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SYSTEMATIC REVIEW

Should the restoration of adjacent implants be splinted or nonsplinted? A systematic review and meta-analysis

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ABSTRACT

Statement of problem. The decision to splint or to restore independently generally occurs during the planning stage, when the advantages and disadvantages of each clinical situation are considered based on the proposed treatment. However, clinical evidence to help clinicians make this decision is lacking.

Purpose. The purpose of this systematic review and meta-analysis was to assess the marginal bone loss, implant survival rate, and prosthetic complications of splinted and nonsplinted implant restorations.

Material and methods. This study was designed according to the Cochrane criteria for elaborating a systematic review and meta-analysis and adopted the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement. Also, this review was registered at the International Prospective Register of Systematic Reviews (PROSPERO) (CRD42017080162). An electronic search in the PubMed/MEDLINE, Cochrane Library, and Scopus databases was conducted up to November 2017. A specific clinical question was structured according to the population, intervention, comparison, outcome (PICO) approach. The addressed focused question was "Should the restoration of adjacent implants be splinted or nonsplinted?" The meta-analysis was based on the Mantel-Haenszel and inverse variance methods to assess the marginal bone loss, implant survival, and prosthetic complications of splinted and nonsplinted implant restorations.

Results. Nineteen studies were selected for qualitative and quantitative analyses. A total of 4215 implants were placed in 2185 patients (splinted, 2768; nonsplinted, 1447); the mean follow-up was 87.8 months (range=12-264 months). Quantitative analysis found no significant differences between splinted and nonsplinted restorations for marginal bone loss. The assessed studies reported that 75 implants failed (3.4%), of which 24 were splinted (99.1% of survival rate) and 51 were nonsplinted (96.5% of survival rate). Quantitative analysis of all studies showed statistically significant higher survival rates for splinted restorations than for nonsplinted restorations. Ceramic chipping, screw loosening, abutment screw breakage, and soft tissue inflammation were reported in the selected studies. The quantitative analysis found no statistically significant difference in the prosthetic complications of splinted and nonsplinted restorations.

Conclusions. Within the limitations of this systematic review and meta-analysis, it was concluded that there was no difference in the marginal bone loss and prosthetic complications of splinted and nonsplinted implant restorations; this is especially true for restorations in the posterior region. However, splinted restorations were associated with decreased implant failure. (J Prosthet Dent 2019;121:41-51)

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Clinical Implications

Studies comparing splinted and nonsplinted restorations supported by implants suggest that splinted restorations provide a greater margin of safety in avoiding implant failure.

Dental implants have been used frequently to support prostheses for patients with partial edentulism and have shown high survival rates.[1,2] However, they are susceptible to biological and mechanical complications ranging from marginal bone loss to loss of the implant.[1,3] Peri-implant bone loss has been related to surgical trauma, peri-implantitis, occlusal overload, biologic width formation, implant macroscopic characteristics at the neck region in contact with the bone, implant-abutment interface design, and position of the microgap[4]; consequently, the control of these factors is essential to treatment success.

Clinicians are unclear as to whether the rehabilitation of adjacent implants should be splinted or not, and the literature suggests that implant length, occlusion, oral hygiene, abutment connection design, and difficulty achieving a passively fitting framework must be considered.[5] Some biomechanical studies have suggested that splinted restorations offer load sharing among the components of the rehabilitation and decrease the stress on cortical bone[5-8]; whereas single-unit restorations (nonsplinted) facilitate oral hygiene, provide better passivity of the framework, and allow restorations with improved emergence profiles and cervical contours.[5,9,10]

Clelland et al[5] reported results of a split-mouth study in which peri-implant bone levels around splinted and nonsplinted restorations supported by implants were not statistically different for internal connection implants greater than 6 mm in length, but screw loosening occurred only on the nonsplinted rehabilitation. However, Vigolo et al[4] showed with a randomized controlled trial that splinted restorations supported by external hexagon implants (diameter=4×10 to 13 mm) showed mean bone loss of 0.7 mm and that the nonsplinted restorations showed mean bone loss of 0.8 mm after a 5-year follow-up; the same amount of difference (0.1 mm) was maintained until the last follow-up (after 10 years), reaching 1.2 mm and 1.3 mm, respectively.

In summary, clinicians who read the published literature in the hope of discovering a clear-cut answer regarding the appropriate technique to adopt in the prosthetic treatment of adjacent implants (splinted or not) will find conflicting results. Indeed, the current literature does not provide even minimal clinical evidence

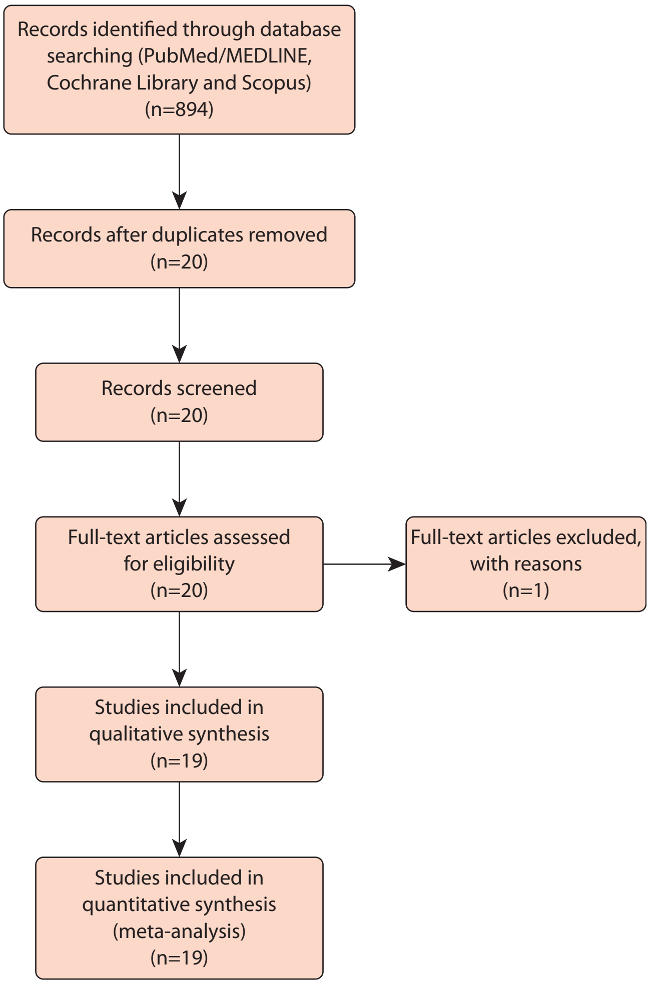


Figure 1. Study design.

to help clinicians make this decision[5] and does not contain a clear guide to correct prosthetic planning. Therefore, the purpose of this systematic review and meta-analysis was to assess the marginal bone loss, implant survival rate, and prosthetic complications of splinted and nonsplinted implant restorations. The null hypotheses of this study were that no differences would be found between splinted and nonsplinted implant restorations regarding marginal bone loss and that no differences would be found in relation to the implant survival rates and prosthetic complications of splinted and nonsplinted implant restorations.

MATERIAL AND METHODS

This study was designed according to the Cochrane criteria (*Cochrane Handbook for Systematic Reviews of Interventions*, v5.1.0)[11] for conducting a systematic review and meta-analysis and adopted the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement.[12] Also, this review was

Table 1. Summary of studies selected

Study and Year of Publication	Patients, N	Mean Age, y	Implants, n	No. of Splinted (S) and Nonsplinted (NS) Implants	Length of Follow-Up, mo	Mean (SD) Marginal Bone Loss Over Follow-up Period, mm	Lost Implant, n	Lost Prosthesis, n	Prosthetic Complication, n
Maló et al 2003[19]	76	41	103	S: 52 NS: 51	12	NR	S: 1 NS: 4	NR	NR
Rocci et al 2003[20]	46	51	97	S: 70 NS: 27	36	NR	S: 3 NS: 5	NR	NR
Rokni et al 2005[21]	74	53	199	S: 76 NS: 123	60	S: -0.5 (0.4) NS: -0.3 (0.4)	NR	0	S: 0 NS: 0
Bilhan et al 2010[22]	36	54.97	126	S: 106 NS: 20	36	Distal S: 0.99 (0.15) NS: 0.96 (0.19) Mesial S: 0.97 (0.14) NS: 0.94 (0.26)	NR	NR	S: 0 NS: 0
Sohn et al 2010[23]	43	55.8	122	S: 103 NS: 19	108	NR	S: 2 NS: 1	NR	NR
Vigolo and Zaccaria 2010[24]	44	51	123	S: 63 NS: 60	60	S: -0.7 (0.2) NS: -0.8 (0.2)	NR	NR	S: 0 NS: 0
Perelli et al 2011[25]	40	NR	50	S: 29 NS: 21	60	NR	S: 3 NS: 4	S: 0 NS: 4	NR
Perelli et al 2012[26]	87	NR	110	S: 47 NS: 63	60	NR	S: 3 NS: 6	S: 0 NS: 6	3[a]
Rodrigo et al 2013[27]	159	NR	223	S: 209 NS: 14	72	NR	S: 1 NS: 1	NR	NR
Sivolella et al 2013[28]	NC	NR	50	S: 20 NS: 30	192	NC	NC	NC	S: 15 NS: 6
Vanlıoğlu et al 2013[29]	95	41.2	231	S: 106 NS: 125	120	NR	NR	S: 2 NS: 2	S: 4 NS: 3
Wagenberg et al 2013[30]	541	58.75	1 187	S: 970 NS: 217	264	S: 0.44 (0.6813) NS: 0.55 (0.8551)	NR	NR	NR
Mendonça et al 2014[31]	198	60.45	453	S: 219 NS: 234	192	S: 1.22 (0.95) NS: 1.27 (1.15)	S: 5 NS: 16	NR	NR
Sohn et al 2014[32]	42	NR	84	S: 69 NS: 15	108	NR	S: 6 NS: 2	NR	NR
Wagenberg and Froum 2015[33]	312	NR	312	S: 240 NS: 72	144	S: 0.5 (0.8) NS: 0.3 (0.65)	NR	NR	NR
Ghaleh Golab et al 2015[34]	272	56.3	469$	S: 232 NS: 237	12	NR	S: 0 NS: 11	NR	NR
Vigolo et al 2015[4]	38	51	114	S: 60 NS: 54	120	S: 1.2 (0.2) NS: 1.3 (0.2)	S: 0 NS: 0	NR	S: 0 NS: 0
Clelland et al 2016[5]	15	56	64	S: 32 NS: 32	36	Machined bevel surface: S: 0.68 (0.82) NS: 0.44 (0.58) Machined bevel surface: S: 0.52 (0.64) NS: 0.14 (0.22)	S: 0 NS: 1	S: 0 NS: 0	S: 1 NS: 5
Shi et al 2017[36]	67	38.29	98	S: 65 NS: 33	96	S: 1.22 (0.81)[b] NS: 1.10 (1.47)[c]	NR	NR	S: 10 NS: 13

NC, not clear; NR, not reported; MBL, marginal bone loss; SD, standard deviation. [a]Did not specify group. [b]MBL of 63 patients. [c]MBL of 32 patients.

registered at the International Prospective Register of Systematic Reviews (PROSPERO) (CRD42017080162).

The inclusion criteria were randomized controlled trials, prospective studies, retrospective studies, clinical human studies, studies that compared crestal bone loss around splinted and nonsplinted restorations supported by implants, studies that offered information about the implant survival of splinted and nonsplinted implant-supported restorations, studies with a follow-up of more than 6 months, and studies published in the English language. Exclusion criteria included any articles that failed to meet the inclusion criteria and studies that evaluated the splinting of implant-supported complete-arch prostheses.

A specific clinical question was structured according to the population, intervention, comparison, outcome (PICO) approach. The addressed focused question was "Should the restoration of adjacent implants be splinted or nonsplinted?" In this process, P represented patients treated with dental implants; I, patients with nonsplinted restorations supported by implants; C, compared with patients with splinted

Table 2. Characteristics of studies selected

Study	Year	Design of Study	Setting of Studies	Implant System/ Connection Type	Diameter/ length (mm)	Implants in Each Arch, n	Localization, n	Type of Prostheses/ Type of Retention	Prosthetic Complications Reported
Maló et al[19]	2003	Prospective	Multicenter	Brånemark System Standard, Mk II, Mk III, Mk IV (Nobel Biocare AB)/ external connection	3.3-5/11-20	Maxilla: 74[a] Mandible: 42[a]	NC	All ceramic/NR	NR
Rocci et al[20]	2003	Retrospective	NC	Brånemark System Mk IV (Nobel Biocare AB)/ external connection	3.3-5/8.5-18	Maxilla: 97	Anterior: 30 Posterior: 67	NR/cement retained	NR
Rokni et al[21]	2005	Prospective	NR	Endopore dental implant system (Innova LifeSciences)/external connection[b]	3.5, 4.1, and 5.0/ 5, 7, 9, and 12	Maxilla: 151 Mandible: 48	Anterior: 35 Posterior: 164	Metal-ceramic[b]/ screw retained	NR
Bilhan et al[22]	2010	Retrospective	University	Straumann-Zimmer Dental and Astra Tech-Bio Lok-BioHorizons /internal connection	NR	NC	NC	NR/cement retained	NR
Sohn et al[23]	2010	Retrospective	Private and university	Endopore (Innova Life Sciences)/NR	4.1, and 5.0/5, 7, 9, and 12	Mandible: 122	Posterior: 122	NR/NR	NR
Vigolo and Zaccaria[24]	2010	Prospective	University	Biomet 3i/ external connection	4.0/10, 11.5, 13	Maxilla: 123	Posterior: 123	Metal-ceramic/ cement retained	No patient reported any prosthetic complications.
Perelli et al[25]	2011	Prospective	NR	Endopore (Innova LifeSciences)/ internal connection[b]	4.1 and 5.0/ 5 and 7	Mandible: 50	Posterior: 50	Metal-ceramic[b]/ cement and screw retained	In 4 cases of single crowns, prosthesis failed; in remaining cases, prostheses could still be used without being replaced.
Perelli et al[26]	2012	Prospective	NR	Endopore (Innova LifeSciences)/ internal connection[b]	4.1 and 5.0/ 5 and 7	Maxilla: 110	Posterior: 110	Metal-ceramic[b]/ cement and screw retained	Two abutments became unscrewed after 3 and 4 years of function and one ceramic chipping was noticed in metal-ceramic fixed dental prosthesis, but author did not specify group. No implant, abutment, or screw fracture occurred. Nine implants failed and were removed. Six were loaded with single crowns and therefore prostheses failed; 3 were splinted to adjacent implants and those prostheses did not fail
Rodrigo et al[27]	2013	Retrospective	Multicenter	SLA-surfaced implants (Straumann)/ internal connection[b]	4.1 and 4.8/6	Maxilla: 16 Mandible: 207	Anterior: 2 Posterior: 221	Metal-ceramic[b]/ cement and screw retained[b]	A single implant in free-end situation failed 3 weeks after loading. The other implant was splinted to a longer implant and failed after 32 months of function because of peri-implantitis in patient who smoked and failed to keep maintenance appointments.
Sivolella et al[28]	2013	Retrospective	University	Biomet 3i and Osseotite (Biomet 3i)/NC	3.75 and 4.0/ 7 and 8.5	Mandible: 50	NC	NR/cement retained	S: 15 veneer chippings NS: 2 veneer chippings, 2 abutment screws worked loose, and 2 abutment screw breakages
Vanlıoğlu et al[29]	2013	Retrospective	University	Straumann/ internal connection	NR	Maxilla: 72[c] Mandible: 105[c]	NC	metal-ceramic/ cement retained	S: 4 porcelain fractures NS: 3 porcelain fractures
Wagenberg et al[30]	2013	Retrospective	NR	NR	3.75, 4.0, 5.0, and 6.0/NR	NC	Anterior: 471 Posterior: 716	NR/NC	NR

(*continued on next page*)

Table 2. (*Continued*) Characteristics of studies selected

Study	Year	Design of Study	Setting of Studies	Implant System/ Connection Type	Diameter/ length (mm)	Implants in Each Arch, n	Localization, n	Type of Prostheses/ Type of Retention	Prosthetic Complications Reported
Mendonça et al[31]	2014	Retrospective	University	NR/internal and external connection	4.1 and 5.0/ 7, 8.5, and 10	Maxilla: 60 Mandible: 393	Posterior: 453	Metal-ceramic/ NR	NR
Sohn et al[32]	2014	Retrospective	University	Endopore (Innova LifeSciences)/NR	4.1 and 5.0/ 7, 9, and 12	Maxilla: 84	Posterior: 84	NR/NR	NR
Wagenberg and Froum[33]	2015	Retrospective	NR	NR	3.75, 4.0, 5.0, and 6.0/NR	NC	NC	NC/NC	NR
Ghaleh Golab et al[34]	2015	Prospective	Multicenter	OPS implants (S&S Biomat)/ one piece	3.0, 3.4, and 4.0 /8, 11, 13, and 15	NC	NC	Metal-ceramic/ cement retained	2 ceramic fracture, 18 interim crown fractures, 23 interim crown mobility, 4 cases of soft tissue inflammation
Vigolo et al[4]	2015	RCT	Private and university	Biomet-3i/ external connection	3.0, 3.4, and 4.0/10, 11.5, and 13	Maxilla: 114	Posterior: 114	Metal-ceramic/ cement retained	Without complications
Clelland et al[5]	2016	Prospective	University	OsseoSpeed (Dentsply Sirona) /internal connection	3.5, 4, and 5/ 6, 8, 9, and 11	NC	Posterior: 82	Metal (gold) and metal-ceramic/ cement and screw retained[d]	S: 1 case of porcelain chipping NS: 5 cases of screw loosening
Shi et al[36]	2017	Retrospective	Hospital	Straumann Standard SLA implants/ internal connection	3.3/10 and 12	Maxilla: 42 Mandible: 56	Posterior: 98	Metal-ceramic/ cemented retained	S: 10 ceramic chipping NS: 5 losses of retention, 8 ceramic chipping

NC, not clear; NS, nonsplinted; NR, not reported; RCT, randomized controlled trial; S, splinted. [a]Number of implants placed in patients informed initially, this number modified after withdrawn of patients. [b]Unpublished information obtained by communication with authors. [c]Number of prostheses. [d]Cement retained in only one patient.

restorations supported by implants; and O, overall marginal bone loss as the primary outcome to be extracted and analyzed in the meta-analysis. The survival rate of the implant and prosthetic complications were secondary outcomes.

An electronic search in the PubMed/MEDLINE, Cochrane Library, and Scopus databases was conducted until November 2017. Furthermore, a manual search was conducted to identify registered trials not yet published as of 2017 from the following journals: *Clinical Oral Implants Research, Clinical Implant Dentistry and Related Research, International Journal of Oral and Maxillofacial Implants, International Journal of Oral and Maxillofacial Surgery, Journal of Oral and Maxillofacial Surgery, International Journal of Prosthodontics, Journal of Dental Research, Journal of Dentistry, Journal of Oral Rehabilitation, Journal of Prosthodontics, The International Journal of Prosthodontics,* and *The Journal of Prosthetic Dentistry.*

Two researchers (V.E.S.B., C.A.A.L.) searched the selected electronic databases independently. The search terms used were as follows: splinted and dental implant OR nonsplinted and dental implant OR nonsplinted and dental implant.

Two researchers (V.E.S.B., C.A.A.L.) independently selected the studies according to their titles and abstracts and classified them as included or excluded. Any disagreements were settled through discussion and consensus with a third researcher (F.R.V.). The articles selected for inclusion were then read by both investigators, and the reference list was manually searched.

The full text of the selected articles was analyzed. The analysis of these selected articles was used to answer the PICO questions. The researcher (V.E.S.B.) collected relevant information from the articles, including authors, number of participants, mean age of participants, total of implants, number of implants for splinted and nonsplinted, range of follow up, mean of marginal bone loss over follow-up period for each group, number of implant loss and percentage of implant survival for each group, percentage of prosthesis survival, number of prosthetic complications, year of study, design of study, setting of study, implant system and connection type used in each study, diameter and length of implant in each study, number of implants in each arch, location of implant (anterior or posterior), type of prosthesis and type of retention, and prosthetic complications reported in each study. Another researcher (R.S.C.) then checked all the collected information. Any disagreements between the investigators were discussed with another researcher (E.P.P.) until consensus was reached. Duplicate-subject publications within separate unique studies were not reported twice.

The risk of bias assessment in the included randomized controlled trials (RCTs) was evaluated using the Cochrane Collaboration Tool for Assessing Risk of Bias in Randomized Trials.[11] The assessment criteria were a domain-based evaluation in which critical assessments were made separately for different domains: random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other bias.[11] For each domain, the risk of bias was graded as high, low, or unclear based on criteria described in the *Cochrane Handbook for Systematic Reviews of Interventions* 5.1.0.[11] Furthermore, the Newcastle-Ottawa scale was used to assess the risk bias of the selected non-RCT studies (prospective, retrospective, and clinical human studies). The Newcastle-Ottawa scale is based on 3 major components: selection, comparability, and outcome for cohort studies. According to that quality scale, a maximum of 9 stars can be given to a study, representing the highest quality.[13] Five or fewer stars represents a high risk of bias, whereas 6 or more stars represents a low risk of bias.[13]

The meta-analysis was based on the Mantel-Haenszel and inverse variance methods. Implant failure was the dichotomous outcome measure evaluated. Marginal bone loss was the continuous outcome measure evaluated for mean differences and the corresponding 95% confidence intervals for both. When statistically significant (P<.10) heterogeneity was detected, a random-effects model was used to assess the significance of treatment effects. When no statistically significant heterogeneity was found, the analysis was performed using a fixed-effects model.[14,15] The risk ratio values were considered significant at P less than .05. A software program (Reviewer Manager 5; Cochrane Group) was used for the meta-analysis and to elaborate the funnel plots.

An asymmetrical funnel plot may indicate publication bias or other biases related to sample size, although the asymmetry may also show a true relationship between trial size and effect size.[16] The heterogeneity was assessed using the Q method (x^2) and the value of I^2.[17] The outcomes were dichotomized into good and poor results. I^2 values above 75 (range = 0-100) were considered to indicate significant heterogeneity.[17]

To analyze the sensitivity of the tests used, a subgroup analysis was performed to identify any potential causes of heterogeneity. Specifically, the subgroups considered were splinting in internal connection, splinting in external connection, and splinting in posterior area. The outcomes accessed were marginal bone loss and implant failure.

The kappa statistic was calculated to define the interreader agreement in the study selection process. According to Landis and Koch,[18] the level of interreader agreement is almost perfect if the value of kappa (κ) is 0.81 to 1.00, substantial if κ is 0.61 to 0.80, moderate if κ is 0.41 to 0.60, fair if κ is 0.21 to 0.40, and poor if κ is less than 0.20.

RESULTS

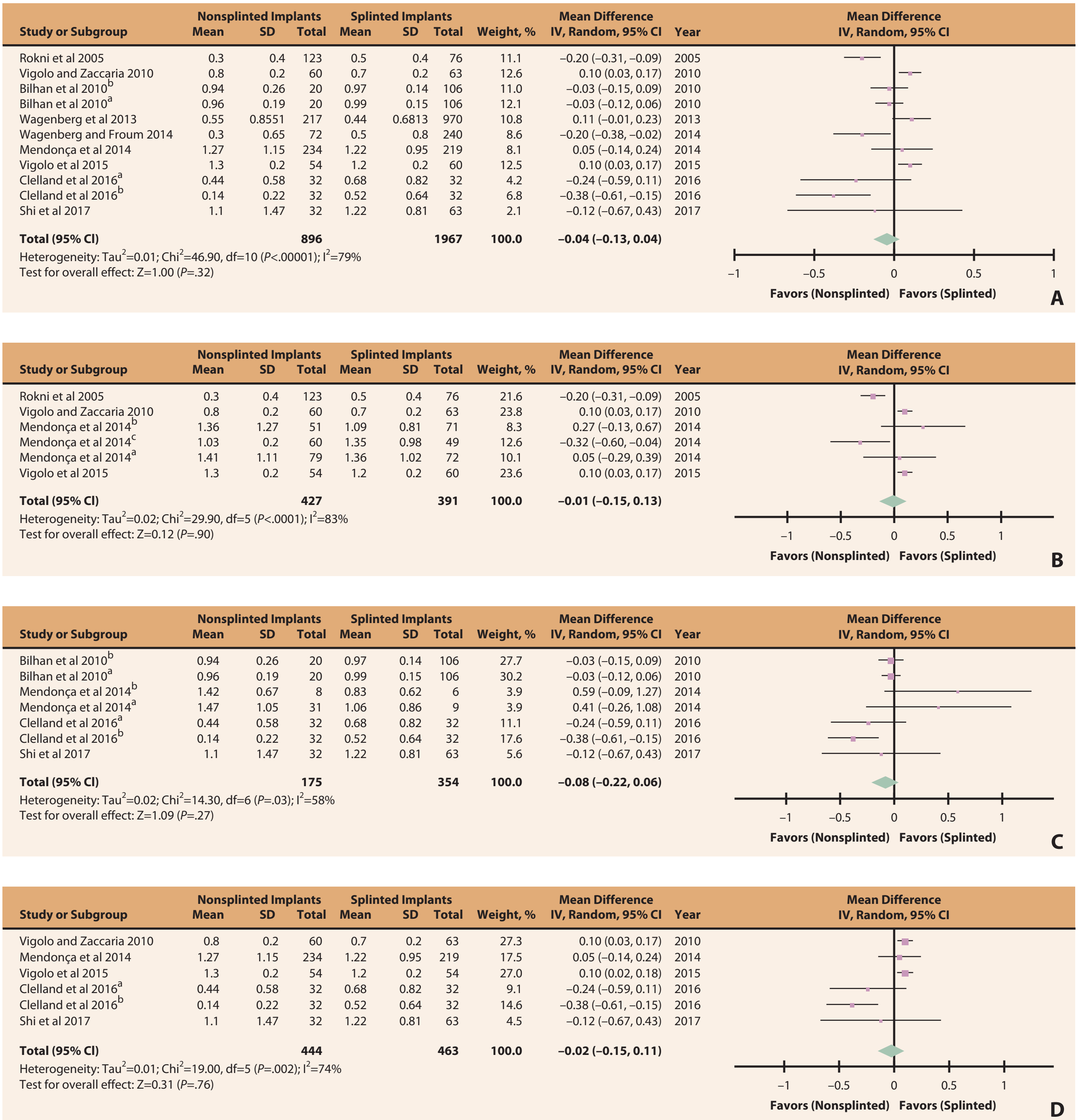
A search of the databases retrieved 894 references (Fig. 1). Applying the inclusion/exclusion criteria to the titles and abstracts of the selected comparative studies left 20 studies (κ=0.95).[4,5,19-36] Upon reading the full texts, 1 study[35] was excluded because it did not report information about crestal bone loss, implant survival, or prosthetic complications of splinted and nonsplinted implants. Details of the search strategy are presented in a flow diagram (Fig. 1).

A total of 19 studies[4,5,19-34,36] were selected for qualitative and quantitative analyses. One was an RCT,[4] 7 were prospective clinical trials,[5,19,21,24-26,34] and 11 were retrospective studies.[20,22,23,27-33,36] A total of 4215 implants were placed in 2185 patients (splinted, 2768; nonsplinted, 1447) with a mean age of 51.4 years old; 6 studies did not report the mean age.[25-28,32,33] The mean follow-up was 87.8 months (range = 12-264 months). The main findings of these studies are presented in Tables 1 and 2. Six studies reported the use of only external connection implants,[4,19,20,21,24,28] 7 studies reported the use of internal connection implant,[5,22,25-27,29,36] 1 study used both connections,[31] 1 study[34] used 1-piece implants, and 4 studies did not specify the connection.[23,30,32,33]

Marginal bone loss was evaluated in 9 studies.[4,5,21,22,24,30,31,33,36] Quantitative analysis found no significant differences between splinted and nonsplinted restorations (P=.32, I^2=79%) (Fig. 2A). Also, the quantitative analysis of marginal bone loss found no significant differences between splinted and nonsplinted restorations for external connection implants (P=.90, I^2=83%) (Fig. 2B)[4,21,24,31] and internal connection implants (P=.27, I^2=58%) (Fig. 2C).[5,22,31,36] Five studies reported information exclusively about marginal bone loss of implants placed in the posterior area.[4,5,24,31,36] In this context, no statistical differences were found between splinted and nonsplinted restorations (P=.76, I^2=74%) (Fig. 2D).

The assessed studies reported that 75 implants failed (3.4%), of which 24 were splinted (99.1% of survival rate) and 51 were nonsplinted (96.5% of survival rate) (Table 1). Eleven studies reported information about failures during their follow-up periods.[4,5,19,20,23,25-27,31,32,34] Quantitative analysis of all studies showed statistically significant higher survival rates for splinted restorations than nonsplinted restorations (P<.001, I^2=0%) (Fig. 3A).

Four studies reported implant failure for external implant connection,[4,19,20,31] and 5 studies reported implant failure for internal connection.[5,25,26,27,31] For external connection implants, splinted restorations showed statistically significant higher survival rates than nonsplinted restorations (P<.001, I^2=0%) (Fig. 3B). In contrast, no significant differences between splinted and nonsplinted restorations were found for internal connection implants (P=.11, I^2=0%) (Fig. 3C). Seven studies reported failure in the posterior area.[4,5,23,25,26,31,32] The quantitative analysis showed statistically significant higher survival rates for splinted restorations than nonsplinted restorations (P=.009,



Study or Subgroup	Nonsplinted Implants Mean	SD	Total	Splinted Implants Mean	SD	Total	Weight, %	Mean Difference IV, Random, 95% CI	Year
Rokni et al 2005	0.3	0.4	123	0.5	0.4	76	11.1	−0.20 (−0.31, −0.09)	2005
Vigolo and Zaccaria 2010	0.8	0.2	60	0.7	0.2	63	12.6	0.10 (0.03, 0.17)	2010
Bilhan et al 2010[b]	0.94	0.26	20	0.97	0.14	106	11.0	−0.03 (−0.15, 0.09)	2010
Bilhan et al 2010[a]	0.96	0.19	20	0.99	0.15	106	12.1	−0.03 (−0.12, 0.06)	2010
Wagenberg et al 2013	0.55	0.8551	217	0.44	0.6813	970	10.8	0.11 (−0.01, 0.23)	2013
Wagenberg and Froum 2014	0.3	0.65	72	0.5	0.8	240	8.6	−0.20 (−0.38, −0.02)	2014
Mendonça et al 2014	1.27	1.15	234	1.22	0.95	219	8.1	0.05 (−0.14, 0.24)	2014
Vigolo et al 2015	1.3	0.2	54	1.2	0.2	60	12.5	0.10 (0.03, 0.17)	2015
Clelland et al 2016[a]	0.44	0.58	32	0.68	0.82	32	4.2	−0.24 (−0.59, 0.11)	2016
Clelland et al 2016[b]	0.14	0.22	32	0.52	0.64	32	6.8	−0.38 (−0.61, −0.15)	2016
Shi et al 2017	1.1	1.47	32	1.22	0.81	63	2.1	−0.12 (−0.67, 0.43)	2017
Total (95% CI)			**896**			**1967**	**100.0**	**−0.04 (−0.13, 0.04)**	

Heterogeneity: Tau^2=0.01; Chi^2=46.90, df=10 (P<.00001); I^2=79%
Test for overall effect: Z=1.00 (P=.32)

Study or Subgroup	Nonsplinted Implants Mean	SD	Total	Splinted Implants Mean	SD	Total	Weight, %	Mean Difference IV, Random, 95% CI	Year
Rokni et al 2005	0.3	0.4	123	0.5	0.4	76	21.6	−0.20 (−0.31, −0.09)	2005
Vigolo and Zaccaria 2010	0.8	0.2	60	0.7	0.2	63	23.8	0.10 (0.03, 0.17)	2010
Mendonça et al 2014[b]	1.36	1.27	51	1.09	0.81	71	8.3	0.27 (−0.13, 0.67)	2014
Mendonça et al 2014[c]	1.03	0.2	60	1.35	0.98	49	12.6	−0.32 (−0.60, −0.04)	2014
Mendonça et al 2014[a]	1.41	1.11	79	1.36	1.02	72	10.1	0.05 (−0.29, 0.39)	2014
Vigolo et al 2015	1.3	0.2	54	1.2	0.2	60	23.6	0.10 (0.03, 0.17)	2015
Total (95% CI)			**427**			**391**	**100.0**	**−0.01 (−0.15, 0.13)**	

Heterogeneity: Tau^2=0.02; Chi^2=29.90, df=5 (P<.0001); I^2=83%
Test for overall effect: Z=0.12 (P=.90)

Study or Subgroup	Nonsplinted Implants Mean	SD	Total	Splinted Implants Mean	SD	Total	Weight, %	Mean Difference IV, Random, 95% CI	Year
Bilhan et al 2010[b]	0.94	0.26	20	0.97	0.14	106	27.7	−0.03 (−0.15, 0.09)	2010
Bilhan et al 2010[a]	0.96	0.19	20	0.99	0.15	106	30.2	−0.03 (−0.12, 0.06)	2010
Mendonça et al 2014[b]	1.42	0.67	8	0.83	0.62	6	3.9	0.59 (−0.09, 1.27)	2014
Mendonça et al 2014[a]	1.47	1.05	31	1.06	0.86	9	3.9	0.41 (−0.26, 1.08)	2014
Clelland et al 2016[a]	0.44	0.58	32	0.68	0.82	32	11.1	−0.24 (−0.59, 0.11)	2016
Clelland et al 2016[b]	0.14	0.22	32	0.52	0.64	32	17.6	−0.38 (−0.61, −0.15)	2016
Shi et al 2017	1.1	1.47	32	1.22	0.81	63	5.6	−0.12 (−0.67, 0.43)	2017
Total (95% CI)			**175**			**354**	**100.0**	**−0.08 (−0.22, 0.06)**	

Heterogeneity: Tau^2=0.02; Chi^2=14.30, df=6 (P=.03); I^2=58%
Test for overall effect: Z=1.09 (P=.27)

Study or Subgroup	Nonsplinted Implants Mean	SD	Total	Splinted Implants Mean	SD	Total	Weight, %	Mean Difference IV, Random, 95% CI	Year
Vigolo and Zaccaria 2010	0.8	0.2	60	0.7	0.2	63	27.3	0.10 (0.03, 0.17)	2010
Mendonça et al 2014	1.27	1.15	234	1.22	0.95	219	17.5	0.05 (−0.14, 0.24)	2014
Vigolo et al 2015	1.3	0.2	54	1.2	0.2	54	27.0	0.10 (0.02, 0.18)	2015
Clelland et al 2016[a]	0.44	0.58	32	0.68	0.82	32	9.1	−0.24 (−0.59, 0.11)	2016
Clelland et al 2016[b]	0.14	0.22	32	0.52	0.64	32	14.6	−0.38 (−0.61, −0.15)	2016
Shi et al 2017	1.1	1.47	32	1.22	0.81	63	4.5	−0.12 (−0.67, 0.43)	2017
Total (95% CI)			**444**			**463**	**100.0**	**−0.02 (−0.15, 0.11)**	

Heterogeneity: Tau^2=0.01; Chi^2=19.00, df=5 (P=.002); I^2=74%
Test for overall effect: Z=0.31 (P=.76)

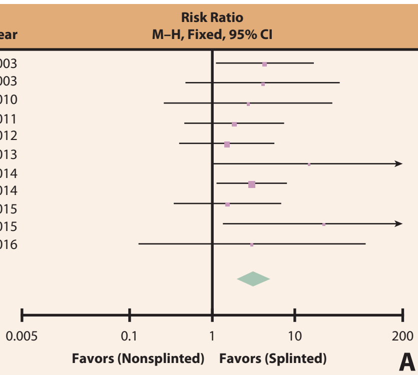
Figure 2. Forest plots. A, Comparison of marginal bone loss between splinted and nonsplinted restorations. B, Comparison of marginal bone loss between splinted and nonsplinted restorations in external connection implants. C, Comparison of marginal bone loss between splinted and nonsplinted restorations in internal connection implants. D, Comparison of marginal bone loss between splinted and nonsplinted restorations in posterior area. CI, confidence interval; IV, inverse variance; SD, standard deviation.

I^2=0%) (Fig. 3D). The comparison between splinted and nonsplinted restorations in the anterior area was not possible because of insufficient data.

Ten studies reported information about prosthetic complications,[4,5,21,22,24,26,28,29,34,36] including ceramic chipping, screw loosening, abutment screw breakage, and soft tissue inflammation. The most common prosthetic complications were ceramic chipping for splinted implants[5,28,29,36] and for screw loosening[5,28,36] and ceramic chipping[28,29,36] for nonsplinted implants. The

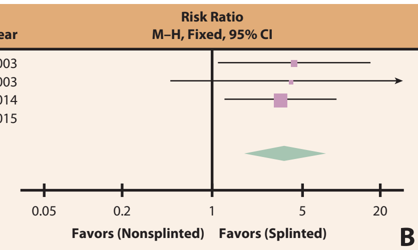
Study or Subgroup	Nonsplinted Implants Events	Nonsplinted Implants Total	Splinted Implants Events	Splinted Implants Total	Weight, %	Risk Ratio M–H, Fixed, 95% CI	Year
Rocci et al 2003	5	27	3	70	9.4	4.32 (1.11, 16.85)	2003
Maló et al 2003	4	51	1	52	5.6	4.08 (0.47, 35.26)	2003
Sohn et al 2010	1	19	2	103	3.5	2.71 (0.26, 28.42)	2010
Perelli et al 2011	4	21	3	29	14.3	1.84 (0.46, 7.37)	2011
Perelli et al 2012	6	63	3	47	19.4	1.49 (0.39, 5.66)	2012
Rodrigo et al 2013	1	14	1	209	0.7	14.93 (0.98, 226.28)	2013
Mendonça et al 2014	16	234	5	219	29.2	2.99 (1.12, 8.04)	2014
Sohn et al 2014	2	15	6	69	12.1	1.53 (0.34, 6.87)	2014
Ghaleh Golab et al 2015	11	237	0	232	2.9	22.52 (1.33, 379.90)	2015
Vigolo et al 2015	0	54	0	60		Not estimable	2015
Clelland et al 2016	1	32	0	32	2.8	3.00 (0.13, 71.00)	2016
Total (95% CI)		**767**		**1122**	**100.0**	**3.18 (1.93, 5.25)**	
Total events	51		24				

Heterogeneity: Chi^2=6.11, df=9 (P=.73); I^2=0%
Test for overall effect: Z=4.53 (P<.00001)



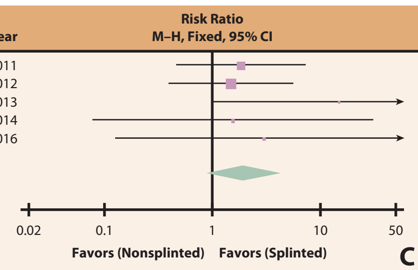
Study or Subgroup	Nonsplinted Implants Events	Nonsplinted Implants Total	Splinted Implants Events	Splinted Implants Total	Weight, %	Risk Ratio M–H, Fixed, 95% CI	Year
Rocci et al 2003	5	27	3	70	23.2	4.32 (1.11, 16.85)	2003
Maló et al 2003	4	51	1	52	13.8	4.08 (0.47, 35.26)	2003
Mendonça et al 2014	14	164	5	198	63.0	3.38 (1.24, 9.19)	2014
Vigolo et al 2015	0	54	0	60		Not estimable	2015
Total (95% CI)		**296**		**380**	**100.0**	**3.70 (1.73, 7.90)**	
Total events	23		9				

Heterogeneity: Chi^2=0.09, df=2 (P=.96); I^2=0%
Test for overall effect: Z=3.37 (P=.0007)



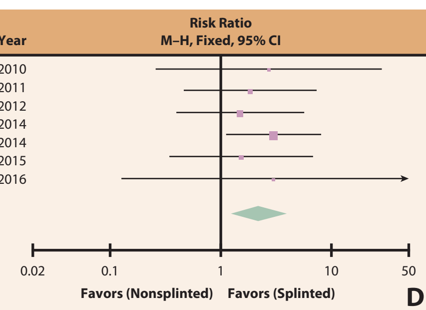
Study or Subgroup	Nonsplinted Implants Events	Nonsplinted Implants Total	Splinted Implants Events	Splinted Implants Total	Weight, %	Risk Ratio M–H, Fixed, 95% CI	Year
Perelli et al 2011	4	21	3	29	34.3	1.84 (0.46, 7.37)	2011
Perelli et al 2012	6	63	3	47	46.8	1.49 (0.39, 5.66)	2012
Rodrigo et al 2013	1	14	1	209	1.7	14.93 (0.98, 226.28)	2013
Mendonça et al 2014	2	70	0	21	10.4	1.55 (0.08, 31.07)	2014
Clelland et al 2016	1	32	0	32	6.8	3.00 (0.13, 71.00)	2016
Total (95% CI)		**200**		**338**	**100.0**	**1.95 (0.86, 4.44)**	
Total events	14		9				

Heterogeneity: Chi^2=2.41, df=4 (P=.66); I^2=0%
Test for overall effect: Z=1.59 (P=.11)



Study or Subgroup	Nonsplinted Implants Events	Nonsplinted Implants Total	Splinted Implants Events	Splinted Implants Total	Weight, %	Risk Ratio M–H, Fixed, 95% CI	Year
Sohn et al 2010	1	19	2	103	4.3	2.71 (0.26, 28.42)	2010
Perelli et al 2011	4	21	3	29	17.5	1.84 (0.46, 7.37)	2011
Perelli et al 2012	6	63	3	47	23.9	1.49 (0.39, 5.66)	2012
Mendonça et al 2014	16	234	5	219	35.9	2.99 (1.12 , 8.04)	2014
Sohn et al 2014	2	15	6	69	14.9	1.53 (0.34, 6.87)	2014
Vigolo et al 2015	0	54	0	60		Not estimable	2015
Clelland et al 2016	1	32	0	32	3.5	3.00 (0.13, 71.00)	2016
Total (95% CI)		**438**		**559**	**100.0**	**2.20 (1.22, 3.99)**	
Total events	30		19				

Heterogeneity: Chi^2=1.06, df=5 (P=.96); I^2=0%
Test for overall effect: Z=2.61 (P=.009)



Study or Subgroup	Nonsplinted Implants Events	Nonsplinted Implants Total	Splinted Implants Events	Splinted Implants Total	Weight, %	Risk Ratio M–H, Random, 95% CI	Year
Rokni et al 2005	0	123	0	76		Not estimable	2005
Bilhan et al 2010[a]	0	20	0	106		Not estimable	2010
Vigolo and Zaccaria 2010	0	60	0	63		Not estimable	2010
Perelli et al 2011	4	21	0	29	11.0	12.27 (0.70 , 216.34)	2011
Perelli et al 2012	6	63	0	47	11.1	9.75 (0.56, 168.89)	2012
Vanlioğlu et al 2013	3	125	4	106	18.4	0.64 (0.15, 2.78)	2013
Sivolella et al 2013	6	30	15	20	22.2	0.27 (0.12, 0.57)	2013
Vigolo et al 2015	0	60	0	54		Not estimable	2015
Clelland et al 2016	5	32	1	32	14.8	5.00 (0.62, 40.44)	2016
Shi et al 2017	13	33	10	63	22.4	2.48 (1.22, 5.04)	2017
Total (95% CI)		**567**		**596**	**100.0**	**1.81 (0.50, 6.64)**	
Total events	37		30				

Heterogeneity: Tau^2=1.82; Chi^2=26.66, df=5 (P<.0001); I^2=81%
Test for overall effect: Z=0.90 (P=.37)

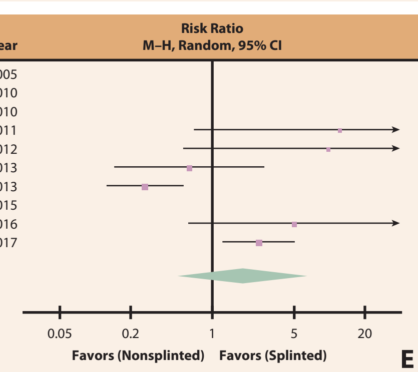


Figure 3. Forest plot. A, Comparison of implant failure between splinted and nonsplinted restorations. B, Comparison of implant failure between splinted and nonsplinted restorations in external connection implants. C, Comparison of implant failure between splinted and nonsplinted restorations in internal connection implants. D, Comparison of implant failure between splinted and nonsplinted restorations in posterior area. E, Comparison of prosthetic complications between splinted and nonsplinted restorations. CI, confidence interval; M-H, Mantel-Haenszel.

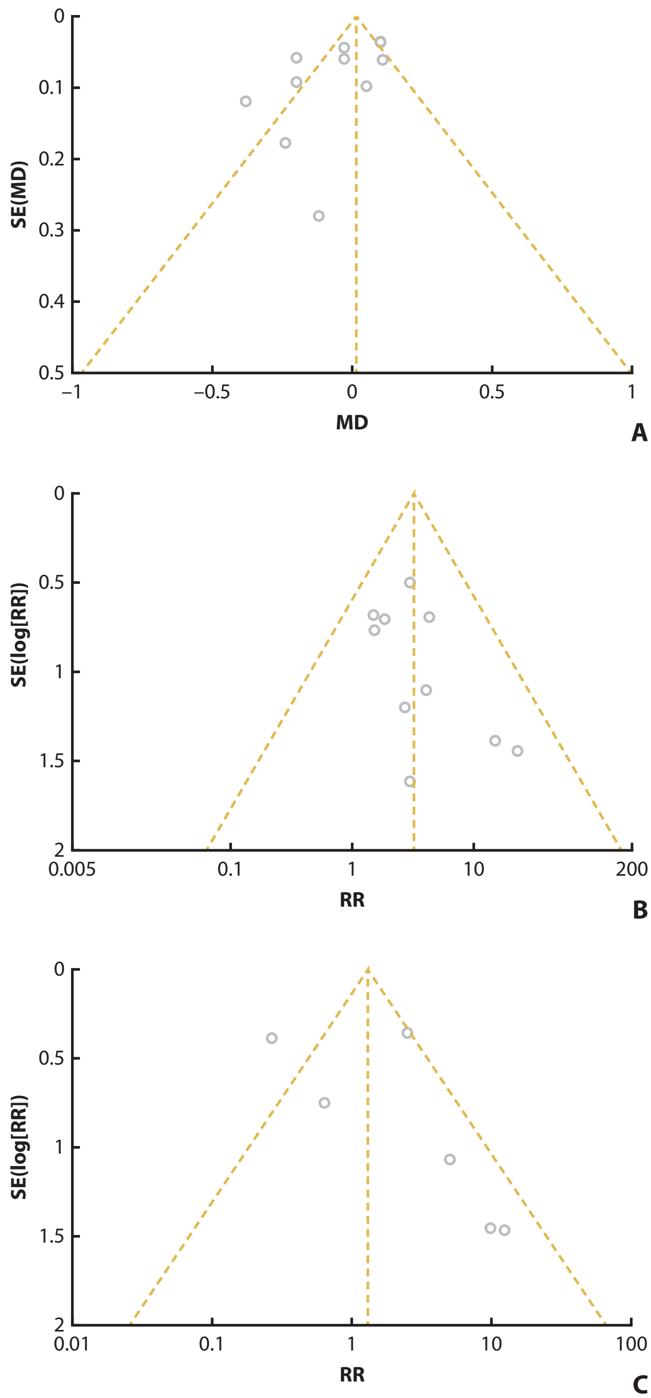


Figure 4. Funnel plots for assessment of publication bias: outcomes. A, Peri-implant bone loss. B, Implant failure. C, Prosthetic complication. MD, mean difference; RR, risk ratio; SE, standard estimates.

quantitative analysis found no statistically significant difference between splinted and nonsplinted restorations for prosthetic complications (P=.37, I^2=81%) (Fig. 3E).

The funnel plot showed asymmetry in relation to the mean differences of the studies analyzed for marginal bone loss (Fig. 4A); however, symmetry of the funnel plot was shown for the implant failure analysis (Fig. 4B). For prosthetic complications, the funnel plot also showed asymmetry (Fig. 4C).

To assess the risk of bias in randomized trials, only 1 study[4] was selected (Supplemental Table 1). Of the 18 non-RCT studies, 4 studies[20,22,28,36] showed 9 stars and 12 studies showed 8 stars,[5,19,21,23-27,29,30,32-34] representing a low risk of bias. The absence of stars was related mainly to "outcome of interest not present at start" (Supplemental Table 2).

DISCUSSION

The decision to splint or not generally occurs during the planning stage, when the advantages and disadvantages of each clinical situation are considered based on the proposed treatment. However, minimal clinical evidence is available to help clinicians make this decision.[5] Thus, the results of the current systematic review and meta-analysis may help clinicians define a rational plan of treatment.

Recently, Al Amri and Kellesarian[37] published a systematic review to compare the crestal bone loss around splinted and nonsplinted adjacent implants. Six clinical studies were included, and the authors concluded that the adjacent implants restored with splinted and nonsplinted fixed restorations did not differ in terms of crestal bone loss. Similarly, the present systematic review did not find statistical difference for marginal bone loss; however, a statistical difference was found for implant survival rate, showing an advantage for splinted restoration. Thus, new information about the topic has been published, justifying a new systematic review.

Ease of hygiene has been reported by patients with nonsplinted restorations.[5] In this context, the biggest difficulty in cleaning the prosthesis may be associated with the highest prevalence of peri-implantitis[38]; this accelerates the pattern of bone loss.[39] In the current systematic review and meta-analysis, the quantitative analysis of marginal bone loss showed no significant differences between splinted and nonsplinted restorations; therefore, the first null hypothesis of this study was not rejected. Possibly this occurred because, to participate in the study, individuals agreed to an adequate maintenance protocol and appropriate oral hygiene. Thus, an adequate maintenance protocol is required for individuals with dental implants, mainly for splinted restorations, to avoid progressive marginal bone loss.

The second null hypothesis of this study was rejected, because implants supporting splinted restorations showed statistically significant higher survival rates than nonsplinted restorations. These data agree with studies that have reported a high survival rate for implants with splinted restorations.[23,27,31,34] Mendonça et al[31] suggest that single restorations in the posterior region could be more susceptible to high masticatory forces, increasing the risk of micromotion above physiologic limits.

Therefore, splinted implants may be indicated in clinical situations where there is a biomechanical risk to reduce the forces on implants and their surrounding tissues.[24]

Splinted restorations showed statistically significant higher survival rates than nonsplinted restorations for external connection implants; in contrast, no significant differences between splinted and nonsplinted restorations were found for internal connection implants. The literature suggests that an external connection implant has more micromotion of the abutment during loading than an internal connection implant[40,41]; thus, splinting restorations retained by external connection implants may improve the stability of the system, decreasing the risk of implant failure. The increased stability of the internal connection implant is associated with the ability to reduce the stress transferred to the crestal bone.[40,41] Therefore, its use with nonsplinted crowns might reduce the risk of implant failure. However, further clinical studies are required to clarify this issue.

Shi et al[36] reported that the prosthetic complication rates (such as veneer ceramic chipping, framework fracture, abutment screw loosening or fracture, implant fracture, and loss of retention) of splinted restorations supported by narrow implants were significantly lower than those of single crowns (15.4% versus 39.4%, respectively). In disagreement with Shi et al,[36] the quantitative analysis of prosthetic complication performed in the current meta-analysis showed no statistically significant difference between splinted and nonsplinted restorations; therefore, the third null hypothesis of this study was not rejected. However, the qualitative analysis showed that the loss of retention occurred with more frequency in nonsplinted restorations.[5,28,36] This might be because of the biomechanical differences between splinted and nonsplinted implants,[8] in which the splinted restoration has tended to share load among the screw components of the restoration.[8,42,43] Clinically, the splinting of posterior implants could be beneficial for reducing loss of retention.[5,36]

To avoid indirect comparison, only studies that offered data of splinted and nonsplinted restorations were selected. As consequence, analysis of the effect of splinting on different implant diameters and lengths, maxilla versus mandible, anterior versus posterior, patients with bruxism, or type of antagonist was not possible. Another study limitation was the inclusion of only 1 RCT in the analysis[4]; consequently, the inclusion of prospective and retrospective studies generated heterogeneity in the sample. The study limitations were a consequence of limited literature on the topic, indicating the need for further RCTs to investigate splinting and its associations.

According to Vigolo and Zaccaria[24] and Vigolo et al,[4] nonsplinted restorations may be a better treatment option when superior esthetics is essential; however, the literature on the topic is scarce. In this context, the clinician's personal preference may influence the choice of treatment plan. Further research is necessary to clarify this scenario.

CONCLUSIONS

Within the limitations of this systematic review and meta-analysis, the following conclusions were drawn:

1. No difference was found in the marginal bone loss and prosthetic complication rates of splinted and nonsplinted implant restorations, especially in the posterior region.
2. However, splinted restorations were associated with a decreased rate of implant failure.

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