The Impact of Crown-to-Implant Ratio on Marginal Bone Loss: A Meta-Analysis on Human Prospective Clinical Trials

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Introduction: Multiple systematic reviews have documented the efficacy of short implants in alveolar sites with moderate vertical height atrophy. Short implants in sites with alveolar ridge atrophy are often restored with elongated restoration, leading to relatively high crown-to-implant (C/I) ratio. It is important to determine whether the increased C/I ratio has any detrimental biological effects on peri-implant bone. To that end, this systematic review sought to examine the long-term effects of C/I ratio on peri-implant marginal bone loss, as reported by prospective clinical trials. **Materials and Methods:** Electronic search of 3 databases and hand searching were performed to identify prospective human trials that had reported both crown/implant ratio and associated peri-implant marginal bone loss with the follow-up of at least 36 months. Random-effect meta-analysis was performed to analyze weighted mean difference (WMD) and confidence interval (CI) for recorded variables according to PRISMA guidelines. Weighted linear regression model was used to evaluate R2 value. **Results:** Publication search yielded 1134 records and after evaluating titles, abstracts and full-texts, 8 prospective trials were included for quantitative data synthesis. Meta-analysis for the comparison of MBL among selected studies showed a WMD of 0.01 mm, with a 95% CI= 0.08 mm to -0.07 mm (p= 0.90). Results failed to detail any significant correlation between C/I ratio and marginal bone loss. Weighted linear regression model and low (0.214) R2 ratio suggested a lack of correlation between MBL and C/I ratio. **Conclusion:** Basad on the available evidence, there is no relationship between C/I ratio within the range tested and marginal bone loss.

Keywords: Systematic Review; Evidence-based Dentistry; Short Dental Implants

Introduction

Insufficient bone volume in the posterior sites due to atrophy of the alveolar ridge or pneumatization of maxillary sinus often pose a challenge to clinicians for placing dental implants. Such situations may require additional and complex surgical interventions (1) to augment insufficient bone volume that may result in longer treatment times, and higher morbidity and costs. On the other hand, such augmentation procedures show a great deal of variability in terms of clinical outcomes (2). An alternative therapy in situations with limited amounts of bone available is the installation of short implants, defined as implants with a length of 8 mm (3).

The use of short implants substantially simplifies the restoration of posterior atrophied ridges and minimizes advanced and complex surgical interventions (4) Recent systematic reviews (5, 6) indicate the survival rate of short implants are comparable to longer ones. Short implants are often restored with elongated restoration, leading to relatively high crown-to-implant (C/I) ratio. In contrast to findings (7-9) with natural dentitions demonstrating that c/r ratio does not influence the clinical performance of tooth-supported reconstructions under healthy conditions, clinicians tend to insert the longest implants possible, presuming a higher success rate with increasing crown-to implant length ratio (c/i ratio).

The C/I ratio has been defined as two distinct categories namely anatomical and clinical. For anatomical C/I ratio, the length of the crown is defined, as the distance between the implant platform and crown top peak, and the implant length is the distance between the most apical point of the implant and the implant platform. On the other hand, for the clinical C/I ratio, the length of the crown is determined as the distance between the first bone-to-implant contact and the most coronal point of the restoration, and the implant length is the distance between the most apical point of the implant and the first bone-to-implant contact (10).

The potential for higher crown-to-implant (C/I) ratios might be unavoidable with the use of short implants (10) that may be detrimental to biologic and/or mechanical implant success. The stability of peri-implant hard and soft tissues is one of the most critical factors for long-term implant maintenance and function, therefore; It is important to determine whether the increased C/I ratio has any detrimental biological effects on peri-implant bone.

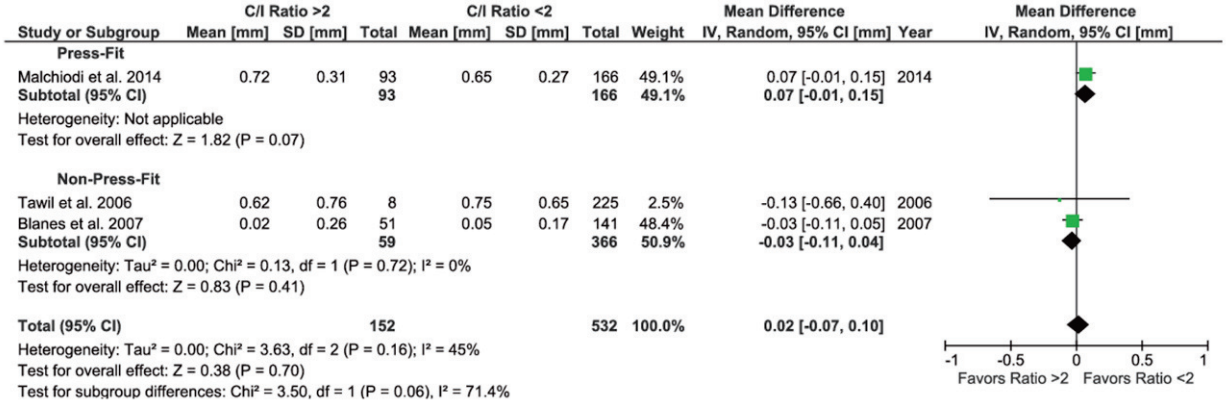


Figure 1. Meta-analysis for the comparison of MBL among selected studies. For press-fit subgroup, the WMD was 0.07 mm, with a 95% CI=-0.01 mm to 0.15 mm (*P*=0.07). For non-press-fit subgroup, the WMD was -0.03 mm, with a 95% CI=-0.11 mm to 0.04 mm (*P*=0.41). For combined analysis, the WMD was 0.02 mm, with a 95% CI=-0.07 mm to 0.10 mm (*P*=0.70). No statistically significant difference between groups with C/I ratio ≥2 and with C/I ratio <2 was detected in any of the analyses

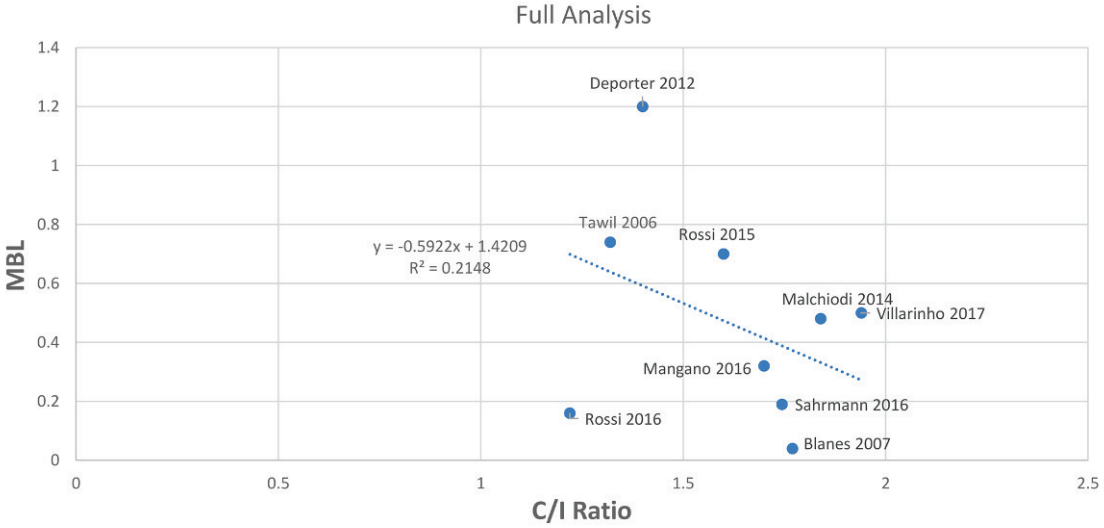


Figure 2. Result of weighted linear regression. The regression analysis showed an extremely small R2 ratio (0.215), indicating an unpredictable correlation between MBL and related C/I ratio

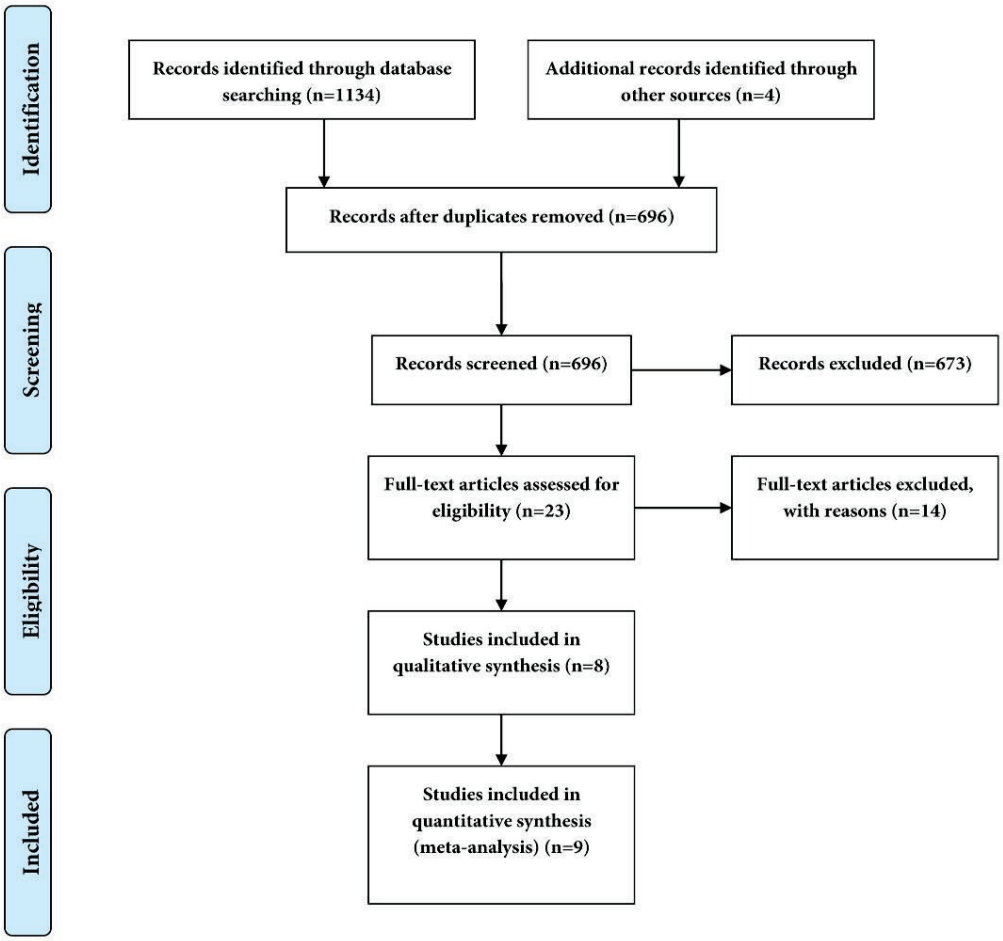
The literature is controversial in regards to data on the effects of crown-to-implant- ratio on marginal bone loss. One recent systematic review (11) concluded that within a certain range, increased C/I ratio has an inverse relationship with marginal bone loss. This finding might be as a result of inclusion of multiple studies with different designs and minimal follow-up periods. On the other hand, a prospective clinical trial (12) with an intermediate long-term follow-up period reported direct effect of increased C/I ratio on crestal bone loss. Hence, this systematic review sought to examine the long- term effects of C/I ratio on peri-implant marginal bone loss, as reported by prospective clinical trials.

Materials and Methods

The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement was used in this review (13).

Patient, intervention, comparison, outcome (PICO) question

P: Healthy patients receiving short or long dental implants, I: Human prospective clinical trials reporting data on marginal bone loss relative to C/I ratio, ≥10 patients and a follow-up period of at least 36 months. C: The effect of C/I ratio ≥2 on marginal bone loss compared to that of C/I ratio ≤2 O: Weighted



Supplemental Figure 1. PRISMA Flow-chart illustrating study selection for systematic review

mean difference (WMD) of marginal bone loss between the implants with C/I ratio ≥ 2 and implants with C/I ratio≤.

Search strategy

Electronic searches of databases namely PubMed/MEDLINE, EMBASE and Dentistry and Oral Sciences Source were performed to identify published peer-reviewed studies in English up to September 2017. For the search in the PubMed, the search terms were as follows, where mh represents the MeSH terms and tiab represents title and/or abstract: ("short implant"[mh] OR "short dental implants"[tiab] OR "alveolar bone atrophy"[mh] OR "crown to implant ratio"[tiab] OR " marginal bone loss"[tiab] OR "C/I ratio"[mh] OR "implant success"[tiab] OR "crestal bone resorption"[tiab]) AND ("dental implants"[mh] OR "bone loss"[mh] OR "partially edentulous"[mh] OR "single crown"[tiab] OR "complication"[tiab] OR "dental prosthesis"[tiab] OR "technical complication"[tiab] OR "bone loss"[tiab] OR "survival rate"[tiab]).

A hand search was also carried out in dental and implant-related journals from January 2000 to September 2017, including Clinical Oral Implants Research, Journal of Clinical Periodontology, Journal of Dental Research, Journal of Periodontology, Clinical Implant Dentistry and Related Research, International Journal of Oral and Maxillofacial Implants, Implant Dentistry, International Journal of Oral and Maxillofacial Surgery, Journal of Oral and Maxillofacial Surgery, Journal of Prosthetic Dentistry, International Journal of Prosthodontics, Journal of Oral Implantology, and International Journal of Periodontics and Restorative Dentistry. European Journal of Oral Implantology was searched from winter 2008 to winter 2017 issues. Furthermore, a search in the references of included papers was conducted for

Table 1. Summary of the features of the included studies

Author	Study Design	F/U period (months)	Patients Features			Implant Features					Type of crown to implant ratio	Prosthetic features			
			N	Age (Year)	Smoker (%)	Length (mm)	Survival rate (%)	Number & Location	Implant type/ Surface	Platform Surface		Splinted/None Splinted	Connection	Restoration	Antagonist
Tawil et al. (2006)	Prospective	53	80	53.6	N/A	≤ 10	N/A	199 overall	Screw type/Turned	S	Anatomic	Splinted & None splinted	External	FPD,S	N/A
Blanes et al. (2007)	Prospective	72	83	60.6	16.80%	6,8,10	97.9	139 Mandible, 53 Maxilla	153 (79.7%) hollow-screw, 26 (13.5%) hollow-cylinder, nine (4.7%) solid screw, four (2.1%) reduced diameter screw/TPS	S	Anatomic & Clinical	Splinted & None splinted	Internal	FPD,S	N/A
Deporter et al. (2012)	Prospective	120	48	20-72	None	7,9	95.5	48 Mandible	Press fit/ sintered porous-surfaced (SPS)	S	Anatomic	Splinted & None splinted	Internal	S	Teeth ,Implants
Malchiodi et al. (2014)	Prospective	36	136	58.9	37.5	5,7,9,12	98.8	100 Mandible, 159 Maxilla	Press fit/sintered porous-surfaced (SPS)	S	Anatomic & Clinical	Splinted & None splinted	Internal	FPD,S	N/A
Rossi et al. (2015)	Prospective	60	35	51	28	6	95	N/A	Screw type/SLActive	S	Anatomic	Non splinted	Internal	S	N/A
Rossi et al. (2016)	RCT	60	30 30	48.4 47.7	20 23.3	6 10	86.7 96.7	18 Mandible, 12 Maxilla 15 Mandible, 15 Maxilla	Screw type/SLA	S	Anatomic	Non splinted	Internal	S	23 natura l 6 ceramic 1 acrylic 21 natural 8 ceramic 0 acrylic 1 metal
Mangano et al.2016	Prospective	60	51	59.8	25.4	6.5	97	44 Mandible, 24 Maxilla	Locking- taper	R	Anatomic	Splinted & None splinted	Internal	S	N/A
Sahrmann et al.(2016)	RCT	36	41 40	52 58	37 33	6 10	98 100	10 Mandible, 31 Maxilla 44 Mandible, 24 Maxilla	SLA	S	Anatomic	Single crowns	Internal	S	Teteth, implants
Villarinho et al.2017	Prospective	36	20	52	N/A	6	91.3	23 Mandible , 23 Maxilla	SLA	S	Anatomic	Splinted & None splinted	Internal	FPD,S	Teeth, Implants

Supplemental Table 1. Risk assessment of publication bias for the included RCTs

Criteria	Rossi *et al.*	Sahrmann *et al.*
Representative of general population	Y	Y
Allocation concealment method	Y	Y
Examiner masked	N	N
Calibration (Intra/inter-examiner)	Y	Y
Defined inclusions/exclusions	Y	Y
Correction for confounding factors	Y	Y
Appropriate statistics methods	Y	Y
All patients accounted for at the end of study	Y	Y
Analysis accounts for patient losses	Y	Y
Estimated potential risk of bias	Unclear	Unclear

Y: YES, N: NO, NA: Not applicable

publications that were not electronically identified. One examiner (VK) performed the search strategy. The screening process is shown in Figure 1. Reviews and case reports were excluded, but the bibliographies of these studies were screened for potential articles to be included.

Inclusion criteria

Studies included in this review were prospective human clinical trials published in English, had treated ≥10 implants in at least 10 patients, ≥36 months follow-up that had reported mean C/I ratio and relative marginal bone loss. Screw shaped implants, either smooth or rough surface, and press-fit implants were included.

Data extraction

Two reviewers (VK and MA) reviewed the papers that met the inclusion criteria and extracted and processed data for analysis. The level of agreement between the reviewers regarding study inclusion was calculated using kappa statistics. If any disagreement was found, an agreement was obtained following a discussion. Characteristics of the included studies and summary of the reconstructive outcomes of the studies evaluated were extracted. If indicated, authors of the potentially qualified papers were contacted for more detailed data.

Quality assessment

The PRISMA (Preferred Reported Items for Systematic Reviews and Meta-Analysis) statement was followed to ensure proper methodology. For non-randomized controlled clinical trials, the Newcastle-Ottawa scale (NOS) was used to assess the quality of such studies for a proper understanding of nonrandomized studies (14). Two reviewers assessed the NOS score independently. The scale includes 8 items that cover three categories: (A) Sample selection (adequate definition and selection of cases and controls); (B) ability to compare study arms and (C) outcome measurement (assessment of same method exposure for all samples and non-response rate). Satisfaction of each item awarded a point to studies. Maximum score was 9 points, and a score ≥6 indicated high quality study whereas a score <6 indicated low quality study. Discrepancies in the score were resolved through discussion by the reviewers. For randomized controlled trials, the following criteria modified from the randomized clinical trial checklist of the Cochrane Center and the CONSORT statement (15) were used: representative of general population, defined inclusions/exclusions, randomization methods, allocation concealment method, masking of the examiner, intervention different only, participants drop-out and analysis accounts for patient losses. The degree of bias was categorized as: low risk if all the criteria were met, unclear riskwhen only one criterion was missing and high risk if two or more criteria were missing. One reviewer (VK) assessed all the included articles and another examiner (MA) confirmed the results.

Data analysis

The primary outcome was the difference of MBL around implants with C/I ratio ≥2 and with C/I ratio <2. The pooled weighted mean difference (WMD) of MBL was estimated using a computer program (RevMan version 5.0, The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, 2008). The contribution of each article was weighed. Random effects meta-analyses of the selected studies were applied to avoid bias being caused by methodological differences between studies. Forest plot was produced to graphically represent the difference in outcomes of C/I ratio ≥2 and C/I ratio <2 groups for all included studies using implant as the analysis unit. A p value= 0.05 was used as the level of significance. Heterogeneity was assessed with chi-square test and I^2 test, which ranges between 0% and 100% and lower values represent less heterogeneity. To avoid the bias from combining different designed implants, subgroup meta-analysis with the same implant design (press-fit or non-press-fit implants) was performed. In addition, the funnel plot was used to assess the presence of the publication bias. If a high heterogeneity was detected, regression analysis would be performed to analyze the potential impact of confounding factors. The reporting of these meta-analyses adhered to the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) statement (16).

To further analyze the effect of C/I ratio on MBL, weighted linear regression model was introduced to evaluate R2 value, using studies as the analysis unit.

Table 2. Summary of the investigated Outcomes for the included studies

No	Author	#implants	Mean C/I ratio	Subgroups C/I ratio	Mean marginal bone loss	Subgroups Marginal bone loss(mm)
1	Tawil *et al.* (2006)	30	ND	<1 (0.88±0.15	0.74±0.65	0.88±0.74
		70		1.00 to 1.20 (1.09±0.06)		0.75±0.71
		58		1.21 to 1.40 (1.30±0.06)		0.73±0.58
		29		1.41 to 1.60 (1.49±0.04)		0.77±0.71
		38		1.61 to 2.00 (1.80±0.11)		0.66±0.54
		8		>2.00 (2.36±0.18)		0.62±0.76
2	Blanes *et al* (2007)	8	1.77 ± 0.56	0-0.99	0.04±0.2	0.34±0.27
		133		1-1.99		0.03±0.15
		51		≥2		0.02±0.26
3	Deporter *et al*(2012)	48	1.4	NA	1.2mm±ND	N/A
4	Malchiodi *et al.* (2014)	96	1.84±0.65	<1.5	0.48 ± 0.29	0.6
		70		1.5-2.0		0.64
		93		>2.0		0.72±0.31
5	Rossi *et al.* (2015)	40	1.6	NA	0.7±0.6	NA
6	Rossi *et al.* (2016)	30	1.49±0.36	NA	0.14	NA
		30	0.95±0.21		0.18	
7	Mangano *et al.* (2016)	51	1.70±0.25	2<	0.32	0.38
		17		>2		0.48
8	Sahrmann *et al.* (2016)	40	1.48±0.33	NA	0.19±0.63	NA
		38	0.86±0.18		0.33±0.71	
9	Villarinho *et al.* (2017)	46	1.6±0.3	NA	0.3±0.5	NA

Results

Study selection

Initial screening yielded a total of 1134 records, 440 of which were identified as duplicates. Additionally, 4 more articles were found through manual screening. After the titles and abstracts were reviewed, 23 articles were identified as full-text articles. Full text of these articles was obtained and thoroughly evaluated. Of these, only 8 articles fulfilled the inclusion criteria and subsequently were included in the qualitative synthesis (Figure 1 and Table 1). The kappa value for inter-reviewer agreement for potentially relevant articles was k=0.87 (titles and abstracts) and k=0.93 (full-text articles), indicating a consistent agreement between the two reviewers.

Features of included articles

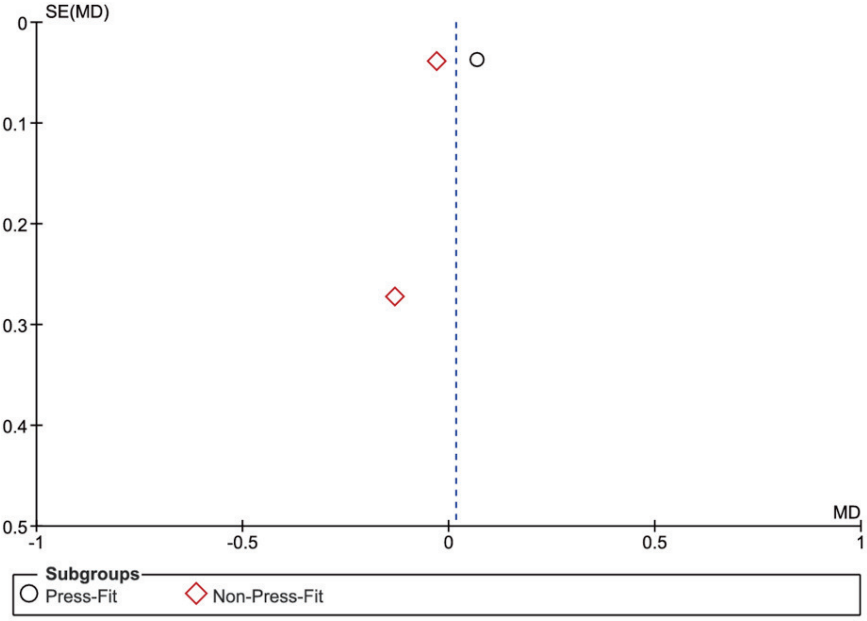
Two RCTs (17, 18) and seven prospective clinical trials (12, 19-24) were included for final analysis. Information regarding the age of the patients was provided by all studies. All of the included studies but one (19) reported the survival rate of the implants and smoking status of the patients (Table 1).

Results of risk of bias assessment

Two included RCTs were identified with an unclear risk of bias. (supplemental Table 1) For non-randomized included studies, assessment of the methodological quality of each article is presented in supplemental Table 2. Of the 6 studies that met the inclusion criteria, 2 (19, 20) were considered to be of low quality, with NOS scores < 6. On the contrary, four studies (12, 21-23) were of relatively high quality, with NOS scores ≥ 6.

Results of meta-analysis for MBL

Three studies (12, 19, 21) reported data on MBL of implants with C/I ratio ≥2 and with C/I ratio <2. Of these four studies, two studies [12] analyzed implants with press-fit design and another two studies (19, 2)1 investigated implants with non-press-fit design. The statistical results from each of the selected studies were converted into effect sizes and combined in the meta-analysis. For press-fit subgroup, the WMD was 0.07 mm, with a 95% CI=-0.01 mm to 0.15 mm (P=0.07). For non-press-fit subgroup, the WMD was -0.03 mm, with a 95% CI=-0.11 mm to 0.04 mm (P=0.07). For non-press-fit subgroup, the WMD was -0.03 mm, with a 95% CI=-0.11 mm to 0.04 mm (P=0.41). For=0.41). For combined analysis, the WMD was 0.02 mm, with a 95% CI=-0.07 mm to 0.10 mm (P=0.70). No statistically significant difference between groups with C/I ratio ≥2 and with C/I ratio <2 was detected in any of the analyses.



Supplemental Figure 2. Funnel plot of meta-analysis of MBL among selected studies

In addition, all comparisons presented a low to moderate heterogeneity among studies. For press-fit subgroup, only one article was included, therefore the heterogeneity could not be assessed. For non-press-fit subgroup and combined analyses, the p value for chi-square test presented 0.72 and 0.16, and I^2 test was 0% and 45%, respectively (Figure 1). This result represented a minimal heterogeneity among the included studies; therefore regression analysis was not conducted. The funnel plot of meta-analysis of MBL among selected studies was presented as supplemental Figure 2. However, since a small number of the included studies was noted, the symmetry of the funnel plot could not be accurately determined.

The result of weighted linear regression was reported as Figure 2. Based on the analysis outcome, when C/I ratio is ranged between 1.22 and 1.94, limited MBL (<1.2 mm) could be expected. However, the regression analysis showed an extremely small R2 ratio (0.214), indicating an unpredictable correlation between MBL and related C/I ratio.

Discussion

For decades, placement of long implants was advocated for minimizing the amount of strain at the peri-implant marginal bone and was considered the standard of care (25, 26), however, the validity of this paradigm started to be questioned soon after the introduction of implant rough surface configurations. (5, 6, , 27) The results of the present review demonstrate that neither clinical nor anatomical C/I ratio within the tested range are reliable predictors for future marginal bone loss.

The effect of increased C/I ratio on prosthetic components and increasing the risk of technical complications such as screw loosening, cement failure, and framework fracture has been hypothesized earlier (28). However, a previous review (26) failed to find any comparative clinical data correlating C/I ratio and technical complications of implant supported reconstructions . In the present review, one randomized controlled trial (18) reported 3.8% more technical complications in the group with higher C/I ratio which was not statistically significant whereas the results of another included RCT (17) did not demonstrate any technical complication in the group with higher C/I ratio. These findings might be in part as a result of improvements and innovations of implant components in the past decade. Another cohort study (23) reported 12% prosthetic complication in the implants with C/I ratio >2 compared to 6% in implants with C/I <2 however this difference was statistically significant. It has been shown (29) that the use of internal connection might minimize prosthetic complications. Interestingly, all the abovementioned studies had utilized implants with internal connections.

Supplemental Table 2. Risk assessment of publication bias for the included prospective case series

Quality criteria	Selection				Comparability		Exposure			Total points (Maximum 9)
	Representativeness of the exposed cohort	selection of non exposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study	Comparability based on design or analysis		Assesment of outcome	Enough exposure time	Adequacy of follow-up	
Tawil et al.2006	¢	¢			¢		¢		¢	6
Blanes et al.2007	¢	¢			¢	¢	¢	¢	¢	7
Deporter et al.2012	¢	¢			¢			¢	¢	5
Machiodi et al.2014	¢	¢	¢		¢	¢	¢	¢	¢	8
Rossi et al.2015	¢	¢	¢		¢	¢	¢	¢	¢	8
Mangano et al.2016	¢	¢			¢	¢	¢	¢	¢	7
Villarinho et al.2017	¢	¢	¢		¢	¢	¢	¢	¢	8

In light of the data from multiple systematic reviews (5, 6) suggesting similar survival rates of the short implants compared to longer ones, the abovementioned controlled trials (17, 18) have interestingly reported different results in this matter. While in one study (18) the survival rate of shorter implants with higher C/I ratio was 98% compared to 100% for longer implants, significantly lower survival rate for shorter implants was reported (86.7% Vs 96.7%) in the latter (17). Given the fact that both studies had utilized the same implant system for single implant borne restorations, one explanation for this finding might be longer follow-up period in one of the studies (17).It should be noted that in the abovementioned study (17), a sudden loss of stability of the implant/ crown unit was noticed in all failures indicating that the implant loss was probably due to a fracture of the supporting bone and not progressive bone loss.

Agreements and disagreements with previous studies/reviews

In contrast to a recent systematic review (11) that concluded within a certain range of C/I, less marginal bone loss could be expected as the value increases, based on the value of coefficient of determination (R2), the results of the regression analysis in the present review demonstrate that C/I is not a good predictor for future marginal bone loss.

Implications for clinical practice

Taking the data of this review and previous reports into consideration, it can be assumed that C/I ratio of about 2 may not result in marginal bone loss beyond expected physiologic annual bone loss. Although no statistically significant difference between groups with C/I ratio ≥2 and with C/I ratio <2 was detected in any of the analyses, the results should be interpretad with caution. The mean C/I ratio in all of the included studies was <2. In clinical situations where short implants are used due to atrophic alveolar bone of limited height, most likely those short implants would be loaded with long crown crowns to compensate for the bone resorption. The outcomes of this additional increased C/I ratio may be different to that of reported of most of the included studies. Of interest, one study (12) reported more crestal bone loss and less success when C/I ratio exceeded certain value (3.1).

Limitations

Some limitations of the present review must be addressed. The search was limited to English language that might potentially introduce a selection bias. Additionally, the included studies were mostly not controlled trials with consistent methodologies that may represent lower level of evidence.

Conclusion

Within the limitations of the present study and the range tested, it can be concluded that the C/I ratio did not influence the clinical performance of implants. Therefore, implant restorations with an increased C/I ratio may be used in the posterior region, however, further studies, preferably including higher C/I ratios, are indicated.

Conflict of Interest: 'None declared'.

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