Systematic Review on Success of Narrow-Diameter Dental Implants

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Purpose: *The aim of this systematic review was to determine the survival and success rates of narrow-diameter implants (NDI) in different clinical indications compared to standard diameter implants.* ***Materials and Methods:*** *Implant diameters were categorized into categories 1 (< 3.0 mm), 2 (3.00 to 3.25 mm), and 3 (3.30 to 3.50 mm). Retro- and prospective studies with more than 10 patients and a follow-up time of 1 year or more were included.* ***Results:*** *A literature search from 1995 to 2012 revealed 10 articles reporting on implant diameters < 3 mm (Category 1), 12 articles reporting on implant diameters 3 to 3.25 mm (Category 2), and 16 articles reporting on implant diameters 3.3 to 3.5 mm (Category 3). The quality of the studies was mostly low with a high risk of bias. Dental implants < 3.0 mm (mini-implants) were one-piece in the edentulous arch and non-loaded frontal region with survival rates between 90.9% and 100%. For dental implants with a diameter between 3.0 and 3.25 mm, most were two-piece implants inserted into narrow tooth gaps without loading and in the frontal region. Survival rates for these implants ranged between 93.8% and 100%. Implants of 3.3 to 3.5 mm were two-piece and were also used in the load-bearing posterior region. Survival rates were between 88.9% and 100%, and success rates ranged between 91.4% and 97.6%. A meta-analysis was conducted for NDI (3.3 to 3.5 mm), which showed no statistically significant difference in implant survival compared to conventional implants with an odds ratio of 1.16 (0.7 to 1.69).* ***Conclusions:*** *Narrow-diameter implants of 3.3 to 3.5 mm are well documented in all indications including load-bearing posterior regions. Smaller implants of 3.0 to 3.25 mm in diameter are well documented only for single-tooth non-load-bearing regions. Mini-implants < 3.0 mm in diameter are only documented for the edentulous arch and single-tooth non-load-bearing regions, and success rates are not available. Long-term follow-up times > 1 year and information on patient specific risk factors (bruxism, restoration type) are also missing.* Int J Oral Maxillofac Implants 2014;29 (Suppl):43–54. doi: 10.11607/jomi.2014suppl.g1.3

Key words: *dental implant, diameter, mini-implants, small diameter, systematic review*

Historically, implants have been used and documented mainly with diameters between 3.75 mm and 4.1 mm. Employing these diameters for numerous indications, scientifically substantiated treatment protocols with excellent long-term results have been established.[1,2] These types of implants are widely regarded as standard-diameter implants. Fracture of the abutment or implant body of a standard-diameter implant is an extremely rare condition, even after long term use. In a recent review from Sánchez-Pérez et al, the authors estimated a risk of approximately two fractures per 1,000 implants in the mouth.[3] One disadvantage of a standard-diameter implant is the fact that, in clinical use, the available horizontal crestal dimensions of the alveolar ridge as well as the spaces between adjacent teeth and dental implants are sometimes too small. Although there is some discussion on the amount of bone (buccal and oral) necessary for a successful dental implant, most authors advise at least 1 mm residual bone present adjacent to the implant surface, which consequently requires a horizontal crestal alveolar width of 6 mm for a standard implant. However, the exact threshold for the residual buccal bone thickness has yet not been scientifically clarified and is still under discussion. Furthermore, based on available studies, a 3-mm interimplant distance seems to be beneficial for adequate papillary fill.[4,5] As implant diameters have been established historically, the

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question has been raised whether optimal implant diameters might be smaller than the "standard diameter" for many indications.

Narrow-diameter implants (NDI) would be beneficial to decrease the rate of augmentations necessary for implant insertion. This might help especially elderly patients or patients with general medical risk factors who would benefit from implant therapy with reduced surgical invasiveness. Epidemic studies showed that especially elderly edentulous patients are not able or willing to undergo expensive surgical procedures.[6,7] Furthermore, there are concerns and restrictions against time-consuming treatments associated with complications and pain.[8,9] The other important indication, for which NDI would be beneficial, are small interdental or interimplant gaps, which are often found in the premolar or incisor region. Therefore, the employment of NDI (≤ 3.5 mm) might broaden the treatment spectrum and also help to reduce or avoid augmentation procedures.

However, several potential biomechanical risk factors have been identified for NDI. In vitro studies and finite element analyses have illustrated that stress values affecting the crestal cortical bone are reciprocal to the dental implant diameter, which means that especially small diameters result in disadvantageous stress peaks at the implant-bone interface.[10] Ding et al showed that the stress values at the implant-bone interface rise more significantly by reducing the diameter from 4.1 mm to 3.3 mm, compared to reducing the diameter from 4.8 mm to 4.1 mm.[11] As a biological implication, inadequate overloading of NDI might possibly lead to disadvantageous peri-implant crestal bone resorption resulting in clinical complications. The implant itself is also more prone to fatigue fracture as a result of a reduced implant diameter.[12] One way of increasing the implant fracture resistance is to use an alloy instead of commercially pure titanium (cpTi). Most available NDIs are made of Ti-Al-V. However, this alloy is lesser biocompatible than cpTi in cell cultures and animal experiments.[13] The clinical relevance of this finding is critically discussed. Recently, a titanium-zirconium (TiZr) alloy is commercially available with increased fatigue resistance and unimpaired biocompatibility compared to cpTi.[14,15]

Until now, the use of NDI has been restricted to certain defined indications with comparable low occlusive loading like incisors or as retaining elements for overdentures. Before NDI can be recommended in a broader clinical setting, the analysis of available external evidence is necessary. The aim of the present systematic review was to determine the survival and success rates of NDI in different clinical indications compared to standard-diameter implants.

MATERIALS AND METHODS

Evaluation criteria were defined in accordance to the PICO(S) (Patient or Population, Intervention, Control or Comparison, Outcome and Study types) criteria.

Patient Selection

The present review includes studies with patients scheduled for insertion of at least one dental implant into the maxilla and/or mandible with insufficient bone volume (eg, narrow alveolar ridge) and/or limited interdental space requiring diameter-reduced endosseous dental implants. The mandatory time interval after tooth removal was defined as ≥ 6 weeks. No simultaneous bone augmentation procedure was allowed. Only healthy patients with no systemic illness affecting bone metabolism and no signs of local infection were included in the studies. There were no restrictions to sex and age.

Intervention: Narrow-Diameter Dental Implants

Only studies involving dental implants ≤ 3.5 mm in diameter were included with no restrictions to implant length. Looking at the different NDI, it becomes obvious that not all implants with a diameter ≤ 3.5 mm are comparable with each other. Following the manufacturers' indications for use, the implant diameters were categorized as follows:

- Category 1: < 3.0 mm (mini-implants)
- Category 2: 3.00 to 3.25 mm (single-tooth indications)
- Category 3: 3.30 to 3.50 mm (broader indications)

Implant type, manufacturer, and implant characteristics were documented.

Implant indications were categorized as follows:

- Edentulous arch (maxilla and/or mandible),
- Single-tooth gap without loading of the prosthesis (eg, second incisor),
- Prosthetic loadbearing in the frontal region,
- Prosthetic loadbearing distal to the canine tooth.

Furthermore, the type of surgery (raising of a full-thickness flap vs transmucosal implant insertion), healing mode (subgingival vs transgingival), and restoration type (fixed vs overdentures) was described.

Control Groups

Within each included study, groups with conventional-sized dental implants (> 3.5 to 4.5 mm) were accepted as control groups.

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Table 1 Systematic Search Strategy

Focus question: How do the survival and success rates and bone level development of narrow-diameter dental implants compare to standard-diameter implants?	
Search strategy	
Population	Edentulous OR partially edentulous
Intervention or exposure	Dental implantation with NDI
Comparison	Other diameters than NDI
Outcome	Implant survival, implant success, marginal bone level under functional loading
Search combination	"small diameter dental implants": 107 hits "narrow diameter dental implants": 68 hits "narrow dental implants": 225 hits "small dental implants": 720 hits "diameter dental implants": 1,107 hits "mini-implants": 767 hits
Database search	
Electronic	PubMed
Journals	–
Selection criteria	
Inclusion criteria	Clinical studies of at least 10 treated patients, published in English prospective: randomized-controlled, non-randomized-controlled, cohort studies retrospective: controlled, case control, "single cohort"
Exclusion criteria	Studies in languages other than English Studies with < 10 patients, case reports, animal models or experimental in vitro studies Reviews Mini-implants for orthodontic anchorage Studies dealing with simultaneous bone augmentation procedures Studies with mean follow-up time < 1 year

Outcome

Outcome parameters were defined with respect to existing reviews and the main outcome parameters of the included studies:

- Dental implant survival under a follow-up of at least 12 months. Survival was defined as in situ or not planned for removal at the time of clinical control.

  Implant success:

- Clinical success (implants in function, no signs of peri-implantitis, etc). There was no unique definition of implant success within the various investigated studies.
- Development of the marginal peri-implant bone level under functional loading.

Study Types

Clinical studies on dental implant survival under functional loading, as well as radiographic analysis of the marginal bone level including at least 10 treated patients and published in English journals were evaluated. The following study designs were included:

- Prospective: randomized-controlled, non-randomized-controlled, cohort studies
- Retrospective: controlled, case control, single cohort

Exclusion Criteria

The following studies were excluded:

- Studies composed of languages other than English
- Studies with < 10 patients, case reports, animal models, or experimental in vitro studies
- Reviews
- Mini-implants for orthodontic anchorage
- Studies dealing with simultaneous bone augmentation procedures
- Studies with mean follow-up time < 12 months

Search Strategy for Identification of Studies

A systematic PubMed literature search was performed between 1995 and 2012, including the following terms (Table 1):

- "Small diameter dental implants": 107 hits
- "Narrow diameter dental implants": 68 hits
- "Narrow dental implants": 225 hits

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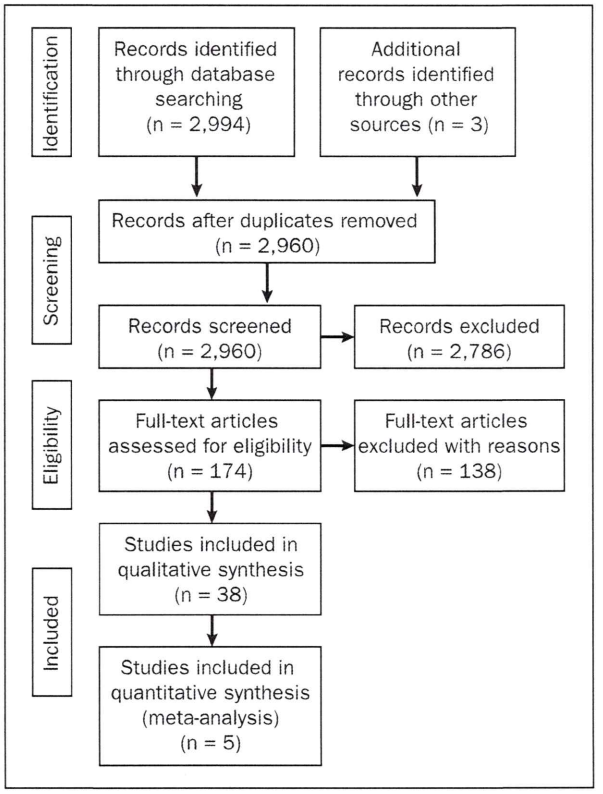

Fig 1 PRISMA Flow Diagram.

- "Small dental implants": 720 hits
- "Diameter dental implants": 1,107 hits
- "Mini-implants": 767 hits

Reference lists of the included articles (including selected reviews) were checked for additional publications of relevance. The last search was performed on November 24, 2012. After reviewing all abstracts, relevant full-text articles were obtained. Outcome parameters, descriptive summaries of the relevant study characteristics, and influence parameters (study design, number of patients, number of inserted dental implants, implant characteristics, indications, surgical technique, healing modus, etc) of the respective included studies were tabulated.

Study Selection, Data Extraction, and Quality Assessment

Two independent observers independently scanned the abstracts and later the pre-selected full-text articles. For studies meeting the inclusion criteria, full-text manuscripts were obtained and evaluated further.

All studies meeting the inclusion criteria were subject to further data extraction. Data were extracted using structured data extraction forms. Any disagreement was discussed and an additional review author was consulted when necessary. Kappa value as a measure of concordance was documented. The PRISMA flow diagram depicts the flow of information through the different phases of a systematic review (Fig 1). It maps out the number of records identified, included and excluded, and the reasons for exclusions.

After a first search, it was clear that no prospective randomized studies could be found for the defined PICO question. Thus, in the present review, the best available external evidence was collected. The authors are aware that the risk of bias is higher compared with other reviews that include only randomized studies. To reduce the risk of bias, the tangible and objective main outcome criterion of implant survival and the objective secondary outcome criterion of marginal bone level changes were chosen.

RESULTS

The electronic search in the database PubMed provided a total of 2,994 abstracts that were considered potentially relevant (Fig 1). In the second phase of study selection, complete texts of 174 articles were sampled and reviewed. Throughout this procedure, 38 articles were selected. These articles were further subdivided into three categories according to the diameter of the investigated implants: 10 articles reporting on implant diameters < 3 mm (category 1), 12 articles reporting on implant diameters 3 to 3.25 mm (category 2), and 16 articles reporting on implant diameters 3.3 to 3.5 mm (category 3) were provided. Altogether in the investigated studies, 3,151 patients received a total of 7,742 NDI. Data on the implant material were only rarely available and could not be interpreted systematically. It should be noted that to the authors' knowledge, < 3 mm implants were all made of Ti-Al-V. In category 3, TiZr alloys were described in three studies.[16–18] Table 2 provides an overview of the different dental implant diameters employed.

Results of Quality Assessment of Selected Studies

The overall proportion of inter-reviewer agreement was 93.4%, indicating an 'excellent' level of agreement.[19] In general, quality and level of evidence of the investigated articles were low. Most of the studies were retrospective analyses. The allocation concealment was at high risk of bias, the lack of reporting characteristics of drop-out, missing blind examiners to assess clinical outcomes, and the lack of CONSORT adherence suggests caution with data interpretation and drawing general conclusions out of these studies.

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Implant Survival, Implant Success, and Marginal Bone Level Under Functional Loading

Diameter Category 1. The mean functional follow-up of the investigated dental implants < 3.0 mm (mini-implants) ranged between 12 and 96 months (Table 3). Most of the implants used were one-piece implants and had a diameter of 1.8, 2.4, or 2.5 mm. The only defined indications were the edentulous arch and the nonloaded frontal region. In five out of seven studies in which the type of flap was described, an open procedure was performed. In most of the studies, the implants were loaded immediately with an overdenture. Survival rates of the dental implants < 3.0 mm were described to be between 90.9% and 100%. Only one study provided an implant success rate (92.9%). In radiological assessments, 24 months after dental implant insertion, the average peri-implant bone loss was 0.98 ± 0.36 mm.

Diameter Category 2. For the investigated dental implants with a diameter between 3.0 and 3.25 mm, mean follow-up was between 12 and 63 months (Table 4). The predominant study design was a single arm prospective or retrospective study. Most of the implants used were two-piece implants with a diameter of 3.0 mm. The leading indication for these implants was the narrow tooth gap without loading and frontal region. The shortest implant length was 10 mm. In every study a flap was raised for implant insertion. Implants were either loaded directly or after a healing time of 6 to 24 weeks. Survival rates for these implants ranged between 93.8% and 100%, and the implant success rate was only described in one study. Average peri-implant bone loss after 12 months was 0.78 ± 0.48 mm.

Diameter Category 3. The literature research showed a follow-up of dental implants in category 3 (3.3 to 3.5 mm) between 12 and 144 months (Table 5). All implants used were two-piece with a shortest length of 8 mm. The indications were not well defined in every case, but also included the load-bearing posterior region. A flap was raised for implant insertion in every study. Healing was either sub- or transgingival. Healing time ranged from 6 to 24 weeks. Survival rates were between 88.9% and 100% and success rates between 91.4% and 97.6%. Radiological assessments indicated an average peri-implant bone loss of 0.31 ± 0.03 mm after 12 months.

Meta-analysis of Survival of NDI Versus Conventional Implants

For category 1, only one study with a control group,[20] and for category 2, only two studies with a control group[20,31] were found in the database. Therefore, a meta-analysis regarding the survival rate could not be conducted for these categories. For category 3, five studies with a control group were found. Begg and Mazumdar's funnel plot, as shown in Fig 2, illustrates a low risk for publication bias for this meta-analysis. Since all studies had quite similar follow-up times, a meta-analysis of the event rate (implant failure) in the test groups (3.3 to 3.5 mm) versus control (standard diameter) was performed. Data are given as odds ratio with 95% confidence interval (CI) and a forest plot was created using RevMan Version 5 (Cochrane IMS). No statistically significant difference in implant survival was demonstrated between NDI (3.3 to 3.5 mm) and conventional implants (odds ratio: 1.16 [0.7 to 1.69]) (Table 6).

Table 2 Dental Implants by Diameter Category

Category	Diameter	Implants
1	< 3.0 mm	3,656
2	3.0–3.25 mm	672
3	3.3–3.5 mm	3,414

DISCUSSION

Up to date, only few comparative prospective clinical studies, especially randomized ones, are available to document survival or success rates of NDI. Therefore, the authors decided to also include observational studies into this review. It should be pointed out that many of these studies did not clearly report a follow-up rate as suggested by the STROBE criteria on reporting observational data.[54] The data from these trials, particularly the retrospective ones, should be interpreted with caution.

Survival rates of NDI appear to be similar compared to those of regular diameter implants (> 3.5 mm). In the current review, the majority of investigated studies reported survival rates > 95% and no study reported survival rates below 88%. This might suggest a reliable therapy option, but evaluation of the success of the employment of small diameter dental implants should not be carried out exclusively by determination of implant survival. The reported indications, implant success, and changes of the marginal bone level should also be considered.[55] There exist various intrinsic and extrinsic factors which may impact peri-implant marginal bone stability. Important intrinsic factors are quantity and quality of surrounding hard and soft tissue. As already stated in the introduction, certain crestal alveolar dimensions as well as distances between adjacent teeth and dental implants are of crucial importance for the establishment and maintenance of a stable biological width. Extrinsic, implant-related factors affecting the marginal bone level are implant design (dimensions,

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Table 3 Summary of Studies on Implants with < 3 mm Diameter (Category 1)

Study	Study type	No. of patients	Mean age (range)	Implant design	Diameter (mm)	Length (mm)	Implants	Indication (jaw region)
Anitua et al[20]	RS	ND	ND	Two-piece	2.5 3.75 (C)	10–15 7.5–18	38 1,654	ND (MAN + MAX)
Anitua et al[21]	RS	51	55 (19–90)	One-piece	2.5	10–15	31	ND (MAN + MAX)
Balaji et al[22]	RS	11	29 (20–52)	One-piece	2.4	13	11	III (MAN + MAX)
Elsyad et al[23]	PS	28	63 (49–75)	One-piece	1.8	12, 14, 16, 18	112	I (MAN)
Froum et al[24]	RS	27		Two-piece	1.8, 2.2, 2.4	7, 10, 14	48	III (MAN + MAX)
Jofre et al[25,26]	RCT	45	(45–90)	One-piece	1.8	15	90	I (MAN)
LaBarre et al[27]	RS	ND	ND	ND	1.8–2.4	ND	626	ND
Morneburg and Proschel[28]	PS	67	69 (53–83)	One-piece	2.5	9, 12, 15	134	I (MAN)
Shatkin et al[29]	RS	531		ND	1.8–2.4	ND	2,514	ND (MAN + MAX)
Vigolo and Givani[30]	RS	44	35 (18–74)	Two-piece	2.9	8.5, 10, 13, 15	52	II (MAX + MAN)

C = control; MAN = mandible; ND = no data available or data cannot be separated; OV = overdenture; PLS = plasma sprayed; PRGF = preparation rich in growth factors; PS = prospective study; RS = retrospective study; RCT = randomized controlled trial; SG = subgingival; TG = transgingival; Ti = titanium; TiZr = titanium-zirconium. Indications: I: edentulous jaw; II: narrow tooth gap without loading; III: loading of the frontal region; IV: loading distal of the canine.

Table 4 Summary of Included Studies on Implants with 3.0 to 3.25 mm Diameter (Category 2)

Study	Study type	No. of patients	Mean age (range)	Implant design	Diameter (mm)	Length (mm)	Implants	Indication (jaw region)
Andersen et al[31]	PS	55	23 (17–54)	Two-piece	3.25 3.75 (C)	13, 15	60 32 28	II, III (MAX)
Anitua et al[20]	RS	ND		Two-piece	3.0 3.75 (C)	10–15	69	ND (MAN + MAX)
Anitua et al[21]	RS	51	55 (19–90)	Two-piece	3.0	10–15	58	ND (MAN + MAX)
Degidi et al[32]	PS	40	(55 ± 17)	Two-piece	3.0	11, 13, 15	93 48 45	IV IV (MAX) IV (MAN)
Degidi et al[33]	RCT	60	32 (18–55)	Two-piece	3.0	13, 15	60 30 30	III (MAX)
Galindo-Moreno et al[34]	PS	69	(32 ± 17)	Two-piece	3.0	11, 13, 15	97	II (MAN + MAX)
Mazor et al[35]	RS	33	49.2 (23–76)	Two-piece	3.0	13	66	II (MAN + MAX)
Oyama et al[36]	PS	13	32.9 (18–84)	Two-piece	3.0	ND	17	II (MAN + MAX)
Polizzi et al[37]	RS	21	30 (13–58)	Two-piece	3.0	10, 13, 15	30	II (MAN + MAX)
Reddy et al[38]	RS	17	(19–74)	One-piece	3.0	ND	31	II (MAN + MAX)
Sohn et al[39]	RS	36	53 (42–72)	One-piece	3.0	12, 15	62	II (MAN + MAX)
Zembic et al[40]	RS	47	31 (17–76)	One-piece	3.0	13, 15	57	II (MAN + MAX)

C = control; MAN = mandible; ND = no data available or data cannot be separated; OV = overdenture; PLS = plasma sprayed; PRGF = preparation rich in growth factors; PS = prospective study; RS = retrospective study; RCT = randomized controlled trial; SG = subgingival; TG = transgingival; Ti = titanium; TiZr = titanium-zirconium. Indications: I: edentulous jaw; II: narrow tooth gap without loading; III: loading of the frontal region; IV: loading distal of the canine.

implant-abutment interface), insertion depth, implant angulation, and the overall number of inserted implants. Additionally, the overall treatment plan has to deal, in some cases, with parafunctional activities like bruxism. The categorization of the implants into three groups according to their diameter was a hypothesis that seems to be supported by the indications in which the respective implants were used:

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Flap elevation	Healing	Healing period (wk)	Restoration type	Follow-up (mo; mean, range)	Implant failures (survival rate)	Implant success rate	Mean bone level (mm)
Yes	ND	ND	OV, fixed	29	1 (97.4%) 9 (99.5%)	ND ND	ND ND
Yes	ND	ND	OV, fixed	48	1 (98.9%)	ND	−1.26 ± 0.5 (24 mo)
Yes	TG	0	Fixed	24	1 (90.9%)	ND	−0.6 (24 mo)
No	TG	0	OV	36	4 (96.4%)	92.9%	−1.26 ± 0.6 (36 mo)
Yes	TG	16–24	Fixed	12–64	0 (100%)	ND	ND
No	TG	0	OV	15–24	0 (100%)	ND	−1.43 ± 1.26 (24 mo, ball-retained) −0.92 ± 0.75 (24 mo, bar-retained)
ND	ND	ND	ND	72	46 (92.6%)	ND	ND
ND	SG	12–16	ND	72	6 (95.5%)	ND	0.7 ± 0.4 (2 y)
ND	ND	ND	OV, fixed	35	145 (94.2%)		
Yes	SG	ND	Fixed	60	3 (94.2%)	ND	0.8 (0.5–1.1) (5 y)

Flap elevation	Healing	Healing period (wk)	Restoration type	Follow-up (mo; mean, range)	Implant failures (survival rate)	Implant success rate	Mean bone level (mm)
Yes	SG	24	Fixed	36	2 (93.8%) 0 (100%)	 ND ND	 −0.5 ± 0.0 (36 mo) −0.4 ± 0.2 (36 mo)
Yes	ND	ND	OV, fixed	29	0 (100%) 9 (99.5%)	ND	ND
Yes	ND	ND	OV, fixed	48	1 (96.8%)	ND	−1.26 ± 0.5 (24 mo)
Yes	TG	24	Fixed	48	0 (100%) 0 (100%) 0 (100%)	ND	−1.16 ± 0.9 (48 mo)
Yes	TG	 0 24	Fixed	36	0 (100%) 0 (100%) 0 (100%)	ND	 −0.85 ± 0.7 (36 mo) −0.75 ± 0.6 (36 mo)
Yes	TG	6–10	Fixed	12	4 (95.9%)	ND	−0.7 ± 1.0 (12 mo)
ND	TG	ND	Fixed	12 ± 1.9	0 (100%)	ND	
Yes	TG	12	Fixed	12	0 (100%)	ND	0.38 ± 0.36 (1 y)
Yes	TG	ND	Fixed	63	1 (96.7%)		Minimal marginal bone loss after 1 y
Yes	TG	16–24	Fixed	12	1 (96.7%)		0.7 (1 y)
Yes	TG	12–20	Fixed	23 ± 4.3	0 (100%)	100%	0.53 ± 0.37 (1 y)
Yes	TG	0	Fixed	13 (9.8–20.8)	1 (98%)		1.6 ± 1.2 (1 y)

Category 1: (< 3.0 mm, mini-implants) These were only described for single non-load-bearing teeth or the edentulous arch in combination with an overdenture. For the latter, no systematic data are available on implant distribution or implant number per arch. Due to the one-piece design, immediate restoration/loading was predominantly performed. It should be noted that despite the fact that more than 3,000 implants were documented, nearly nothing is known about success rates or long-term success.

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Table 5 Summary of Included Studies on Implants with 3.3 to 3.5 mm Diameter (Category 3)

Study	Study type	No. of patients	Mean age (range)	Implant design	Diameter (mm)	Length (mm)	Implants	Indication (jaw region)
Al-Nawas et al[16]	RCT	89	66 (49–86)	Two-piece	3.3	8, 10,12, 14	178	I (MAN)
							89	
							89	
Anitua et al[20]	RS	ND		Two-piece	3.3	8.5 - 18	804	ND
					3.75 (C)	7.5 - 18	1,654	ND
Arisan et al[41]	RS	139	55 (21–80)	Two-piece			316	ND
					3.3	8 - 14	235	
					3.4	9.5 - 15	81	
Barter et al[17]	PS	22	54 (22–73)	Two-piece	3.3	ND	22	III, IV (MAN + MAX)
Cordaro et al[42]	RS	31	43 (13–84)	Two-piece	3.5	10, 12	44	II, III (MAN)
Haas et al[43]	RS	607	52 (22–86)	Two-piece			1,920	ND (MAN + MAX)
					3.3	10, 13, 15	198	
					4.0 (C)		1,722	
Hallman[44]	PS	40	57 (19–86)	Two-piece	3.3	8, 10, 12	160	ND (MAN + MAX)
Lazzara et al[45]	RS	ND		Two-piece	3.3	ND	82	ND (MAN)
					3.3		120	ND (MAX)
					4.0 (C)		147	ND (MAN)
					4.0 (C)		279	ND (MAX)
Lee et al[46]	RS	338	52.5 (20–85)	Two-piece	3.3–3.5	10, 11.5, 12, 13	541	ND (MAN + MAX)
Malo and de Araujo Nobre[47]	RS	147	47.5 (26–77)	Two-piece	3.3	10, 11.5, 13, 15	247	IV (MAN + MAX)
Romeo et al[48]	RS	188	55.8 (21–74)	Two-piece	3.3	10, 12	122	ND (MAN + MAX)
					4.1 (C)		208	ND (MAN + MAX)
Spiekermann et al[49]	RS	136	60 (24.5–87.4)	Two-piece	3.3	ND	127	ND
					4.0 (C)		99	
					4.0 (C)		38	
Veltri et al[50]	RS	12	58 (42–74)	Two-piece	3.5	9, 13, 15, 17	73	I (MAX)
Yaltirik et al[51]	RS	28	(18–65)	Two-piece	3.3	10, 12, 14	48	II, III, IV (MAX + MAN)
Zarone et al[52]	PS	30	(21–45)	Two-piece	3.3	10, 12, 14	34	II (MAX)
Zinsli et al[53]	PS	149	62 (19–87)	Two-piece	3.3	8, 10, 12	298	I, II, III, IV (MAX + MAN)

C = control; MAN = mandible; ND = no data available or data cannot be separated; OV = overdenture; PLS = plasma sprayed; PRGF = preparation rich in growth factors; PS = prospective study; RS = retrospective study; RCT = randomized controlled trial; SG = subgingival; TG = transgingival; Ti = titanium; TiZr = titanium-zirconium. Indications: I: edentulous jaw; II: narrow tooth gap without loading; III: loading of the frontal region; IV: loading distal of the canine.

Category 2: (3.0 to 3.25 mm) In contrast to mini-implants, these were mostly two-piece implants with a shape similar to standard implants. They were predominantly documented in non-load-bearing single-tooth gaps. No load-bearing areas were described. Despite the fact that more than 600 implants are documented, only a few studies reported on success rates. Long-term data were also rare in this group.

Category 3: (3.3 to 3.5 mm) In this group all indications were described, including the load-bearing posterior region. The documentation of success rates was rather promising. Some long-term studies are available.

In the present analysis, we found no differences in the implants' survival rate between studies using the flap reflection of flapless surgery. Interestingly, only implants with a diameter < 3.0 mm were used in a flapless procedure. In general, very narrow one-piece screws with a diameter below 2.5 mm are placed in a flapless procedure with a transgingival healing mode and immediate loading. In contrast, the "classical"

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Flap elevation	Healing	Healing period (wk)	Restoration type	Follow-up (mo; mean, range)	Implant failures (survival rate)	Implant success rate	Mean bone level (mm)
Yes	TG	6–8	OV	12	3 (98.3%) 1 (98.9%) 2 (97.8%)	 96.6% 94.4%	 −0.3 ± 0.5 (12 mo) −0.3 ± 0.6 (12 mo)
Yes	ND	ND	OV, fixed	29	8 (99%) 9 (99.5%)	ND ND	ND ND
Yes	 TG SG	12–24	OV, fixed	60–124	14 (92.3%) 5 (97.9%) 9 (88.9%)	91.4%	−1.3 ± 0.1 (10 y)
Yes	TG	10–14	Fixed	24	1 (95.2%)	ND	−0.33 ± 0.54 (24 mo)
ND	ND	ND	Fixed	18–42, 23	0 (100%)	94%	ND
Yes	SG	12–24	ND	27	86 (95.5%) 14 (92.9%) 72 (95.8%)	ND	ND
Yes	TG	12–24	OV + fixed	12	1 (99.4%)	96.3%	−0.35 ± 1.05 (12 mo)
ND	ND	ND	ND	60	9 (96%) 11 (95.5%) 8 (95%) 12 (92%)	ND	ND
Yes	ND	ND	Fixed	144, 58.8	9 (98.1%)	91.8%	0.07 ± 0.20 (annual change)
Yes	TG, SG	16–24	Fixed	132	12 (95.1%)	ND	1.74 ± 0.9 (10 y)
Yes	TG	12–24	OV, fixed	84	3.3 mm diameter: MAX: 1 (98.1%) MAN: 2 (96.9%) 4.1 mm diameter: MAX: 1 (98.8%) MAN: 2 (97.9%)	3.3 mm diameter: MAX: 96.1% MAN: 92% 4.1 mm diameter: MAX: 97.6% MAN: 93.8%	3.3 mm diameter: 1.5 ± 1.5 4.1 mm diameter: 1.4 ± 1.1 (7 y)
ND	SG	ND	OV	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
Yes	SG	24	Fixed	12	0 (100%)	ND	0.30 ± 0.13 (1 y)
Yes	TG	12–24	Fixed	60	3 (93.75%)	ND	ND
Yes	SG	16	Fixed	39	0 (97.06%)	94.12%	1.2 ± 0.6 (2 y)
ND	TG	12–24	OV, fixed	60	9 (98.7%)		

two-piece dental implants are inserted with flap elevation procedure and a certain healing period (regardless of sub- or transgingival mode). Comparative data on this aspect are missing. The lengths of the implants used in the analyzed studies of this review were all in a high to normal range, meaning that a combination of short and diameter-reduced implant was not used.

The idea of avoiding augmentations or invasive surgery by using NDI is intriguing but has not been tested by any of the studies. For short implants, randomized studies comparing short implants with augmentation and standard implants are available.[56–58] It would be desirable to have similar studies for diameter-reduced implants in the future. A clear definition of the indications and reporting of success and follow-up rates is mandatory.

For implant-retained overdentures, the number, distance, and distribution (geometry of loaded area) of the employed NDIs (eg, two versus four versus six) might be of significance for implant success and development

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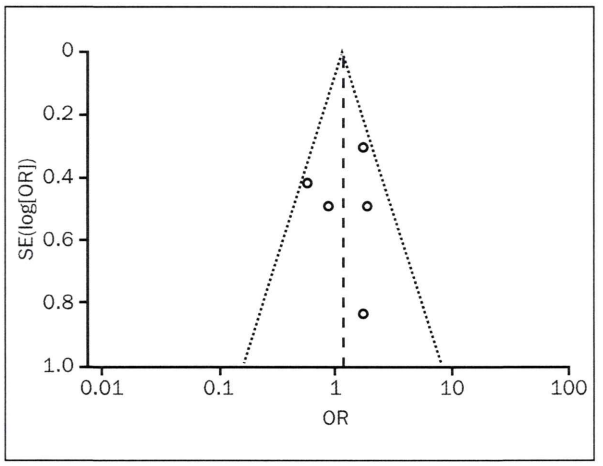
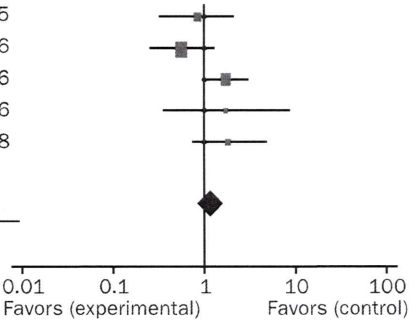


Fig 2 Funnel plot calculated for selected studies (n = 5) reporting on narrow diameter (3.3 to 3.5 mm; category 3) versus conventional implants. Each study is represented by a dot. The x-axis quantifies the treatment effect, the y-axis the study size.

Table 6 Forest plot of survival of narrow diameter (3.3 to 3.5 mm; category 3) versus conventional implants

	Narrow		Standard			Odds ratio		
Study or subgroup	Events	Total	Events	Total	Weight (%)	M-H Fixed	95% CI	Year
Spiekermann et al[49]	8	127	10	137	18.5	0.85	0.33, 2.24	1995
Lazzara et al[45]	8	202	29	426	36.8	0.56	0.25, 1.26	1996
Haas et al[43]	14	198	72	1,722	28.3	1.74	0.96, 3.15	1996
Romeo et al[48]	3	122	3	208	4.4	1.72	0.34, 8.67	2006
Anitua et al[20]	8	804	9	1,654	12.0	1.84	0.71, 4.78	2008
Total (95% CI)		1,453		4,147	100.0	1.16	0.79, 1.69	
Total events	41		123					

Heterogeneity: $Chi^2 = 6.44$, $df = 4$, $P = .17$, $I^2 = 38\%$.
Test for overall effect: $Z = 0.75$, $P = .45$.



of the marginal bone level. Unfortunately, no respective studies could be identified.

Another very important, but not yet scientifically adequate investigated aspect is whether adjacent NDIs are splinted or blocked against each other. Only one study dealt with splinted NDIs.[26] According to Jofre et al, splinted mini-implants (1.8 mm in diameter) with a rigid superstructure decreased the bone stress level in comparison with single mini-implants. Consequently, splinted mini-implants supporting a mandibular overdenture showed less marginal bone loss compared with nonsplinted mini-implants.[26]

CONCLUSIONS

Dental implants with narrow diameters of 3.3 to 3.5 mm are well documented in all indications including load-bearing posterior regions for a follow-up time of 1 year. Smaller implants with diameters 3.0 to 3.25 mm are well documented only for single-tooth non-load-bearing regions. Mini-implants < 3.0 mm in diameter are only documented for the edentulous jaw and single-tooth non-load-bearing regions. Long-term data and success rates for the latter are not available. Due to missing comparative studies, no conclusion can be drawn about the possibility of reducing the burden of care by using NDI. As suggested by the concept of internal evidence and patient preferences, the individual decision for NDI or augmentations and regular diameter implants should take into account patient-specific risk factors, which are often not reported in the available studies.

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