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SYSTEMATIC REVIEW

A meta-analysis of the accuracy of different measuring techniques to evaluate the marginal and internal gap of a fixed dental prosthesis: The American Academy of Fixed Prosthodontics, Research in Fixed Prosthodontics Committee

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ABSTRACT

Statement of problem. Marginal gaps and the internal adaptation of a fixed dental prosthesis are important parameters related to a successful clinical outcome. Several methods have been used to measure these 2 parameters. In addition to conventional analog methods, digital methods have recently been developed. Nevertheless, statistical comparisons of these different approaches are scarce.

Purpose. The purpose of this study was to evaluate the results of the various measuring methods reported in the current literature and compare their results.

Material and methods. An electronic literature search comprising articles published from January 1990 to June 2023was conducted through the MEDLINE (PubMed) and Web of Science databases. After a quality assessment screening, 17 articles were identified for inclusion in the meta-analysis. Data were used for the random-effects model, forest plots were drawn, and significance tests were conducted in the meta-analysis software program of the Cochrane Collaboration (RevManv5.3.5). Additionally, heterogeneity tests and a risk of bias analysis were performed.

Results. In the general comparison of conventional and digital methods, the data did not show significant differences, and the results presented low homogeneity. When the cross-sectional method (CSM) was compared under a scanning electron microscope with the silicone replica Geomagic software program (SRG) method, CSM recorded significantly smaller gap values than SRG and presented high homogeneity. Meanwhile, in the comparison of CSM with the silicone replica technique (SRT) and the triple scan method (TSM), CSM recorded larger gap values than SRT and TSM, and the data did not show a significant difference. All of these results presented low homogeneity.

Conclusions. A comparison of most techniques revealed no significant differences in the internal and marginal gaps, except for SRG, which recorded significantly smaller gaps than CSM. However, the conclusions of these findings are limited because of concerns about bias and heterogeneity and because the found marginal gap data are just one way to assess the consistency and reliability of each method. (J Prosthet Dent 2025;134:42-49)

Fixed dental prostheses (FDPs) have a longstanding record of success. When restoring or replacing a deteriorated dentition with single or multi-unit FDPs, multiple factors should be taken into consideration to ensure an optimal prognosis. Among others, these factors include the patient's oral health, the quality of the abutment tooth, the quality of the tooth preparation, the restorative materials selected, the accuracy of the adaptation of the restoration to the underlying tooth preparation, and the choice of luting agent. In particular, the adaptation accuracy of an FDP to the tooth preparation is critical to its long-term success. Ideally, a restoration with a favorable prognosis should have a consistent marginal gap with a uniform internal gap and positive seating of the restoration over the abutment's marginal area.[1–3] Poor marginal adaptation may lead to cement degradation and dissolution, plaque accumulation, microleakage, recurrent dental caries, gingival inflammation, pulpal inflammation/necrosis, decreased fracture strength, and decreased bond

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Clinical Implications

Generally, no to little significant difference was found in the ability of conventional and digital methods to measure the marginal gaps and internal adaptation of fixed dental prostheses. However, digital measurement methods did show some practical advantages over conventional approaches.

strength,[3–6] along with premature dislodgement of the restoration. Consequently, marginal and internal gaps are critical factors.

The first extra coronal metal restorations date back to 1907 when Taggart modified the lost wax technique for inlays and metal crowns for the fabrication of indirect restorations.[7] Over the past 100-plus years, the lost wax technique has been the standard for the fabrication of indirect cast restorations. The associated techniques have been modified and improved over the years to fabricate accurately fitting restorations with minimal marginal gap widths. However, to this day, the conventional techniques pose many challenges that can contribute to ultimate discrepancies in the internal and marginal adaptation of indirect restorations, such as dimensional changes with impression and gypsum materials, consistency of die spacer thickness, wax instability, investing and metal casting procedures, and pressing techniques for pressable ceramics. With the advancement in digital technologies, improvements in the fit of restorations were anticipated with computer-aided design and computer-aided manufacturing (CAD-CAM). However, routinely achieving an excellent marginal adaptation remains a challenge. Digital data acquisition with intraoral scanning, extraoral laboratory scanning of impressions or casts, 3-dimensional (3D) printing of wax patterns for conventional lost wax fabrication, and the milling of metal or ceramic blocks all contribute to the overall adaptation of a restoration.[1]

To date, no true consensus regarding the optimal cement space required for a restoration has been reached. A wide range of 25 μm to 200 μm can be found in the dental literature,[8–12] and the optimal space is likely dependent on the selected restorative materials.

The American Dental Association (ADA) specification No. 8 recommends the cement space to be 25 μm to 40 μm when using zinc phosphate cement,[8,9] while others have suggested a marginal gap of 120 μm as clinically acceptable.[10–12] Marginal adaptation is often evaluated by clinicians through direct observation and the use of an explorer. However, this approach is subjective and can only be performed well when access to the margin of the restoration is unrestricted. Eventually, to better evaluate the adaptation of indirect restorations, silicone try-in pastes have been advocated.[1]

As investigators focused on the adaptation of restorations, several methods for in vitro measurements of internal gaps were developed, and these methods have evolved as new technologies became available. Marginal and internal gaps have been measured by using the cross-sectional method (CSM) under scanning electron microscopy (SEM) or by the silicone replica technique (SRT).[13] The first method evaluates the fit by sectioning cemented restorations on abutment replicas and observing these cross-sections under a light microscope or SEM. Because destruction of the restoration and abutment is required, this method limits the use of the CSM to in vitro situations.[14,15] In contrast, the SRT can be used clinically because it is a nondestructive method where a light-body silicone material is inserted between the restoration and the abutment. After complete polymerization of the silicone, the restoration is removed, and the thin layer of the light-body silicone is then covered by a medium-body silicone to strengthen the light-body material. The silicone replica is then sectioned, and the different cross-sections can be analyzed and measured microscopically.[16]

Another nondestructive measurement method is microcomputed tomography (μCT), which uses a high-resolution 3D X-ray image of the restoration-abutment complex. This approach offers access to the inner geometry in both 2D and 3D and is a relevant measurement technique for marginal and internal adaptation. Alternatively, optical coherence tomography (OCT) uses higher-resolution images in real time by using coherent light.[17,18]

Other digital nondestructive measurement methods have been developed, such as the triple-scan method (TSM), using optical scans of the intaglio and cameo surfaces of the restoration and scans of the abutment and the seated restoration. These scans are merged in metrology software to calculate the marginal and internal gaps. TSM is, therefore, nondestructive, 3D, and accurate.[19,20] Additionally, reference-point matching (RPM) can be accomplished, where the software program uses defined points to merge the scans.[21]

The digital silicone-replica technique (D-SRT) is a digital measurement method that has been commonly used. The silicone replica is converted into a virtual image by using digital scanning and image superimposition techniques. This method has the advantages of 3D digital analysis with less risk of damaging the replica.[22] Finally, a combined method of conventional and digital techniques has been used, the silicone replica Geomagic (SRG) method. Here, a silicone impression of the cement space is made, then optically scanned after polymerization and aligned with the original abutment scan in a metrology software program (Geomagic Control X; 3D Systems Inc).[23]

Although all these measuring methods of marginal and internal adaptation have been reported in the dental literature and practical advantages have been compared, the authors are unaware of a statistical comparison of the outcomes of different measuring methods. Therefore, this study evaluated the results of the various measuring methods in the current literature and compared their results. The null hypothesis was that no significant difference would be found in the technique for evaluating the internal gap and marginal gap of single unit crowns or FPDs.

MATERIAL AND METHODS

The study was conducted according to the Preferred Reporting Items for Systematic Review and MetaAnalyses (PRISMA) statement.[24] The focused question of the search was in a population, intervention, comparison, outcomes (PICO) format: Is there a difference in the technique for evaluating the internal gap and marginal gap of alloy crowns, metal-ceramic crowns, ceramic crowns, and metal-ceramic crowns?

An electronic literature search comprising articles published from January 1990 to June 2023 was performed in the MEDLINE (PubMed) and Web of Science databases. The search strategy included the following terms ("marginal adaptation" OR "marginal fit" OR "marginal accuracy" OR "marginal precision" OR "marginal gap" OR "marginal discrepancy" OR "marginal misfit" OR "marginal vertical adaptation" OR "marginal vertical misfit" OR "marginal vertical discrepancy" OR "marginal vertical accuracy" OR "marginal vertical fit" OR "marginal vertical precision" OR "fitting" OR "misfit" OR "gaps" OR "passive fit" OR "precision fit" OR "internal discrepancy" OR "internal accuracy" OR "internal fit" OR "fidelity" OR "marginal vertical gap") AND ("digital scan" OR "scanning electron microscope" OR "SEM" OR "cross-sectional method" OR "silicone replica technique" OR "triple scan method" OR "micro-computed tomography" OR "optical coherence tomography" OR "silicone replica" OR "triple scan" OR "digital scan" OR "impression technique" OR "silicone impression" OR "silicone impression material" OR "replica" OR "micro CT" OR "photo" OR "digital photo" OR "sectioning" OR "direct view" OR "cross section" OR "cross sectioning" OR "replica" OR "profile projector" OR "micrometer") AND ("digital" OR "conventional" OR "destructive" OR "non-destructive" OR "assessment" OR "evaluation" OR "assessment method" OR "assessment technique" OR "2D analysis" OR "3D analysis" OR " 2 dimensional analysis" OR "3 dimensional analysis") AND ("crown" OR "dental crown" OR "tooth crown" OR "jacket crown" OR "full jacket crown" OR "dental prostheses" OR "single crown" OR "FDP" OR "FPD" OR "porcelain fused to metal" OR "PFM" OR "monolithic" OR "3-unit" OR "bridge" OR "long span" OR "framework"). No language, publication date, or publication status restrictions were imposed. The search was subsequently expanded by searching reference lists of articles consulted to identify additional relevant articles. Full texts of all potentially related articles were obtained from available sources on the internet.

Articles selected for inclusion were based on the following inclusion criteria: studies evaluating the internal gap and marginal gap for alloy crowns, metal-ceramic crowns, ceramic crowns, and porcelain-fused-to-ceramic-substrate crowns; articles that included multi-unit fixed partial dentures (FPDs); articles reporting on digital or conventional assessment techniques, including digital scans, SEM, CSMs, SRTs, MCT, and OCT; research that used assessment methods such as 2D analysis, 3D analysis, digital scans, and other techniques relevant to evaluating the internal and marginal gaps of single dental crowns; studies involving dental prostheses, including single crowns, single FDPs, single-unit metal-ceramic crowns, and single-unit monolithic ceramic crowns; and studies focusing on the permanent dentition either in vitro or in vivo.

Articles were excluded based on the following exclusion criteria: studies not focused on the assessment of internal gaps or marginal gaps for dental restorations for the specified crown types; research lacking information on the techniques used for evaluating internal gap and marginal gap; publications not reporting on the adaptation of dental crowns or using assessment methods unrelated to the present study's objectives; articles with insufficient data or unclear methodologies for assessing internal and marginal gaps; studies with a focus on primary dentition; duplicate publications reporting on the same participant group, with preference given to the most informative and relevant article; and publications with incomplete or inaccessible full texts. In the event that more than 1 publication resulted from the same study, only the most informative and relevant article was included.

Two examiners (P.L., E.C.) independently conducted the literature search to maximize the number of studies included. The 2 examiners assessed all selected articles for the predefined inclusion and exclusion criteria and conducted independent eligibility assessments. Discussion and consensus resolved any disagreement.

A methodological quality assessment was performed according to the standards described in the Cochrane Handbook for Systematic Reviews of Interventions (v5.1.0).[25] Two reviewers (PK and EC) evaluated the selected trials independently, and disagreements were resolved through discussion or consultation with a third reviewer (PL). The Newcastle-Ottawa quality assessment scale was also provided to further analyze the selected article.[26]

Information was extracted from each included study in July 2023 (Table 1). The data were subsequently

Table 1. Characteristics of included studies

Study ID Author (Year)	Restoration Type	Fabrication Method	Method of Marginal Discrepancy Measurements	Number of Specimen	Number of Measurements	Article Type (Language)
Park et al (2017)	Crown	CAD-CAM Milled	Silicone replica and 2D–3DSA	15	16	English
Boitelle et al (2018)	Crown	CAD-CAM Milled	Silicone replica and triple scan method	60	8	English
Mai et al (2019)	Crown	CAD-CAM milled	Computer-aided replica technique, Replica technique, Sectioning technique	1	4	English
Ziller et al (2019)	Crown	CAD-CAM milled	SEM and 3D (Geomagic)	38	25	English
Ram et al (2019)	Crown	Lost-wax	Micro CT scan and sectioning technique	20	1	English
Schonberger et al (2019)	3-unit FPD	CAD-CAM milled	Replica technique and Sectioning technique	44	1	English
Son et al (2019)	Crown	CAD-CAM milled	Cross sectional and silicone replica and triple scan method and micro-computed tomography and optical coherence tomography	1	unclear	English
Hasanzade et al (2020)	Crown	CAD-CAM milled, printed	Silicone replica and digital reference point	12	4 (unclear)	English
Peng et al (2020)	Crown	CAD-CAM milled, pressed	micro CT scan and silicone replica	42	8 per specimen	English
Piras et al (2020)	Crown	CAD-CAM milled	Micro CT scan and stereomicroscope	30	120 per specimen	English
Vasiliu et al (2020)	Crown	CAD-CAM milled	Micro CT scan and silicone replica	32	2 per specimen	English
Schlenz et al (2020)	Crown	CAD-CAM milled, lost-wax	Digital IOS, digital GOM and silicone replica	20	4	English
Ahmadi et al (2020)	Crown	CAD-CAM milled	3D-triple scan, stereomicroscope, SEM	20	(Not specified)	English
Schlenz et al (2020)	Crown and FPD	CAD-CAM Milled	Digital IOS, digital GOM and silicone Replica	30	16 per tooth	English
Sadr et al (2022)	Crown	CAD-CAM Milled. lost-wax	Triple scanning method, replica weighting method, direct view	20	8	English
El-Ashkar et al (2023)	Crown	CAD-CAM milled	3DSA, Silicone replica technique, direct view	16	468	English
Refaie et al (2023)	Crown	CAD-CAM milled	Silicone replica technique and vertical marginal gap technique	20	16	English

entered into the meta-analysis software program of the Cochrane Collaboration (RevManv5.3.5). By using the random-effects model, forest plots were drawn, and significance tests were conducted by comparing the following items: conventional methods and digital methods in general; SRT and MCT; SRT and OCT; SRT and TSM; SRT and digital replica method with Geomagic (D-GOM); SRT and IOS-based digital approach (D-IOS); SRT and reference point matching (RPM); CSM and SRT; CSM and TSM; and CSM and sagittal silicon replica with Geomagic.

A risk of bias analysis and heterogeneity tests were also performed. Statistical tests for heterogeneity including 2 tests and the calculation of I^2 were applied. A low P value (or a large 2 statistic relative to its degree of freedom) provided evidence of heterogeneity of treatment effects (variation in effect estimates beyond chance). I^2 is a more useful statistic for quantifying inconsistency and is presented in the forest plots. It describes the percentage of the variability in effect and estimates which is the result of heterogeneity rather than sampling error (chance). A value greater than 50% may be considered substantial heterogeneity.[27–29]

RESULTS

The search strategy resulted in a total of 386 articles from MEDLINE (PubMed) and 520 articles from Web of Science. These articles were reduced to 54 after the initial exclusion based on the content of the abstracts and were read and examined in detail. Following consideration of the inclusion and exclusion criteria, 17 articles were identified for inclusion in the meta-analysis. Figure 1 provides an overview of the literature search and article. Table 1 provides a summary of the studies included in the meta-analysis. By using the risk of bias analysis (Tables 2, 3 and Fig. 2), 2 of the studies were classified as having a low risk of bias, 14 of the studies were classified as having a medium risk of bias, and 1 study was classified as having a high risk of bias. The summary of the results is displayed in Table 4. When comparing the conventional methods with digital methods, the data did not show a significant difference, and the results presented low homogeneity.

When comparing the CSM under SEM methods with other methods, several differences were identified. When comparing the CSM and SRG, CSM recorded statistically significantly smaller internal and marginal gaps compared with SRG and presented high homogeneity. Meanwhile, in the comparison of CSM with SRT and the TSM, CSM recorded larger internal and marginal gaps compared with SRT and TSM; however, the results were not statistically significant. All results presented low homogeneity.

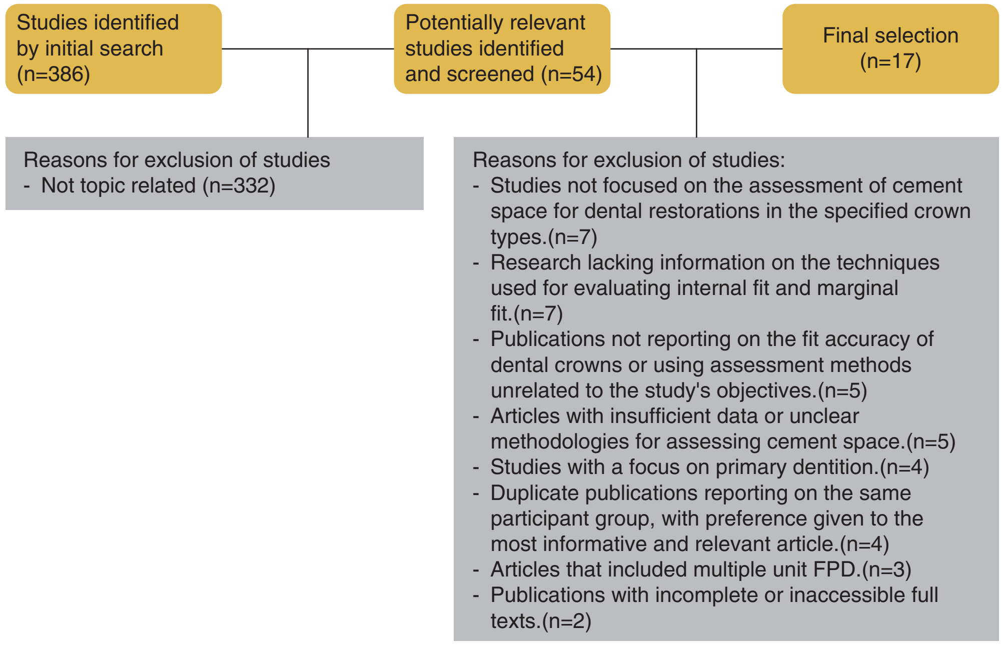

Figure 1. Flow diagram summarizing literature search and article selection.

Table 2. Methodological quality of selected studies

Study ID Author (Year)	Question								Risk of Bias*
	Selection Randomly?	Blinding of the Outcome Assessors?	Explained the Incomplete Outcome Date?	Reporting all Outcomes?	Criteria Clear?	Repeat Measurement?	Calculate Sample Size?	Intraexaminer Reliability?	
Park et al (2017)	no	no	yes	yes	yes	yes	no	no	moderate
Boitelle et al (2018)	no	no	yes	yes	yes	yes	no	no	moderate
Mai et al (2019)	no	yes	yes	yes	yes	yes	no	yes	low
Ziller et al (2019)	no	unclear	yes	yes	yes	yes	no	no	moderate
Ram et al (2019)	no	no	yes	yes	yes	no	no	no	moderate
Schonberger et al (2019)	no	no	yes	yes	yes	no	no	no	moderate
Son et al (2019)	no	no	yes	yes	yes	no	no	no	moderate
Hasanzade et al (2020)	no	unclear	yes	yes	yes	unclear	no	yes	low
Peng et al (2020)	no	unclear	yes	yes	yes	no	no	no	moderate
Piras et al (2020)	no	no	yes	yes	yes	yes	no	no	moderate
Vasiliu et al (2020)	no	unclear	yes	yes	yes	no	no	no	moderate
Schlenz et al (2020)	no	unclear	yes	yes	yes	unclear	no	unclear	moderate
Ahmadi et al (2020)	no	unclear	unclear	unclear	yes	yes	no	no	high
Schlenz et al (2020)	no	no	yes	yes	yes	no	no	no	moderate
Sadr et al (2022)	no	no	yes	yes	yes	no	no	no	moderate
El-Ashkar et al (2023)	no	no	yes	yes	yes	no	no	no	moderate
Refaie et al (2023)	no	no	yes	yes	yes	no	no	no	moderate

#. The following criteria were evaluated as "yes," "no," or "unclear":
1. Were the specimens chosen randomly?
2. Were the outcome assessors blinded to intervention?
3. Was the withdrawal/dropout rate described and clearly explained?
4. Was it clearly reports all expected outcomes, including those that were pre-specified?
5. Were the inclusion/exclusion criteria clear?
6. Was the parameter measured several times?
7. Was the sample size calculation reported?
8. Was the data recorded by the same operator? Or do they have the test of intra-examiner reliability?

[*] A study was graded to have a low risk of bias if it yielded 5 or more "yes" answers to the 8 questions, moderate risk if it yielded 3 to 4 "yes" answers, and high risk if it yielded 2 "yes" answer or less.

Table 3. NEWCASTLE – OTTAWA quality assessment of selected studies

Study ID Author (Year)	Selection	Comparability	Outcome
Park et al (2017)	****	**	***
Boitelle et al (2018)	****	**	***
Mai et al (2019)	****	**	***
Ziller et al (2019)	***	*	**
Ram et al (2019)	***	*	***
Schonberger et al (2019)	***	**	**
Son et al (2019)	***	**	**
Hasanzade et al (2020)	****	*	*
Peng et al (2020)	****	*	***
Piras et al (2020)	***	*	***
Vasiliu et al (2020)	***	*	**
Schlenz et al (2020)	***	*	***
Ahmadi et al (2020)	***	**	**
Schlenz et al (2020)	***	*	***
Sadr et al (2022)	****	*	**
El-Ashkar et al (2023)	***	*	**
Refaie et al (2023)	****	*	**

Table 4. Forest plots summary of comparison

Subgroups	Test for Overall Effect and Heterogeneity	Studies	Participants
General Comparison (Conventional versus Digital)			
	P=.94, I^2=73%	8	968
CSM Comparison			
SRT	P=.54, I2=73%	3	158
TSM	P=.76, I^2=94%	2	260
SRG	P<.001, I^2=47%	2	88
SRT Comparison			
MCT	P=.15, I^2=94%	6	448
TSM	P=.35, I^2=78%	2	30
D-GOM	P=.88, I^2=0%	2	300
D-IOS	P=.80, I^2=0%	2	300
RPM	P=.79, I^2=0%	2	68
OCT	P=.48, I^2=97%	2	92

Diamond symbol represent overall mean and 95% confidence interval (95% CI) for each group of comparisons. P<.05 or mean including 0 represent 2 measurements not statistically significantly different.

When comparing SRT methods with all other methods, SRT recorded larger internal and marginal gaps, except when compared with OCT. However, the results were not statistically significantly different, and the results presented high homogeneity.

DISCUSSION

This meta-analysis compared conventional methods with digital methods and assessed the accuracy of the different techniques used to evaluate the internal and marginal gaps of crowns and FDPs. The study's search strategy yielded 387 articles through PubMed and 520 articles on the Web of Science, eventually reducing to 17 studies that met the stated inclusion and exclusion criteria. Transparent and systematic procedures were used to select the articles, as depicted in the flow diagram (Fig. 2), clarifying the study's approach.

The risk of bias analysis identified a potential concern regarding the validity of some of the findings that should be considered when interpreting the results. Furthermore, the study observed low homogeneity in some results because of variations in study designs, methodologies, and sample sizes among the included studies. Understanding the sources of heterogeneity is essential to interpreting the outcomes properly.

Comparing conventional methods with digital methods did not reveal a significant difference in the found internal and marginal gaps, suggesting that digital approaches could be suitable alternatives to conventional methods. Although conventional methods such as CSM or SRT did not present an advantage in this meta-analysis, they did have several practical disadvantages over digital methods. CSM requires at least 50 measuring points per single specimen and is destructive, so it is only applicable in a laboratory setting. SRT uses low-viscosity silicone, which is easily torn, resulting in inaccurate 2D analysis.[15] Finally, both methods require cutting in the oblique plane, which makes this method susceptible to inconsistency because of human error.[29]

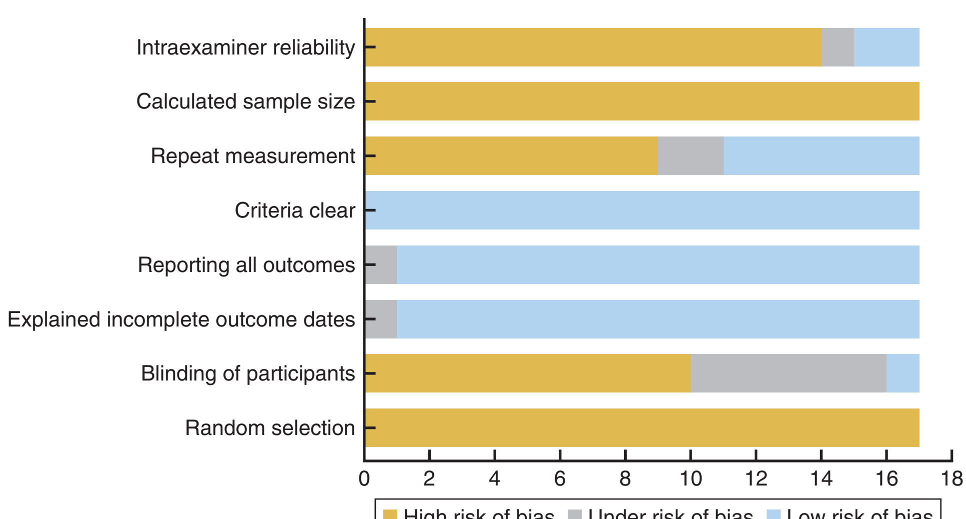

Figure 2. Risk of bias graph.

Nevertheless, digital techniques also have their limitations. OCT may offer unclear results when measuring thick or optically opaque materials,[18] and TSM requires a complex experimental setup and expertise because miscalculations can easily be made when superimposing images.[18,20] To reduce such miscalculations, RPM can be used.[21] In the current study, a lack of homogeneity in the results of digital methods was noted, which may stem from the diverse application of digital methods and variations in equipment and software used in the studies. Standardization efforts could help reduce heterogeneity in future meta-analyses.

Significant differences were recorded when comparing the conventional CSM methods with the digital SRG, indicating the potential advantages of SRG over CSM in specific applications. However, no statistically significant differences were observed when comparing CSM with the SRT and TSM groups. This result suggests the need for further exploration of contextual factors. The high homogeneity in these results implies a consistent and reliable pattern across studies.

Similarly, comparing SRT methods with other techniques produced higher values in most cases, suggesting SRT's potential superiority for certain outcome measures. Nevertheless, the lack of significant differences in these comparisons warrants a cautious interpretation of the results. The high homogeneity observed in these findings enhances their reliability and consistency, indicating the stability of SRT's performance across studies.

Limitations of the study included that a significant proportion of included studies was classified as having a moderate or high risk of bias, potentially compromising the validity of the results. Additionally, the heterogeneity in findings stemming from variations in study designs and methodologies complicated interpretation. Digital techniques, although considered alternatives to conventional methods, have limitations such as unclear results with thick or optically opaque materials and the complexity of certain methods such as TSM. Moreover, the lack of homogeneity in digital methods suggests the need for standardization efforts. While significant differences were observed in specific comparisons, further exploration of contextual factors is warranted. Finally, the observed gap sizes were influenced by multiple factors other than the inherent precision of each measuring technique, including the manufacturing process of the restorations and material properties. Therefore, a smaller gap does not necessarily reflect the superiority of a measurement method in terms of accuracy. Instead, it could be influenced by how each method interacts with the material and surface characteristics of the restorations.

CONCLUSIONS

Based on the results of this meta-analysis, the following conclusions were drawn.

1. The SRG technique recorded significantly smaller internal and marginal gaps compared with the CSM.
2. Comparison of all other techniques recorded no significant differences in internal and marginal gaps.
3. The marginal gap data formed a single aspect of assessing each method's consistency and reliability.

REFERENCES

1. (a)I. Rissin L, Wetreich G. Utilization of elastomeric materials to evaluate the accuracy of cast restorations prior to cementation. *J Prosthet Dent*. 1983;49:585–586;
(b)Beuer F, Korczynski N, Rezac A, et al. Marginal and internal fit of zirconia-based fixed dental prostheses fabricated with different concepts. *Clin Cosmet Investig Dent*. 2010;2:5–11.
2. Holmes JR, Bayne SC, Holland GA, Sulik WD. Considerations in the measurement of marginal fit. *J Prosthet Dent*. 1989;62:405–408.
3. Chien EC. Evaluating 3D fit of lithium disilicate restorations with a novel virtual measuring technique. Boston: ProQuest Dissertations Publishing; 2017.
4. Jacobs MS, Windeler AS. An investigation of dental luting cement solubility as a function of the marginal gap. *J Prosthet Dent*. 1991;65: 436–442.
5. Sorensen JA. A rationale for comparison of plaque-retaining properties of crown systems. *J Prosthet Dent*. 1989;62:264–269.
6. Felton DA, Kanoy BE, Bayne SC, Wirthman GP. Effect of in vivo crown margin discrepancies on periodontal health. *J Prosthet Dent*. 1991;65:357–364.
7. Asgar K. Casting metals in dentistry: Past - present - future. *Advances in Dental Research*. 1988;1:33–43.
8. American Dental Association. ANSI/ADA Specification No. 8 for zinc phosphate cement. Guide to Dental Materials and Devices. Chicago: American Dental Association,; 1971:87–88.
9. von Fraunhofer JA. Dental Materials at a Glance. Oxford: Wiley-Blackwell,; 2010.
10. Belser UC, MacEntee MI, Richter WA. Fit of three porcelain-fused-to-metal marginal designs in vivo: a scanning electron microscope study. *J Prosthet Dent*. 1985;53:24–29.
11. Sulaiman F, Chai J, Jameson LM, Wozniak WT. A comparison of the marginal fit of In-Ceram, IPS Empress, and Procera crowns. *Int J Prosthodont*. 1997;10:478–484.
12. McLean JW, von Fraunhofer JA. The estimation of cement film thickness by an in vivo technique. *Br Dent J*. 1971;131:107–111.
13. Sorensen JA. A standardized method for determination of crown margin fidelity. *J Prosthet Dent*. 1990;64:18–24.
14. Beuer F, Aggstaller H, Edelhoff D, Gernet W, Sorensen J. Marginal and internal fits of fixed dental prostheses zirconia retainers. *Dent Mater*. 2009;25:94–102.
15. Schlenz MA, Vogler JAH, Schmidt A, Rehmann P, Wöstmann B. Chairside measurement of the marginal and internal fit of crowns: A new intraoral scan–based approach. *Clin Oral Investig*. 2019;24:2459–2468.
16. Laurent M, Scheer P, Dejou J, Laborde G. Clinical evaluation of the marginal fit of cast crowns-validation of the silicone replica method. *J Oral Rehabil*. 2008;35:116–122.
17. Pahlevaninezhad H. Nano-optic endoscope for high-resolution optical coherence tomography in vivo. *Nat Photonics*. 2018;12:540–547.
18. Makishi P, Thitthaweerat S, Sadr A, et al. Marginal adaptation of different adhesive systems to dentin by optical coherence tomography. *Dent Mater*. 2013;29:e46.
19. Boitelle P, Tapie L, Mawussi B, Fromentin O. Evaluation of the marginal fit of CAD-CAM zirconia copings: Comparison of 2D and 3D measurement methods. *J Prosthet Dent*. 2018;119:75–81.
20. Ahmadi E, Tabatabaei MH, Sadrs SM, Atri F. Comparison of the marginal discrepancy of PFM crowns in the CAD/CAM and lost-wax fabrication techniques by triple scanning. *Dent Med Probl*. 2020;57: 417–422.
21. Orteu JJ. 3-D computer vision in experimental mechanics. *Opt Laser Eng*. 2009;47:282–291.
22. Moldovan O, Luthardt RG, Corcodel N, Rudolph H. Three-dimensional fit of CAD/CAM-made zirconia copings. *Dent Mater*. 2011;27:1273–1278.
23. Zeller S, Guichet D, Kontogiorgos E, Nagy WW. Accuracy of three digital workflows for implant abutment and crown fabrication using a digital measuring technique. *J Prosthet Dent*. 2019;121:276–284.
24. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Med*. 2009 Jul 21;6:e1000097.

25. Higgins JPT, Green S. Cochrane handbook for systematic reviews of interventions. Version 5.1.0. *The Cochrane Collaboration* 2011.
26. Wells GA, Shea B, O'Connell D, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomized studies in meta-analyses. Ottawa: Ottawa Hospital Research Institute; 2011.
27. Egger M, Smith GD, Phillips AN. Meta-analysis: Principles and procedures. *Br Med J.* 1997;315:1533–1537.
28. Barza M, Trikalinos TA, Lau J. Statistical considerations in meta-analysis. *Infect Dis Clin North Am.* 2009;23:195–210.
29. Haase SC. Systematic reviews and meta-analysis. *Plast Reconstr Surg.* 2011;127:955–966.

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Noteworthy Abstracts of the Current Literature

Trans-mucosal platforms for dental implants: Strategies to induce muco-integration and shield peri-implant diseases

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Objectives: Trans-mucosal platforms connecting the bone-anchored implants to the prosthetic teeth are essential for the success of oral rehabilitation in implant dentistry. This region promotes a challenging environment for the successfulness of dental components due to the transitional characteristics between soft and hard tissues, the presence of bacteria, and mechanical forces. This review explored the most current approaches to modify trans-mucosal components in terms of macro-design and surface properties.

Methods: This critical review article revised intensely the literature until July 2023 to demonstrate, discuss, and summarize the current knowledge about marketable and innovative trans-mucosal components for dental implants.

Results: A large number of dental implant brands have promoted the development of several implant-abutment designs in the clinical market. The progress of abutment designs shows an optimistic reduction of bacteria colonization underlying the implant-abutment gap, although, not completely inhibited. Fundamental and preclinical studies have demonstrated promising outcomes for altered-surface properties targeting antibacterial properties and soft tissue sealing. Nanotopographies, biomimetic coatings, and antibiotic-release properties have been shown to be able to modulate, align, orient soft tissue cells, and induce a reduction in biofilm formation, suggesting superior abilities compared to the current trans-mucosal platforms available on the market.

Significance: Future clinical implant-abutments show the possibility to reduce peri-implant diseases and fortify soft tissue interaction with the implant-substrate, defending the implant system from bacteria invasion. However, the absence of technologies translated to commercial stages reveals the need for findings to "bridge the gap" between scientific evidences published and applied science in the industry.

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