REVIEW ARTICLE

WILEY | CLINICAL ORAL IMPLANTS RESEARCH

Systematic review of clinical and patient-reported outcomes following oral rehabilitation on dental implants with a tapered compared to a non-tapered implant design

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Abstract

Background: Dental implants are available in different shapes.

Aims: This systematic review aims to address whether tapered compared to non-tapered implants demonstrate similar clinical and patient-reported outcomes. The review follows the preferred reporting items for systematic reviews and meta-analyses (PRISMA) format.

Materials & Methods: We searched electronic databases including MEDLINE through PubMed and the Cochrane Central Register of Controlled Trials for randomized clinical trials (RCT) that compare tapered versus non-tapered implants with at least 10 treated participants and a minimum mean follow-up time of 3 years. There were no restrictions to a particular treatment indication or outcome measures. Two authors independently conducted screening, risk of bias assessment, and data extraction of eligible trials in duplicate. We applied the Cochrane risk of bias assessment tool to consider risk of bias.

Results: We identified 18 different RCTs, of which three reported outcomes at 3 years or greater. The three trials described the results of 245 participants with 388 implants at 3 years, from the initially 306 participants with 494 implants at baseline. The three trials compared, respectively, two, two, and three different commercially available implant brands and reported only clinically insignificant differences. We judged all three trials to be at moderate risk of bias. The low number and heterogeneity of RCTs did not allow for meta-analyses.

Discussion and conclusion: Appropriate professional judgment in clinical decision making must include a comprehensive diagnosis of the patient's jawbone quality and quantity and consideration of osteotomy protocol in accordance with the patient's treatment preferences, where the shape of the dental implant is only one contributory factor.

KEYWORDS
clinical decision making, humans, osteotomy, randomized controlled trials

1 | INTRODUCTION

The dental implant market has increased tremendously over the last 15 years, reflected by the number of available implant brands. In 2003, some 80 manufacturers produced an estimated 220 different implant brands (Jokstad et al., 2003). Today, the numbers have proliferated to an estimated 500 manufacturers producing 4,000 different implant brands. Different resources on the Internet attempt to keep track of the plethora

of brands with varying success. To the authors' knowledge, the most comprehensive resource (Osseosource.com) identifies about 2,000 different dental implants. A noteworthy trait is that in 2003, there were about 12 implant brands identified by having a "tapered" implant body (Jokstad et al., 2003), while today, about 50% of all implant brands on the market are "tapered." For example, the cited Web site (Osseosource. com) lists 908 tapered and 1,082 cylindrical root-formed dental implants. Even though the exact number of manufacturers and implant brands is unknown, it is clear that the industry has responded to the demand from the clinicians to manufacture dental implants marketed as "tapered," "conical," "ovoid," "root formed," or derivatives of these terms.

The alleged clinical benefits of using tapered rather than non-tapered implants under different clinical circumstances focus on enhanced "primary stability." This quantity is represented by measurements of implant insertion torque, named by some previously as implant placement resistance, alternatively by resonance frequency analysis (RFA). Special emphasis is on implants placed in soft bone (O'Sullivan, Sennerby & Meredith, 2000) or extraction sockets (Martinez, Davarpanah, Missika, Celletti & Lazzara, 2001), eventually in combination with implant site preparation using twist drills with a diameter less than the diameter of the implant, dubbed, for example, as "soft-bone protocols" or as "underpreparation" (O'Sullivan, Sennerby, Jagger & Meredith, 2004). The longterm clinical and patient-reported outcomes following oral rehabilitation using dental implants with a tapered design compared to a non-tapered appear not to have been systematically reviewed and critically appraised.

A tapered dental implant, often named "conical" in several non-English languages, is identifiable by displaying some convergence of the implant outer walls toward the apex of the endosseous part of the implant body, that is, the portion of the implant body intended to be positioned within the bone. Implants with diverging walls coronally from the crestal bone are not considered as "tapered" in the literature. For example, the ITI Type F-implant, perhaps better known today as the Straumann tissue-level implant, was originally described by its developers as having a "cup-" (Sutter & Schroeder, 1988), alternatively a "trumpet-shaped" (Scacchi, 2000) coronal neck, but is not considered tapered.

The literature provides little guidance on how to define the "tapered" dental implant. There are no textbook chapters or review papers specific to this topic. The term "tapered dental implant" is not defined in any international standards, including ISO-16443-2014 (ISO, 2014). The Glossary of Prosthodontic Terms (GPT-9) has defined "taper" in context with the axial walls of a tooth preparation, but nothing relative to dental implants

(Academy of Prosthodontics, 2017). A third authoritative source, that is, The Glossary of Oral and Maxillofacial Implants, describes definitions of three different dental implant body designs, that is, cylindrical, stepped, and tapered (Laney, 2007a,b,c). While the explanations for cylindrical and stepped dental implants seem precise, the description of a tapered dental implant is clearly unsatisfactory for the purpose of this systematic review (SR). That is, "*Shape of an implant body when viewed in profile, lengthwise. A tapered implant usually narrows apically*" (Laney, 2007c). The first sentence applies to any geometric contour; while the second sentence would have been correct if "usually" had been omitted. For the purpose of this SR, we considered it necessary to develop a distinct definition of a "tapered dental implant." We therefore amended the definition for a stepped implant, that is, "*Specific implant shaft design that incorporates concentric steps that narrow in width toward the apex of the implant*" (Laney, 2007b). In the current SR, a tapered implant is recognized as a *cylindrical implant where the endosseous part narrows in diameter toward the apex*. This definition encompasses any dental implant where the diameter at the bone crest level is wider than the diameter at the apical end, and regardless of the vertical cervical–apical position of the narrowing along the longitudinal axis of the implant body. Hence, the definition encompasses all implants where the taper is located in the cervical, middle, or apical parts only, as well as implants that taper continuously from the cervical platform to the apex (Figure 1).

The objective of this SR was to address the question: In patients with dental implant restorations, do tapered compared to non-tapered implants demonstrate similar clinical and patient-reported outcomes?

2 | MATERIAL AND METHODS

2.1 | Protocol and registration

The protocol of this review was registered in the PROSPERO database in 2016 (registration number CRD42016049607) (www.crd. york.ac.uk/PROSPERO).

2.2 | Eligibility criteria

The criteria for study inclusion were a randomized clinical trial (RCT) comprising a comparison between a tapered versus non-tapered implant design with at least 10 treated study participants and a minimum mean follow-up time of 3 years. Exclusion criteria were RCTs (i)
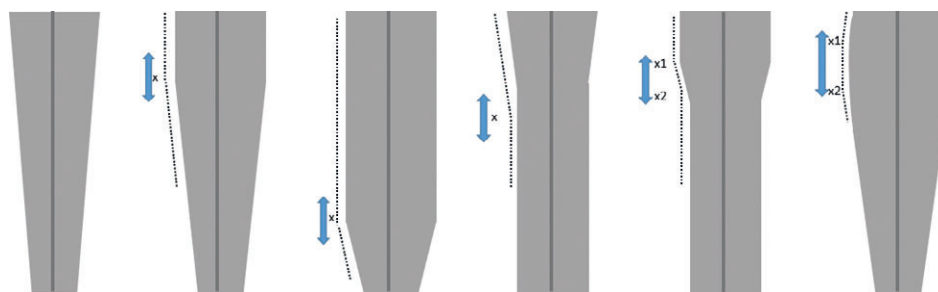
FIGURE 1 Examples of variations of tapering, which the definition in the current systematic review designates as "tapered" dental implants

using zygomatic or orthodontic implants, (ii) trials lacking any objective outcome measurements, (iii) trials with focus on post-restoration interventions of adverse treatment outcomes, for example, of peri-implantitis, dehiscence, fenestration, repairs, and (iv) trials that included study participants undergoing reconstructions due to extensive loss of oromaxillofacial tissues, for example, caused by trauma, cancer, or congenital defects. Only full publications in peer-reviewed scientific journals in English were considered for inclusion.

2.3 | Information sources and search

We searched MEDLINE through PubMed (URL: https://www.ncbi. nlm.nih.gov/pubmed, the Cochrane Central Register of Controlled Trials (CENTRAL) (URL: http://onlinelibrary.wiley.com/cochranelibrary/search and the personal bibliographical database of one of the authors (A.J.). The search strategy in Pubmed was as follows: *((jaw, edentulous [Mesh Term]) OR (edentulous) OR (edentulism)) AND (((((dental implantation, endosseous[MeSH Terms]) OR "dental implants"[MeSH Terms]) OR endosseous implant*) OR dental implant*))AND (taper* OR conical NOT connection*) AND (Success OR survival OR Function OR esthetic* OR complicat* OR maintenance OR Bone OR patient satisfaction OR quality of life OR treatment outcome[MESH Terms]).*

The Gray literature was assessed by searches in the abstract database of IADR (International Association for Dental Research) (URL: https://live. blueskybroadcast.com/bsb/client/_new_default.asp?action=HOME&-Client=404900) as well as Google Scholar (URL: http://scholar.google. com). The final digital searches were completed in December 2017.

Digital searches were complemented with hand searching the reference lists of the publications identified digitally, and by browsing the most recent issues of the following scientific journals: Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, European Journal of Implantology, Implant Dentistry, International Journal of Oral Maxillofacial Implants, International Journal of Oral Maxillofacial Surgery, International Journal of Periodontics and Restorative Dentistry, International Journal of Prosthodontics, Journal of Clinical Periodontology, Journal of Dental Research, Journal of Oral Implantology, Journal of Oral and Maxillofacial Surgery, Journal of Oral Rehabilitation, and Journal of Periodontology.

2.4 | Study selection and data collection process

Two individuals screened for study eligibility of studies independently, and subsequently reached a consensus for inclusions. In situations with multiple publications from a single clinical study, the report with the longest follow-up time was selected for data extraction. However, earlier reports were appraised if particular details about materials and methods were lacking in the selected articles. We contacted the corresponding authors of the primary publications that reported an observation time less than 3 years to inquire about any existence of further publications.

2.5 | Data items

Data extracted from the individual studies included items 18–20 in the PRISMA checklist (Appendix S1), that is, (i) characteristics of the individual studies, (ii) risk of bias within the individual studies, and (iii) the results of individual studies. Characteristics of the individual studies included identification of the lead author and description of the study participants' condition, the years when the implants were placed, and whether the study was conducted in a single or multiple universities, public health, or private practice settings. The number of study participants and implants placed with the mean follow-up time was supplemented with a description of implant type(s) with details on design of taper. Details of the actual intervention included the following: (i) status of the pre-implant surgery situation, (ii) implant surgery details, (iii) the post-surgery details, and (iv) type of superconstruction.

2.6 | Risk of bias in individual studies

Elements that possibly could limit the study internal and external validity included an assessment of the stated study objective versus its conclusions, the choice and quality of statistical tests, and the source of funding of the study. The Cochrane risk of bias assessment tool (Higgins et al., 2011) was applied to estimate risk of bias of individual trials.

2.7 | Summary measures

The primary outcomes were complications associated with the surgery and restorative phase, implant and restoration success and survival, maintenance needs patient-reported function, satisfaction, quality of life, and aesthetics; all outcomes measured at 3 years or greater after implant placement. Secondary outcomes were peri-implant bone loss and peri-implant soft tissue indices established at 3 years or greater after implant placement.

2.8 | Synthesis of results and risk of bias across studies

The pre-hoc objective was to undertake meta-analyses and estimate risk ratios and differences in means. As the review progressed, it became clear that the evidence base was too weak for such statistical analyses. Hence, this SR does not include summary measures or formal statistics to examine possible publication bias or selective reporting.
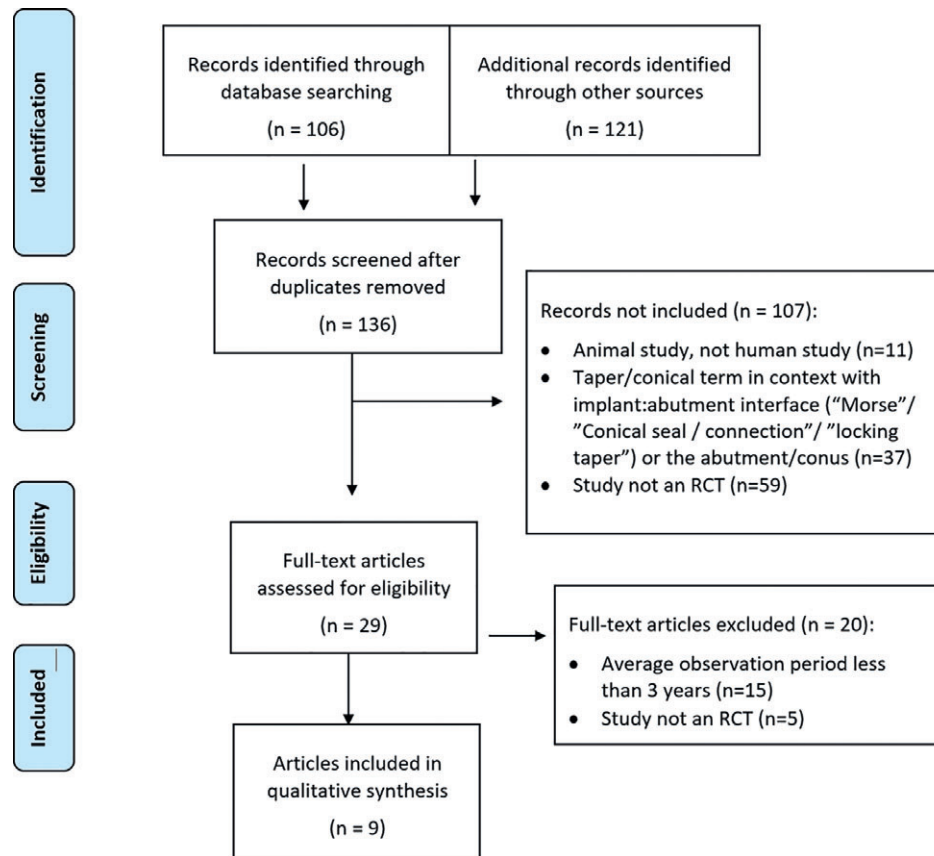
2.9 | Additional analyses

No subgroup analyses were planned.

3 | RESULTS

3.1 | Study selection

We identified initially approximately 230 reports (Figure 2). After screening the abstracts, the great majority (*n* = 107) were considered not eligible according to the inclusion criteria. The predominant reasons were not an RCT trial (*n* = 59) or that the term "taper" or

FIGURE 2 Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flowchart*. Reports on tapered versus non-tapered dental implant. *Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Med 2009;6:e1000097

"conical" were descriptors of the interface between the implant and the abutment, for example, in context with "Morse taper," "conical seal/connection," or "locking taper," alternatively a description of the (non-endosseous) implant abutment or conus (n = 37). A third reason for ineligibility was that the study did not include human study participants (n = 11). The remaining 29 articles were read in full. Nine of these articles were selected for data extraction. The major reason for non-inclusion was a mean follow-up of less than 3 years (n = 15), and/or that the study was not an RCT (n = 5). The nine papers reported data from two industry-funded international multicenter parallel-group RCTs initiated in January 2006 (Cecchinato, Lops, Salvi & Sanz, 2015; Ferrus et al., 2010; Huynh-Ba et al., 2010; Sanz et al., 2010, 2014; Tomasi et al., 2010) and in April 2006 (Arnhart et al., 2012; Kielbassa et al., 2009), respectively, and from one non-sponsored split-mouth RCT conducted in a single university clinic in Rome, Italy and initiated in January 2010 (Pozzi, Tallarico & Moy, 2014) (Table 1).

It was planned initially to estimate by use of kappa statistics the strength of agreement between the two reviewers on abstract screening, full-text screening, and methodological quality assessment. However, the low yield of n = 3 RCTs that both raters agreed to include, hence inferring a κ = 1, rendered other formal calculations of kappa statistics inconsequential.

TABLE 1 Identified RCT trials (n = 3) from identified reports (n = 9)

RCT # 1, Implants placed between 2006.01 and 2008	
1. Cecchinato et al. (2015)	3-year data
2. Sanz et al. (2014)	3-year data
3. Tomasi et al. (2010)	<3-year data
4. Huynh-Ba et al. (2010)	<3-year data
5. Ferrus et al. (2010)	<3-year data
6. Sanz et al. (2010)	<3-year data
RCT #2, Implants placed between 2006.04 and 2007.05	
1. Arnhart et al. (2012)	3-year data
2. Kielbassa et al. (2009)	<3-year data
RCT # 3, Implants placed between 2010.01 and 2010.06	
Pozzi et al. (2014)	3-year data

3.2 | Study characteristics

The reports of the two parallel-group RCTs described outcomes after 3 years and the single split-mouth RCT after 3.5 years (Table 2). The first trial evaluated *Fixture Microthread Osseospeed* implants (Astra Tech, Mölndal, Sweden) with a straight versus a conical neck

TABLE 2 Study characteristics

RCT	Setting	Patient situation	N orig.	Implant product	Time (years)	N exam.	Outcomes (P)rimary (S)econdary
#1	Multicenter (4): University clinic, Madrid, Spain; Bern, Switzerland, Gothenburg, Sweden & Private practice, Rome, Italy	Partial & Single Maxilla Anterior.	95p. 101i.	(Astra Tech) Fixture MicroThreadOsseoSpeed Cyl: Cylindrical neck: ø3.5/4 mm Lengths 8/9 mm(51i.) Con: Conical neck: ø4.5-3.5(cervical)/5.0-4.5(apical) mm Lengths 11/13 mm(50i.) (Tapering in cervical third of body)	3	84p. 84i.	Primary: Thickness of the facial bone wall; clinical assessment[a] Secondary: • Crestal bone-level change; periapical radiographs • Soft tissue inflammation (0/1); clinical assessment and periodontal probe • Papilla fill (Jemt score); clinical assessment and periodontal probe • Soft tissue recession; clinical assessment and periodontal probe • BuccalBone; cone-beam computer tomography
#2	Multicentre (12): University clinics, Graz, Wien, Austria; Liege, Belgium; Berlin, Freiburg, Witten, Germany; Jerusalem, Israel; Milano, Rome, Italy; Madrid, Seville, Spain; Bern, Switzerland	Edentulous & Partial & Single Mandible & Maxilla.	177p. 325i.	(Nobel Biocare) ø3.5/4.3 mm Lengths 8-16 mm T1a: NobelActive(117i.) T1b: NobelActive (OnePiece) (82i.) T2: Nobel Replace-Tapered (126i.) (Both tapered, but different tapering)	3	127p. 236i.	Primary: Marginal bone-level change; periapical radiographs Secondary: • Implant survival and success according to criteria described by van Steenberghe (1997) • All adverse events • Soft tissue parameters, sulcus bleeding (0,1,2), plaque score (0,1) & papilla fill (Jemt score); clinical assessment and periodontal probe
#3	University Clinic, Rome, Italy	Partial or Bilateral single Mandible Posterior.	No drop-out	(Nobel Biocare) Lengths 10/11.5 mm T1: NobelActive: ø3.9 mm T2: Nobel Speedy Groovy: ø4.1 mm (Both tapered, but diffferent tapering)	3.5	34p. 68i.	Primary: Success of implants and prostheses Secondary: • Marginal bone-level change; periapical radiographs • Periodontal-indices/soft tissue parameters, sulcus bleeding (0-3), plaque score (0,1) & papilla fill; clinical assessment and plastic periodontal probe • Implant stability;(RFA) at 4 months

[a]Per clinicaltrials.gov, registration NCT00711282.

Con, conical; Cyl, cylindrical; i, implant; p, patient; RFA, resonance frequency analysis; T, test group.

immediately following tooth extractions (Cecchinato et al., 2015; Ferrus et al., 2010; Huynh-Ba et al., 2010; Sanz et al., 2010, 2014; Tomasi et al., 2010). The two other RCTs compared *NobelActive* implants (Nobel Biocare, Gothenburg, Sweden) versus *NobelReplace* (Arnhart et al., 2012; Kielbassa et al., 2009), respectively, *NobelSpeedy* (Pozzi et al., 2014) implants placed in healed sites. All three implant designs display a taper, but differ with regard to degree of taper and configuration of the screw threads. The rates of dropouts of study participants ranged between none among 34 patients with 68 implants (Pozzi et al., 2014) and approximately 30% in one of the larger multicenter trials that started with originally 177 study participants (Arnhart et al., 2012; Kielbassa et al., 2009).

3.3 | Risk of bias within studies

According to the Cochrane bias tool, all three RCTs were deemed to have low risk of selection and performance bias (Table 3). A power calculation was described satisfactorily in all three RCTs. Detection bias was considered moderate as no precautions were described regarding masking of the radiographs to avoid distinguishing between the implant designs. The relatively high dropout rates in the two multicenter trials (Arnhart et al., 2012; Cecchinato et al., 2015) imply a possible attrition bias, and may raise concern about the representativeness of the findings. The risk of reporting bias was considered low for all three RCTs. The two multicenter trials (Cecchinato et al., 2015; Ferrus et al., 2010; Huynh-Ba et al., 2010; Sanz et al., 2010, 2014; Tomasi et al., 2010) and (Arnhart et al., 2012; Kielbassa et al., 2009) were funded by the manufacturer of the implants that were tested. None of the RCTs reported any details about fiducial arrangements with the patients, that is, whether they received free professional care and/or components or paid full fees. One of the studies did not report whether it had been approved by an independent research ethics board (Pozzi et al., 2014). In sum, all three RCTs were considered to have moderate bias.

3.4 | Results of individual studies

The clinical performance of both tapered as well as non-tapered implants placed in healed sites (Arnhart et al., 2012; Pozzi et al., 2014) and in extraction sockets (Cecchinato et al., 2015) appears to be good after 3 years, with only minor clinically relevant differences in reported outcomes (Table 4). None of the RCTs reported any patient-reported outcome measurements (PROMs). The variable experimental clinical variables in the identified studies preclude making any strong conclusions about potentially influential factors on the reported clinical outcomes. One particular detail of importance that unfortunately is missing in all three RCTs is the lack of detail about the implant site osteotomy procedures and qualities. RCT #1 (Cecchinato et al., 2015; Ferrus et al., 2010; Huynh-Ba et al., 2010; Sanz et al., 2010, 2014; Tomasi et al., 2010) cite "in accordance with the guidelines described in the Astra Tech Manual surgical procedures." RCT #2 (Arnhart et al., 2012; Kielbassa et al., 2009) lacked all details about this aspect, likely because of the heterogeneous treatment indications and extensive

range of participating clinical settings. RCT #3 described "Drill sequence was chosen according to the manufacturer's instructions in relation to the bone quality," which may or may not include underprepared implant sockets (Pozzi et al., 2014).

3.5 | Risk of bias across studies

The risk of bias across studies appears to be low. All three RCTs reported clinically relevant outcomes, although a lack of patient-reported outcomes was identified.

4 | DISCUSSION

4.1 | Summary of evidence

The main finding of this SR is that the evidence basis is currently insufficient to conclude whether tapered implants have any benefits compared to non-tapered dental implants in terms of survival or success rates at 3 years or greater. The limited evidence of long-term clinical outcomes signifies that the question of whether tapered dental implants have any merits compared to non-tapered remains uncertain for a range of potential clinical indications.

4.2 | Agreements and disagreements with other reviews

Similar conclusions were made in two recent comparable SRs focused on the effects of implant design on clinical outcomes (Esposito, Ardebili & Worthington, 2014; Jokstad et al., 2016). The first SR includes only RCTs of dental implants indicated because of different clinical conditions, including single space and partially edentate situations in both jaws (Esposito et al., 2014), while the second SR presents data from all clinical studies where implants have been compared in a fully edentulous maxilla (Jokstad et al., 2016).

4.3 | Limitations

A pro-hoc decision was made to not include reports of clinical studies with less than a mean follow-up time of 3 years. Consequently, we did not extract the data from twenty clinical studies (Table 5), which are not to say that the information in these studies is unimportant. One prevailing reason why many clinicians seem to favor tapered implants is to maximize the "primary stability" of the implant body in extraction sites and in soft bone, with the expectation that "high values" lower the risk of adverse outcomes associated with an immediate or early loading of the implant. Hence, many publications with a focus on implants with a tapered design address the subject from the perspective of an implant that potentially remain immobile during the healing process, particularly in type 4 bone and extraction sockets. It is intriguing that the prevailing idea of good "primary stability" represented by insertion torque or RFA does not appear to correlate well with measurements of actual implant micromotion in-vitro enabled by the adoption of new measurement technologies

TABLE 3 Bias assessment

RCT	Study design	Study objective (sic)	Statistics	REB	Funding	Seq. generat	Allocate conceal	Blinding pat	Blinding outcom	Incomplete data	Select reporting	Other	Sum
#1 Parallel – 2 arms	Implant A vs Implant B 2 × 50p	To study the peri-implant soft tissues response, by evaluating both the recession and the papilla indexes of patients treated with implants with two different configurations.	• Mann–Whitney-U • Wilkinson signed rank	"Approved by the local ethics review boards"	Astra Tech AB, Sweden	Low	Low	Low	High	High	Low	Moderate	Moderate
#2 Parallel – 3 arms	Implant A vs Implant B vs Implant C 64p, 53p & 60p	To compare two versions of a variable-thread dental implant design to a standard tapered dental implant design in cases of immediate functional loading	• Mixed Model-covariance • Kruskal–Wallis • Mann–Whitney-U • Spearman's correlation • Wilcoxon signed rank • Cox regression	"Approved by independent Institutional Review Boards by all participating centers"	Nobel Biocare Services, Switzerland ref. (T-117)	Low	Low	Low	High	High	Low	Moderate	Moderate
#3 Split	Implant A vs Implant B 2 × 34p	To compare the clinical and radiological outcomes of two implant designs with different prosthetic interfaces and neck configurations.	• Paired-t • Fisher's exact • Mann-Whitney-U	".. the Helsinki Declaration" No IRB reported	Not receive any materials/ products or financial support	Low	Low	Low	High	Low	Low	Moderate	Moderate

TABLE 4 Study results

	Pre-surgery details	Surgery details	Post-surgery details	Prosthes	Outcomes (C)ylindrical (T)apered	PROMs	Major findings
RCT #1	Tooth extracted, socket state defined	Immediate placement, no grafting, healing abutment, semi-submerged healing 4 months	Prosthesis delivery 22 weeks following implant placement	Allceram/ metal-ceram/ zirconia-crown	Primary: Facial bone thickness (mm) Raw data not show Secondary: • Crestal bone-level change (mm) Cyl: 0.0 Con: +0.3 • Soft tissue inflammation (0/1) Raw data not shown • Papilla fill (mean Jemt score) Cyl: 2.0 Con: 2.1 • Soft tissue recession (mm) Cyl: 0.2 Con: 0.2	None reported	• Both implant types allowed proper soft and hard tissue healing to occur with infrequent mucosal inflammation and maintained marginal bone levels • Both interproximal papilla filling and the mid-facial mucosa stability were not influenced by implant type
RCT #2	Site healed at least 6 months. 3% of the implants were placed in bone quality IV (Lekholm& Zarb classification)	«Per manufacturer instruction»	Immediate temporary→ healing → permanent restore within 1 year	Crown/partial FDP/full FDP-cement/ screw	Primary: Marginal bone level change (mm) T1:0.9 T2:0.2 T3:0.9 Secondary: • Implant survival (%) T1a:96 T1b:96 T2:96 • Implant success (%) T1a:94 T1b:96 T2:95 • All adverse events (n) T1a:21 T1b:11 T2:18 • Sulcus bleeding T1a:15 T1b:10 T2:30 • Papilla (mean Jemt score) T1a:1.6 T1b:1.7 T2:1.6 • Plaque (%) T1a:29 T1b:38 T2:47	None reported	• No significant differences in cumulative survival rates were seen among implant type. • The bone remodeling up to 3 years was comparable for implants A1 and B, while the one-piece implant A2 had significantly less overall bone loss
RCT #3	Site healed at least 6 months. Bone quality not reported.	Ab, Flap, drill per manufacturer instruction, no grafting, bone crest placement, submerged healing 8 weeks	Healing abutment connection → 1 week, impression	Metal-ceram-crown	Primary: Success of implants & prostheses (%) T1: 100 T2:100% Secondary: • Marginal bone level change (mm) Vert:T1: 0.7 T2: 1.3 Hor. T1:0.2 T2: 0.6 • Periodontal-indices/soft tissue parameters, sulcus bleeding, plaque score & papilla index; Raw data lacking • Implant stability (ISQ) T1: 82 T2:82	None reported	• Vertical bone loss was statistically different (0.58 ± 0.10 mm) between the two implant types

Con, conical; Cyl, cylindrical; FDP, fixed dental prosthesis; RCT, randomized clinical trial.

(Freitas, Bonfante, Giro, Janal & Coelho, 2012; Pagliani et al., 2013; Sennerby et al., 2015).

The term "tapered implant" includes a range of different designs (Figure 1), which we attempted to embrace within our definition described in the introduction section of this SR. However, the static strain that is induced in the cortical and trabecular bone, respectively, given the different designs will vary, and from this perspective, one may argue that adopting the term "tapered" implant as all-inclusive is unsatisfactory. Even though the current literature basis is rather limited as reflected in the current SR, it will be helpful to refer to a better identification concept than "tapered" versus "cylindrical" or "non-tapered," especially for future authors of SRs and meta-analyses. Recent new descriptors in advertisements and the research literature are "cylindrico-conical," "cylindrical-conical," and "reverse conical neck". A proposal for a classification that perhaps better can differentiate between the current estimated 4,000 implant brands would be to describe coronal neck, defined as the portion meant to be in contact with cortical bone plus the coronal, central and apical thirds meant to be located in the trabecular bone.

The influence on clinical outcomes of one particular design element of an implant body, such as the taper, cannot be determined separately from other design elements, for instance, the thread and apical morphology and the implant surface roughness (Jokstad et al., 2003). A case illustration is the Brånemark System Conical Self-Tapping Fixture launched in the early nineties by Nobel Pharma, the predecessor of Nobel Biocare. (U.S. FDA K925760, approved 1993). The machined coronal part of the implant body flared out to produce a wider diameter at the implant platform. After some years, the product was discontinued from sale in the market because of poor clinical performance. Yet, another implant with a comparable macro-geometry of the coronal part, but with an external serrated surface micro-roughened by titanium oxide blasting, was launched a few years later by Astra Tech (U.S. FDA K931767, approved 1994). This product, the Fixture ST, demonstrated far superior clinical outcomes (Norton, 1998), and its design is reflected in many of today's implants marketed by different manufacturers.

4.4 | Implications for clinical practice

4.4.1 | Limitation of space

A logical indication where the placement of a tapered rather than a non-tapered implant is when there is limited space, whether there is a likelihood of perforating the labial plate or of damaging an adjacent vital structure or a neighboring tooth (Fleming, 1994). None of the RCTs identified in the current SR were designed with such study objective. Moreover, existing SRs on best management of implant fenestration have not interpreted the extracted data relative to implant design in their primary studies (Chiapasco & Zaniboni, 2009; Merli et al., 2016; Storgård Jensen & Terheyden, 2009). Nevertheless, regardless of any scientific research or precise data, it seems reasonable that many clinicians likely prefer tapered implants because they often will fit into an edentulous space better than straight-walled implants. There is also anecdotal experience in clinical practices where patients routinely partake in shared treatment decision making that psychological and emotional aspects influence the decision process as a tapered shape resembles more a natural tooth form coupled with a perceived less risk of injuring adjacent vital structures.

4.4.2 | Time-to-loading

The principal quest for tapered implant designs originates from the desire to provide immediate placement following tooth extractions, eventually also in combination with an immediate restoration. Initially, claims were made that an implant placed immediately following an extraction could conserve peri-implant bone and preserve the adjacent soft tissues including the papilla as long as the clinician adhered to particular protocols. As the extraction socket morphology and the implant body were seldom analogous, early strategies included the placement with a combination of membranes with or without grafting materials, alternatively to use a wide diameter implant. The use of wide-bodied implants produced unpredictable, outcomes, which opened for stepped and subsequently taper implants as alternatives, especially when there was a risk of perforating the labial plate in the aesthetic zones (Garber, Salama & Salama, 2001). In this context, it should be recognized that the current recommendation for the selection of implant dimensions and positioning is primarily dictated by the prosthetic emergence profile in areas of aesthetic priority (Buser, Martin & Belser, 2004).

4.4.3 | Bone quality and quantity

"Poor bone quality" is often associated with an argument that a tapered implant should be preferred rather than a non-tapered to secure a high "primary stability," which is synonymous to implant immobility at the time of surgical placement. Only three of the RCTs identified in this SR compare implants placed in the posterior maxilla (Mangano et al., 2017; Markovic et al., 2013; Simmons et al., 2017) and only clinically insignificant differences between the designs are reported. There is on the other hand a substantial number of non-RCTs that report outcomes of regular as well as experimental transient implants placed in the posterior maxilla that allude to particular benefits of specific implant design features. There is also an additional vast volume of research papers stemming from laboratory and animal experiments where tapered versus non-tapered implants have been compared. The extrapolation to recommendations for clinical practice of the data from these many otherwise excellent research papers is fraught with difficulties. As a start, the term "poor bone quality" is often, but incorrectly equated to type IV bone, according to a widespread categorical scoring system for jaw anatomy (Lekholm & Zarb, 1985). However, "poor" does not appear in the original description of type IV bone, but rather "*A thin layer of cortical bone surrounding a core of low density trabecular bone.*" The authors continue with a warning that it is only by

TABLE 5 Studies that were not included, and reason for non-inclusion (n = 20)

Reference	Study design	Study objective (sic)	Reason
Waechter et al. (2017)	RCT-split (SignoVinces: Geometry A – Integra cylindrical vs Geometry B- Duo tapered)	To compare the clinical outcomes of tapered and cylindrical implants and to study their effect on bone site characteristics and peri-implant health during healing.	<3 years. (90 days)
McCullough and Klokkevold (2017)	RCT-split (Megagen: Geometry A –Anyridge tapered vs Geometry B- EZPlus cylindrical)	To evaluate the role of macro-thread design on implant stability in the early post-operative healing period using resonance frequency analysis.	<3 years. (8 weeks)
Mangano et al. (2017)[a]	RCT-split (Megagen: Geometry A –Anyridge tapered vs Geometry B- EZPlus cylindrical)	To evaluate the effects of fixture design and surface on the early bone formation around immediately loaded implants inserted in the human posterior maxilla	<3 years. (8 weeks)
Simmons et al. (2017)[a]	RCT, 3 arms (Denstply: Geometry A -Osseospeed ± under-preparation vs Geometry B-Osseospeed TX-tapered apex)	To compare a parallel wall design implant to a tapered apex design implant when placed in the posterior maxilla using two different surgical protocols.	<3 years. (1 year)
Stanford et al. (2016)[a]	RCT, 2 arms (Dentsply: Geometry A-Osseospeed EV vs Geometry B-Osseospeed TX-tapered apex)	To evaluate implant system design, surgical and prosthetic aspects, and the effect on marginal bone levels of two related implant systems.	<3 years. (1 year)
Torroella-Saura et al. (2015)[a]	RCT-split (Implant A-Biocom cylindrical vs Implant B-MIS-Seven tapered)	To evaluate the effect of two different designs, tapered vs cylindrical, on the primary stability of implants placed with an immediate loading protocol in edentulous mandibles to support fixed prostheses within occlusal contacts during the first 48 h.	<3 years. (3 months)
Linkevicius, Puisys, Svediene, Linkevicius and Linkeviciene (2015)[a]	RCT-split (Implant A-Certain-Prevail cylindrical vs Implant B-Tapered-Laser-Lok)	To compare how laser-micro-textured implants and implants with platform switching maintain crestal bone stability in thin peri-implant tissues.	<3 years. (1 year)
Kan, Roe and Rungcharassaeng (2015)	Retrospective study with concurrent controls	To examine the effects of implant morphology (tapered vs cylindrical) and the final drill-implant diameter discrepancy (FD-IDD) of six implant systems on the incidence of rotational instability during immediate implant placement and provision-alization in the aesthetic zone.	Not a RCT
Pera et al. (2014)	CCT, 2 arms (Biomet 3i: Geometry A-Osseotite cylindrical & Geometry B-Osseotite-NT tapered)	To report the 6-year outcomes for patients rehabili-tated with an immediate loading protocol of the maxilla (Columbus Bridge Protocol).	Not a RCT
Kim et al. (2013)[a]	RCT, 2 arms (Implant A-Osstem TSIII HA vs Implant B-Zimmer TSV)	To compare clinical outcomes and stability following immediate loading of two types of tapered implants in the partially edentulous posterior maxilla and mandible.	<3 years. (1 year)
Kadkhodazadeh, Heidari, Abdi, Mollaverdi and Amid (2013)[a]	RCT, 3 arms (Implant A –AllFit-SSO cylindrical vs Implant B-SPI-Element cylindrical vs Implant C-SPI-Contact tapered)	To use intra-oral radiographs to evaluate changes in marginal bone levels around three different implant designs after 1 year.	< 3 years, (1 year)
Markovic et al. (2013)	Prospective case series×2 (Implant A - BlueSky-Bredent & Implant B-Straumann-Standard plus)	To investigate the relationship between surgical techniques and implant macro-design (self-tapping/non-self-tapping) for the optimization of implant stability in the low-density bone present in the posterior maxilla using resonance frequency analysis	Not an RCT
Kim, Lee, Kim, Park and Moon (2010)[a]	RCT-split (AstraTech-OsseoSpeed Fixture: Geometry A-Cylindrical vs Geometry B-Conical)	To evaluate and to compare the effect of the conical neck design on marginal bone loss around two types of implants, one with a straight shape and the other with a conical neck design, when both implants were provided with micro-threads to the top of the fixture	<3 years. (1 year)

(Continues)

TABLE 5 (Continued)

Reference	Study design	Study objective (sic)	Reason
Park et al. (2010)[a]	RCT, 2 arms (Implant A -Osstem vs Implant B-Straumann-Standard)	To compare the implant stability and clinical outcomes obtained with two types of non-submerged dental implants that have different thread designs and surface treatments	<3 years. (1 year)
Lang et al. (2007)	RCT, 2 arms (Straumann: Geometry A- Standard plus cylindrical vs Geometry B- TE tapered)	To compare the clinical and patient-based outcomes of immediately placed cylindrical and tapered screw-shaped implants with focus on early aspects of implant stability, the need for augmentation and post-surgical transmucosal healing	<3 years. (12 weeks)
Östman et al. (2005)	Prospective case series (Nobel Biocare: Brånemark Mk4/Replace-Selectin underprepared sites) compared to historical reference group data	To evaluate the clinical outcome and stability of directly loaded oxidized titanium implants after a modified surgical protocol and inclusion by primary implant stability	Not an RCT
O'Sullivan et al. (2004a)	Prospective case series x2, (Nobel Biocare: Geometry A-Brånemark standard in underprepared sites & Geometry B-Brånemark Mk4)	To compare selected parameters associated with implant insertion using two different methods of enhancing implant primary stability and to identify any relationship between these parameters and changes in the stability of each implant during the initial 6-month healing period following implant insertion	Not an RCT
Åstrand et al. (2003)	RCT, 2 arms (Geometry A-Brånemark Mk2 vs Geometry B-Brånemark Mk4)	To compare the outcome of using the tapered Brånemark System Mark IV fixture with the outcome of using earlier Brånemark fixtures in a controlled study	<3 years. (1 year)
Friberg et al. (2003)	RCT-split, 2 arms (Geometry A-Brånemark standard vs Geometry B-Brånemark Mk4)	To compare the early behavior of a modified (prototype Mk IV, Brånemark System, Nobel Biocare AB, Gothenburg, Sweden: test) implant with that of the standard Brånemark implant (control) in regions of mainly type 4 bone	<3 years. (1 year)
Gatti and Chiapasco (2002)	RCT, 2 arms (Geometry A-Brånemark-conical vs Geometry B-Brånemark Mk2)	To compare the long-term outcome of immediately loaded implant-retained mandibular overdentures supported by four screw-type one-piece transmucosal implants with that of four screw-type two-piece implants inserted in the interforaminal area of the mandible	<3 years. (2 years)

[a]Corresponding author contacted to confirm that no further data existed.

explorative drilling "*that the true bone quality present in the jaw can be determined*" given that on the radiographs of that period, the trabecular bone was masked by the cortical bone layer. "Poor quality bone" is difficult to define from the perspective of the likelihood of an osseointegration of a surgically placed dental implant, and investigators have struggled to identify its foremost and secondary determinants among mechanical properties such as density, hardness, and stiffness as well as morphological characteristics such as height of cortical passage and trabecular bone pattern characteristics such as trabecula number, thickness, and separation in combination with biomarkers of physiological properties such as healing ability and regenerative ability. Added to this complexity is that the prevailing non-destructive method to measure implant immobility is by RFA, which does not yet seem to be a reliable predictor of future osseointegration (Atieh, Alsabeeha & Payne, 2012; Manzano-Moreno, Herrera-Briones, Bassam, Vallecillo-Capilla & Reyes-Botella, 2015).

4.5 | Primary stability

Retaining the implant immobility after surgical placement, that is, "primary stability," during the healing process is a surrogate outcome and not a criterion of clinical success (Chang, Lang & Giannobile, 2010; Shadid, Sadaqah & Othman, 2014). One may even question whether "primary stability" per se has any prognostic value at all, given that extreme values of "primary stability" can be achieved with unconventional and outdated implant designs such as the "basal implants," for example, the *Bicortical Screw*, the "fin implants," for example, the *Tatum "D" implant*, or the "expanding implants," for example, the *Sargon implant*.

Alternative methods to better retain immobility after surgical placement of conventionally designed dental implants have been suggested (Martinez et al., 2001), including under-preparation in diameter of an osteotomy, or the placement of a tapered implant into a cylindrical osteotomy, thereby compressing the cortical bone

coronally (O'Sullivan et al., 2000). Several in vitro studies show that the relative gain of under-preparation in terms of increased insertion torque or RFA values can be increased by 50%–100%, dependent on the discrepancy between the osteotomy and implant body diameters (Campos et al., 2015). In contrast, the comparative studies in Table 5 describe the differences between the tapered versus non-tapered designs up to maximum 10% at baseline in terms of implant insertion torque (O'Sullivan, Sennerby & Meredith, 2004; Kielbassa Kielbasa 2009, Park et al., 2010; Torroella-Saura et al., 2015; Stanford et al., 2016) or RFA values (Friberg et al., 2003; Kim, Lee, Lee & Yi, 2013; Markovic et al., 2013; McCullough & Klokkevold, 2017; O'Sullivan, Sennerby, Jagger & Meredith, 2004; Östman, Hellman & Sennerby, 2005; Park et al., 2010; Simmons et al., 2017; Waechter et al., 2017). Moreover, the minor differences at baseline decrease to clinically insignificant after 8 weeks (McCullough & Klokkevold, 2017) and 12 weeks (Park et al., 2010), or to no differences after 90 days (Waechter et al., 2017), 6 weeks (Simmons et al., 2017), 3 months (Markovic et al., 2013; Torroella-Saura et al., 2015), and 6 months (Östman et al., 2005; Simmons et al., 2017).

The biological effects of the different methods of increasing "primary stability" are difficult to quantify in humans. It is reasonable to assume that there is an upper threshold beyond which overcompression of bone during placement will be detrimental to implant success (Cha et al., 2015). It has been shown in animal models that bone compression by undersized osteotomies show different patterns of osseointegration depending on the extent of compression (Tabassum, Meijer, Walboomers & Jansen, 2011). Recent animal model data suggest, however, that bone condensation should perhaps be avoided as it may not contribute positively to implant osseointegration (Wang et al., 2017).

In sum, the literature in general implies that among the three major determinants for whether a cylindrical/tapered/hybrid dental implant placed in an osteotomy made by an appropriate cylindrical/tapered/hybrid rotary instrument will remain immobile in the jaw bone is by ranking (i) bone quality and quantity > (ii) osteotomy preparation > (iii) implant geometry elements and -surface.

5 | CONCLUSIONS

A systematic search for best evidence to clarify whether patients with dental implant restorations benefit from receiving tapered compared to non-tapered implants in terms of clinical and patient-reported outcomes at 3 years or greater identified three RCTs that report only clinically insignificant differences. Several RCTs that report outcomes up to 2 years describe minimal differences about primary stability at implant placement and at their last respective follow-up examinations.

Retaining the implant immobility after surgical placement, that is, "primary stability," during the healing process is recognized as a critical element in implant therapy and can be challenging in conditions of poor bone quality or when providing immediate implant placement with or without immediate function. Appropriate professional judgment in clinical decision making must include a comprehensive

diagnosis of the patient's jawbone quality and quantity and consideration of osteotomy protocol in accordance with the patient's treatment preferences, where the shape of the dental implant is only one contributory factor.

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