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REVIEW ARTICLE

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Narrow-diameter implants: A systematic review and meta-analysis

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Abstract

Objectives: Narrow-diameter implants (NDI) are claimed to be a reasonable alternative to bone augmentation procedures. The aim of this comprehensive literature review was to conduct a meta-analysis comparing the implant survival of NDI and standard diameter implants (SDI) and to provide recommendations and guidelines for application of NDI.

Material and methods: An extensive systematic literature search was performed in the PubMed/MEDLINE and the Cochrane Library databases. NDI were classified into Category 1 (implant diameter <3.0 mm, "mini-implants"), Category 2 (implant diameter 3–3.25 mm) and Category 3 (implant diameters 3.3–3.5 mm). Clinical studies at all levels of evidence with at least 10 patients included and a follow-up time of at least 12 months were included. The primary outcome criterion was the survival rates of NDI.

Results: Seventy-six studies were identified for qualitative and 16 studies for quantitative synthesis. Quality assessment illustrated a high risk of bias for the included literature. Mean implant survival rates were 94.7 ± 5%, 97.3 ± 5% and 97.7 ± 2.3% for Categories 1, 2 and 3. Meta-analysis indicated a statistically significant lower implant survival of Category 1 NDI compared to SDI ([OR], 4.54; [CI], 1.51–13.65). For Category 2 and Category 3, no statistical significant differences in implant survival were seen compared to SDI ([OR], 1.06; [CI], 0.31–3.61 and [OR], 1.19; [CI], 0.83–1.70).

Conclusion: NDI of Category 1 performed statistically significantly worse than SDI and were mainly described for the rehabilitation of the highly atrophic maxilla or mandible. Category 2 and Category 3 NDI showed no difference in implant survival compared to SDI. Category 2 NDI were mostly used for the rehabilitation of limited interdental spaces in anterior single-tooth restorations. NDI of Category 3 were described in all regions, including posterior single-tooth restorations. However, resilient long-term data and data on the possible risk of biological and technical complications with wide platform teeth on NDI are missing so far.

KEYWORDS
meta-analysis, narrow diameter, review, small dental implants, survival

1 | INTRODUCTION

High success rates and excellent predictability of dental implant treatment have been demonstrated in countless clinical studies and a multiplicity of indications (Al-Nawas et al., 2012; Moraschini, Poubel, Ferreira & Barboza Edos, 2015; Schiegnitz et al., 2015). In addition, oral rehabilitation with dental implants may provide an increase in oral health-related quality of life (Heydecke, Locker, Awad, Lund & Feine, 2003; Schiegnitz et al., 2017). However, atrophy of the alveolar crest with reduced bone width and height due to trauma, malformation, neoplasia, denture wearing and marginal periodontitis is a challenging limitation for dental implant placement. In these cases, additional surgical procedures can be necessary to augment the insufficient bone volume and reconstruct the detrimental vertical, horizontal or sagittal intermaxillary relationships (Al-Nawas & Schiegnitz, 2014). In this context, a wide variety of augmentation procedures are described in the literature, depending on location and size of defect, such as maxillary sinus floor augmentation and vertical and/or lateral alveolar ridge augmentation (Al-Nawas & Schiegnitz, 2014). However, these augmentation procedures are time and cost-consuming and demand surgical expertise to minimize patients' morbidity and prevent complications such as postoperative pain, infections, nerve damage, bone fractures, hemorrhage, wound dehiscences and implant or augmentation failures. Furthermore, it has to be considered that in medically compromised patients (e.g., patients with a history of radiation in the head and neck region or with antiresorptive medication), augmentation procedures may carry a higher risk of complications (Schiegnitz, Al-Nawas, Kammerer & Grotz, 2014; Walter, Al-Nawas, Wolff, Schiegnitz & Grotz, 2016). Therefore, alternative concepts such as narrow-diameter implants (NDI) are becoming of increasing clinical and scientific interest. The avoidance of augmentation or other invasive surgery using NDI may reduce morbidity for the patient. However, studies evaluating patient-reported outcomes (PRO) such as health-related quality of life (HRQoL) in patients receiving NDI vs. standard diameter implants (SDI) with augmentation procedures are missing so far.

The definition of NDI is inconclusive in published studies, but in general a narrow-diameter implant is taken to have a diameter ≤3.5 mm. This general classification does not give full consideration to the different clinical indications for NDI. Therefore, the classification of Klein et al. (Klein, Schiegnitz & Al-Nawas, 2014) was implemented in this systematic review as it incorporates these parameters. In this classification, NDI are divided into the following three categories:

Category 1: <3.0 mm ("mini-implants")
Category 2: 3.0–3.25 mm
Category 3: 3.30–3.50 mm

For all three categories, numerous clinical studies have been published with promising survival and success rates (Klein et al., 2014). However, clinical evidence comparing NDI to SDI remains controversy. The aim of this comprehensive literature review was to conduct a meta-analysis comparing the implant survival of NDI and SDI. In addition, recommendations and guidelines for application of NDI were provided.

2 | MATERIAL AND METHODS

2.1 | Protocol development

This systematic review and meta-analysis were written and conducted according to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) statement (Liberati et al., 2009). The following focused question in the Patient, Intervention, Comparison and Outcome (PICO) format was posed (Stone, 2002): "In edentulous or partially edentulous patients, is implant survival, implant success, marginal bone adaptation and oral health-related quality of life outcomes of narrow diameter implants different to implant survival, implant success, marginal bone adaptation and oral health-related quality of life outcomes of standard diameter implants?". The primary outcome criterion was the survival rates of NDI. The secondary outcome criteria were implant success, marginal bone level and oral health-related quality of life. Regarding implant success, different definitions of implant success were used in the included studies. This has to be kept in mind, when interpreting the results of our study.

2.2 | Systematic search strategy and study selection

An extensive search in the electronic databases of the PubMed/MEDLINE and the Cochrane Library was performed in continuation of the review of Klein et al., (2014) for articles published between January 2013 and January 2017. Data from January 1995 to December 2012 were extracted from Klein et al., (2014). Second, the reference lists of related review articles and publications were systematically screened. As studies comparing NDI with SDI with simultaneous bone augmentation are very rare, we included all studies in meta-analysis which compared NDI with SDI without and with simultaneous bone augmentation. The specified key words and inclusion and exclusion criteria for qualitative and quantitative synthesis are displayed in Table 1. Soon, inclusion criteria for qualitative synthesis were studies at all levels of evidence with at least 10 patients and a mean follow-up time of implant survival of at least 12 months after implant placement, which were published in English. Inclusion criteria for quantitative synthesis were studies at all levels of evidence with at least 10 patients in the intervention and comparison group. The two reviewers Eik Schiegnitz [ES] and Bilal Al-Nawas [BA]) independently extracted the data from the studies. The data extracted were sorted as quantitative or qualitative and tabulated for ease of comparison. Articles that did not meet the inclusion criteria were excluded. Any disagreement between the authors regarding inclusion of a certain article and data extraction was resolved by discussion. The PRISMA flow diagram shows the

TABLE 1 Systematic search strategy

Focused question (PICO)	In edentulous or partially edentulous patients, is implant survival, implant success, marginal bone adaption and oral health-related quality of life of narrow-diameter implants different to implant survival, implant success, marginal bone adaption and oral health-related quality of life of standard diameter implants?	
Search strategy	Population	Edentulous OR partially edentulous
	Intervention or exposure	Dental implantation with narrow-diameter implants (NDI)
	Comparison	Other diameters than NDI
	Primary outcome	Implant survival
	Secondary outcome	Implant success, marginal bone level, oral health-related quality of life
	Search combination	"small diameter dental implants" "narrow-diameter dental implants" "narrow dental implants" "small dental implants" "diameter dental implants" "mini-implants"
Database search	Electronic	PubMed, Cochrane library
	Journals	Clinical Oral Implants Research, International Journal of Oral Maxillofacial Implants, Clinical Implant Dentistry and Related Research, Implant Dentistry, Journal of Implantology, Journal of Periodontology, Journal of Clinical Periodontology
Selection criteria	Inclusion criteria for qualitative synthesis	• Clinical studies at all levels of evidence, except expert opinion • At least 10 with NDI-treated patients • Mean follow-up time of implant survival of at least 12 months after implant placement • Published in English
	Exclusion criteria for qualitative synthesis	• Clinical studies with <10 treated patients • Animal studies • Reviews, meta-analyses • Multiple publications on the same patient population • Mini-implants for orthodontic anchorage • Studies with mean follow-up time of implant survival <1 year after implant placement
	Inclusion criteria for quantitative synthesis	• Clinical studies at all levels of evidence, except expert opinion • Intervention group: at least 10 with NDI-treated patients • Comparison group: at least 10 with SDI-treated patients • Mean follow-up time of implant survival of at least 12 months after implant placement • Published in English
	Exclusion criteria for quantitative synthesis	• Clinical studies with <10 treated patients • Animal studies • Reviews, meta-analyses • Multiple publications on the same patient population • Mini-implants for orthodontic anchorage • Studies with mean follow-up time of implant survival <1 year after implant placement

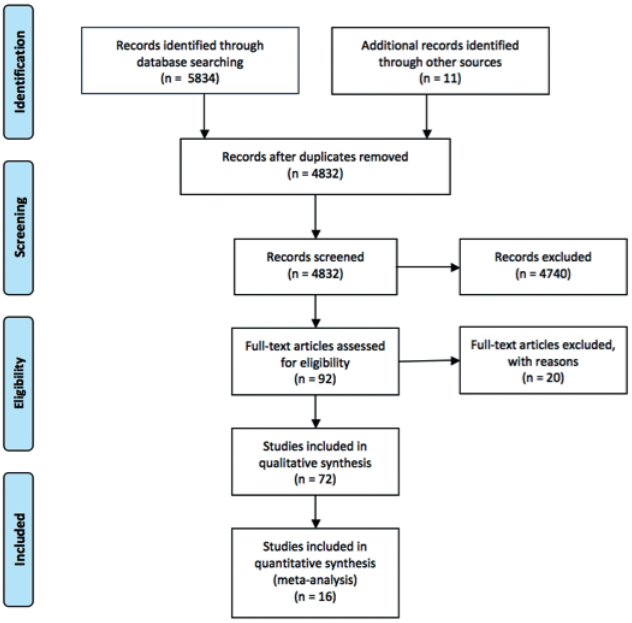

FIGURE 1 PRISMA flowchart

flow of information through the different phases of the review process (Figure 1).

2.3 | Risk of bias/quality assessment

The quality of the included articles in quantitative synthesis was evaluated as described before (Vignoletti et al., 2012; Willenbacher, Al-Nawas, Berres, Kammerer & Schiegnitz, 2016). With this technique, the quality of the included studies was classified according to the Cochrane statements, the CONSORT statements, the MOOSE statement and the STROBE statements. In this way, the studies were checked for the following six criteria: randomization, blinding of the patient and/or the examiner, definition of inclusion and exclusion criteria, selection of a representative population group (at least 20 patients overall and 10 patients in each group), reporting of the follow-up and reasons for dropout and identical treatment between groups except for the intervention (Table 2). As blinding of the patient and/or the examiner is nearly impossible in surgical implant studies, this point was described as not applicable. Studies fulfilling all of the above-mentioned criteria were then categorized with a low potential risk of bias. Studies in which one of the criteria did not match were described as having a moderate risk of bias and studies where two or more of the criteria were missing were as having a high potential risk of bias.

2.4 | Statistical analysis

Meta-analysis was performed applying the statistical software package RevMan (Review Manager [Computer program], version 5.3, Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014) to calculate the overall estimated effects

TABLE 2 Quality criteria of the included articles

Study	Randomization	Blinding	Appropriate and clearly focused question of the study	Identical treatment except for intervention	Defined criteria for 1. Inclusion 2. Exclusion	Appropriate no. of implants (test/control)	Follow-ups completed/ dropouts/reason for dropout (yes/no)	Conflict of interest was stated	Source of funding	Risk of bias
Temizel, Heinemann, Dirk, Bourauel and Hasan (2017)	No	NA	Yes	Yes	1. Yes 2. Yes	Yes	Yes	No	ND	High
Anitua, Saracho, Begona and Alkhraisat (2016)	No	NA	Yes	Yes	1. Yes 2. No	Yes	No	Yes	ND	High
de Souza et al. (2015)	Yes	NA (Yes)	Yes	Yes	1. Yes 2. Yes	Yes	Yes	Yes	FAPESP (grant no. 11/00688-7, scholarship 11/23347-0)	Low
Anitua et al. (2008)	No	NA	Yes	Yes	1. No 2. No	Yes	No	Yes	Biotechnology Institute (BTI)	High
Pieri et al. (2017)	No	NA	Yes	Yes	1. Yes 2. Yes	Yes	No	Yes	No	High
Aunmeungtong et al. (2017)	Yes	NA (Yes)	Yes	Yes	1. Yes 2. Yes	Yes	Yes	No	ND	Moderate
Andersen, Saxegaard, Knutsen and Haanaes (2001)	No	NA (Yes)	Yes	Yes	1. Yes 2. Yes	Yes	Yes	No	Implant Innovations Inc.	High
Herrmann et al. (2016)	No	NA	Yes	Yes	1. Yes 2. Yes	Yes	Yes	Yes	ND	High
Ioannidis et al. (2015)	Yes	NA	Yes	Yes	1. Yes 2. Yes	Yes	Yes	Yes	ITI Foundation	Low
Schiegnitz et al. (2016)	No	NA	Yes	Yes	1. No 2. No	Yes	Yes	Yes	ND	High
Zweers, van Doornik, Hogendorf, Quirynen and Van der Weijden (2015)	No	NA	Yes	Yes	1. Yes 2. Yes	Yes	Yes	Yes	No	Moderate
Benic et al. (2013)	Yes	NA	Yes	Yes	1. Yes 2. Yes	Yes	Yes	Yes	ITI Foundation	Low
Haas, Mensdorff-Pouilly, Mailath and Watzek (1996)	No	NA	Yes	Yes	1. No 2. No	Yes	No	No	ND	High
Lazzara et al. (1996)	No	NA	Yes	Yes	1. Yes 2. Yes	Yes	Yes	No	ND	High
Romeo et al. (2006)	No	NA	Yes	Yes	1. Yes 2. Yes	Yes	Yes	No	ND	High
Spiekermann, Jansen and Richter (1995)	No	NA	Yes	Yes	1. No 2. No	Yes	No	No	ND	High

ND, not described; NA, not applicable.

and to create the forest plots and funnel plots. Funnel plots are a scatterplot of treatment effect (*x*-axis) against a measure of study precision (*y*-axis) (Egger, Davey Smith, Schneider & Minder, 1997). The overall estimated effect was categorized as significant where $p < 0.05$.

3 | RESULTS

3.1 | Study selection and study characteristics

A total of 5845 records were identified through the electronic search and manual search (Figure 1). After exclusion of duplicates and screening of titles and abstracts, 92 studies were left for full-text assessment. At last, 72 studies were included in the qualitative analysis and 16 studies in the quantitative analysis. The selected studies were subdivided into three categories according to the diameter of the investigated implants: 22 studies reporting on implants of Category 1 (Table 3) with 1280 patients and 5,441 NDI, 19 studies reporting on implants of Category 2 with 823 patients and 1,133 NDI (Table 4) and 35 studies reporting on implants of Category 3 with 3,842 patients and 5,612 NDI (Table 5). Altogether in the included articles, 12,186 NDI were inserted. The study of Anitua, Orive, Aguirre, Ardanza & Andia, 2008 was included in all three categories, and the studies of Anitua et al., 2010 and Mangano et al., 2013 were included in Category I and Category II. Data on the influence of NDI on oral health-related quality of life were rarely documented. Therefore, this secondary outcome could not be addressed.

3.2 | Quality assessment/risk of bias

Quality assessment showed a huge variety across the included studies in quantitative analysis (Table 2). Three studies showed a low potential risk of bias, two studies a moderate risk of bias and 11 studies a high potential risk of bias (Figure 2). Therefore, a high risk of bias for the included literature was seen. This has to be kept in mind when interpreting the results of the review.

3.3 | Implant survival, implant success and marginal bone level

3.3.1 | Category 1

The most prevalently used implant type in Category 1 was one-piece implant with a diameter between 1.8 and 2.4 mm (Table 6). Mean follow-up was 34 ± 20 months and ranged between 12 and 78 months (Table 3). Mean survival rate was 94.7 ± 5% (range 80%–100%). The most frequently described indications were the edentulous arch and single non-load-bearing teeth in the anterior region. Types of final restorations were mainly complete overdentures. Most of the studies reported survival rates; only one study indicated an implant success rate of 92.9%. Mean marginal bone loss ranged from 0.6 mm to 1.43 mm. Regarding the applied surgical protocol, procedures ranged from minimally invasive transmucosal implant insertion to the raising of a full-thickness flap. Most of the studies described an immediate loading protocol for the overdenture. Regarding the secondary outcome criteria oral health-related quality, several clinical studies showed an increase in terms quality of life after treatment with NDI of Category 1 (Elsyad, 2016; Enkling, Saftig, Worni, Mericske-Stern & Schimmel, 2017; Preoteasa, Imre & Preoteasa, 2014).

3.3.2 | Category 2

In Category 2, 17 of 19 studies investigated SDI with a diameter of 3.0 mm (Table 6). Mean follow-up was 29 ± 17 months (range 12 to 63 months), and mean survival rate was 97.3 ± 5% (range 80.5%–100%). The leading indication and the mainly used final restorations for these implants were single-tooth restoration in the anterior region. Implant success rates were described in three studies and constituted 100%. The included studies indicated a mean marginal bone loss between 0.09 mm and 1.6 mm. Concerning the secondary outcome criteria of oral health-related quality of life, none of the investigated studies addressed this point.

3.3.3 | Category 3

In Category 3, the most prevalent implant type was of two-piece design with a diameter of 3.3 mm (Table 6). Analysis of the included studies indicated a mean survival rate of 97.7 ± 2,3% (range 91% to 100%) after a mean follow-up of 39 ± 24 months (range 12–109 months). There were several studies representing long-term survival for NDI of category 3 (Arisan, Bolukbasi, Ersanli & Ozdemir, 2010; Hasegawa et al., 2017; Mangano et al., 2014; Romeo et al., 2006; Schiegnitz et al., 2016). The indications were often imprecisely defined, but also included the load-bearing posterior region. Types of final restorations were mixed. Implant success rates ranged between 91.4% and 100%. Mean marginal bone loss ranged from 0.1 mm to 2.17 mm. As in Category 2, the secondary outcome criteria oral health-related quality of life was not evaluated.

3.4 | Meta-analysis of implant survival of NDI vs. implant survival of SDI 2

Meta-analysis showed a significant difference in implant survival between NDI of Category 1 and SDI (odds ratio [OR], 4.54; confidence interval [CI], 1.51–13.65; Figure 3). Begg and Mazumdar's funnel plot for this meta-analysis is shown in Figure 4. Meta-analysis of studies comparing implant survival in NDI of Category 2 and SDI revealed no statistically significant difference ([OR], 1.06; [CI], 0.31–3.61; Figure 5). Begg and Mazumdar's funnel plot indicated a low risk for publication bias for this meta-analysis (Figure 6). In addition, no statistically significant difference was seen comparing implant survival of NDI of Category 3 and SDI ([OR], 1.19; [CI], 0.83–1.70; Figure 7). Begg and Mazumdar's funnel plot for this meta-analysis is

displayed in Figure 8. When interpreting these results of the meta-analysis, the Forrest plots show that the effects among most of the categories are driven mostly by one study and the confidence intervals are large for most of the analyses due to the paucity of events and heterogeneity of study design and outcome measure. Therefore, drawing definite conclusions out of these data is not recommended.

4 | DISCUSSION

Patient preference for minimally invasive treatment options such as rehabilitation without bone augmentation is generally high (Pommer et al., 2014). Therefore, the aim of this systematic review was to perform a meta-analysis comparing the implant survival of NDI and SDI. NDI were classified into Category 1 (<3.0 mm, "mini-implants"), Category 2 (3.00–3.25 mm) and Category 3 (3.30–3.50 mm) as described before (Klein et al., 2014). Quality assessment of the included studies showed an enormous variety, as prospective randomized studies were rare. In addition, survival follow-up times showed a wide variation. Reasons for implant failures and implant success were missing in most of the included studies. Therefore, that the best possible available external evidence evaluated has a high risk of bias compared to other reviews that include only randomized studies should be kept in mind when considering the results of this review.

According to the results of our meta-analysis, the mean survival rates of NDI of Category 1 were promising (94.7 ± 5%). However, this is significantly lower than the survival rates of SDI. These results may not be surprising, as these mini-implants were generally inserted in highly atrophic edentulous jaws that represent surgically challenging situations. Studies comparing survival and success of NDI compared to SDI with augmentation procedures in high atrophic situations are missing so far. Mean marginal bone loss of Category 1 NDI ranged from 0.6 mm to 1.43 mm, similar to those of SDI (Di Girolamo, Calcaterra, Gianfilippo, Arcuri & Baggi, 2016; Helmy, Alqutaibi, El-Ella & Shawky, 2017). In a recent systematic review, the use of mini-implants to retain complete overdentures was examined (Lemos et al., 2017). The results showed a similar survival rate of 92.32% after a mean follow-up time of 30 months for the mini-implants. Marginal bone loss values were described in the majority of the studies below 1.5 mm. Regarding patient-centered outcomes, several clinical studies illustrated an increase in terms of aesthetics, satisfaction and quality of life after rehabilitation treatment with mini-dental implants (Aunmeungtong, Kumchai, Strietzel, Reichart & Khongkhunthian, 2017; Elsyad, 2016; Enkling et al., 2017; Preoteasa et al., 2014). In conclusion, application of a minimum of 4 or 6 mini-implants in mandibular or maxillary arches for retaining overdenture prostheses is considered a promising alternative treatment when insertion of SDI is due to extreme bone atrophy is not possible (Bidra & Almas, 2013; Lemos et al., 2017). Due to the one-piece design, most of the studies reported immediate restoration and immediate loading protocols. Regarding the suitable retention system (e.g., bar, ball or locator), there is no strong evidence for the superiority of one system over the others regarding patient satisfaction, survival, peri-implant bone loss and other clinical factors (Carlsson, 2014; Laverty, Green, Marrison, Addy & Thomas, 2017).

Regarding NDI of Category 2, mean implant survival was 97.3 ± 5% after a mean follow-up of 29 ± 17 months. Meta-analysis indicated comparable implant survival between NDI of Category 2 and SDI. These NDI were mainly inserted to replace the maxillary lateral or mandibular incisor teeth. These sites often present limited interdental space or a thin alveolar crest. Placing an implant too close to the adjacent teeth may result in loss of proximal bone height, which can negatively influence the final position of the papillae and supracrestal soft tissues (King et al., 2016; Tarnow, Cho & Wallace, 2000). Therefore, in evaluating anterior single-tooth restorations, aesthetic outcome and stability of peri-implant soft tissues are the main foci of interest besides implant survival. However, these outcome parameters were seldom assessed. Pieri, Siroli, Forlivesi & Corinaldesi, (2014) showed high mean pink aesthetic scores and stable facial soft tissues after a follow-up of 3 years. King et al., (2016) indicated stable soft tissues and clinically insignificant changes in probing depth and gingival zenith stores. These promising results should be confirmed by larger multicenter studies. Regarding the surgical protocol and the loading protocol, there were insufficient data in the included studies to recommend the superiority of one of the protocols.

NDI of Category 3 showed a mean survival rate of 97.5 ± 2.4% after a mean follow-up of 39 ± 24 months. Meta-analysis of the literature showed comparable survival rates for Category 3 NDI and SDI. The indications in the included studies were often mixed and ill-defined. However, there were several studies showing promising results for NDI of Category 3 for the posterior jaw. A recent review on the clinical performance of narrow-diameter titanium–zirconium implants (TiZr) indicated that these implants could be reliable for restorations in the posterior region, even when replacing single missing molars (Badran et al., 2017; F. E. Lambert et al., 2015; Tolentino et al., 2016). However, long-term data are rare so far.

After finalization of the systematic literature review, several further clinical studies were published (Cabrera-Dominguez, Castellanos-Cosano, Torres-Lagares & Machuca-Portillo, 2017; A. B. de Souza et al., 2017; Froum, Shi, Fisselier & Cho, 2017; Giannakopoulos et al., 2017; Grandi, Svezia & Grandi, 2017; Malo, de Araujo Nobre, Lopes & Ferro, 2017; Shi et al., 2017). These studies support the concluded results of our systematic review, and no relevant differences in clinical conclusions were found. For example, a 36-month split-mouth randomized controlled clinical study showed that 3.3-mm NDI placed to support single crowns in the posterior region did not differ to 4.1-mm SDI in regard to marginal bone level, implant survival and success rates (de Souza et al., 2017). A retrospective cohort study with a mean follow-up time of 120 months confirmed high long-term survival rates, high patient satisfaction, acceptable complication rates and marginal bone loss for 3.3 mm NDI (Shi et al., 2017).

TABLE 3 Summary of included studies of Category 1, continuation of Klein et al. (2014) [In PDF format, this table is best viewed in two-page mode]

Study	Study type	No. of patients	Implant design	Diameter (category)	Length (mm)
Enkling et al. (2017)	PS	20	One-piece	1.8 (I)	13–15
Temizel et al. (2017)	**PS**	**32**	**One-piece (I) Two-piece (C)**	**1.8–2.4 (I) 3.3–3.7 (C)**	**13–15 (I) 11–13 (C)**
Zygogiannis, Wismeijer and Parsa (2016)	PS	10	One-piece	1.8–2.4 (I)	10–15
Schwindling and Schwindling (2016)	RS	25	One-piece	1.8, 2.1, 2.4 (I)	10–18
Anitua et al. (2016)	**RS**	**20 (II) ND (C)**	**Two-piece**	**2.5 (I) ND (I)**	**10 –15 (I) ND (C)**
Lambert, Botilde, Lecloux and Rompen (2016)	PS	20	One-piece	2.0, 2.5 (I)	10–13
de Souza et al. (2015)	**RCT**	**120**	**One-piece**	**2.0 (I) 4.0 (C)**	**10**
Mundt, Schwahn, Stark and Biffar (2015)	RS	133	One-piece	1.8, 2.1, 2.4 (I)	10–18
Maryod, Ali and Shawky (2014)	PS	36	One-piece	1.8 (I)	15
Preoteasa et al. (2014)	PS	23	One-piece	1.8, 2.1, 2.4 (I)	10–18
Mangano et al. (2013)	PS	16	One-piece	2.7 (I)	10–13
Tomasi, Idmyr and Wennstrom (2013)	PS	21	One-piece	1.8, 2.1, 2.4 (I)	7–14
Elsyad, Gebreel, Fouad and Elshoukouki (2011)	PS	28 (49–75; 63)	One-piece	1.8 (I)	12–18
Jofre, Cendoya and Munoz (2010), Jofre, Hamada, Nishimura and Klattenhoff (2010)	RCT	45 (45–90)	One-piece	1.8 (I)	15
Anitua et al. (2010)	RS	51 (19–90; 55)	One-piece	2.5 (I)	10–15
Balaji, Mohamed and Kathiresan (2010)	RS	11 (20–52; 29)	One-piece	2.4 (I)	13
Anitua et al. (2008)	**RS**	**ND**	**Two-piece**	**2.5 (I) 3.75 (C)**	**10–15 7.5–18**
LaBarre, Ahlstrom and Noble (2008)	RS	ND	ND	1.8–2.4 (I)	ND
Morneburg and Proschel (2008)	PS	67 (53–83; 69)	One-piece	2.5 (I)	9, 12, 15
Froum, Cho, Cho, Elian and Tarnow (2007)	RS	27	One-piece	1.8–2.4 (I)	7–14
Shatkin, Shatkin, Oppenheimer and Oppenheimer (2007)	RS	531	ND	1.8–2.4 (I)	ND
Vigolo and Givani (2000)	RS	44 (18–74; 35)	Two-piece	2.9 (I)	8.5, 10, 13, 15

Studies included in meta-analysis are highlighted with bold characters; MAX, maxilla; MAN, mandible; ND, no data available or data cannot be separated; PS, prospective study; RS, retrospective study; RCT, randomized controlled trial. I, Category 1 (narrow diameter implants); II, Category 2 (narrow diameter implants); C, Control (standard diameter implants).

TABLE 3 (additional columns)

No. of implants	Indication (jaw region)	Follow-up (months: range; mean)	Implant failures; survival rate	Implant success rate	Mean marginal bone loss (mm)
80	Edentulous jaw (MAN)	12	0; 100%	ND	ND
99 (I) 35 (C)	**Edentulous jaw (MAN)**	**24**	**0; 100% (I) 1; 97.1% (C)**	**ND**	**ND**
110	Edentulous jaw (MAN)	18	0; 100%	ND	−1.05 ± 0.81 (mesial, 18 months) −1.02 ± 0.7 (distal, 18 months)
99	Edentulous jaw (MAN)	33 (2–87)	8; 91.9%	ND	ND
37 (II) 160 (C)	**Fixed prostheses (MAN + MAX)**	**78 (0–116) ND (C)**	**1; 97.3% (II) 1; 99.3% (C) $p = 0.267$**	**ND**	**−0.70 ± 0.55 (mesial, 78 months) −0.72 ± 0.56 (distal, 78 months)**
30	Temporary restorative option (MAN + MAX)	42	1; 96.6%	ND	ND
236 (I) 152 (Ia with 4 NDI) 84 (Ib with 2 NDI) 80 (with 2 SDI)	**Edentulous jaw (MAN)**	**12**	**31; ND 16; 89% (Ia) 15; 82% (Ib) 1; 99% (C)**	**ND**	**ND**
MAX: 336 MAN: 402	Edentulous jaw (MAX, MAN)	MAX: 27.1 MAN: 29.4	MAX: 15; 94.3% (5-year) MAN: 11; 95.7% (5-year)	ND	ND
144	Edentulous jaw (MAN)	36	7 of 120; 94.2%	ND	ND
110	Edentulous jaw (MAX, MAN)	36	8; 92.7%	ND	ND
22	Fixed Partial Prostheses (MAN + MAX)	24	0; 100%	ND	ND
80	Edentulous jaw (MAX, MAN)	12	16; 80%	ND	ND
112	Edentulous jaw (MAN)	36	4; 96.4%	92.9%	−1.26 ± 0.6 (36 months)
90	Edentulous jaw (MAN + MAX)	15–24	0; 100%	ND	−1.43 ± 1.26 (24 months, ball-retained) −0.92 ± 0.75 (24 months, bar-retained)
31	ND (MAN + MAX)	48	1; 98.9%	ND	−1.26 ± 0.5 (24 months)
11	Anterior single-tooth restoration(MAN + MAX)	24	1; 90.9%	ND	−0.6 (24 months)
38 1654	**ND ND**	**29**	**1; 97.4% (I) 9; 99.5% (C)**	**ND ND**	**ND ND**
626	ND	72	46; 92,6%	ND	ND
134	Edentulous jaw (MAN)	72	6; 95.5%	ND	−0.7 ± 0.4 (24 months)
48	Anterior single-tooth restoration (MAN + MAX)	12–64	0; 100%	ND	ND
2514	ND (MAN + MAX)	35	145; 94.2%	ND	ND
52	Single-tooth restorations and partial prostheses (MAX + MAN)	60	3; 94.2%	ND	−0.8 mm (0.5–1.1 mm) (60 months)

TABLE 4 Summary of included studies of Category 2, continuation of Klein et al. (2014) [In PDF format, this table is best viewed in two-page mode]

Study	Study type	No. of patients	Implant design	Diameter (category)	Length (mm)	No. of implants
Pieri et al. (2017)	**RS**	**127**	**Two-piece**	**3.0 (II) 4.0–4.5 (C)**	**11–15**	**113 (II) 126 (C)**
Aunmeungtong et al. (2017)	**RCC**	**60**	**One-piece**	**3.0 (II) 3.75 (C)**	**12 (II) 10 (C)**	**40 (II) 20 (C)**
King et al. (2016)	PS	38	Two-piece	3.0 (II)	11–15	62
Maiorana et al. (2015)	PS	69	Two-piece	3.0 (II)	11–15	97
Pieri et al. (2014)	PS	50	Two-piece	3.0 (II)	11–15	50
Lauritano, Grassi, di Stasio, Lucchese and Petruzzi (2014)	RS	21	One-piece	3.0 (II)	≤12	84
Mangano et al. (2013)	PS	16	One-piece	3.2 (II)	10–13	15
Mazor, Lorean, Mijiritsky and Levin (2012)	RS	33 (23–76; 49.2)	Two-piece	3.0 (II)	13	66
Oyama, Kan, Rungcharassaeng and Lozada (2012)	PS	13 (18–84; 32.9)	Two-piece	3.0 (II)	ND	17
Galindo-Moreno et al. (2012)	PS	69 (32 ± 17)	Two-piece	3.0 (II)	11; 13; 15	97
Zembic et al. (2012)	RS	47 (17–76; 31)	One-piece	3.0 (II)	13, 15	57
Sohn et al. (2011)	RS	36 (42–72; 53)	One-piece	3.0 (II)	12, 15	62
Anitua et al. (2010)	RS	51 (19–90; 55)	Two-piece	3.0 (II)	10–15	58
Degidi, Nardi and Piattelli (2009a)	PS	40 (55 ± 17)	Two-piece	3.0 (II)	11;13,15	93
Degidi, Nardi and Piattelli (2009b)	RCT	60 (18–55; 32)	Two-piece	3.0 (II)	13; 15	60 30 (immediate loading) 30 (one-stage loaded)
Reddy, O'Neal, Haigh, Aponte-Wesson and Geurs (2008)	RS	17 (19–74)	One-piece	3.0 (II)	ND	31
Anitua et al. (2008)	**RS**	**ND**	**Two-piece**	**3.0 (II) 3.75 (C)**	**10–15**	**69 (II) 1654 (C)**
Andersen et al. (2001)	**PS**	**55**	**Two-piece**	**3.25 (II) 3.75 (C)**	**13–15**	**60 32 (II) 28 (C)**
Polizzi, Fabbro, Furri, Herrmann and Squarzoni (1999)	RS	21 (13–58; 30)	Two-piece	3.0 (II)	10, 13, 15	30

Studies included in meta-analysis are highlighted with bold characters; MAX, maxilla; MAN, mandible; ND, no data available or data cannot be separated; PS, prospective study; RS, retrospective study; RCT, randomized controlled trial. I, Category 1 (narrow diameter implants); II, Category 2 (narrow diameter implants); C, Control (standard diameter implants).

TABLE 4 (additional columns)

Indication (jaw region)	Follow-up (months: range; mean)	Implant failures; survival rate	Implant success rate	Mean marginal bone loss (mm)
Posterior splinted partial fixed restoration (MAX, MAN)	**60**	**2; ND (II) 4; ND (C) $p = 0.37$**	**ND**	**−0.95 ± 0.84 (II) −1.2 ± 0.86 (C) $p = 0.06$ (60 months)**
Edentulous jaw (MAN)	**12**	**0; 100% (II) 0; 100% (C)**	**0; 100% (II) 0; 100% (C)**	**−0.53 ± 0.41 (IIa) −0.60 ± 0.45 (IIb) −1.33 ± 0.6 (C) (12 months)**
Anterior region (MAX, MAN)	36	2; 96.8%	ND	−0.23 (36 months)
Anterior region (MAX, MAN)	36	4; 95.9%	ND	−0.09 (36 months)
Anterior region (MAX, MAN)	36	0; 100%	100%	−0.24 ± 0.15 (36 months)
Anterior region (MAN)	12	10; 80.5%	ND	ND
Fixed Partial Prostheses (MAN, MAX)	24	0; 100%	ND	ND
Single-tooth restoration (MAN + MAX)	12 ± 1.9	0; 100%	ND	ND
Single-tooth restoration of incisors (MAN + MAX)	12	0; 100%	ND	−0.38 ± 0.36 (12 months)
Anterior region (MAN + MAX)	12	4; 95.9%	ND	−0.7 ± 1.0 (12 months)
Single-tooth restoration in anterior region (MAX + MAN)	13 (9.8–20.8)	1; 98%	ND	−1.6 ± 1.2 (12 months)
Maxillary lateral incisors and mandibular incisors (MAN + MAX)	23 ± 4.3	0; 100%	100%	−0.53 ± 0.37 (12 months)
Mixed Indications (MAN + MAX)	48	1; 96.8%	ND	−1.26 ± 0.5 (24 months)
Fixed partial posterior restorations (MAX, MAN)	48	0; 100%	ND	−1.16 ± 0.9 (48 months)
Single lateral incisor (MAX)	36	0; 100% 0; 100% (immediate loading) 0; 100% (one-stage loaded)	ND	−0.85 ± 0.7 (immediate loading, 36 months) −0.75 ± 0.6 (one-stage loaded, 36 months)
Single-tooth restoration in anterior region (MAN + MAX)	12	1; 96,7%	ND	−0.7 (12 months)
ND	**29**	**0; 100% 9; 99.5%**	**ND**	**ND**
Anterior region (MAX)	**36**	**2; 93.8% 0; 100%**	**ND**	**−0.5 ± 0.0 (II; 36 months) −0.4 ± 0.2 (C; 36 months)**
Single-tooth restoration of incisors (MAN + MAX)	63	1; 96,7%	ND	Minimal marginal bone loss after 12 months

TABLE 5 Summary of included studies of Category 3, continuation of Klein et al. (2014) [In PDF format, this table is best viewed in two-page mode]

Study	Study type	No. of patients	Implant design (one-piece: I; two-piece: II)	Diameter	Length (mm)
Hasegawa et al. (2017)	RS	242	Two-piece	3.3 (III) 3.75–5 (C)	10–15 (III) 7–18 (C)
Schiegnitz et al. (2016)	**RS**	**90**	**Two-piece**	**3.3 (II) 4.1 (C1) 4.8 (C2)**	**8–14**
Woo, Kim, Kang, Kim and Yang (2016)	RS	66	Two-piece	3.5 (III)	8–11
Herrmann et al. (2016)	**RS**	**107 (III) 204 (C)**	**Two-piece**	**3.3 (III) 4.1–4.8 (C)**	**8–14 (III) 12–14 (C)**
Zembic, Tahmaseb, Jung and Wismeijer (2016)	PS	20	Two-piece	3.3 (III)	8–12
Tolentino et al. (2016)	RCT	10	Two-piece	3.3 (III) TiZr vs. Ti	
Moraguez, Vailati, Grutter, Sailer and Belser (2017)	PS	10	Two-piece	3.3 (III)	10–12
Muller et al. (2015)	RCT	91	Two-piece	3.3 (III)	8–14
Al-Nawas et al. (2015)	PS	359	Two-piece	3.3 (III)	8–14
Temmerman, Keestra, Coucke, Teughels and Quirynen (2015)	PS	28	Two-piece	3.5 (III)	8–15
Ioannidis et al. (2015)	**RCC**	**20 (III) 20 (C)**	**Two-piece**	**3.3 (III) 4.1 (C)**	**≥ 8**
Quirynen et al., 2015 (Quirynen et al., 2015)	RCT	89	Two-piece	3.3 (III) TiZr vs. Ti	8–14
Zweers et al. (2015)	**RS**	**119**	**Two-piece**	**3.3 (III) 4.1 (C)**	**8–14 (III) 10–14 (C)**
Lambert et al. (2015)	PS	20	Two-piece	3.3 (III)	ND
El-Sheikh and Shihabuddin (2014)	PS	20	Two-piece	3.3 (III)	8–12
Mangano et al. (2014)	PS	279	Two-piece	3.3 (III)	8–14
Tolentino et al. (2014)	PS	42	Two-piece	3.3 (III) TiZr vs. Ti	8–12
Benic et al. (2013)	**RCC**	**40**	**Two-piece**	**3.3 (TiZr, III) 4.1 (Ti, C)**	**8–14**
Cordaro, Torsello, Mirisola di Torresanto and Baricevic (2013)	RS	10	Two-piece	3.3 (III)	10–12
Lee et al. (2013)	RS	338	Two-piece	3.3–3.5 (III)	10–13
Barter, Stone and Bragger (2012)	PS	22	Two-piece	3.3 (III)	ND

(Continues)

TABLE 5 (additional columns)

No. of implants (category)	Indication (jaw region)	Follow-up (months: range; mean)	Implant failures; survival rate	Implant success rate	Mean marginal bone loss (mm)
132 (III) 775 (C)	Mixed indications (MAN, MAX)	71.3 (12–137)	4; 97% (III) 19; 97% (C) $p = 0.762$	ND	ND
24 (III) 138 (C1) 27 (C2)	**Mixed indications (MAN, MAX)**	**62 ± 3.1**	**1; 95.8% (III) 6; 95.7% (C1) 0; 100% (C3)**	**ND**	**ND**
98	Posterior edentulous region (MAN, MAX)	37.45 ± 12.80	0; 100%	ND	−0.14 ± 0.39 (37.45 months)
154 (III) 396 (C)	**Mixed indications (MAN, MAX)**	**22.4 ± 8.2 (III) 28.4 ± 10.1 (C)**	**4; 97.4% (III) 6; 98.5% (C)**	**ND**	**ND**
40	Edentulous jaw (MAX)	12	1 of 38; 97.3%	ND	−0.7 ± 1.1 (12 months)
20	Single restorations in the posterior region (MAN)	12	0; 100%	100%	−0.32 ± 0.27 (TiZr) −0.35 ± 0.24 (Ti) $p = 0.60$ (12 months)
20	Fixed dental prostheses for incisors (MAX)	60	0; 100%	ND	−2.17 ± 0.38 (60 months)
182 91 (TiZr) 91 (Ti)	Edentulous jaw (MAN)	60	1; 98.9% (TiZr) 2; 97.8% (Ti)	95.8% (TiZr) 92.6% (Ti)	−0.60 ± 0.69 (TiZr) −0.61 ± 0.83 (Ti) (60 months)
603	Mixed indications (MAN, MAX)	24	10 of 409; 97.6%	97.4%	No bone loss was at 81.2% of implants
100	Mixed indications (MAN, MAX)	36	0; 100%	ND	−0.18 ± 0.55 (36 months)
20 (III) 20 (C)	**Anterior and premolar single crowns (MAN, MAX)**	**36**	**0; 100% (III) 0; 100% (C)**	**ND**	**−0.10 (III) −0.21 (C) (36 months)**
75 (TiZr) 75 (Ti)	I (MAN)	36	1; 98.7% (TiZr) 2; 97.3% (Ti)	98.7% (TiZr) 97.3% (Ti)	−0.78 ± 0.75 (TiZr) −0.60 ± 0.71 (Ti) (36 months)
238 150 (III) 88 (C)	**Edentulous jaw (MAN)**	**36**	**0; 100% (III) 0; 100% (C)**	**ND**	**−0.32 (III) −0.14 (C) $p = 0.002$ (36 months)**
39	Temporary implants in anterior regions (MAX, MAN)	12	2 of 38; 94.7%	94.7%	−0.35 (12 months)
40	Posterior fixed partial dentures (MAN, MAX)	12	0; 100%	ND	−0.49 to 0.6 (12 months)
324	Mixed indications (MAN, MAX)	64.8	4 of 320; 98.7% at 10-year follow-up	ND	−0.69 ± 0.28 (120 months)
21 (TiZr) 21 (Ti)	Single restorations (MAN, MAX)	12	1; 95.2% (TiZr) 1; 95.2% (Ti)	95.2% (TiZr) 95.2% (Ti)	ND
20 (III) 20 (C)	**Anterior and premolar single crowns (MAX, MAN)**	**12**	**0; 100% (III) 0; 100% (C)**	**ND**	**−0.41 ± 0.66 (III) −0.40 ± 0.53 (C) $p = 0.696$ (12 months)**
40	Edentulous jaw (MAX)	13.5 (12–16)	0; 100%	97.5%	−0.55 ± 0.5 (13.5 months)
541	Fixed dental prostheses (MAN, MAX)	58.8	9; 98.1% (12-year survival)	91,8%	0.07 ± 0.20 (annual change)
22	Mixed indications (MAN, MAX)	24	1; 95.2%	ND	−0.33 ± 0.54 (24 months)

(Continues)

TABLE 5 (Continued) [In PDF format, this table is best viewed in two-page mode]

Study	Study type	No. of patients	Implant design (one-piece: I; two-piece: II)	Diameter	Length (mm)
Malo and de Araujo Nobre (2011)	RS	147	Two-piece	3.3 (III)	10; 11.5; 13; 15
Yaltirik, Gokcen-Rohlig, Ozer and Evlioglu (2011)	RS	28	Two-piece	3.3 (III)	10, 12, 14
Al-Nawas et al. (2011)	RCT	89	Two-piece	3.3 (III) TiZr vs. Ti	8–14
Arisan et al. (2010)	RS	139	Two-piece	3.3 (III) 3.4 (III)	8–14 9.5–15
Veltri, Ferrari and Balleri (2008)	RS	12	Two-piece	3.5 (III)	9, 13, 15, 17
Anitua et al. (20082008**)**	**RS**	**ND**	**Two-piece**	**3.3 (III) 3.75 (C)**	**8.5–18 7.5–18**
Cordaro, Torsello, Mirisola Di Torresanto and Rossini (2006)	RS	31	Two-piece	3.5 (III)	10; 12
Romeo et al. (2006)	**RS**	**188**	**Two-piece**	**3.3 (III) 4.1 (C)**	**10, 12**
Zarone, Sorrentino, Vaccaro and Russo (2006)	PS	30	Two-piece	3.3 (III)	10, 12, 14
Zinsli, Sagesser, Mericske and Mericske-Stern (2004)	PS	149	Two-piece	3.3 (III)	8, 10, 12
Hallman (2001)	PS	40	Two-piece	3.3 (III)	8, 10, 12
Haas et al. (1996)	**RS**	**607**	**Two-piece**	**3.3 (III) 4.0 (C)**	**10, 13, 15**
Lazzara et al. (1996)	**RS**	**ND**	**Two-piece**	**3.3 (III) 3.3 (III) 4.0 (C) 4.0 (C)**	**ND**
Spiekermann et al. (1995)	**RS**	**136**	**Two-piece**	**3.3 (III) 4.0 (C) 4.0 (C)**	**ND**

Studies included in meta-analysis are highlighted with bold characters; MAX, maxilla; MAN, mandible; ND, no data available or data cannot be separated; PS, prospective study; RS, retrospective study; RCT, randomized controlled trial. I, Category 1 (narrow diameter implants); II, Category 2 (narrow diameter implants); C, Control (standard diameter implants).

Caution in the use of NDI has been recommended in posterior regions because of concerns regarding reduced osseointegration surface, an increased probability of fracture compared with SDI and disadvantageous peri-implant crestal bone resorption due to stress values affecting the crestal cortical bone, which are reciprocal to the implant diameter (Pieri, Forlivesi, Caselli & Corinaldesi, 2017). Regarding bone stability, the included studies showed comparable peri-implant bone loss for NDI compared to SDI. However, longer follow-up studies are needed to confirm these results. A recent study of Pieri et al. that investigated fixed partial denture treatment in posterior mandibular and maxillary jaws with NDI of Category 2 or SDI showed higher implant survival and lower biological complications for SDI, however, not statistically significant (Pieri et al., 2017). In contrast, a higher

TABLE 5 (additional columns - continued)

No. of implants (category)	Indication (jaw region)	Follow-up (months: range; mean)	Implant failures; survival rate	Implant success rate	Mean marginal bone loss (mm)
247	Posterior region (MAN + MAX)	60	12; 95.1%	ND	1.74 ± 0.9 mm (120 months)
48	Mixed indications (MAX + MAN)	60	3; 93.75%	ND	ND
178, 89 (TiZr), 89 (Ti)	Edentulous jaw (MAN)	12	3; 98.3% 1; 98.9% (TiZr) 2; 97.8% (Ti)	96.6% 94.4%	−0.3 ± 0.5 (12 months) −0.3 ± 0.6 (12 months)
316, 235, 81	ND	109 (60–124)	14; 92.3% 5; 97.9% 9; 88.9%	91.4%	−1.3 ± 0.1 (120 months)
73	Edentulous jaw (MAX)	12	0; 100%	ND	0.30 ± 0.13 (12 months)
804, 1654	**ND ND**	**29**	**8; 99% (III) 9; 99.5% (C)**	**ND ND**	**ND ND**
44	Incisors (MAN)	23 (18–42)	0; 100%	94%	ND
122, 208	**ND (MAN + MAX) ND (MAN + MAX)**	**84**	**III MAX: 1; 98.1% III MAN: 2; 96.9% C MAX: 1; 98.8% C MAN: 2; 97.9%**	**III MAX: 96.1% III MAN: 92% C MAX: 97.6% C MAN: 93.8%**	**III: 1.5 ± 1.5 mm C: 1.4 ± 1.1 mm (84 months)**
34	Edentulous jaw (MAX)	39	0; 97.06%	94.12%	1.2 ± 0.6 mm (24 months)
298	Mixed indications (MAX + MAN)	60	9; 98.7%	ND	ND
160	ND (MAN + MAX)	12	1; 99.4%	96.3%	−0.35 ± 1.05 (12 months)
1920, 198, 1722	**ND (MAN + MAX)**	**27**	**86; 95.5% 14; 92.9% (III) 72; 95.8% (C)**	**ND**	**ND**
82, 120, 147, 279	**ND (MAN) ND (MAX) ND (MAN) ND (MAX)**	**60**	**3 of 76; 96% 5 of 112; 95,5% 7 of 139; 95% 22 of 267; 92%**	**ND**	**ND**
127, 99, 38	**ND**	**60**	**8; 91% 7; 95% 3; 97%**	**ND**	**0.34 ± 0.52 mesial, 0.36 ± 0.49 distal 0.26 ± 0.35 mesial, 0.29 ± 0.34 distal 0.53 ± 0.53 mesial, 0.54 ± 0.619 distal (60 months)**

risk of prosthetic complications was seen for NDI. These complications include abutment and implant fracture, screw loosening or fracture, and ceramic fracture (Allum, Tomlinson & Joshi, 2008; Assaf, Saad, Daas, Abdallah & Abdallah, 2015). This increased biomechanical risk is explained by minor mechanical properties of the components due to their smaller dimensions and material composition (Assaf et al., 2015). As always, the patients have to be informed in detail about all possible treatment options with their possible advantages and disadvantages and the practitioner should have the knowledge to offer all of these treatment options.

As a consequence of new product developments in the dental implant market with new designs such as two-piece 2.9 mm implants, we suggest a new classification for NDI that considers

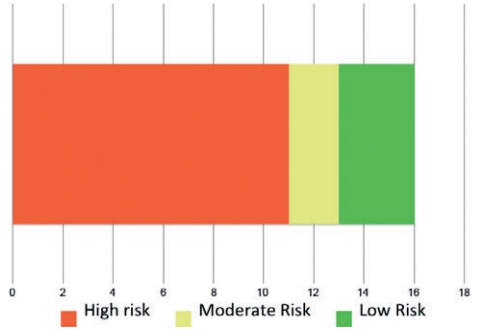

FIGURE 2 Risk of bias across studies

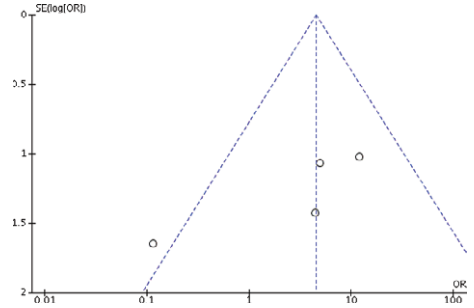

FIGURE 4 Funnel plot calculated for selected studies reporting on NDI (Category I) vs. SDI

TABLE 6 The number of inserted dental implants for the different diameter categories

Category	Diameter (mm)	Number of studies	Number of implants
1	1.8	3	346
	1.8–2.4	10	4,504
	2.0	1	236
	2.4	1	11
	2.5	5	270
	2.7	1	22
	2.9	1	52
2	3.0	17	1,086
	3.2	1	15
	3.25	1	32
3	3.3	29	4,440
	3.3, 3.4	1	316
	3.5	4	315
	3.3–3.5	1	541

more precisely the described indications in the recent literature. However, due to the high risk of bias and heterogeneity in the included studies, further clinical studies have to prove the long-term success of NDI.

Category 1: Implants with a diameter of < 2.5 mm ("mini-implants"), described mostly for the highly atrophic edentulous arch and for single non-load-bearing teeth in the frontal region.

Category 2: Implants with a diameter of 2.5 mm to <3.3 mm, described mostly for single-tooth restoration in the anterior region (mainly to replace the maxillary lateral or mandibular incisor teeth).

Category 3: Implants with a diameter of 3.3 mm to 3.5 mm, described for all regions, including posterior single-tooth restorations.

To date, most implants of category 1 are one-piece implants. One-piece implants with a diameter of more than 3.0 mm are rarely described in the literature.

5 | CONCLUSION

Within the limits of this meta-analytic approach to the literature with the identified high risk of bias and heterogeneity in the included studies therein, the included studies describe NDI as a possible treatment alternative with promising survival rates. Their clinical advantage might be in the extension of treatment options. NDI of Category 1 performed statistically significantly worse than SDI and were mainly described for the rehabilitation of the highly atrophic maxilla or mandible. Category 2 and Category 3 NDI indicated no difference in implant survival compared to SDI. Implants of Category 2 were mostly used for the rehabilitation of limited interdental spaces in anterior single-tooth restorations. NDI of Category 3 were described in all regions, including posterior single-tooth restorations. However, long-term data are rare and there is a lack of data on peri-implant tissue values and prosthetic considerations, for example, the possible risk of biological and technical complications with wide platform teeth on NDI. These parameters have to be evaluated in future clinical studies.

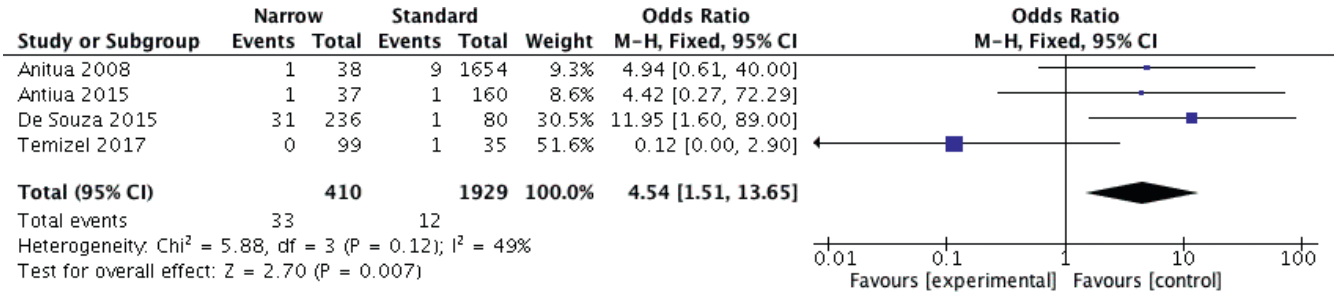

FIGURE 3 Forest plot of survival of NDI (Category I) vs. SDI

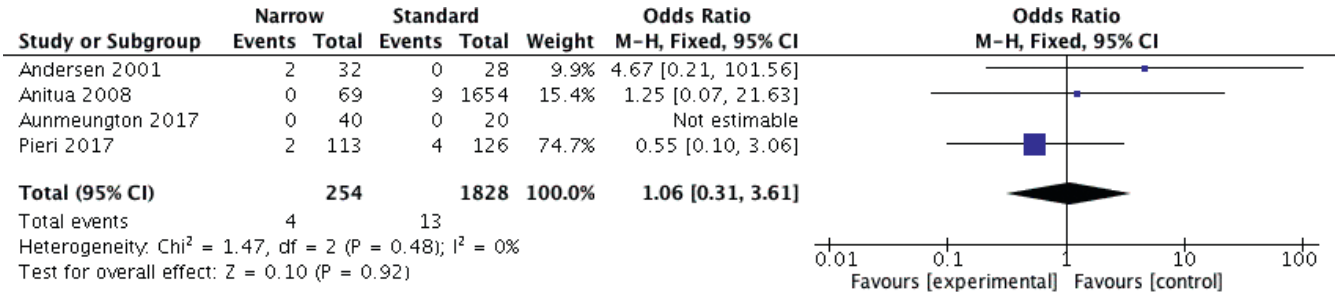

FIGURE 5 Forest plot of survival of NDI (Category 2) vs. SDI

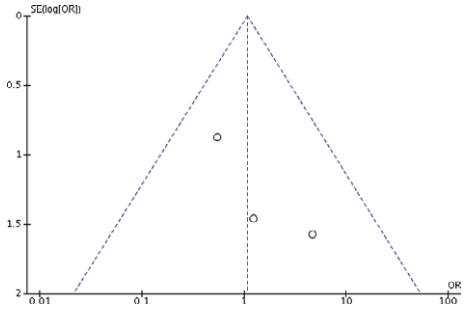

FIGURE 6 Funnel plot calculated for selected studies reporting on NDI (Category II) vs. SDI

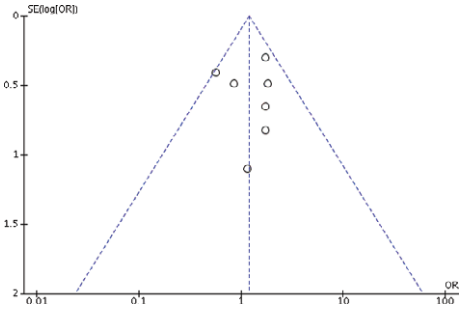

FIGURE 8 Funnel plot calculated for selected studies reporting on NDI (Category III) vs. SDI

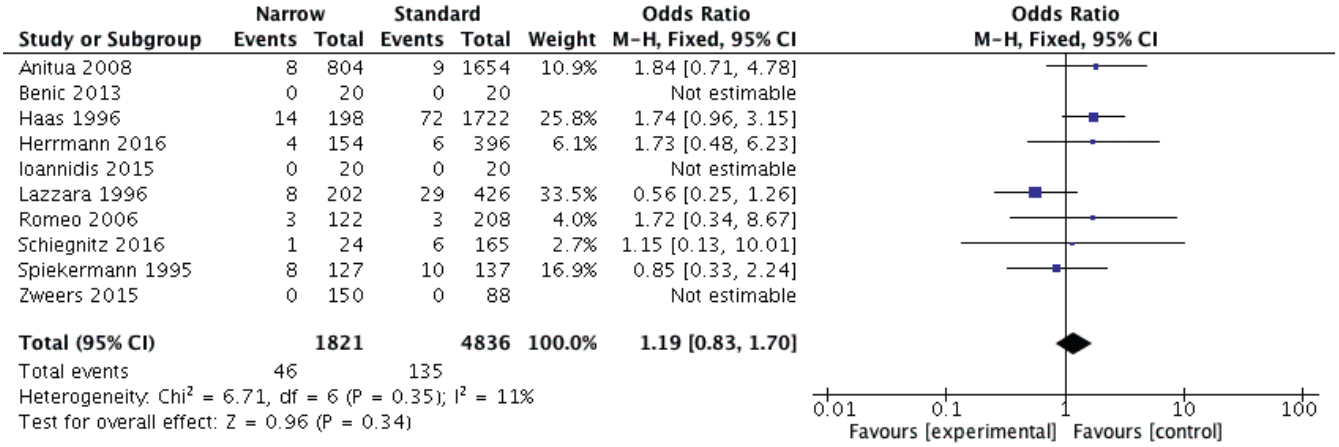

FIGURE 7 Forest plot of survival of NDI (Category 3) vs. SDI

CONFLICT OF INTEREST

Dr. Eik Schiegnitz reports lectures, personal fees and/or grants from Dentsply, Geistlich, Medartis, Septodont and Straumann outside the submitted work. Prof. Dr. Bilal Al-Nawas reports lectures, personal fees and/or grants from Camlog, Dentsply, Geistlich, Medartis, Nobel Biocare, Straumann and Zimmer outside the submitted work.

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