maxilla and mandible, is such that it virtually mandates off axial loading for dental implants when placed in those areas.

Immediately placed and restored dental implants were among the earliest descriptions of dental implant usage. Those early descriptions however predated the description of osseointegration and instead utilized implants that were supported by connective tissue. (Schnitman & Shulman, 1980). With the recognition that direct bone to implant contact was possible, a new level of predictability and durability was achieved. (Adell, Lekholm, Rockler, & Brånemark, 1981) The earliest descriptions of osseointegration called for the avoidance of physical contact with any recently placed implant. The thought was that if contact could be eliminated by placing the implant beneath the oral mucosa or through the oral mucosa (Buser, Belser, & Lang, 1998) with relief provided to the tissue surface of the overlying prosthesis, healing of the bone to the implant could occur predictably. The early descriptions of osseointegration were specific relative to the design, at a micro- and macrostructural level, material, surgical technique, and prosthetic technique. (Albrektsson et al., 1986) Those early descriptions recommended an undisturbed healing time of 3–6 months depending upon the anatomic location of implant placement.

Patient response to this somewhat lengthy healing phase was acceptable but fell short of enthusiastic. With time, the microstructure and macrostructure of the implants were modified to allow shorter healing times that thereby allowed earlier functional loading of dental implants. One treatment approach that gained clinical acceptance involved the use of extra implants, more than four or five implants in each jaw, whereby the additional implants would be used to support prostheses until the traditionally distributed four or five implants were allowed to osseointegrate (Balshi & Wolfinger, 1997). Schnitman, Wohrle, & Rubenstein (1990), Schnitman, Wohrle, Rubenstein, DaSilva, & Wang (1997) described this technique and also described anticipation of failure of those extra implants that were used to immediately support the prosthesis. Instead, the survival rate of the immediately loaded implants, at the time of planned loading of the traditionally placed implants, was considered acceptable (Schnitman et al., 1997).

An alternative treatment approach was described by Krekmanov, Kahn, Rangert, & Lindstrom (2000) whereby the distal implants were intentionally tilted in a posterior direction thereby reducing the length of prosthetic cantilevers while still maintaining an optimal number of replacement teeth. The secondary benefit of this treatment approach was to reduce the number of implants that would be necessary to secure a dental prosthesis. The investigators found that both aims were met without any adverse effect on the survival of the implants. Malo, Rangert, & Nobre (2003) combined the use of intentionally tilted posterior implants with a minimal number of implants that were functionally loaded on the day of implant placement. This treatment approach was described as the “all-on-four” technique. The investigations found a high level of predictability for this treatment in both jaws.

With time, different implant manufacturers began to create transmucosal abutments that were at an angle to the central long axis of the implant. (Brosh, Pilo, & Sudai, 1998; Clelland, Lee, Bimbenet, & Brantley, 1995; Kao, Gung, Chung, & Hsu, 2008; Tian et al., 2012)

No consistent scientific studies identified problems with angled abutments. This observation led to an appreciation that intentional nonaxial loading could allow more strategic positioning of implants while taking advantage of the nonaxial positioning of the implant. Anatomic structures could be engaged by tilting implants in such a way as to create more separation between anterior and posterior implants thereby creating a foundation that could support fixed dental prostheses while using fewer dental implants (Krekmanov et al., 2000).

The primary aim of this systematic review of the literature was to determine the clinical performance of dental implants that are intentionally tilted toward distal aspect of edentulous jaws when compared with implants that are placed following the long axis of the residual alveolar ridge, in the edentulous patients. The secondary aim was to determine the biomechanical stability of implant-retained prostheses that depend upon angulated transmucosal abutments to effectively realign the implant with the prosthesis that it supports.

2 | MATERIALS AND METHODS

A systematic review of the scientific dental implant literature was conducted to address the question of performance of implants that are either loaded through axial forces or through the intentional tilting of the implant for strategic purposes. PRISMA was followed in reporting this systematic review.

The following focused question using the PICO format was developed. In patients who require replacement of all teeth in one or both dental arches using dental implants to support/retain fixed dental prostheses using intentionally tilted or angulated (toward the posterior portion of the mouth) posterior dental implants will be compared to traditionally placed axial dental implants to determine factors and outcomes relating to implant and prosthesis prognosis, biological and prosthesis complications, and patient-reported outcome measures (PROMs). A systematic review was performed using PubMed, Cochrane Central Register of Controlled Trials or EMBASE databases. Gray literature was searched through electronic screening using the New York Academy of Medicine Grey Literature report (http://greylit.org) and through Google Scholar.

Population-based search terms including dental implant, oral implant, endosseous implant, edentulous, immediate load, immediate loading, immediate provisional utilization, or immediate function were used. Considering the intervention that was performed the following terms were used: tilted, angulated, tipped, implant restoration, implant supported prosthesis, implant supported fixed dental prosthesis, implant supported FDP, all on four, or provisional. The comparison group was searched using the terms: vertical, straight, planned, traditional, parallel or axial. The outcomes that were searched were: implant prognosis, implant survival, implant success, prosthetic complications, prosthetic survival, prosthetic success, need for grafting, treatment time, patient satisfaction, clinician satisfaction, provisional, interim or definitive. The complete search strategy was listed in Table 1.

Manual searching was performed of the following journals: Clinical Oral Implants Research, International Journal of Oral Maxillofacial Implants, Clinical Implant Dentistry and Related Research, Journal of Prosthetic Dentistry, Journal of Prosthodontics, and International Journal of Prosthodontics. In addition, personal communications were solicited of authors involved in previous studies for any of these search terms.

Inclusion and exclusion criteria were identified and agreed upon prior to identification of articles for this review. The two authors agreed upon the search terms and search strategy prior to initiation of the study. Upon completion of item generation all titles were reviewed and an initial item reduction was performed based upon study irrelevance. A review of the abstracts associated with each article that was deemed relevant was then performed for the secondary item reduction. The final item reduction occurred after the reading of the full-text articles. Kappa agreement of inter-rater reliability was performed during the item reduction process. Agreement was established through direct communication and discussion of articles. All the included studies were reviewed and determined their levels of evidence. Level I study was defined as individual good quality RCT with narrow confidence interval and systematic review (with homogeneity) of RCTs. Level II study was defined as individual cohort study (including low-quality RCT) and systematic review (with homogeneity) of cohort studies. Level III study was defined as individual case–control study and systematic review (with homogeneity) of case–control studies. Level IV study was defined as case series and poor-quality cohort and case–control studies. Level V study was defined as expert opinion without explicit critical appraisal (Oxford Centre for Evidence-based Medicine, 2009).

Meta-analysis was planned if a sufficient number of homogeneous level I studies were available to address the PICO question. In the event that there were not sufficient numbers of homogeneous level I studies or if all level I studies were heterogeneous in nature the plan was to use descriptive statistics for the available level I studies. Once the level I studies were exhausted the same approach was to be used with level II studies. Any studies that were assessed as levels III or IV would be used for descriptive purposes only or could be used to provide further support or to refute the data obtained from the previous analyses. Likewise, any gray literature that was identified would be used to support or refute the findings from the level I and level II studies.

3 | RESULTS

Using the search terms described in the materials and methods a total of 811 articles were identified. Among the 811 articles identified via electronic and hand-search, 765 were excluded with author agreement subsequent to title and abstract review. A total of 46 articles that were identified as particularly relevant to this study design were then assembled for full-text evaluation. Upon the evaluation of the full-text a total of 42 articles were identified (Figure 1).

TABLE 1 Systematic search strategy

Focus Question	In patients who require replacement of all teeth in one or both dental arches using dental implants to support/retain fixed dental prostheses using intentionally tilted or angulated (toward the posterior portion of the mouth) posterior dental implants will be compared to traditionally placed axial dental implants to determine factors and outcomes relating to implant and prosthesis prognosis, biological and prosthesis complications, and patient-reported outcome measures (PROMs).
Search strategy	
Population	1. Dental implant [MeSH Terms] OR oral implant OR endosseous implant 2. Jaw, Edentulous [MeSH Terms] OR Mouth, Edentulous [MeSH Terms] OR Fully Edentulous OR complete edentulous OR full-arch OR partially edentulous OR partial edentulism OR complete edentulism OR terminal dentition OR failing dentition OR Full Arch 3. Immediate load OR Immediate loading OR Immediate provizionalization Or Immediate function
Intervention or Exposure	4. tilted OR tipped OR angulated OR tilting OR tipping 5. implant restoration OR implant supported prosthesis OR implant supported fixed dental prosthesis OR implant supported FDP OR implant supported FPD OR all-on-four OR all-on-4 OR provisional OR four-implant
Comparison	6. vertical OR straight OR planned OR traditional OR parallel OR axial OR upright
Outcome	7. implant prognosis OR implant survival OR implant success OR prosthetic complications OR prosthetic survival OR prosthetic success OR need for grafting OR treatment time OR patient satisfaction OR clinician satisfaction OR provisional OR Definitive OR interim
Search combination	1 OR 2 OR 3 AND (4 OR 5) AND 6 AND 7
Database search	
Language	English
Electronic database	PubMed (Medline) Cochrane Central Register of Controlled Trials (CENTRAL) EMBASE
Manual journal search	Clinical Oral Implants Research International Journal of Oral Maxillofacial Implants Clinical Implant Dentistry and Related Research Journal of Oral Implantology Implant Dentistry Journal of Prosthetic Dentistry Journal of Prosthodontics International Journal of Prosthodontics Personal communications on Grey Literatures
Selection criteria	
Inclusion criteria	Randomized controlled trials (RCT) Nonrandomized studies (NRS) Multicenter studies Published between 2003 and 2017 Follow-up period of at least 12 months Humans Adult (19+)
Exclusion criteria	Failure to identify inclusion criteria Methodology, technique, or review article Multiple publications on the same patient population Lack of identifiable information specific to prosthodontic procedures Patient pool of 10 or less Non-English language Animal studies Histologic or nonclinical outcomes Failure to report treatment outcomes on the dental implants or prostheses

Kappa agreement of inter-rater reliability was performed. Cohen's κ was run to determine if there was agreement between the two authors' judgments during the first, second, and final item reduction. During the first item reduction (title review), there was good agreement between the 2 authors' judgments, κ = 0.8016 (95% CI, 0.738–0.866). During the second item reduction (abstract review), there was very good agreement between the 2 authors' judgments, κ = 0.872 (95% CI, 0.782–0.963). During the final item reduction (full-text review), there was very good agreement between the 2 authors' judgments, κ = 0.954 (95% CI, 0.865–1) (Altman, 1991; McHugh, 2012).

The identified articles were then sorted into the different levels of evidence. (Table 2). The Cochrane Collaboration tool was used to

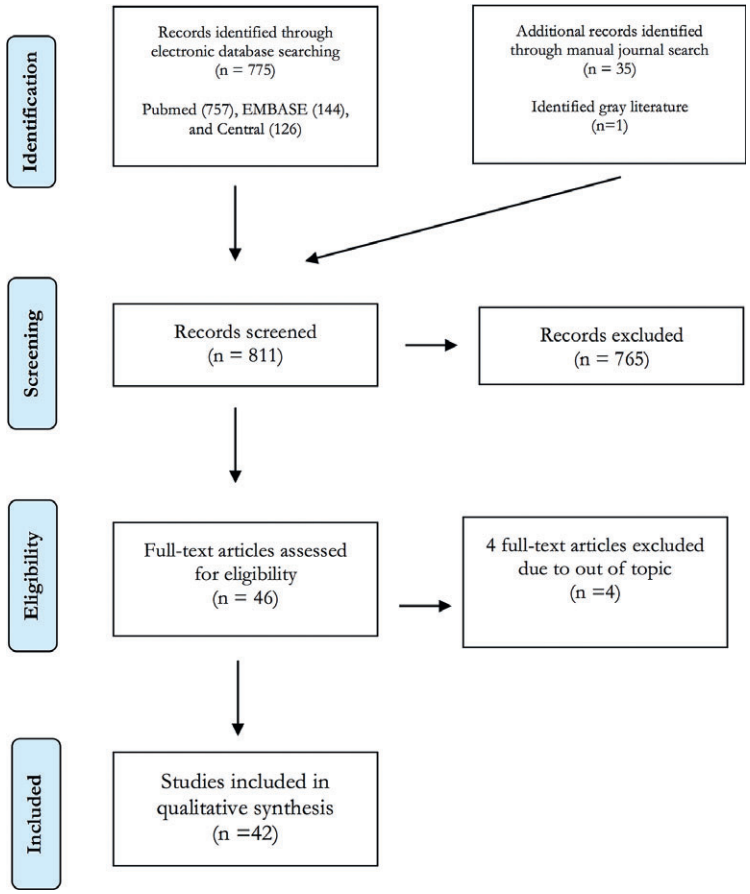

FIGURE 1 Search strategy (PRISMA flow diagram)

assess the quality of randomized controlled trials (RCTs) (Table 3), and the Newcastle-Ottawa Scale (NOS) was used to assess the quality of nonrandomized studies (Table 4). Level I and level II studies were reread and data were extracted from these studies (Tables 5–10). Likewise, the studies were evaluated to determine the final value of these articles to the literature review and data analysis that was drawn from it.

Upon final assessment of 42 articles it was determined that there were two level I studies. (Crespi, Vinci, Capparé, Romanos, & Gherlone, 2012; Tallarico, Meloni, Canullo, Caneva, & Polizzi, 2016) However, these studies did not aim to directly compare tilted to axial implants. One randomized controlled trial compared definitive acrylic resin prostheses with or without a cast metal framework that were immediately loaded and supported by axial and tilted implants. (Crespi et al., 2012) Although this study was not designed specifically to compare the tilted versus axial implants, 3-year overall implant survival rate was reported at 100% for axially positioned implants and at 96.59% for tilted implants, with a prosthetic survival rate of 100%. In addition, no statistically significant differences were found in marginal bone loss between tilted (maxilla: 1.11 ± 0.32 mm and mandible: 1.12 ± 0.35 mm) and axial implants (maxilla: 1.10 ± 0.45 mm and mandible: 1.06 ± 0.41 mm) at 3 years ($p > 0.05$). The second randomized controlled trial compared four implants supported prostheses (two axial and two tilted, all-on-4 protocol) to six-implants supported prostheses (all axial implants, all-on-6 group). (Tallarico, Meloni, et al., 2016) It showed that the all-on-6 group underperformed in comparison to the all-on-4 group relative to implant survival while the all-on-4 group exhibited more complications. Neither the numbers of implant failures nor the numbers of complications were statistically significant, and consequently, the performance of the two comparison groups was considered to be statistically equivalent.

Twenty level II studies were evaluated and were likewise heterogenous in nature. The level II studies that were available on this topic were not specifically focused on the performance of the implants per se but were instead studies that evaluated the targeted number of implants that would be placed per arch. Most studies focused on the clinical performance of four implants placed in the edentulous maxilla or mandible. Only one level II study focused on the direct comparison between axially placed and tilted implants (Krennmair et al., 2016). In this particular 3-year prospective clinical trial, 21 patients with four axially placed implants (axial group: two anterior and two posterior implants) and 20 patients with four implants (tilted group: two anterior axially placed and two distal tilted implants) were all restored with implant supported mandibular full-arch fixed dental prostheses. 37 out of 41 patients (19 patients in the axial group and 18 patients in the tilted group) and 148 out of 164 implants were followed at the 1-, 2-, and 3-year evaluation (dropout rate: 11.8%) presenting 100% implants and prostheses survival rates. The study showed that there were no

TABLE 2 Studies Included for Data Extraction

Levels of Evidence	Numbers	Studies
Level I	2	Crespi et al. (2012) Tallarico, Meloni et al. (2016)
Level II	20	Capelli et al. (2007) Francetti et al. (2008) Testori et al. (2008) Tealdo et al. (2008) Agliardi et al. (2010) Hinze et al. (2010) Francetti et al. (2012) Grandi et al. (2012) Weinstein et al. (2012) Malo, Nobre, and Lopes (2012) Di et al. (2013) Krennmair et al. (2014) Pera et al. (2014) Browaeys et al. (2015) Gherlone, Ferrini, Crespi, Gastaldi, and Capparé (2015) Ayna et al. (2015) Krennmair et al. (2016) Piano et al. (2016) Najafi et al. (2016) Li et al. (2017)
Level IV	15	Babbush, Kutsko, and Brokloff (2011) Paulo Malo, de Araújo Nobre, Lopes, Moss, and Molina (2011) Butura, Galindo, and Jensen (2011) Galindo and Butura (2012) Cavalli et al. (2012) Maló, de Araújo Nobre, Lopes, Francischone, and Rigolizzo (2012) Krennmair, Seemann, Weinländer, Krennmair, and Piehslinger (2013) Maló, de Araújo Nobre, and Lopes (2013) Thomas J Balshi, Wolfinger, Slauch, and Balshi (2014) Sannino, Bollero, Barlattani, and Gherlone (2015) Tallarico, Canullo, et al. (2016) Sannino and Barlattani (2016) Drago (2016) Niedermaier et al. (2017) Babbush, Kanawati, and Kotsakis (2016)
Previous Systematic reviews and Meta-Analysis	4	Ata-Ali, Peñarrocha-Oltra, Candel-Marti, and Peñarrocha-Diago (2012) Menini et al. (2012) Del Fabbro and Ceresoli (2014) Chrcanovic, Albrektsson, and Wennerberg (2015)

statistical significant differences between axial and tilted groups regarding clinical implant and prosthesis outcomes, including survival rates, biological and mechanical complications, peri-implant marginal bone resorption, pocket depth, bleeding index and gingival index.

In most studies, the posterior implants were titled toward the distal between 30 and 45 degrees from the long axis of residual ridges, and the dental implants were placed with minimal insertion torque of 30 Ncm. 17 and 30 degrees transmucosal prosthetic abutments were used to align the angulations of prosthetic screw access. Immediate loading protocol with screw-retained provisional resin prostheses was commonly used to provide patients the interim prostheses. The survival rate of tilted implants varied in the included studies, with the lowest reported survival rate at 89.4% during first 12 months follow-up (Tealdo et al., 2008) to the highest reported survival rate at 100% during 5 years follow-up (Ayna, Gülses, & Açil, 2015) and 97.50% at 7 years follow-up (Li, Di, Zhang, & Lin, 2017). In the authors' assessments, there were no differences in the implant survival rates between tilted and axial implants. When comparing the marginal bone loss around the implants, no significant differences were found between tilted and axial implants in most included studies. Although most studies did not report the survival rates for the interim prosthesis, 100% survival rates of definitive prosthesis were commonly documented. Two studies reported the remake of definitive prosthesis due to the loss of dental implants (Di et al., 2013; Najafi, Siadat, Akbari, & Rokn, 2016).

For the interim prosthesis, the most commonly reported prosthetic complication included fracture of interim prosthesis, (Agliardi, Panigatti, Clerico, Villa, & Malo, 2010; Francetti et al.,

TABLE 3 Risk of Bias for Randomized Controlled Trials by the Cochrane Collaboration's tool. Levels of risk or bias: high, unclear, and low

Study	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias) (patient-reported outcomes)	Blinding of outcome assessment (detection bias) (Mortality)	Incomplete outcome data addressed (attrition bias)	Selective reporting (reporting bias)	Other sources of bias
Crespi et al. (2012)	High	Low	High	Unclear	High	Low	Low	High
Tallarico, Meloni, et al., (2016)	High	Low	High	Unclear	High	Low	Low	High

2008; Francetti, Romeo, Corbella, Taschieri, & Del Fabbro, 2012; Grandi, Guazzi, Samarani, & Grandi, 2012; Krennmair, Seemann, Weinländer, Krennmair, & Piehslinger, 2014), screw loosening, (Krennmair et al., 2014; Testori et al., 2008) and fracture of veneering material.(Hinze, Thalmair, Bolz, & Wachtel, 2010; Krennmair et al., 2014) For the definitive prosthesis, the fracture of metal framework was uncommon, and was reported in 2 incidences from 2 articles. (Francetti et al., 2012; Pera et al., 2014) Other most commonly reported complications on definitive prostheses included fracture or wear of veneering material or artificial teeth, the need for readaptation of prosthesis to tissue to compensate for continuing resorption, abutment or prosthetic screw loosening, prosthetic screw fracture, and loss of screw access restoration (Ayna et al., 2015; Di et al., 2013; Francetti et al., 2012; Hinze et al., 2010; Krennmair et al., 2014; Najafi et al., 2016; Pera et al., 2014).

Patient-reported outcome measures (PROMs) were reported in different studies to demonstrate the overall clinical efficacy when combining anterior axial implants and posterior tilted implants in treating edentulous patients. (Ayna et al., 2015; Capelli, Zuffetti, Del Fabbro, & Testori, 2007; Di et al., 2013; Francetti et al., 2008; Krennmair et al., 2014; Li et al., 2017; Pera et al., 2014; Testori et al., 2008; Weinstein, Agliardi, Fabbro, Romeo, & Francetti, 2012) Patients generally reported satisfactory outcomes regarding aesthetics, phonetics, ease of maintenance, and functional efficiency. However, the survey instruments were greatly varied in different studies, and rarely was a reliable and validated psychometric instrument used to collect these patient-reported outcomes.

One article was identified from the authors knowledge of submitted or planned journal articles. (Eckert, 2017) This article qualified as gray literature. The study was a single cohort study that demonstrated 1,903 implants (Bone Level Tapered implants 4.1 mm or 3.3 mm; Straumann) placed over a 16-months time period. In this study anterior implants were placed along the axis of the residual ridge and posterior implants were intentionally tilted toward the distal approximately 30° or more. The treatment protocol indicated a plan to utilize the minimum number of implants necessary to achieve the immediate loading treatment protocol. The average number of implants placed in the maxilla was 4.3 implants per maxilla while the average number in the mandible was 4.1 implants. Immediate loading protocol was followed after implant surgery with screw-retained acrylic resin prostheses in 440 of 441 planned arches. The mean observation time in this study was 260 days. Of the 1,903 implants that were placed, all but six of the implants received angled abutments. In the posterior, the implants were intentionally tilted to the distal and a 30° angled abutment was used to create an apparent screw access opening slightly forward and more vertical than the implant angle would have established. The anterior implants followed the angulation of the alveolar ridge and this resulted in a forward angle of the anterior implant relative to the occlusal plane. In the anterior maxilla, 30° angled abutments were required for most implants. In the mandible the majority of the anterior implants were corrected using 17° angled abutments. No difference in implant performance, axial vs tilted, was identified. This study also reported no significant differences in implant survival based upon insertion torque.

TABLE 4 Quality assessment and risk of bias for nonrandomized trials by the Newcastle-Ottawa Scale. Higher scores indicate lower risk of bias in a study

	Selection				Comparability		Outcome			
Study	Representativeness of the exposed cohort	Selection of the nonexposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study	Control for main factor	Control for additional factor	Assessment of outcome	Follow-up long enough for outcomes to occur	Adequacy of follow-up of cohorts	Total scores (9/9)
Capelli et al. (2007)	0	★	★	★	★	0	★	0	0	5
Francetti et al. (2008)	0	★	★	★	★	0	★	0	0	5
Testori et al. (2008)	0	★	★	★	★	0	★	0	0	5
Tealdo et al. (2008)	0	★	★	★	★	★	★	0	★	7
Agliardi et al. (2010)	0	★	★	★	★	★	★	0	0	6
Hinze et al. (2010)	0	★	★	★	★	0	★	0	★	6
Francetti et al. (2012)	0	★	★	★	★	0	★	★	★	7
Grandi et al. (2012)	0	★	★	★	★	0	★	0	0	5
Weinstein et al. (2012)	0	★	★	★	★	0	★	0	★	6
Malo et al. (2012)	0	★	★	★	★	0	★	0	0	5
Di et al. (2013)	0	★	★	★	★	0	★	0	★	6
Krennmair et al. (2014)	0	★	★	★	★	★	★	0	★	7
Pera et al. (2014)	0	★	★	★	★	★	★	★	★	8
Browaeys et al. (2015)	0	★	★	★	★	★	★	★	★	8
Gherlone et al. (2015)	0	★	★	★	★	0	★	0	★	6
Ayna et al. (2015)	0	★	★	★	★	★	★	★	★	8
Krennmair et al. (2016)	0	★	★	★	★	★	★	★	★	8
Piano et al. (2016)	0	★	★	★	★	0	★	0	0	5
Najafi et al. (2016)	0	★	★	★	★	★	★	0	★	7
Li et al. (2017)	0	★	★	★	★	0	★	0	★	6

TABLE 5 Study design of the included Level I and Level II studies

Publication year	First author	Study level	Numbers of patients	Study jaw	Patient's age (years)	Follow-up duration	Implants used in the study
2012	Crespi R	1	36 (22 women and 14 men)	Maxilla: 24 Mandible: 2	54.6 (range: 41–81)	3 years	PAD System; Sweden-Martina
2016	Tallarico M	1	40 (19 women and 21 men)	Maxilla: 40	63 (range:42–87)	5 years (mean of 63.8 months, ranging 60–84 months)	NobelSpeedy Groovy implants; Nobel Biocare AG
2007	Capelli M	2	65 (43 women and 22 men)	Maxilla: 41 Mandible: 24	59.2 (range: 28–83)	Up to 52 months	Osseotite NT; Biomet 3i
2008	Francetti L	2	62 (34 women and 28 men) Assessed—44 patients only	Mandible: 44	56 (range: 35–77)	44 patients follow-up >1 year, (mean of 22.4 months, ranging 6–43 months)	Brånemark System MK IV NobelSpeedy Groovy
2008	Testori T	2	41 (26 women and 15 men) Assessed—30 patients	Maxilla: 30	59.2 ± 9.5 (range 38–84)	30 patients follow-up >1 year, (mean of 22.1 months, ranging 3–42 months)	Osseotite NT Implant; Biomet 3i
2008	Tealdo T	2	21 (10 women and 11 men)	Maxilla: 21	58	Mean of 20 months, ranging 13–28 months	Osseotite and Osseotite NT; Biomet 3i
2010	Agliardi E	2	173 (93 women and 80 men) Assessed—154 patients	Enrolled: Maxilla: 72 Mandible: 101 Assessed: Maxilla: 61 Mandible: 93	57.3 ± 8.5 (range 42–74)	154 patients follow-up >1 year. Maxilla: mean of 26.9 ± 12.5 months, ranging 12–55 months Mandible: mean of 31.3 ± 14 months, ranging 12–59 months	Brånemark Systems MKIV: 92 NobelSpeedy Groovy: 404
2010	Hinze M	2	37 (19 women and 18 men)	Maxilla: 19 Mandible: 18	64.6 (range 39–84)	1 year	NanoTite Tapered Implants; Biomet 3i
2012	Francetti L	2	47 (22 women and 25 men)	Maxilla: 16 Mandible: 33	53 (range 44–63)	Maxilla: mean of 33.8 months, ranging 22–40 months Mandible: mean of 52.8 months, ranging months 30–66 months	Brånemark System MK IV: 92 NobelSpeedy Groovy: 104
2012	Grandi T	2	47 (25 women and 22 men)	Mandible: 47	62.3 ± 9.4 (range 52–78)	18 months	Tapered implants (JDEvolution, JDentalCare, Modena, Italy)
2012	Weinstein R	2	20 (12 women and 8 men)	Mandible: 20	60.8 ± 8.8 (range 44–77)	Mean of 30.1 ± 8.6 months, ranging 20–48 months,	Brånemark System MKIV: 12 NobelSpeedy Groovy: 68

(Continues)

TABLE 5 (Continued)

Publication year	First author	Study level	Numbers of patients	Study jaw	Patient's age (years)	Follow-up duration	Implants used in the study
2012	Maló P	2	142 (86 women and 56 men)		53.7 (range 20–78)	Mean of 26 months, ranging 1–107 months.	MkIII implant (Nobel Biocare) MkIV implant (Nobel Biocare) NobelSpeedy implant (Nobel Biocare)
2013	Di P	2	69 (32 women and 37 men)	Maxilla: 38 Mandible: 48	56.78 (range 37–74)	Mean of 33.7 months, ranging 12–56 months,	Brånemark Mk III: 52 NobelSpeedy Groovy: 292 (TiUnite, Nobel Biocare).
2014	Krennmair S	2	24 (10 women and 14 men)	Mandible: 24	61.5 ± 11.9 (range 38–84)	24 months	Camlog; Screw-Line Promote plus; Wimsheim, Germany
2014	Pera P	2	37 (20 women and 17 men)	Maxilla: 37	55.1 (range 43–71)	Mean of 72.5 months, ranging 72–76 months,	Osseotite; Biomet 3i: 56 Full Osseotite; Biomet 3i: 108
2015	Browaeys H	2	20 (14 women and 6 men)	Maxilla: 9 Mandible: 11	55 (range 35–74)	3 years	Mk III Groovy: for mandible, $n = 44$ Nobel Speedy Groovy: for maxilla, $n = 44$
2015	Gherlone EF	2	14 (8 women and 6 men)	Maxillae: 6 Mandible: 8	56.3 (range 43–80)	12 months	Winsix; BioSAFin, Ancona, Italy
2015	Ayna M	2	27 (19 women and 8 men)	Mandible: 27	64.4 ± 10.8 (range 43–77)	5 years	Nobel Speedy
2016	Krennmair S	2	37 Axial group: 19 (12 women and 7 men) Tilted group: 18 (10 women and 8 men)	Mandible: 37	Axial Group 66.7 ± 9.6 (range 43–84) Tilted Group 62.6 ± 9.7 (range 42–77)	3 years	Camlog; Screw-line, Promote, Wimsheim
2016	Piano S	2	21	Maxilla	66 years (range 56–81 years)	2 years	Straumann SLActive Bone Level implants
2016	Najafi H	2	30 (14 women and 16 men)	Maxilla: 14 Mandible: 25	59.3 ± 11.7 (range 28–89)	32.5 ± 13.6 months	Brånemark System MKIII or MKIV Nobel Speedy Groovy Nobel Replace selec
2017	Li S	2	17 (7 women and 10 men)	Maxilla: 7 Mandible: 13	39.4 (range 28–45)	Mean of 5 years, ranging 2–7 years	Brånemark System MK III: 44 Nobel Speedy Groovy: 8 Nobel Active: 28

(Continues)

TABLE 6 Surgical and prosthetic protocol used in the included Level I and Level II studies

Publication year	First author	Total implants placed	Tilted implants placed	Axial implant placed	Tilted implant inclination (degrees)	Implant insertion torques (Ncm)	Loading protocol	Abutment angles	Definitive prosthesis loading at	Prosthesis design
2012	Crespi R	176	Maxilla: 48 Mandible: 40	Maxilla: 48 Mandible: 40	Mandible: 30°–35° Maxilla: 30°-35°	>40	Immediate Within 24 hr and with definitive prosthesis	Anterior Implant: 17° Posterior implant: 30°	24 hr	Screw-retained acrylic resin prosthesis: 21 Screw-retained cast metal-frame prosthesis: 23
2016	Tallarico M	200 All-on-4: 80 All-on-6: 120				35–45	Immediate A prefabricated, screw-retained, fully acrylic or metal-reinforced acrylic resin provisional restoration, without any cantilever, delivered immediately.	Distal: 17° or 30° Mesial: 0° or to implant level	Patient returned for impression at 4 months and delivery at 5 months.	Definitive prosthesis with CAD/CAM titanium or zirconia frameworks and layered with either pink and/or white material (not specified).
2007	Capelli M	342 Maxilla: 246 Mandible: 96	130 Maxillary: 82 Mandible: 48	212 Maxillary: 164 Mandible: 48	Maxilla: 30°–35° Mandible: 25°–35°	30–50	Immediate Provisional full-arch restorations made of a titanium framework and acrylic resin teeth were delivered within 48 hr of surgery	If implant inclination exceeded 30 degrees, angulated abutments were used.	3 months	Complete full-arch prostheses were fabricated with a titanium framework combined with new acrylic resin teeth composed of 12 elements
2008	Francetti L	248	124	124	30°	40–50	Acrylic temporary prosthesis with 10 teeth was delivered within 48 hr	Distal: 30° Mesial: Straight	After 4–6 months	CAD-CAM Procera system
2008	Testori T	246	82	164	30°–35°	30	Immediate The provisional screw-retained prosthesis was delivered within 48 h from surgery using temporary provisional cylinders with fiber-reinforced acrylic teeth.		3 months	Seven Screw-retained, fabricated with a titanium framework (CRESCO Astra Tech Implant System) with acrylic resin teeth; the remaining 33 prostheses were porcelain-cemented restorations with a cast mesiostructure connecting all the implants on each side.
2008	Tealdo T	111	47	64		>40	Immediate Screw-retained fixed provisional prostheses supported by palladium-alloy frameworks within 24 hr after surgery, no cantilevers distal to the distal implants.	Conical abutments (0°, 17°, 25°, and 45°)	18 weeks	All of the definitive prostheses consisted of palladium-alloy frameworks; the occlusal surfaces were designed completely in porcelain or acrylic resin artificial teeth. All of the definitive prostheses were screw retained.

(Continues)

TABLE 6 (Continued)

Publication year	First author	Total implants placed	Tilted implants placed	Axial implant placed	Tilted implant inclination (degrees)	Implant insertion torques (Ncm)	Loading protocol	Abutment angles	Definitive prosthesis loading at	Prosthesis design
2010	Agliardi E	692	346	346	Maxilla: 30°–45° Mandible: 30°	>30	Immediate Acrylic provisional prosthesis	Maxilla: Distal: 30° (*n* = 144) Mesial: 0° (*n* = 127) 17° (*n* = 20) Mandible: Distal: 30° (*n* = 202) Mesial: 0° (*n* = 202)	4–6 months	CAD-CAM Proceras System (Nobel Biocare, Stockholm, Sweden)
2010	Hinze M	148 Maxilla: 76 Mandible: 72	74	74	30°	>30	Immediate Within 24 hr, 10 units screw-retained full-arch acrylic resin provisional restorations.		6 months	Complete full-arch prostheses were supported by metal frameworks combined with high-density acrylic resin.
2012	Francetti L	196 Maxilla: 64 Mandible: 132	98	98	30°	40–50	Immediate An acrylic temporary prosthesis with 10 teeth was delivered within 48 hr of implant placement.	Distal: 30° Mesial: 0°	4–6 months	CAD-CAM Procera system and consisting of 12 teeth
2012	Grandi T	188	94	94		>45	Immediate 10-unit screw- retained, provisional fixed dental prosthesis with a metal framework (nonprecious alloy) within 48 hr after surgery	Distal: 30° (*n* = 94) Mesial: 0° (*n* = 82) 17° (*n* = 12)	6 months	
2012	Weinstein R	80	40	40	30°	50	Immediate An acrylic temporary prosthesis with 10 teeth was delivered within 48 hr of surgery with centric and lateral contacts limited at the intercanine zone.	Distal: 17° or 30° Mesial: 0°	4–6 months	CAD- CAM Procera system (Nobel Biocare AB).
2012	Maló P	227 Maxilla: 133 Mandibule: 94			Maxilla: up to 45° Mandible: 30°–45°	35	Immediate A high-density acrylic resin prosthesis with titanium cylinders was manufactured at the dental laboratory and inserted on the same day, usually 2–3 hr postsurgically.	Distal: 30° Mesial: 0°, 17° or 30°	6 months	Depending on patient desires, the definitive prosthesis featured either a titanium framework and all-ceramic crowns or a titanium framework and acrylic resin prosthetic teeth.

(Continues)

TABLE 6 (Continued)

Publication year	First author	Total implants placed	Tilted implants placed	Axial implant placed	Tilted implant inclination (degrees)	Implant insertion torques (Ncm)	Loading protocol	Abutment angles	Definitive prosthesis loading at	Prosthesis design
2013	Di P	344	172	172	Maxilla: up to 45°	>35 N	Immediate 10–12 units interim all acrylic prostheses (without metal frameworks) delivered approximately 6 hr after implant placement.	0° (*n* = 113) 17° or 30° (*n* = 231)	6 months	12 acrylic resin teeth units with a metal framework
2014	Krennmair S	96	48	48		>30	Immediate A simple metal bar was connected to the copings to obtain reinforcement of the interim prostheses, and they were inserted within 24 hr.	Distal: 30° (*n* = 12) 20° (*n* = 36) Mesial: 0° (*n* = 48)	3 months	Cobalt-chromium screw-retained prostheses. All prostheses consisted of 12 acrylic veneering (1 molar per side) with the extension varying in size.
2014	Pera P	164				>40	Immediate The screw-retained provisional prostheses with metal frameworks were placed within 24–36 hr of the surgery.	Distal: 17°, 25°, 30° 0°: *n* = 6 17°: *n* = 77 25°: *n* = 75 30°: *n* = 6	4 months	Metal framework with acrylic resin or a microfilled hybrid composite resin
2015	Browaeys H	80	40	40	Between 20° and 40°	< 50	Immediate. Within 48 hr, the 10-unit provisional resin-based prosthesis was delivered and installed in the mouth	Distal: 30° Mesial: 0°	3–4 months	The final prosthetic work was performed by the referring dentist, but no other details provided.
2015	Gherlone EF	56	28	28	30° to 35°	>40	Immediate 5 hr after implant placement, screw-retained full-arch interim prosthesis by only all acrylic resin frameworks were positioned.	Distal: 30° Mesial: 17°	4 months A digital scan body was used to finalize definitive prosthesis. (Lava COS; 3M)	Definitive prostheses were made by acrylic resin masticatory surfaces and metal frameworks for increased strength and rigidity
2015	Ayna M	108	54	54	45°	>35	Immediate All implants were immediately loaded within 24 hr.	Distal: 30° Mesial: 0°		The patients were assigned to the different groups (ceramics/acrylic) according to their own choice. (14 acrylic, and 13 ceramics)
2016	Krennmair S	148	36	112		>30	Conventional loading Patient returned for impression and uncovering at 2 months.	Axial implant: 0 degree Tilted implant:20° and 30°	Patient returned for impression and uncovering at 2 months.	Screw-retained Cobalt-Chromium acrylic resin prosthesis. All prostheses consisted 12 acrylic veneering.

(Continues)

TABLE 6 (Continued)

Publication year	First author	Total implants placed	Tilted implants placed	Axial implant placed	Tilted implant inclination (degrees)	Implant insertion torques (Ncm)	Loading protocol	Abutment angles	Definitive prosthesis loading at	Prosthesis design
2016	Piano S	84	42	42	≤ 30°	>25	Immediate The framework was created by laser welding the titanium copings to the preproduced CAD/CAM titanium bars, and acrylic resin was used for the overdenture veneering. 12–14 units. Delivered within 48 hr.	Distal: 0° (*n* = 22) 25° (*n* = 16) Mesial: 0° (*n* = 26) 25° (*n* = 20)	3 months	After 3 months, the interim prostheses were relined, if any soft tissues remodeling occurred. Acrylic resin was used for prosthesis relining. A direct resin addition technique was performed.
2016	Najafi H	156	78 Maxillae: 28 Mandible: 50	78 Maxillae: 28 Mandible: 50	45°	≥35 Ncm for the immediate loading group <35 Ncm for delayed group	Immediate group: On the third day after surgery, the final metal resin prosthesis was delivered Delayed group : During the second surgery, which was carried out after four months, the abutments were connected and the remaining prosthetic procedures were the same as those in the IL group	Distal: 30° Mesial: 0°		It appeared that authors used the original interim as the definitive prosthesis.
2017	Li S	80	40	40	30°–40°	35–45	Immediate 10–12 units heat-cured acrylic resin prostheses without metal frameworks were delivered to the patients approximately 6 hr after surgery.	Distal: 17° or 30° Mesial: 0°, 17° or 30°	4–6 months	High-precision CAM metal framework with a wrap-around heat-cured acrylic resin, as well as 12 acrylic resin teeth units, or all-ceramic crown units

TABLE 7 Implant outcomes in the included Level I and Level II studies

Publication year	First author	Overall implant survival	Percentages of surviving tilted implants	Percentages of surviving axial implants	Implant survival differences	Marginal bone loss (mean ± *SD*) (mm) on all implants	Marginal bone loss (mean ± *SD*) (mm) on tilted implants	Marginal bone loss (mean ± *SD*) (mm) on axial implants	Marginal bone loss differences
2012	Crespi R	3 years Maxilla: 98.96% Mandible: 97.5%	3 years Maxilla: 97.97% Mandible: 95% Overall: 96.59%	3 years Maxilla: 100% Mandible: 100%			At 1 year: Maxilla: 1.05 ± 0.29 Mandible: 1.05 ± 0.32 At 2 year: Maxilla: 1.07 ± 0.46 Mandible: 1.09 ± 0.29 At 3 years: Maxilla: 1.11 ± 0.32 Mandible: 1.12 ± 0.35	At 1 year: Maxilla: 1.10 ± 0.35 Mandible: 1.04 ± 0.30 At 2 year: Maxilla: 1.08 ± 0.41 Mandible: 1.04 ± 0.35 At 3 years: Maxilla: 1.10 ± 0.45 Mandible: 1.06 ± 0.41	No statistically significant differences ($p > 0.05$) in crestal bone loss were found in either arch between tilted and axial implants at 12, 24, and 36 months.
2016	Tallarico M	5 years All-on-6: 95% All-on-4: 98.75%			Not statistically significant differences ($p = 0.246$) between All-on-4 and All-on-6 groups	5-year All-on-4: 1.7 ± 0.42 All-on-6: 1.51 ± 0.36			Not statistically different between All-on-4 and All-on-6 groups at 5 years. ($p = 0.117$)
2007	Capelli M	Maxillary: 97.59% up to 40 months (mean follow-up, 22.5 months) Mandibular: 100% with up to 52 months of follow-up (mean follow-up, 29.1 months).	3 years 98.46%	3 years 98.58%			1 year Maxillary: 0.88 ± 0.59 ($n = 42$ implants) Mandible: 0.75 ± 0.55 mm ($n = 32$ implants)	1 year Maxillary: 0.95 ± 0.44 ($n = 84$ implants) Mandible: 0.82 ± 0.64 mm ($n = 32$ implants)	No significant difference in crestal bone loss between tilted and upright implants was detected at the 12-month follow-up evaluation in either jaw.
2008	Francetti L	1 year 100%	1 year 100%	1 year 100%			1 year 0.7 ± 0.5	1 year 0.7 ± 0.4	No significant difference in marginal bone loss was found between tilted and axial implants at 1-year evaluation.
2008	Testori T	3 year 97.58%	3 year 97.10%	3 year 97.90%			1 year 0.8 ± 0.5	1 year 0.9 ± 0.4	Marginal bone loss around axial and tilted implants at 12-month evaluation was similar
2008	Tealdo T	1 year 92.8%	1 year 89.40%	1 year 95.30%	No statistically significant differences between tiled and axial implants	1 year 0.84	1 year Mesial: 0.92 Distal: 1.04	1 year Mesial: 0.62 Distal: 0.86	

(Continues)

TABLE 7 (Continued)

Publication year	First author	Overall implant survival	Percentages of surviving tilted implants	Percentages of surviving axial implants	Implant survival differences	Marginal bone loss (mean ± *SD*) (mm) on all implants	Marginal bone loss (mean ± *SD*) (mm) on tilted implants	Marginal bone loss (mean ± *SD*) (mm) on axial implants	Marginal bone loss differences
2010	Agliardi E	1 year Maxilla: 98.4% Mandible: 99.7%	1 year 99.70%	1 year 98.84%		1 year Maxilla: 0.9 ± 0.7 (*n* = 204 implants) Mandible: 1.2 ± 0.9 (*n* = 292 implants) Such difference was not statistically significant.			No significant differences in bone loss were found between axially placed and tilted implants.
2010	Hinze M	1 Year Maxilla: 96.6% Mandible: 98.7%	1 Year 94.60%	1 Year 96%	No significant differences in bone loss were found between axially placed and tilted implants.		1 year 0.76 ± 0.49	1 year 0.82 ± 0.31	No significant differences in bone loss were found between axially placed and tilted implants.
2012	Francetti L	100%	100%	100%			Mandible: 6 m: 0.47 ± 0.22 12 m:0.48 ± 0.23 18 m: 0.64 ± 0.37 24 m: 0.67 ± 0.38 36 m: 0.69 ± 0.52 48 m: 0.81 ± 0.40 60 m: 0.39 ± 0.18 Maxilla: 6 m: 0.35 ± 0.27 12 m: 0.32 ± 0.28 18 m: 0.72 ± 0.23 24 m: 0.63 ± 0.38 36 m: 0.85 ± 0.34	Mandible: 6 m: 0.52 ± 0.22 12 m: 0.57 ± 0.42 18 m: 0.67 ± 0.35 24 m: 0.90 ± 0.49 36 m: 0.92 ± 0.43 48 m: 0.92 ± 0.55 60 m: 0.51 ± 0.17 Maxilla: 6 m: 0.38 ± 0.34 12 m: 0.40 ± 0.27 18 m: 0.61 ± 0.49 24 m: 0.44 ± 0.37 36 m: 0.85 ± 0.74	No significant difference in marginal bone loss was found between axial and tilted implants; and between mandible and maxilla, at each comparable time frame.
2012	Grandi T	18 months 100%	18 months 100%	18 months 100%		6 m: 0.31 ± 0.12 12 m: 0.58 ± 0.11 18 m: 0.7 ± 0.11	6 m: 0.36 ± 0.14 12 m: 0.6 ± 0.16 18 m: 0.74 ± 0.14	6 m: 0.27 ± 0.17 12 m: 0.57 ± 0.13 18 m: 0.68 ± 0.14	No significant differences in bone loss were found between axially placed and tilted implants at the 6-month, the 12-month and the 18-month follow-up
2012	Weinstein R	1 Year 100%	1 Year 100%	1 Year 100%			1 Year: 0.7 ± 0.4 (*n* = 36 implants)	1 Year: 0.6 ± 0.3 (*n* = 36 implants)	Marginal bone loss around axial and tilted implants was similar at 12-month evaluation. Such difference was not statistically significant ($p > 0.05$)
2012	Maló P	2-year estimate Maxilla: 97.7% 3 Year estimate Mandible: 94.8%				1 year: Maxilla: 1.3 ± 0.4 Mandible: 1.4 ± 0.3 3 year: Maxilla: 1.6 ± 0.4 5 year: Mandible: 1.7 ± 0.6			

(Continues)

TABLE 7 (Continued)

Publication year	First author	Overall implant survival	Percentages of surviving tilted implants	Percentages of surviving axial implants	Implant survival differences	Marginal bone loss (mean ± *SD*) (mm) on all implants	Marginal bone loss (mean ± *SD*) (mm) on tilted implants	Marginal bone loss (mean ± *SD*) (mm) on axial implants	Marginal bone loss differences
2013	Di P	56 months Overall: 96.2% Maxilla: 92.8% Mandible: 99.0%	56 months 93.60%	56 months 98.83%	The implant survival rate was significantly elevated in mandibular versus maxillary implants		56 months 0.8 ± 0.4	56 months 0.7 ± 0.2	Marginal bone level changes were statistically similar on the upright and the tilted implants
2014	Krennmair S	2 years 100%	2 years 100%	2 years 100%		12 m: 0.18 ± 0.20 24 m: 0.40 ± 0.29			Marginal bone level changes were statistically between 12 and 24 months. $p < 0.001$
2014	Pera P	6 years 97.58%				1 year: 1.14 6 year: 1.52	1 year: 1.01 ± 0.75 3 year: 1.32 ± 1.20 6 Year: 1.44 ± 1.24	1 year: 1.24 ± 0.90 3 year: 1.51 ± 1.22 6 Year: 1.58 ± 1.22	No significant differences in bone loss were found in tilted versus upright implants.
2015	Browaeys H	3 years 100%	3 years 100%	3 years 100%		61 implants (out of 80) were taken into account for statistical analysis of bone level changes: 1 year: 1.13 ± 0.94 3 years: 1.61 ± 1.40	1 year: 1.14 ± 1.14 3 years: 1.67 ± 1.22	1 year: 1.13 ± 0.71 3 years: 1.55 ± 0.73	This difference was statistically significant ($p < 0.001$) between 1 year and 3 years follow-up, indicative of ongoing bone loss Bone loss was not significantly different between straight and tilted implants ($p = 0.605$) after 3 years
2015	Gherlone EF	12 months 100%	12 months 100%	12 months 100%			12 months Maxilla: 1.07 ± 0.81 Mandible: 1.10 ± 0.89	12 months Maxilla: 1.07 ± 0.99 Mandible: 1.02 ± 0.72	No statistically significant differences ($p > 0.05$) in crestal bone loss between tilted and upright implants was detected at 12-month follow-up evaluation in either jaws.
2015	Ayna M	5 Years 100%	5 Years 100%	5 Years 100%			1 year region 35: 0.89 ± 0.11 region 45: 0.93 ± 0.13 5 Year region 35: 1.24 ± 0.13 region 45: 1.30 ± 0.13	1 year region 32: 0.47 ± 0.14 region 42: 0.52 ± 0.11 5 Year region 32: 0.78 ± 0.10 region 42: 0.78 ± 0.10	Bone loss was significantly more pronounced around the distal implants (regions 35 and 45), with the differences amounting to a factor of 2–3 ($p < 0.0001$ throughout).

(Continues)

TABLE 7 (Continued)

Publication year	First author	Overall implant survival	Percentages of surviving tilted implants	Percentages of surviving axial implants	Implant survival differences	Marginal bone loss (mean ± *SD*) (mm) on all implants	Marginal bone loss (mean ± *SD*) (mm) on tilted implants	Marginal bone loss (mean ± *SD*) (mm) on axial implants	Marginal bone loss differences
2016	Krennmair S	3 years 100%	3 years 100%	3 years 100%		1 year: 1.11 ± 0.4 2 year: 1.26 ± 0.42 3 year: 1.40 ± 0.41	Tilted Group At 1 year: Posterior implant 1.0 ± 0.5 At 2 year Posterior implant 1.2 ± 0.5 At 3 years Posterior implant 1.4 ± 0.4	Axial Group At 1 year: Anterior: 1.1 ± 0.4 Posterior: 1.1 ± 0.3 At 2 year: Anterior: 1.3 ± 0.3 Posterior: 1.2 ± 0.3 At 3 years: Anterior 1.4 ± 0.4 Posterior 1.4 ± 0.3 Tilted Group At 1 year: Anterior: 1.2 ± 0.4 At 2 year: Anterior: 1.4 ± 0.5 At 3 years: Anterior 1.5 ± 0.5	There were also no differences for marginal bone reduction for posterior and for anterior implants (region) comparing between axial group and tilted group. The time effect proved as statistically relevant for marginal bone reduction in anterior and posterior region ($p < 0.01$).
2016	Piano S	2 years 100%	2 years 100%	2 years 100%		2 years 0.34 ± 0.45	2 years 0.34 ± 0.46	2 years 0.35 ± 0.44	No significant difference between mean marginal bone loss of anterior and posterior implants was found ($p = 0.89$).
2016	Najafi H	13 months delayed: 99% immediate: 100% Maxilla: 98.2% Mandible: 100%	13 months 100%	13 months 98.71%		13 months: Maxilla: 0.88 ± 0.17 Mandible: 0.81 ± 0.2 Delayed Loading: 0.81 ± 0.16 Immediate Loading: 0.87 ± 0.25	13 months 0.82 ± 0.24	13 months 0.84 ± 0.27	No statistically significant difference was observed between the mean marginal bone loss of axial and tilted implants ($p > 0.05$), maxillary and mandibular implants ($p > 0.05$), or immediately loaded and delayed loaded groups ($p > 0.05$).
2017	Li S	7 years 98.75%	7 years 97.50%	7 years 100%		1 year: 0.8 ± 0.4 7 year: 1.2 ± 0.3	1 year: 0.9 ± 0.4 3 year: 0.9 ± 0.4 5 year: 1.1 ± 0.4 7 year: 1.2 ± 0.4	1 year: 0.8 ± 0.4 3 year: 0.9 ± 0.4 5 year: 1.0 ± 0.3 7 year: 1.2 ± 0.3	No statistical difference in all follow-ups ($p > 0.05$)

TABLE 8 Prosthesis survival in the included Level I and Level II studies

Publication year	First author	Prosthesis survival
2012	Crespi R	100%
2016	Tallarico M	100%
2007	Capelli M	100%
2008	Francetti L	100%
2008	Testori T	100%
2008	Tealdo T	100%
2010	Hinze M	100%
2012	Francetti L	100%
2012	Grandi T	100%
2012	Maló P	100%
2013	Di P	96.5% (Due to the loss of 2 implants at the same side in 3 patients)
2014	Krennmair S	100%
2014	Pera P	100%
2015	Browaeys H	100%
2015	Gherlone EF	100%
2015	Ayna M	100%
2016	Krennmair S	100%
2016	Piano S	100%
2016	Najafi H	96.1% for the delayed loading group 100% for the immediate loading group 92.2% for the maxillary group 100% for the mandibular group
2017	Li S	100% (20/20) for definitive prostheses 85% (17/20) for provisional prostheses

4 | DISCUSSION

The current systematic review was conducted to determine the clinical performance of intentionally tilted implants versus axially positioned implants. During the item reduction process, inter-rater reliabilities (Cohen's κ) were calculated to measure agreement among the two data collectors. Substantial inter-rater agreements were obtained in the different stages of item reduction process, indicating high degree of agreement between two authors in the identification process for included studies. Based on the evaluation criteria in a previous systematic review, RCTs were assessed with the Cochrane Collaboration's tool. Articles were judged to be at low risk of bias if there was adequate sequence generation, allocation concealment and blinding, and if one or more criteria were not met, then the study would be determined at high risk of bias. For the nonrandomized studies, the studies were considered at low risk of bias in the case of Newcastle-Ottawa Scale (NOS) scores of 7 stars or higher. (Soto-Peñaloza, Zaragozí-Alonso, Peñarrocha-Diago, & Peñarrocha-Diago, 2017) Among all the studies evaluated, both level I studies and 12 out of 20 level II studies showed high risk of bias (Tables 3 and 4).

The results of this study indicate that the implants that are generally described as "titled" are the distal implants whereas the implants that are described as axially placed and loaded are located in the anterior portions of the jaw. With the intentionally titled implant being located in the posterior portion of the jaw, these implants are subject to higher occlusal force simply because their proximity to the condyle is closer than are anterior implants. As such it would not be surprising to see some effect on implant performance that is routinely subject to a higher immediate loading. Based upon the systematic review of the literature, an analysis of the descriptive data suggested no differences in implant performance relative to anatomic location.

The level I and II articles reviewed in this systematic review appear to demonstrate no difference in clinical performance when compared to historical literature. The level I and II articles were sufficiently heterogeneous relative to the design of the studies as to prevent quantitative data accumulation/synthesis. Nonetheless there was consistent descriptive confirmation that the tilted implants demonstrated no difference relative to implant survival of the axially loaded implants (Table 7). Based on the high prosthesis survival rates (Table 8), the biomechanical stability is high. Although catastrophic complication in the definitive prosthesis, such as the fracture of metal framework, was uncommon, high prevalence of prosthetic complications was reported for both interim and definitive prostheses (Table 9). The fracture of interim acrylic prosthesis, and fracture or wear of veneering material or artificial teeth in both interim and definitive prostheses can be resolved with chairside or laboratory repairs, and occlusal adjustment in conjunction with the use of an occlusal guard. The prosthetic screw loosening or fracture can be resolved by refining the occlusal contacts and re-tightening or replacement of prosthetic screws. The need for periodic postinsertion observation and prosthetic maintenance is recommended for the edentulous patients receiving interim and definitive implant prostheses, supported by both intentionally tilted implants and axially positioned implants.

Patient-reported outcome measures (PROMs) (Table 10) showed the patient's satisfaction toward aesthetics, phonetics, ease of maintenance, and functional efficiency after the completion of treatment with definitive implant prostheses supported by both intentionally tilted implants and axially positioned implants. However, the variations of self-developed survey instruments made the comparisons across studies challenging. For the future studies, a reliable and validated psychometric instrument is recommended for collecting patient-center outcomes to ensure the quality of the results of studies. For instance, Oral Health Impact Profile (OHIP-49) (Slade & Spencer,

TABLE 9 Biological and prosthesis complications in the included Level I and Level II studies

Publication year	First author	Biological complication	Prosthesis complication	Complication comparison
2012	Crespi R	1 patient, a 76-year-old nonsmoking woman, reported severe discomfort, pain, and swelling in the anterior maxilla 3 months after surgery.	2 all acrylic resin prostheses showed fracture of acrylic resin 3% of sites showed occlusal screw lessening within first 6 months	The same clinical outcome was seen for patients treated with the so-called All-on-Four protocol, regardless of whether the acrylic resin restorations were reinforced with metal.
2016	Tallarico M	All-on-4 group 1 patient with pain and swelling without suppuration during osseointegration, around distal implants. 1 patient with peri-implantitis after the definitive prosthesis delivery, within the first year of loading All-on-6 group 1 patient with pain and swelling without suppuration during osseointegration, around distal implants. 2 patients with peri-implantitis after the definitive prosthesis delivery, within the first year of loading	All-on-4 group: 2 prosthetic screws loosening in provisional restorations 1 fracture of the acrylic provisional prostheses. 3 fractures of the veneering material of the definitive implant supported complete FDP All-on-6 group: 1 fracture of the acrylic provisional prostheses. 1 fracture of the veneering material of the definitive implant supported complete FDP	Both group experienced some technical and biological complications with no statistically significant differences between groups (p = 0.501).
2008	Francetti L	One patient reported a light hypoesthesia on the left side of the lower lip after surgery which resolved after 6 months.	The most frequent prosthetic complication was the fracture of the acrylic prosthesis that occurred in seven cases (11%). No fracture of the definitive prostheses reported.	
2008	Testori T	No biological complication was reported	Only screw loosening, which occurred in seven provisional prostheses (17.5%), affecting prosthesis stability. The screw loosening occurred on three tilted and four axially placed implants.	
2008	Tealdo T		No loose abutment screws or fractures of prosthesis frameworks reported in the study.	
2010	Agliardi E	None of the patients reported any postsurgical biological complication.	Fracture of the acrylic prosthesis that occurred in 24 cases (15.6%), of which 14 in the mandible (15%) and 10 in the maxilla (16.4%).	

(Continues)

TABLE 9 (Continued)

Publication year	First author	Biological complication	Prosthesis complication	Complication comparison
2010	Hinze M	The only biological complication observed was extensive bruising in 2 patients.	Technical complication: 1. Fracture of acrylic veneer material in 4 provisional prostheses (10.8%). 2. 1 definitive reconstruction displayed fracture of the veneer material (3.7%). 3. Loss of the screw access hole restoration occurred in 9.5% of the anchors. 4. Occlusal screw loosening was observed in 6% of cases,	
2012	Francetti L	Three axial mandibular implants in two patients showed peri-implantitis, with about 3 mm of marginal bone loss, suppuration, and bleeding on probing Peri-implantitis was detected after 3 years of loading in one implant placed in a 50-year-old female patient, and after 18 months in two implants placed in a 60-year-old male patient. Both patients were nonsmokers.	Fracture of the acrylic prosthesis that occurred in 5 cases (15%) in the mandible and in 3 cases in the maxilla (19%) 1 fracture of the final mandibular framework has been recorded in 1 female patient after 3 years of loading (3%).	
2012	Grandi T	No other immediate postsurgical complications. Two patients had an episode of peri-implant microsites and were treated with nonsurgical debridement of the affected implants.	3 patients (6.3%) had a fracture of the provisional restoration, but all of the definitive prostheses remained stable throughout the study period without any complications.	
2012	Weinstein R	No complication was recorded during surgical and prosthetic procedures.	No adverse event occurred.	
2012	Maló P	Peri-implant pathology was associated with 6 implants (in 6 patients: 3 in the maxilla and 3 in the mandible) distributed within, the dehiscence subgroup 5 implants) and the fenestrations subgroup 1 implant).	6 prostheses fractured. 2 in the maxilla and 4 in the mandible) in 6 patients with bruxism. Abutment screws loosened in 13 patients. No other aesthetic or functional complications.	

(Continues)

TABLE 9 (Continued)

Publication year	First author	Biological complication	Prosthesis complication	Complication comparison
2013	Di P	All implant failures occurred at 8–10 weeks after placement. No biological complications occurred.	Three fixed prostheses were changed to removable dentures until new implants could be placed in 2–3 months, and fixed prostheses were again immediately placed because two implants were lost on the same side in three patients. Three abutment screws loosened and five artificial teeth separated from the acrylic resin base. Fracture occurred near the implant metal coping in three provisional restorations. No fracture occurred near the cantilever area.	
2014	Krennmair S	Swelling, hematoma and some minor discomfort were reported in individual cases 2 patients with 4 implants had an episode of peri-implant mucositis at the 1st year evaluation 1 patient presented with gingival hyperplasia at 2 implants	Provisional Prosthesis: 2 Abutment screw loosening (8.3%), 5 provisional prostheses fractured (20.8%), 6 acrylic teeth fractured (20.8%), 3 acrylic teeth were repaired in office (12.5%) and 4 prostheses needed denture rebasing/reduction (16.7%). Definitive Prosthesis: No metal framework/denture fractures; however, there were 9 acrylic teeth fractures (1st year: 7 teeth fractures in 5 patients; 2nd year: 2 teeth in 1 patient) repaired in the laboratory, 6 acrylic teeth repairs in office (1st year: 2 teeth in 2 patients; 2nd year: 4 teeth in 2 patients) and 18 patients had their prostheses rebased (1st year: 13; 2nd year: 5) as a result of soft tissue shrinkage.	
2014	Pera P		Minor fractures of acrylic (n = 7) Major fractures of acrylic (n = 2) Fracture of the metal framework (n = 1) Loosening of the prosthetic screws (n = 6)	
2015	Browaeys H		No complications such as fractures occurred during the surgical phase or the delivery of the immediate restoration.	
2015	Gherlone EF		No occlusal screw loosening was observed.	

(Continues)

TABLE 9 (Continued)

Publication year	First author	Biological complication	Prosthesis complication	Complication comparison
2015	Ayna M		All acrylic restorations showed some extent of abrasion that was, however, neither aesthetically nor functionally relevant. Veneer fractures occurred in 4 patients, all with acrylic suprastructures (28.6%). Three of those fractures (all on canine teeth) were superficial and could be repaired in situ; only one reached the metal framework, and the denture had to be repaired in the laboratory. Besides a single loosening of a fixation screw, there were no prosthetic complications in patients with ceramic suprastructures.	
2016	Krennmair S	Total Incidence Axial Implant group: Anterior implant Mucositis: 14 Gingival Hyperplasia: 4 Fistula: 2 Recession: 7 Total: 27 Posterior implant Mucositis: 4 Gingival Hyperplasia: 2 Fistula: 0 Recession: 6 Total: 12 Tilted Implant group: Anterior implant Mucositis: 8 Gingival Hyperplasia: 3 Fistula: 0 Recession: 3 Total: 14 Posterior implant Mucositis: 4 Gingival Hyperplasia: 4 Fistula: 2 Recession: 8 Total: 18	Total Incidence Axial Implant group: Abutment screw loosening: 4 Acrylic tooth fracture: 8 Acrylic tooth repaired in office: 7 Acrylic denture base fracture: 2 denture rebasing/reduction: 15 denture cleaning (discoloration): 28 screw access acrylic repair: 7 Opposing denture teeth fracture: 6 Opposing denture rebasing: 2 Total: 79 Tilted Implant group: Abutment screw loosening: 8 Acrylic tooth fracture: 6 Acrylic tooth repaired in office: 4 Acrylic denture base fracture: 2 denture rebasing/reduction: 17 denture cleaning (discoloration): 20 screw access acrylic repair: 8 Opposing denture teeth fracture: 5 Opposing denture rebasing: 0 Total: 70	In total there were 39 biological complications (183 mucositis, 63 gingival hyperplasia, 23 fistula, 133 recessions) in the axial group I and 32 biological complications (123 mucositis, 73 gingival hyperplasia, 23 fistula, 113 recessions) in the tilted group II. (no significance) The overall incidence of prosthetic maintenance per patient/year did not differ between axial group (1.36) and tilted group (1.36).

(Continues)

TABLE 9 (Continued)

Publication year	First author	Biological complication	Prosthesis complication	Complication comparison
2016	Piano S		No screw loosening, fracture or abutment fracture, or framework fractures were observed during the follow-up period. No subject lost the retention of the prosthesis during the follow-up period.	
2016	Najafi H		The most common mechanical complication was acrylic tooth chipping (16 jaws, 41%). Other complications were abutment screw loosening (one jaw, 2.5%), prosthetic screw loosening (two jaws, 5.1%) and prosthetic screw fracture (two jaws, 5.1%)	
2017	Li S	One implant (1.25%) showed peri-implantitis (the same implant failure due to peri-implant pathology) with a pocket of 5 mm and concurrent bone loss >2 mm with bleeding on probing.	5 patients (29.4%) showed mechanical complications in provisional or definitive prostheses. Provisional Prosthesis: 3 provisional prostheses fractured (15%, the same 3 failed prostheses). Artificial teeth separation occurred in 2 mandibular and 1 maxillary provisional prostheses (15%. One patient (5.88%) had phonetic changes 2 weeks after surgery. Definitive Prosthesis: Loose abutment screws were observed in 2 mandibular definitive prostheses (10%)	

TABLE 10 Patient-reported outcome measures (PROMs) in the included Level I and Level II studies

Publication year	First author	Patient-centered outcome
2007	Capelli M	Patient completed a satisfaction evaluation questionnaire regarding aesthetics, phonetics, ease of maintenance, and functional efficiency. The questionnaire was repeated at each annual evaluation. All patients were satisfied with the phonetics, aesthetics, and psychological and functional aspects once treatment was completed.
2008	Francetti L	At each follow-up, patient's satisfaction for aesthetics and function was evaluated by a questionnaire. Satisfaction for both aesthetics and function increased over time.
2008	Testori T	28 patients (70%) completed the questionnaire for satisfaction evaluation after 1-year follow-up. (5 points Likert scale) Aesthetics (teeth and smile) was judged as excellent or very good by 75% of patients, good by 21.4% of them and sufficient by one patient (3.6%). Mastication function was considered excellent or very good by 69.2% of patients and good by 30.8%. Ease of maintenance was considered excellent or very good in 35.7% of cases, good in 42.9%, sufficient in 14.3% of cases, and poor by 7.1% of patients. Phonetics was judged excellent or very good in 85.7% of cases and sufficient in 14.3%. All patients affirmed that their quality of life had improved after the treatment.
2012	Weinstein R	The patients' satisfaction for function, aesthetics, and phonetics was assessed by means of a questionnaire. The answers were based on a 5-point Likert-type scale, ranging from 1 ("poor") to 5 ("excellent"). Eighteen patients filled in the questionnaire for satisfaction evaluation after 12 months follow-up: aesthetics (teeth aspect and color, and smile appearance) was judged as excellent or very good by 66.7% of patients, while phonetics and mastication were considered excellent or very good by 77.8 and 88.9% of patients, respectively.
2013	Di P	Each patient's response to the treatment outcome in the context of function, aesthetics, and phonetics was assessed via a questionnaire administered at the 6- and 12- month recall visits. The scoring for each subject was as follows: 5 = excellent, 4 = very good, 3 = good, 2 = sufficient, and 1 = poor. All patients were satisfied with the function and aesthetic aspects of their prostheses (an excellent rating for 95.6% of patients). Phonetic change occurred in three patients within 2 weeks of implant placement. Although patients showed different levels of oral hygiene and maintenance at follow-up, all oral hygiene methods provided satisfactory periodontal maintenance. The water sprayer was preferred by most patients.
2014	Krennmair S	5-point Likert scale questionnaire Patients provided high subjective satisfaction rates at 1st year and 2nd year examination for the following items: in general with restoration, chewing, prosthesis stability, speech, and aesthetic outcomes. Patients' subjective satisfaction score rating assessed by 5 items was high at the 1- (score: 4.6 ± 0.4) and 2-year evaluation (score: 4.7 ± 0.36).
2014	Pera P	Patients anecdotally reported good satisfaction with regard to the functionality and aesthetic appearance of their prostheses
2015	Ayna M	The subjective improvement as expressed by the Oral Health Impact Profile (OHIP) score was dramatic. An initially substantial impairment (approximately 30 out of a maximum of 56 points, suggesting an intermediate burden) was practically canceled after denture integration, and the score increased only slightly during observation. There were no differences between patients with acrylic and ceramic dentures.
2017	Li S	No details were provided. However, the following descriptions were given: The mastication function and aesthetics as well as the quality of life of GAP patients were tremendously improved by immediate implant and restoration, which was in line with the low complaint about aesthetics and function. The immediate loading procedure significantly reduced the treatment time and overall cost for Chinese patients.

1994) and its short form (OHIP-14) (Slade, 1997) are among the most commonly used survey instruments for the assessment of subjective treatment outcome in dentistry with good reliability and validity. Only one included study utilized German version of the OHIP-14 to assess the impact of the all-on-4 treatment approach on quality of life in the patient population with edentulous mandible, and the patient's quality of life significantly improved after treatment (Ayna et al., 2015).

The unpublished report, (Eckert, 2017) describes no significant difference in implant performance relative to insertion torque of the implants. The authors hypothesize that insertion torque is a design feature of an implant that is not specifically related to the relative micromotion that occurs during functional loading. In essence, when immediate loading occurs, the dental prosthesis serves to protect the implants through rigid fixation thereby reducing micromotion and allowing the biological process of osseointegration to occur.

The concept that the anterior implants are generally placed in such a way as to create axial loading, forces down the long axis of the implant with the implant being perpendicular to the occlusal plane, might be called into question. From the descriptive information that is available, it appears that the anterior implants are placed within the alveolar bone, a situation that often has the implant inclined toward the facial thereby not being subject to axial load. Perhaps there is no true axial loading of any of the implants but, without the presence of a periodontal ligament, the concept of axial loading may not be a critical factor toward the performance of dental implants.

Future research on this topic should continue to assess the long-term clinical performance of implants used to support and retain fixed prostheses in the edentulous jaws. Careful attention should be paid to the angulation of implants which is indirectly identified through the use of angled transmucosal abutments. Those abutments would only be necessary if the angle of the implant must be redirected to accommodate the prosthesis. Consistent documentation of the use of angled abutments and correlation between those implant abutments and the anatomic location of the abutments may prove valuable. In addition, the ongoing documentation of clinical performance of implants relative to insertion torque should continue however the demand for high insertion torque in all clinical settings may be called into question.

5 | CONCLUSIONS

Based upon this systematic review of the scientific literature related to the use of intentionally tilted dental implants when compared to axially loaded implants, the following observations are made

- Level I studies that are designed to directly compare the performance of tilted implants to that of axially loaded implants were not identified.
- An analysis of the descriptive data from Level I and Level II studies suggests no differences in clinical performance of implants whether placed in an axial or in a tilted configuration.
- Lower-level studies and a large population unpublished study appear to confirm the observations regarding the clinical performance of tilted implants in comparison to axially loaded implants.
- Insufficient information is available regarding the most appropriate number of implants needed to provide immediate support and retention of a definitive prosthesis however there are numerous low-level studies that demonstrate acceptable performance when four implants are used to support and retain full-arch fixed prostheses.

CONFLICT OF INTEREST

Dr. Lin reports personal fees from Straumann, grants from Ivoclar, grants from ITI, grants from Straumann, outside the submitted work. Dr. Eckert reports personal fees from Straumann, personal fees from Osstell, personal fees from Ivoclar, personal fees from Rodo, personal fees from Quintessence Publishing, personal fees from ClearChoice Management System, outside the submitted work.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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