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SYSTEMATIC REVIEW

Comparison of external, internal flat-to-flat, and conical implant abutment connections for implant-supported prostheses: A systematic review and network meta-analysis of randomized clinical trials

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ABSTRACT

Statement of problem. The implant abutment connection interface has been considered one of the major factors affecting the outcome of implant therapy. However, drawbacks of traditional meta-analyses are the inability to compare more than 2 treatments at a time, which complicates the decision-making process for dental clinicians, and the lack of a network meta-analysis.

Purpose. The purpose of this network meta-analysis was to assess whether the implant abutment connection influences the outcome of implant-supported prostheses.

Material and methods. An electronic search was undertaken to identify all randomized clinical trials comparing the effect of at least 2 different implant abutment connection designs published from 2009 up to May 2020. Outcome variables were implant survival rate, peri-implant marginal bone loss, and biologic and prosthetic complication rates at 12 months after prosthetic loading. Relevant information was extracted, and quality and risk of bias assessed. Pairwise meta-analyses and network meta-analyses based on a multivariate random-effects meta-regression were performed to assess the comparisons (α=.05 for all analyses).

Results. For peri-implant marginal bone loss and prosthetic complications, conical interfaces were determined to be the most effective, with significant differences when compared with external hexagonal connections (P=.011 and P=.038, respectively). No significant differences were found among the implant abutment connections in terms of survival and biologic complications (P>.05 in all direct, indirect, and mixed comparisons).

Conclusions. After 1 year of loading, conical connections showed lower marginal bone loss and fewer prosthetic complications than external hexagonal connections. However, the implant abutment connection design had no influence on the implant survival and biologic complication rates. (J Prosthet Dent 2023;130:327-40)

Over recent decades, the use of dental implants for oral rehabilitation has shown good long-term results in a wide variety of situations.[1,2] Maintaining peri-implant bone tissue is essential for the long-term success of dental implants.[3] Traditionally, peri-implant marginal bone loss (MBL) of less than 1.5 mm during the first year after functional loading and less than 0.2 mm annually thereafter has been assumed to be normal.[4,5] However, the criteria for defining success in implant dentistry are controversial.[6-8]

A wide variety of dental implant designs, materials, and surface technologies, as

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Clinical Implications

Based on this systematic review and network meta-analysis of randomized clinical trials, dental clinicians are advised to use implant systems with a conical implant abutment connection in patients with risk factors for marginal bone loss and/or prosthetic complications.

well as surgical and prosthetic protocols, have been proposed to improve the stability of the peri-implant tissues.[9-14] The implant abutment connection interface has been considered one of the major factors modulating peri-implant bone level changes.[15,16]

Dental implant connections can be classified into external and internal, with internal connections being further divided into passive joint or flat-to-flat systems (such as triangles, hexagons, octagons) and conical or Morse taper interfaces. External connections are characterized by having the interface above the platform of the implant.[17] These have been extensively used since the development of the first osseointegrated implant, the Brånemark implant system.[18] Although still widely used today, external connections have disadvantages, including micromovement at the implant abutment level, which has been proposed as a potential risk factor for biologic and mechanical complications.[19,20] Internal connections were introduced to overcome such drawbacks. These have reduced screw loosening and screw fracture and enhanced dissipation of loading forces along the implant walls.[17,21,22] Moreover, in vitro studies have reported that internal connections, particularly conical ones, reduce the implant abutment gap and subsequent bacterial penetration.[23,24] Additionally, the use of prosthetic abutments with a smaller diameter than that of the implant platform—a concept known as platform switching—may limit vertical MBL.[25-27]

Because many clinical trials have compared identical or different dental implants with different connections, several meta-analyses have been published on this topic.[17,19,28-31] However, a potential drawback of traditional meta-analyses is the inability to compare more than 2 treatments at a time, which complicates the clinician's decision-making process. Moreover, the absence of direct comparisons among more than 2 interventions means that traditional meta-analysis cannot estimate the resulting comparative benefits and drawbacks.[32] Network meta-analysis (NMA), also known as multiple treatment meta-analysis or mixed treatment meta-analysis, overcomes this limitation.[33]

Therefore, the aim of the present study was to analyze the relevant data from randomized clinical trials (RCTs) and assess which implant abutment connection design (external, internal flat-to-flat, or conical) is the most effective for restoring missing teeth with dental implants. Two null hypotheses were formulated: that the implant survival rate and complications (mechanical or biologic) would be similar for all the different prosthetic interface connections and that no differences in terms of peri-implant MBL would be identified among the implant abutment connections.

MATERIAL AND METHODS

This study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Network Meta-Analyses (PRISMA-NMA) statement[34] (Supplemental Table 1, available online) and was registered in the international database of prospectively registered systematic reviews in health and social care (PROSPERO) under number CRD42018099154.

The patients, intervention, comparison, outcomes, and time (PICOT) question to be addressed was as follows: In people with missing teeth replaced by dental implants in completely or partially edentulous mandibular or maxillary alveolar arches (P), what is the effect of external, internal flat-to-flat, or conical implant abutment connection design (I) on implant survival rate, peri-implant MBL, biologic complication rate, and prosthetic complication rate (O) when compared with a positive control implant abutment connection design (C) within the first 12 months of functional loading (T)?

The inclusion criteria were RCTs including split mouth and/or multiarm designs comparing 2 or 3 different implant abutment connection designs with a minimum follow-up of 12 months after prosthetic loading. The review excluded trials published before 2009 and/or with fewer than 10 participants/implants in the control and/or intervention group.

The primary outcome was implant survival. The secondary outcome measurements were radiographic peri-implant MBL—from prosthesis delivery to 12 months after functional loading—and biologic and prosthetic complications. Peri-implant MBL was expressed in millimeters, whereas implant survival and biologic and prosthetic complications were expressed in absolute values and percentages.

An electronic search of the MEDLINE (OVID), the Cochrane Library (Wiley), Scopus (Elsevier), and the Web of Science (Thomson Reuters) databases up to May 1, 2020, was conducted to identify all relevant human studies published as of 2009, without language restrictions (Supplemental Table 2, available online). Additionally, non–peer-reviewed literature was searched (OpenGrey, 2011), as well as the US National Institutes of Health (National Institutes of Health, 2000), to identify additional potential candidates to be included. The

Table 1. Studies selected for qualitative and quantitative synthesis

Authors, Year Country	Design	Surgical Site	Interventions	Manufacturers
Cannata et al, 2017 Italy[47]	Multicenter RCT (parallel)	Participants partially edentulous in maxilla or mandible, requiring 1 implant-supported prosthesis; residual bone height ≥10 mm and thickness ≥5 mm measured on CT scan	CC	JDIcon. J Dental Care.
			IFF	JDEvolution. J Dental Care.
Canullo et al, 2012 Italy[48]	Multicenter RCT (split-mouth)	Partially edentulous participants, requiring fixed implant-supported prosthesis in posterior maxilla with 2 adjacent implants; bone thickness wide enough to insert 4-mm-diameter implants	IFF	Amplified. P-I Brånemark.
			EH	External hexagon. P-I Brånemark.
Cooper et al, 2015 USA[49]	Multicenter RCT (parallel)	Partially edentulous participants, requiring 1 or more single implants in anterior maxilla; bone width ≥5.5 mm	CC	OsseoSpeed. Dentsply Implants.
			IFF	NobelSpeedy Replace. Nobel Biocare.
			IFF + PS	NanoTite Certain Prevail. Biomet 3i.
Cooper et al, 2016 USA[50]	Multicenter RCT (parallel)	Participants with partial edentulism, Kennedy Class I or II in maxilla or mandible, requiring 2 or 3 dental implants to support individual crowns; bone thickness wide enough to insert 4.5-mm-diameter fixtures	CC	OsseoSpeed. Dentsply Implants.
			EH	Osseotite Standard. Biomet 3i.
Crespi et al, 2009 Italy[51]	RCT (parallel)	Participants requiring extraction of 1 or 2 single-rooted teeth, replaced by dental implants; ≥4 mm of bone beyond root apex and preserving 4 bony walls	CC	Ankylos Plus. Dentsply Implants.
			EH	Seven. Sweden & Martina.
Esposito et al, 2015 Italy[52]	Multicenter RCT (parallel)	Any patient requiring 1 implant-supported prosthesis, with any type of bone quality and jaw location	CC	EZ plus. MegaGen Implant.
			EH	EZ plus. MegaGen Implant.
Felice et al, 2014 Italy[53]	Multicenter RCT (split-mouth)	Any patient, requiring at least 2 implant-supported crowns or partial fixed prostheses supported by ≤3 dental implants; sufficient bone volume to insert ≥9-mm-long and ≥3.8-mm-diameter implants	CC	Way Milano. Geass. y
			IFF	Kentron. Geass.
Glibert et al, 2018 Belgium[54]	RCT (split-mouth)	Maxillary edentulous participants; sufficient residual bone volume to insert 4 implants with 4-mm diameter and 9- to 11-mm length	CC	Deep Conical Cylindrical. Southern Implants.
			EH	External Hex. Southern Implants.
Gultekin et al, 2013 Turkey[55]	RCT (split-mouth)	Participants partially edentulous in axilla or mandible with ≥2 teeth absent; sufficient residual bone volume to place ≥8-mm-long and ≥3.5-mm-diameter implants	CC	Nobel Active. Nobel Biocare.
			IFF	Nobel Replace Tapered Groovy. Nobel Biocare. d
Hsu et al, 2016 USA[56]	RCT (parallel)	Participants with single-tooth gap in esthetic zone; sufficient bone volume for single implant as measured on CT scan	CC	SuperLine. Dentium.
			IFF	Zimmer Tapered Screw-Vent. Zimmer Dental.
Kielbassa et al, 2009 Germany[57]	Multicenter RCT (parallel)	Participants missing ≥1 teeth in maxilla or mandible; sufficient residual bone volume to place ≥10-mm-long and ≥3.5-mm-diameter implants	CC	NobelActive. Nobel Biocare.
			IFF	NobelReplace Tapered Groovy. Nobel Biocare.
			EH	NobelActive. Nobel Biocare.
Kim et al, 2019 Republic of Korea[58]	RCT (parallel)	Participants who need to restore single mandibular second molar; residual bone height ≥9 mm and thickness ≥9 mm measured on CT scan	CC	Luna. Shinhung.
			EH	Sola. Shinhung.
Menini et al, 2019 Italy[59]	Multicenter RCT (split-mouth)	Participants with unfavorable prognoses for maxillary or mandibular dentition demanding immediate fixed-implant prosthesis	IFF	Shelta. Sweden & Martina.
			EH	Syra. Sweden & Martina.
Peñarrocha-Diago et al, 2013 Spain[60]	RCT (parallel)	Maxillary or mandibular edentulous participants; sufficient residual bone volume to insert 2-8 implants; residual bone height ≥6 mm and thickness ≥7 mm measured on CT scan	CC	InHex. Mozo-Grau.
			EH	Osseous. Mozo-Grau.
Pessoa et al, 2017 Brazil[61]	RCT (split-mouth)	Mandibular edentulous participants; sufficient residual bone volume, measured on CT scan, to insert 4 implants 13 mm in length and 3.8 mm in diameter.	CC	Unitite. SIN.
			EH	Unitite. SIN.
Pieri et al, 2011 Italy[62]	RCT (parallel)	Participants requiring extraction of 1 maxillary premolar, replaced by dental implant, with ≥4 mm of bone beyond root apex and preserving 4 bony walls	CC	Smiler. Samo Biomedica.
			IFF	Smiler. Samo Biomedica.
Pozzi et al, 2014 Italy[63]	RCT (split-mouth)	Participants partially edentulous in mandible, Kennedy Class I. II or III, requiring ≥2 single implant-supported crowns; sufficient bone volumes to accommodate dental implants without augmentation procedure	CC	NobelActive. Nobel Biocare.
			EH	NobelSpeedy Groovy. Nobel Biocare.
Sanz-Martín et al, 2017 Spain[64]	RCT (parallel)	Participants partially edentulous in posterior maxilla or mandible; sufficient residual bone volume to place ≥7-mm-long and ≥3.8-mm-diameter implants	CC	Premium TG. Sweden & Martina.
			IFF	Premium SP. Sweden & Martina.

CC, conical connection; EH, external hexagon; IFF, internal flat-to-flat; PS, platform switching; RCT, randomized controlled trial.

research was completed by checking the reference lists of the selected articles and reviews.

Two reviewers (O.C.-F., L.R.-P.) independently selected the studies in accordance with the inclusion criteria. A third reviewer (R.F.) resolved any disagreements. The Cohen kappa coefficient (κ) was calculated to measure the level of agreement of the reviewers. The authors were contacted when necessary for clarification

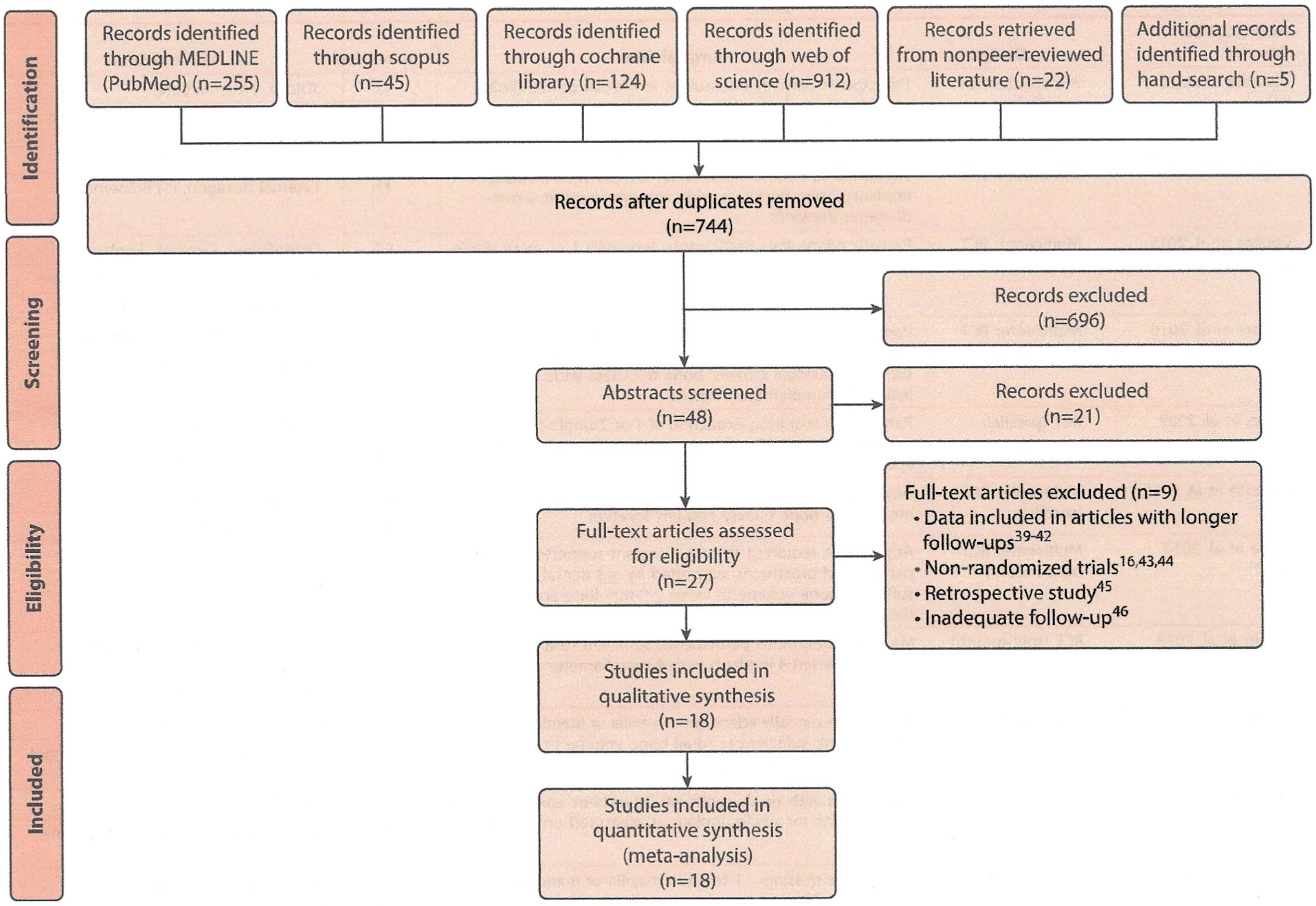

Figure 1. Screening process flowchart.

of missing information. When multiple reports from the same study were identified, the first publication addressing the outcomes of interest 12 months after the prosthetic loading was included. The data were extracted independently by 2 reviewers (O.C.-F., L.R.-P.) under the supervision of a third reviewer (R.F.). Tables were created to summarize the following data (if available): author(s), year of publication, country of origin, study design, and details related to participants, intervention(s), and outcomes.

As suggested in the Cochrane Handbook for Systematic Reviews of Interventions (version 5.1.0), 2 reviewers (O.C.-F., L.R.-P.) independently evaluated the risk of bias and methodological quality of each RCT by using the Cochrane Collaboration Risk of Bias Tool.[35] Except for the blinding domain, which was assessed separately for clinical and radiological outcomes, the others were judged at the study level.

Pairwise meta-analyses (PMA) using a random-effects model were performed for the studies that directly compared different implant abutment connection designs. For dichotomous outcomes, odds ratios (ORs) with 95% confidence intervals (CIs) were used to estimate the effect of an intervention. For continuous outcomes, mean differences (MDs) and standard deviations were used to summarize the data for each group. A $\chi 2$ P value <.10 and an I^2 value greater than 50% were interpreted as indicating significant heterogeneity.[36] Consequently, subgroups of different characteristics based on variations in the experimental treatment protocol (such as RCT design, risk-of-bias quality, insertion timing, load timing, platform switching, and implant design) were isolated and subjected to linear meta-regression to identify them as possible sources of covariance. Had any cluster contained ≥10 meta-analyzed trials, publication bias analysis would have been performed.[35]

Subsequently, an NMA was conducted to compare the implant abutment connections for each outcome variable simultaneously. To review the network geometry, a network graph was generated and analyzed: each implant abutment connection cluster was drawn as a node, and direct comparisons between them were represented by links between the nodes. The NMA was based on a multivariate random-effects metaregression.[37] Inconsistency was assessed substantively by comparing the results obtained through PMA and NMA and

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of clinical outcomes (detection bias)	Blinding of radiological outcomes (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Cannata, et al, 2017	+	+	−	+	+	+	+
Canullo, et al, 2012	+	+	+	+	+	+	+
Cooper, et al, 2015	?	+	+	−	+	+	+
Cooper, et al, 2016	+	?	−	−	+	+	+
Crespi, et al, 2009	+	+	+	+	+	+	+
Esposito, et al, 2015	+	+	+	+	+	+	+
Felice, et al, 2014	+	+	+	−	+	+	+
Glibert, et al, 2018	+	?	−	−	+	+	+
Gultekin, et al, 2013	+	?	?	−	+	+	+
Hsu, et al, 2016	+	−	−	−	+	+	+
Kielbassa, et al, 2009	+	−	−	−	+	+	+
Kim, et al, 2018	+	+	−	−	+	+	+
Menini, et al, 2019	+	+	?	−	+	+	+
Peñarrocha, et al, 2012	+	−	+	−	+	+	+
Pessoa, et al, 2017	?	?	+	+	+	+	+
Pieri, et al, 2011	+	+	?	−	+	+	+
Pozzi, et al, 2014	+	−	+	−	+	+	+
Sanz-Martin, et al, 2017	+	+	−	−	+	+	+

Figure 2. Risk of bias assessment of studies included based on the Cochrane Risk of Bias tool.

statistically by fitting both consistency and inconsistency through design-by-treatment interaction models.[37] Outcome variables were ranked by using the surface under the cumulative ranking (SUCRA) curve.[38] The SUCRA is a numeric presentation of the overall ranking and presents a single number associated with each treatment, with values ranging from 0% to 100%.[38] A high SUCRA value (close to 100) indicates that a particular implant abutment connection is very likely to be the best, or one of the best. Conversely, SUCRA values close to 0 suggest that the interface is probably the worst.

The statistical analysis was carried out with software programs (Stata14; StataCorp, Review Manager 5.3; The Cochrane Collaboration) (α=.05 for all analyses).

RESULTS

The initial electronic database search returned 1363 references. Nine articles were excluded after full-text evaluation.[16,39-46] Altogether, 18 RCTs fulfilled the eligibility criteria and were selected for qualitative and quantitative synthesis (Table 1).[47-64] The reviewer agreement rate was 95.2%, with a κ coefficient of 0.88 (almost perfect agreement). A flowchart of the screening process is shown in Figure 1.

Fourteen of the 18 RCTs included were considered to have a high risk of bias.[47,49,50,53-60,62-64] Most of the studies showed a high or unclear risk for the blinding of clinical and/or radiological outcomes. Figure 2 and Supplemental Table 3 (available online) summarize the quality of the RCTs included.

Fifty-two of the 1042 participants in the 18 studies included could not be analyzed because of dropouts within the follow-up period (weighted mean dropout rate: 2.91%). Seven of the trials meta-analyzed had a split-mouth design.[48,53,54,55,59,61,63] By implant abutment connection type, 344 participants (586 implants) were treated with external interfaces, 393 (526 implants) with internal flat-to-flat designs, and 517 participants (791 implants) with an internal conical connection. The results for each individual RCT included are reported in Table 2.

The survival and biologic analyses included 18 (1903 implants in 1042 participants)[47-64] and 14 RCTs (1492 implants in 820 participants),[47,48,51-53,56-64] respectively (Table 2 and Fig. 3A, 3B). No statistically significant differences among any of the implant abutment connections assessed were found in either the PMAs of direct comparisons or the NMA model (P>.05 in all direct, indirect, and mixed comparisons) (Table 3 and Supplemental Figs. 1, 2, available online).

The peri-implant MBL analysis included 18 studies involving 1585 implants in 1042 participants (Table 2 and Fig. 3C).[47-64] Meta-analysis of the direct comparisons showed significantly less peri-implant MBL in conical connections when compared with external (MD: -0.25 mm; 95% CI: -0.43 to -0.05; P=.01; I^2: 81%) and internal flat-to-flat (MD: -0.27 mm; 95% CI: -0.53 to -0.02; P=.04; I^2: 95%) interfaces. No statistically significant differences were found between internal flat-to-flat and external designs (MD: -0.33 mm; 95% CI: -1.18 to 0.53; P=.46; I^2: 95%) (Table 3 and Supplemental Fig. 3, available online). Heterogeneity was explained by differences in the

Table 2. Comparison of studies selected

Variable	Study, Year			
	Cannata et al, 2017[47]	**Canullo et al, 2012**[48]	**Cooper et al, 2015**[49]	**Cooper et al, 2016**[50]
Intervention				
CON1	CC	IFF	CC	CC
CON2	IFF	EH	IFF	EH
Nº of implants (participants) [dropouts]				
CON1	45 (45) [0]	40 (40) [0]	48 (48) [0]	47 (19) [0]
CON2	45 (45) [1]	40 (40) [0]	93 (93) [4]	46 (20) [0]
Age of participants				
CON1 (SD) [range]	52.3 (16.8)	58.2 [NR]	43 (15)	55.2 (11.8)
CON2 (SD) [range]	51.2 (17.3)		46 (16.4)	51.0 (11.0)
Platform switching				
CON1	Yes	Yes	Yes	Yes
CON2	Yes	No	Mixed	No
Insertion timing	Post-extractive & healed sites	Healed sites	Healed sites	Healed sites
Load timing	Delayed	Delayed	Immediate	Delayed
Prosthesis design	ISCs & FPDs	ISCs	Cemented ISCs	Cemented ISCs
Identical macrotopography and microtopography	Yes	Yes	No	No
Mean MBL				
CON1 (SD)	0.56 (0.53)	0.44 (0.25)	0.22 (0.28)	0.48 (0.55)
CON2 (SD)	0.60 (0.62)	1.47 (0.46)	1.26 (0.83)	0.68 (1.2)
MD (95% CI)	-0.04 (-0.28 to 0.20)	-1.03 (-1.19 to -0.87)	-1.04 (-1.24 to -0.84)	-0.20 (-0.59 to 0.19)
P	.745	<.001*	<.001*	.317
Implant survival				
CON1 (%)	44 (97.78)	40 (100)	48 (100)	45 (95.74)
CON2 (%)	45 (100)	40 (100)	80 (86.02)	44 (95.65)
OR (95% CI)	0.33 (0.01-8.22)	NC	16.27 (0.95-279.83)	1.02 (0.14-7.58)
P-value	.496	NA	.055	.982
Biologic complications				
CON1 (%)	2 (4.44)	0 (0)	NR	NR
CON2 (%)	1 (2.22)	0 (0)		
OR (95% CI)	2.05 (0.18-23.41)	NC		
P	.565	NA		
Technical complications				
CON1 (%)	0 (0)	NR	NR	1 (2.13)
CON2 (%)	1 (2.22)			11 (23.91)
OR (95% CI)	0.33 (0.01-8.22)			0.07 (0.01-0.56)
P	.496			.012*

Variable	Study, Year			
	Crespi et al, 2009[51]	**Esposito et al, 2015**[52]	**Felice et al, 2014**[53]	**Glibert et al, 2018**[54]
Intervention				
CON1	CC	CC	CC	CC
CON2	EH	EH	IFF	EH
Nº of implants (participants) [dropouts]				
CON1	30 (22) [0]	154 (98) [7]	71 (64) [6]	42 (21) [1]
CON2	34 (23) [0]	173 (102) [2]	73 (64) [6]	42 (21) [1]
Age of participants				
CON1 (SD) [range]	48.7 [25-67]	52.5 (14.1)	52.0 [19-80]	65.0 [44-86]
CON2 (SD) [range]		50.1 (14.5)		
Platform switching				
CON1	Yes	Yes	Yes	Yes
CON2	No	No	No	Yes
Insertion timing	Post-extractive	Post-extractive & healed sites	Post-extractive & healed sites	Healed sites
Load timing	Immediate	Immediate & delayed	Delayed	Immediate
Prosthesis design	ISCs & FPDs	ISCs. FPDs. FCDs & ODs	ISCs & FPDs	ODs
Identical macrotopography and microtopography	No	Yes	No	Yes

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

Variable	Study, Year			
	Crespi et al, 2009[51]	Esposito et al, 2015[52]	Felice et al, 2014[53]	Glibert et al, 2018[54]
Mean MBL				
CON1 (SD)	0.2 (0.43)	0.94 (0.84)	0.73 (0.59)	0.25 (0.37)
CON2 (SD)	0.17 (0.39)	1 (1.03)	0.84 (0.59)	0.31 (0.41)
MD (95% CI)	0.03 (-0.17 to 0.23)	-0.06 (-0.37 to 0.25)	-0.11 (-0.30 to 0.08)	-0.06 (-0.23 to 0.11)
P-value	.772	.702	.268	.491
Implant survival				
CON1 (%)	30 (100)	152 (98.70)	71 (100)	42 (100)
CON2 (%)	34 (100)	170 (98.27)	70 (95.89)	39 (92.86)
OR (95% CI)	NC	1.34 (0.22-8.13)	7.10 (0.36-139.95)	7.53 (0.38-150.46)
P	NA	.75	.198	.186
Biologic complications				
CON1 (%)	0 (0)	2 (1.30)	1 (1.41)	NR
CON2 (%)	0 (0)	1 (0.58)	1 (1.37)	
OR (95% CI)	NC	2.26 (0.20-25.21)	1.03 (0.06-16.77)	
P	NA	.507	.984	
Technical complications				
CON1 (%)	0 (0)	5 (3.25)	0 (0)	NR
CON2 (%)	3 (8.82)	10 (5.78)	0 (0)	
OR (95% CI)	0.15 (0.01-2.98)	0.55 (0.18-1.64)	NC	
P	.212	.281	NA	

Variable	Study, Year			
	Gultekin et al, 2013[55]	Hsu et al, 2016[56]	Kielbassa et al, 2009[57]	Kielbassa et al, 2009[57]
Intervention				
CON1	CC	CC	CC	CC
CON2	IFF	IFF	IFF	EH
N[c] of implants (participants) [dropouts]				
CON1	43 (21) [2]	13 (13) [0]	58 (32) [1]	59 (32) [1]
CON2	50 (21) [2]	13 (13) [0]	63 (30) [1]	41 (26) [4]
Age of participants				
CON1 (SD) [range]	41.3 [19-59]	58.5 (14.1)	49.5 (13.1)	49.5 (13.1)
CON2 (SD) [range]		56.9 (10.9)	46.9 (14.6)	49.9 (13.6)
Platform switching				
CON1	Yes	Yes	Yes	Yes
CON2	No	No	No	No
Insertion timing	Healed sites	Healed sites	Healed sites	Healed sites
Load timing	Delayed	Delayed	Immediate	Immediate
Prosthesis design	NR	ISCs	ISCs. FDPs & FCDs	ISCs. FDPs & FCDs
Identical macrotopography and microtopography	No	No	No	No
Mean MBL				
CON1 (SD)	0.35 (0.13)	0.21 (0.56)	0.95 (1.37)	0.95 (1.37)
CON2 (SD)	0.83 (0.16)	0.74 (0.47)	0.63 (1.18)	0.64 (0.97)
MD (95% CI)	-0.48 (-0.54 to -0.42)	-0.53 (-0.93 to -0.13)	0.32 (-0.22 to 0.86)	0.31 (-0.21 to 0.83)
P	<.001*	.015*	.246	.247
Implant survival				
CON1 (%)	43 (100)	13 (100)	56 (96.55)	57 (96.61)
CON2 (%)	50 (100)	13 (100)	60 (95.24)	40 (97.56)
OR (95% CI)	NC	NC	1.40 (0.23-8.26)	0.71 (0.06-8.13)
P-value	NA	NA	.489	.785
Biologic complications				
CON1 (%)	NR	0 (0)	1 (1.72)	1 (1.69)
CON2 (%)		0 (0)	1 (1.59)	1 (2.44)
OR (95% CI)		NC	1.09 (0.07-17.80)	0.69 (0.04-11.35)
P		NA	.953	.795

(*continued on next page*)

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

Variable	Study, Year			
	Gultekin et al, 2013[55]	Hsu et al, 2016[56]	Kielbassa et al, 2009[57]	Kielbassa et al, 2009[57]
Technical complications				
CON1 (%)	NR	NR	5 (8.62)	4 (6.78)
CON2 (%)			4 (6.35)	3 (7.32)
OR (95% CI)			1.39 (0.35-5.45)	0.92 (0.19-4.35)
P			.636	.918

Variable	Study, Year			
	Kielbassa et al, 2009[57]	Kim et al, 2019[58]	Menini et al, 2019[59]	Peñarrocha-Diago et al, 2013[60]
Intervention				
CON1	IFF	CC	IFF	CC
CON2	EH	EH	EH	EH
N^c of implants (participants) [dropouts]				
CON1	62 (30) [1]	11 (11) [1]	40 (20) [0]	72 (7) [2]
CON2	41 (27) [4]	11 (11) [1]	43 (20) [0]	69 (8) [1]
Age of participants				
CON1 (SD) [range]	46.9 (14.6)	NR [20-66]	64.0 [47-79]	56.9 [44-77]
CON2 (SD) [range]	49.9 (13.6)			
Platform switching				
CON1	No	Yes	No	Yes
CON2	No	No	No	No
Insertion timing	Healed sites	Healed sites	Post-extractive	Healed sites
Load timing	Immediate	Delayed	Immediate	Delayed
Prosthesis design	ISCs. FDPs & FCDs	ISCs	FCDs	FCDs & OD
Identical macrotopography and microtopography	No	Yes	Yes	No
Mean MBL				
CON1 (SD)	0.63 (1.18)	0.04 (0.63)	1.64 (0.77)	0.12 (0.17)
CON2 (SD)	0.64 (0.97)	0.59 (0.95)	1.53 (0.83)	0.38 (0.51)
MD (95% CI)	-0.01 (-0.49 to 0.47)	-0.55 (-1.22 to 0.12)	0.11 (-0.23 to 0.45)	-0.26 (-0.36 to -0.16)
P-value	.968	.126	.533	<.001*
Implant survival				
CON1 (%)	60 (96.77)	11 (100)	39 (97.50)	71 (98.61)
CON2 (%)	39 (95.12)	11 (100)	42 (97.67)	68 (98.55)
OR (95% CI)	1.54 (0.21-11.38)	NC	0.93 (0.06-15.36)	1.04 (0.06-17.03)
P-value	.673	NA	.959	.976
Biologic complications				
CON1 (%)	0 (0)	0 (0)	0 (0)	1 (1.39)
CON2 (%)	1 (2.44)	0 (0)	0 (0)	1 (1.45)
OR (95% CI)	0.22 (0.01-5.43)	NC	NC	0.96 (0.06-15.62)
P	.352	NA	NA	.976
Technical complications				
CON1 (%)	4 (6.45)	0 (0)	1 (2.50)	NR
CON2 (%)	3 (7.32)	2 (18.18)	2 (5.00)	
OR (95% CI)	0.87 (0.19-4.12)	0.17 (0.01-3.88)	0.53 (0.05-6.03)	
P	.864	.263	.606	

Variable	Study, Year			
	Pessoa et al, 2017[61]	Pieri et al, 2011[62]	Pozzi et al, 2014[63]	Sanz-Martín et al, 2017[64]
Intervention				
CON1	CC	CC	CC	CC
CON2	EH	IFF	EH	IFF
N^c of implants (participants) [dropouts]				
CON1	12 (12) [0]	19 (19) [1]	34 (34) [0]	33 (19) [6]
CON2	12 (12) [0]	19 (19) [1]	34 (34) [0]	28 (18) [4]
Age of participants				
CON1 (SD) [range]	63.1 [18-75]	45.8 [26-67]	52.2 [39-59]	57.7 (11.9)
CON2 (SD) [range]		46.6 [32-65]		59.7 (10.5)

(*continued on next page*)

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

Variable	Pessoa et al, 2017[61]	Pieri et al, 2011[62]	Pozzi et al, 2014[63]	Sanz-Martín et al, 2017[64]
	Study, Year			
Platform switching				
CON1	Yes	Yes	Yes	No
CON2	No	No	No	Yes
Insertion timing	Healed sites	Post-extractive	Healed sites	Healed sites
Load timing	Immediate	Immediate	Delayed	Delayed
Prosthesis design	FCDs	Screwed ISCs	Cemented ISCs	ISCs & FPDs
Identical macrotopography and microtopography	Yes	Yes	No	No
Mean MBL				
CON1 (SD)	0.17 (0.54)	0.19 (0.17)	0.51 (0.34)	0.26 (0.22)
CON2 (SD)	1.17 (0.44)	0.49 (0.25)	1.1 (0.52)	0.11 (0.2)
MD (95% CI)	-1.00 (-1.39 to -0.61)	-0.30 (-0.44 to -0.16)	-0.59 (-0.84 to -0.34)	0.15 (0.01-0.29)
P	<.001*	<.001*	<.001*	.037*
Implant survival				
CON1 (%)	12 (100)	18 (94.74)	34 (100)	33 (100)
CON2 (%)	12 (100)	19 (100)	34 (100)	26 (92.9)
OR (95% CI)	NC	0.32 (0.01-8.26)	NC	6.32 (0.29-137.37)
P	NA	.489	NA	.241
Biologic complications				
CON1 (%)	0 (0)	1 (5.26)	0 (0)	2 (6.06)
CON2 (%)	0 (0)	0 (0)	0 (0)	3 (10.71)
OR (95% CI)	NC	3.16 (0.12-82.64)	NC	0.54 (0.08-3.47)
P-value	NA	.489	NA	.514
Technical complications				
CON1 (%)	NR	0 (0)	NR	0 (0)
CON2 (%)		2 (10.53)		4 (14.29)
OR (95% CI)		0.18 (0.01-4.00)		0.08 (0.00-1.58)
P		.278		.097

CC, conical connection; CI, confidence interval; CON1, connection 1; CON2, connection 2; EH, external hexagon; FCDs, fixed complete dentures; FPDs, fixed partial dentures; IFF, internal flat-to-flat; ISCs, implant-supported crown; MD, mean difference; NA, not applicable; NC, not calculable; NR, not reported; ODs, overdentures; OR, odds ratio; SD, standard deviation.
*Significantly associated ($P<.05$).

methodological quality (conical versus external designs), prosthetic loading approach (internal flat-to-flat versus external), and insertion timing of the studies (conical versus internal flat-to-flat). The results were homogeneous and consistent with the overall analysis when only studies with low risk of bias, postextractive implant placement, and immediate prosthetic loading were selected (Supplemental Fig. 4, available online). The NMA model revealed statistically significant differences for the comparison between conical and external implant abutment interfaces (MD: -0.35 mm; 95% CI: -0.62 to -0.08; P=.011) (Table 3).

Ten of the RCTs included evaluated the prosthetic complications rate in 834 participants (1246 implants) (Table 2 and Fig. 3D).[47,50-53,57-59,62,64] Statistically significant differences were found between conical and external implant abutment connections in the PMAs of direct comparisons (OR: 0.36; 95% CI 0.14 to 0.92; P=.03; I^2: 21%) (Table 3 and Supplemental Fig. 5, available online) and in the NMA model (OR: 0.35; 95% CI 0.13 to 0.95; P=.038) (Table 3). Regarding treatment ranking, conical implant abutment designs provided the best results for implant survival (82.9%), peri-implant MBL (96.3%), and prosthetic complications (93.9%) (Fig. 4).

For all the outcomes measured (implant survival, peri-implant MBL, and prosthetic and biologic complication rates), no significant inconsistency was identified within the evidence networks as a whole (P>.05) (Supplemental Table 4, available online). In addition, the direct estimate of the summary effect did not differ from the indirect estimate in most comparisons.

DISCUSSION

The NMA tested whether the implant abutment connection had an influence on the outcome of an implant-prosthetic rehabilitation. The results indicated that conical connection groups were associated with significantly less peri-implant MBL and fewer prosthetic complications than external interfaces, without compromising implant survival; thus, the first null hypothesis was partially confirmed and the second rejected.

Nevertheless, the results of this NMA should be treated with caution because of uncontrolled factors that

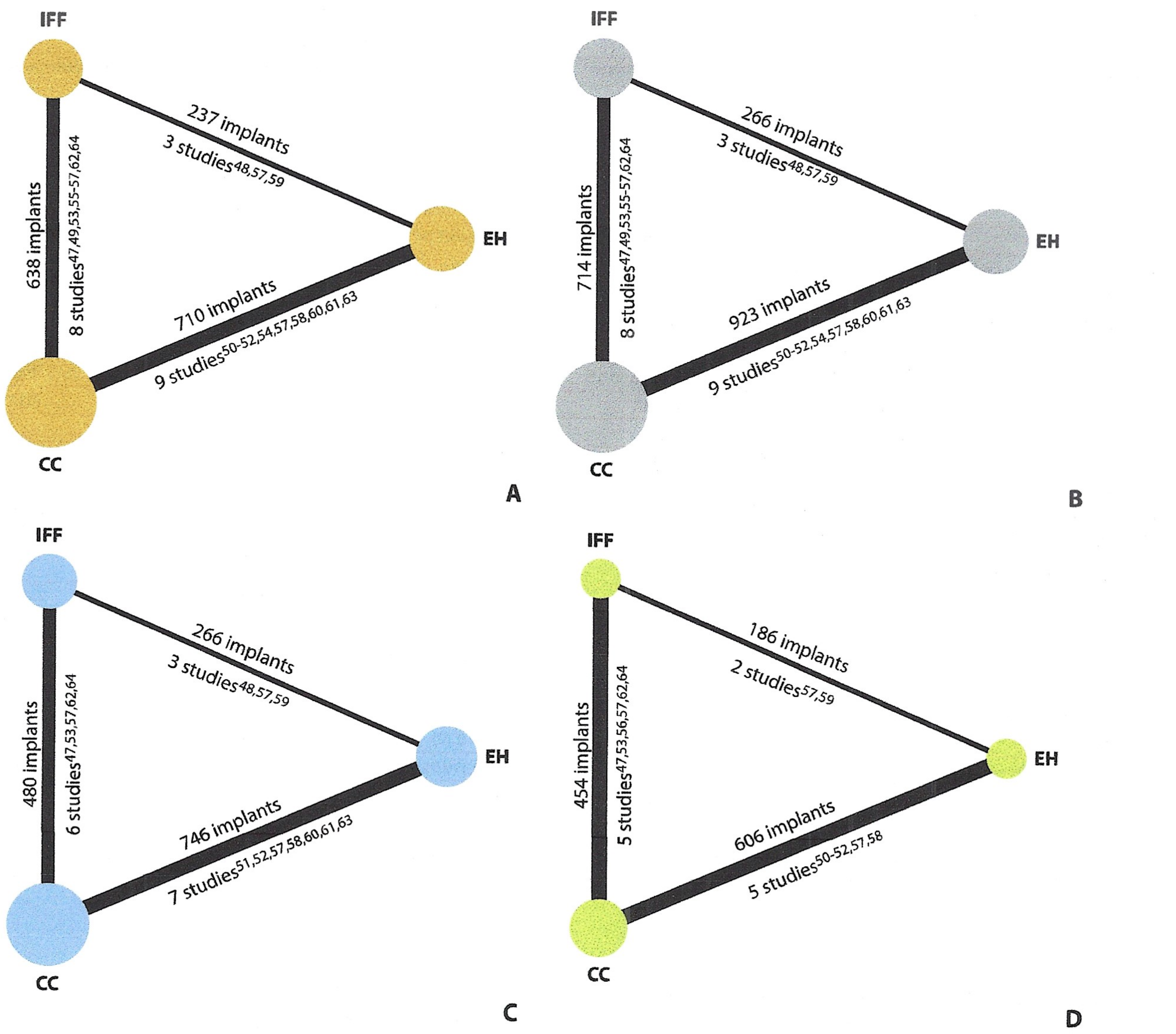

Figure 3. Network meta-analysis graph (net diagram). Each node represents one implant abutment connection category (cluster). A, Implant survival. B, Biologic complications. C, Peri-implant marginal bone loss. D, Prosthetic complications. CC, conical connection; EH, external hexagonal; IFF, internal flat-to-flat.

may also have had a direct impact on the outcomes assessed. Uncontrolled factors included implant-related (diameter, length, macroscopic design, surface treatment, and cervical roughness of the implant),[10,25,26] surgery-related (including clinical situation, flap design, surgical trauma, insertion depth in relation to the alveolar crest, and re-establishment of biologic width),[13] prosthesis-related (design, materials and configuration, occlusal forces, micromovements of the abutment, and loading protocol),[11] and patient-related (smoking habit, systemic disease, oral microbiology, individual bone pattern, and peri-implant mucosal tissue thickness).[12,14] Only 8 of the 18 selected studies[47,48,54,58,59,61,62,64] assessed the impact of the implant abutment connection design when using implants with identical macrodesigns and microdesigns. Such factors could have affected the reliability and quality of the results, thus compromising the transitivity assumption.[33] Consequently, subanalyses were used to assess the impact of the interface in association with some of these confounders.

Bias was another challenge in the review, as nearly 3-quarters of the trials presented a potential risk of bias (Fig. 2). In addition, because few of the articles that were reviewed compared the same interventions, publication bias was not assessed.[35] In addition, internal validity might be compromised because most of the RCTs were conducted in multiple private practices,[47,48,52,53] and in 12 studies, implant placements were performed by several surgeons and/or prosthodontists, leading to a potential operator-dependent bias.[47-50,52,53,57-60,63,64] Finally, a priori sample size calculation was only determined in 6 of

Table 3. Results for comparisons of implant abutment connections

Variable	PMA MBL (mm) Number of S tudies	Number of Implants	MD (95% CI)	P	I²	NMA MBL MD (95% CI)	P
CC vs							
IFF	8	638	-0.27 (-0.53 to 0.02)	.04[a]	95%	-0.20 (-0.48.0.07)	.154
EH	9	710	-0.25 (-0.45 to -0.05)	.01[a]	81%	-0.35 (-0.62.-0.08)	.011[a]
IFF vs							
EH	3	237	-0.33 (-1.18 to 0.53)	.46	95%	-0.14 (-0.48.0.19)	.420

Variable	PMA Survival Number of studies	Number of Implants	Survival Rate[b]	OR (95% CI)	P	I²	NMA Survival OR (95% CI)	P
CC vs								
IFF	8	714	326/330 vs 363/384	2.21 (0.66-7.45)	.20	15%	1.86 (0.78-4.39)	.240
EH	9	923	454/461 vs 452/462	1.32 (0.48-3.66)	.59	0%	1.40 (0.64- 3.06)	.449
IFF vs								
EH	3	266	121/124 vs 139/142	1.30 (0.25-6.62)	.75	0%	0.76 (0.29-1.99)	.695

Variable	PMA Biologic Complications Number of Studies	Number of Implants	Biologic Rate[c]	OR (95% CI)	P	I²	NMA Biologic Complications OR (95% CI)	P
CC vs								
IFF	6	480	7/239 vs 6/241	1.05 (0.26-4.22)	.89	0%	1.26 (0.48-3.35)	.654
EH	7	746	4/372 vs 3/374	1.23 (0.27-5.66)	.79	0%	1.00 (0.36-2.77)	>.999
IFF vs								
EH	3	266	0/142 vs 1/124	0.22 (0.01-5.73)	.35	NA	0.79 (0.22-2.80)	.730

Variable	PMA Prosthetic Complications Number of Studies	Number of Implants	Prosthetic Rate[2]	OR (95% CI)	P	I²	NMA Prosthetic Complications OR (95% CI)	P
CC vs								
IFF	5	454	5/226 vs 11/228	0.47 (0.11-1.92)	.29	26%	0.63 (0.49-1.52)	.109
EH	5	606	10/301 vs 29/305	0.36 (0.14-0.92)	.03[a]	21%	0.35 (0.13-0.95)	.038[a]
IFF vs								
EH	2	186	5/102 vs 5/84	0.75 (0.20-2.80)	.67	0%	0.72 (0.25-2.10)	.556

CC, conical connection; CI, confidence interval; EH, external hexagon; IFF, internal flat-to-flat; MD, mean difference; NA, not applicable; NMA, network meta-analysis; OR, odds ratio; PMA, pairwise meta-analysis. [a]Significantly associated (*P*<.05). [b](number of surviving implants)/total randomized. [c](number of prosthetic complications)/total randomized.

the studies,[50,55,57,61,63,64] leading to a potentially high type 2 error (failure to reject a false null hypothesis) in the remaining trials.

Previous studies have reported that internal interfaces, particularly conical ones, are more favorable than external connections,[21,23,27,28] possibly explaining the results observed in the present meta-analysis, which were consistent with those reported in a recent NMA in terms of peri-implant MBL.[29] However, 9 of the articles included in the present review were not included in that article. In addition, 5 articles selected for that article were excluded in the present study: 4 were multiple reports on the same participants,[39-42] and 1 was a prospective observational study.[16] Additionally, in the previous meta-analysis, a quantitative analysis was not performed on the complications (technical or biologic) or the survival rate.

Although survival of an implant is the ultimate goal, maintaining bone levels is a key criterion for implant success. While peri-implant MBL was observed in all the implant abutment connections assessed, in most of the selected studies, it lay within the success criteria range proposed in generally accepted classifications.[4,5] Accordingly, further long-term RCTs with larger sample sizes comparing implants with the same macrotopography and microtopography are needed to elucidate the results obtained. Moreover, new success criteria should be developed based on MBL rates over certain time intervals rather than on the peri-implant MBL value after a given time.[6]

As the period in function increases, so does the risk of developing a complication.[30] For these reasons, although a minimum of 5 years of follow-up is recommended for implant survival and success assessment,[8] the present

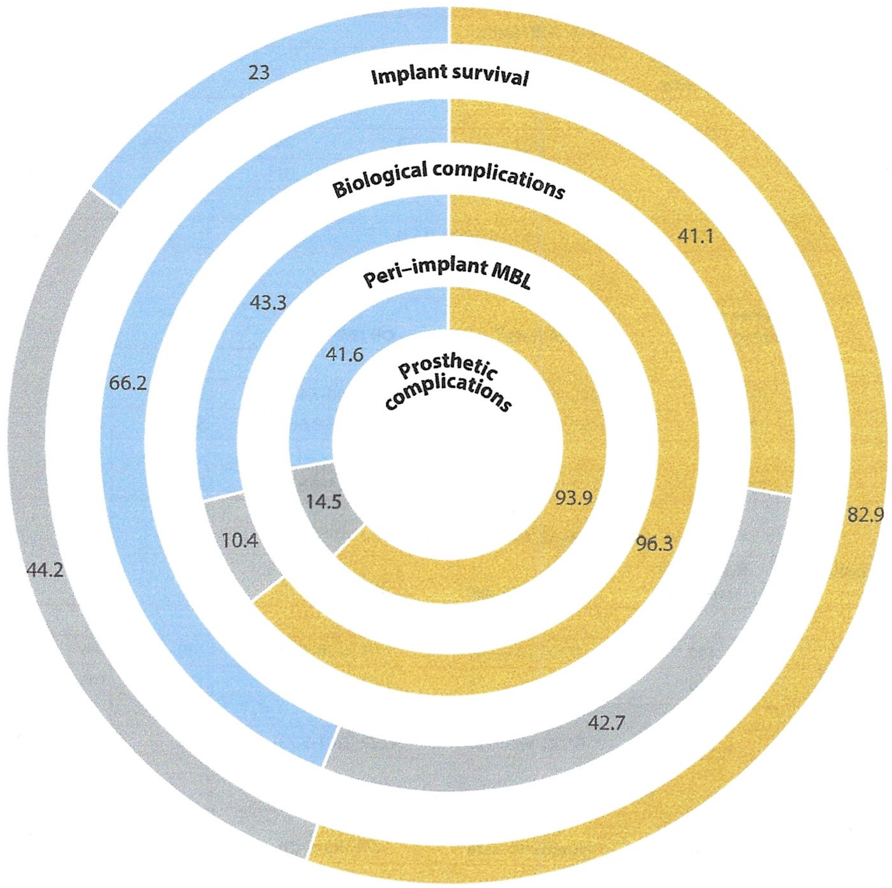

Figure 4. Illustration of surface under cumulative ranking (SUCRA) analysis for implant survival, biologic complications, peri-implant marginal bone loss, and prosthetic complications. MBL, marginal bone loss.

authors decided not to introduce time as another potential confounding variable. In fact, only 1 of the selected studies mentions a follow-up period of 5 years[41]; the authors reported a steady state in crestal bone levels between 1 and 5 years after loading, with a pattern similar to that of peri-implant MBL between conical and external interfaces.[41] Interestingly, no mechanical complications were reported in the external group, but conical connections tended to develop more peri-implant diseases, although the difference was not statistically significant.

Although the implant abutment connection could be considered a risk factor for late implant failure, it has been suggested that its impact on the risk of developing biologic and/or mechanical complications is greater.[19] The present review confirms this because no differences in terms of survival were found among the connections. However, future long-term RCTs should be conducted to confirm this absence of association.

Knowledge of the mechanical and functional limitations of implant abutment connection types is essential because they might be directly related to the success of the procedure.[30] Despite the short follow-up period, conical interfaces exhibited a significantly lower risk of developing prosthetic complications in comparison with external designs. Nevertheless, several confounding factors such as screw preload torque and abutment materials could have influenced the outcomes.[20,31]

CONCLUSIONS

Based on the findings of this systematic review and network meta-analysis of RCTs, the following conclusions were drawn:

1. Conical implant abutment designs provided the best results for implant survival, peri-implant MBL, and prosthetic complications after 1 year of loading as assessed with NMA.
2. For peri-implant MBL and prosthetic complications, conical interfaces showed significant differences when compared with external hexagonal connections.

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