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SYSTEMATIC REVIEW

Precision of measurement methods for assessing the fit of screw-retained implant-supported fixed partial dentures: A systematic review of in vitro studies

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ABSTRACT

Statement of problem. Considerable variability exists in the measurement methods for assessing the fit of screw-retained implant-supported fixed partial dentures (FPDs) because of the lack of standardization. Scientific evidence comparing the precision and reliability of various measurement methods remains limited.

Purpose. The purpose of this systematic review of in vitro studies was to evaluate the precision of various measurement methods for assessing the fit of screw-retained implant-supported FPDs.

Material and methods. An electronic search was conducted in MEDLINE (via Ovid), Embase (via Ovid), Scopus, and Web of Science for articles published between January 2020 and August 2025, with PubMed screened additionally for ahead-of-print records not yet indexed in MEDLINE. Eligible articles were selected based on predefined inclusion and exclusion criteria, and relevant data were extracted. The Quality Assessment Tool For In Vitro Studies (QUIN Tool) was used to evaluate the methodological quality of the included studies. The coefficient of variation (CV) was calculated to evaluate the precision of each measurement method.

Results. After screening and applying the eligibility criteria, 13 of the initial 1851 records were identified for inclusion. Quality assessment showed that 5 studies had a low risk of bias and that 8 had a medium risk. All included studies evaluated the marginal fit of FPDs, with none assessing internal fit. Across these studies, 6 measurement techniques and 2 test conditions were used. Under the 1-screw test (OST), radiographic evaluation showed the lowest CV (13.7%), indicating the highest precision, while the profile projection exhibited the greatest variability (70.7%). Under the all-screws test (AST), optical microscopy demonstrated the greatest repeatability with a CV of 20.5%, closely followed by 3-dimensional confocal laser scanning microscopy (3D CLSM) at 23.4%.

Conclusions. Most techniques showed greater repeatability under OST than AST. Radiographic evaluation was the most precise method under OST, while optical microscopy demonstrated the highest precision under AST. These findings offer valuable guidance for selecting measurement techniques to determine the fit accuracy of screw-retained implant-supported FPDs. (J Prosthet Dent 2026;135:753.e1-e11)

The fit of implant-supported fixed prostheses is critical to achieving their long-term success.[1–3] As a theoretical parameter for assessing the fit of implant prostheses, passive fit has been generally defined as a condition under which no stress or strain is exerted on the prosthetic components, implants, or peri-implant bone.[4] However, in clinical practice, absolute passivity cannot be achieved when an implant superstructure is seated on implant abutments or directly on implants.[5] Nevertheless, it remains essential to evaluate and achieve an accurate fit for implant-supported fixed prostheses because of the potential biological and mechanical complications associated with misfit.[1,5,6] Generally, a misfit threshold ranging from 10 to 150 μm has been considered clinically acceptable to minimize the risk of biomechanical complications, despite the lack of international consensus and the broader range of misfit values reported in laboratory and clinical studies.[1,6]

An implant-supported fixed partial denture (FPD) can be either cement-retained or screw-retained.[7] However, achieving passive fit is more challenging for screw-retained implant-supported FPDs than cement-retained

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Clinical Implications

These findings support the use of radiographic evaluation and optical microscopy in both research and clinical settings where accurate assessment of marginal fit is essential. Selecting more precise methods may improve consistency in evaluating fit and contribute to improved prosthetic outcomes.

ones, as cement-retained prostheses are designed with a cement space, which can reduce the stresses resulting from less precise prostheses.[3,7,8] In contrast, screw-retained frameworks do not benefit from a cement space or mobility, making them more sensitive to misfit.[9] Additionally, an increased number of implants, greater angulation, and longer span length may contribute to a higher risk of misfit in implant components for screw-retained implant-supported FPDs.[10,11]

Prosthesis fit has been categorized as marginal fit and internal fit, typically assessed by measuring dimensional discrepancies at the marginal and internal implant-framework interfaces.[7,12,13] The gaps between the prostheses and implants can be measured using either 2-dimensional (2D) or 3-dimensional (3D) techniques, and the results provide a direct indication of the level of misfit.[1,14] However, considerable variability exists in the measurement methods for assessing the fit of screw-retained implant-supported FPDs because of the lack of standardization.[15] Although a range of recent techniques have been used to inspect the dimensional discrepancy, including optical microscopy, stereomicroscopy, scanning electron microscopy (SEM), and radiographic evaluation, their application in fit assessment remains substantially inconsistent.[1,16] Screw-tightening tests used during the measurement process are another key procedural factor, as they determine the conditions under which gap values are obtained. The 1-screw test (OST) or the Sheffield test is efficient for the clinical evaluation of framework fit.[2] However, some studies have used the all-screws test (AST) with all screws being tightened before the misfit is assessed.[10,17,18] Considerable variability in measurement methods across studies poses challenges for comparing the fit outcomes of screw-retained implant-supported FPDs. Although previous reviews have summarized various measurement techniques, the comparisons have been mainly descriptive,[1] and comprehensive evaluations with quantitative analyses of the precision and reliability of recently developed methods are still lacking.

Therefore, the purpose of this systematic review was to synthesize the measurement methods recently used to assess the fit of screw-retained implant-supported FPDs and to quantitatively evaluate the precision of these methods by focusing on both measurement techniques and test conditions. The null hypothesis was that no difference would be found in the precision of measurement methods for assessing the fit of screw-retained implant-supported FPDs.

MATERIAL AND METHODS

This systematic review was conducted by following a previously registered protocol with the International Prospective Register of Systematic Reviews (PROSPERO) database (CRD420251104509) and adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[19] The focused question of the search was in a population, intervention, comparison, outcome (PICO) format: In screw-retained implant-supported FPDs (P), what is the precision (O) of different measurement methods for assessing fit (I/C)?

An electronic literature search was conducted for articles published from January 2020 to August 2025 in MEDLINE (via Ovid), Embase (via Ovid), Scopus, and Web of Science. In addition, PubMed was screened for ahead-of-print records not yet indexed in MEDLINE. Based on the focused PICO question, the search strategy was developed with assistance from a librarian and included the following terms: ("implant-supported") AND (frame* OR bar OR prosthes*) AND (fit OR passivity OR "marginal adaptation" OR "internal adaptation" OR misfit OR discrepanc* OR gap*), with publication dates restricted to the period from January 2020 to August 2025. The search strategy was subsequently adapted to meet the indexing and syntax requirements of each database.

The retrieved literature records were collated in a reference management software program (EndNote 21; Clarivate Analytics). After the removal of duplicates, 2 reviewers (Z.H., V.B.) independently screened the articles through title, abstract, and full text based on the predefined inclusion and exclusion criteria (Table 1). Discussion and consensus with a third reviewer (A.S.) resolved disagreements. Authors, study types, sample size (N), units, number of implants, fixation, groups, fit assessment conducted, test conditions, measurement techniques used to assess fit, results, and the precision of measurement methods were extracted from each included study, synthesized, and tabulated. The coefficient of variation (CV) was calculated to indicate the precision of the measurement methods, computed as the standard deviation divided by the mean and expressed as a percentage. This indicator reflected relative variability independent of measurement scale, allowing comparisons across techniques.[20] Furthermore, the weighted average CV was computed to account for differences in sample sizes across studies and to provide a more representative and comparable assessment of precision across measurement techniques and test conditions.[20,21]

Table 1. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Articles published in English	Articles published in languages other than English
In vitro studies	Case reports, technique reports, reviews, expert opinions, and non-randomized observational studies
Articles published from January 2020 to August 2025	Articles published prior to 2020
Studies evaluating the marginal or internal fit of screw-retained implant-supported FPDs before veneering, mechanical cycling, thermal cycling, or any additional treatments	Studies not involving screw-retained implant-supported FPDs, not assessing their marginal or internal fit, or assessing fit only after additional treatments
Articles with detailed measurement methodology and reported marginal or internal gap values	Articles lacking detailed measurement methodology or missing outcome data related to marginal or internal gaps

FPD, fixed partial denture.

A methodological quality assessment was performed for the included studies by using the Quality Assessment Tool For In Vitro Studies (QUIN Tool) evaluating 12 domains, including sample size justification, randomization, blinding, and outcome reporting on a weighted scoring system.[22] Each selected study was independently evaluated by 2 reviewers (Z.H., V.B.) based on 12 scored criteria. Following the developers' recommendations, studies were classified as low risk (>70%), medium risk (50–70%), or high risk (<50%). Any disagreements were resolved through discussion or consultation with a third reviewer (A.S.).

RESULTS

The detailed search strategy and results are presented in Figure 1. Initially, the electronic search resulted in 1851 publications (314 MEDLINE, 433 Embase, 335 Scopus,

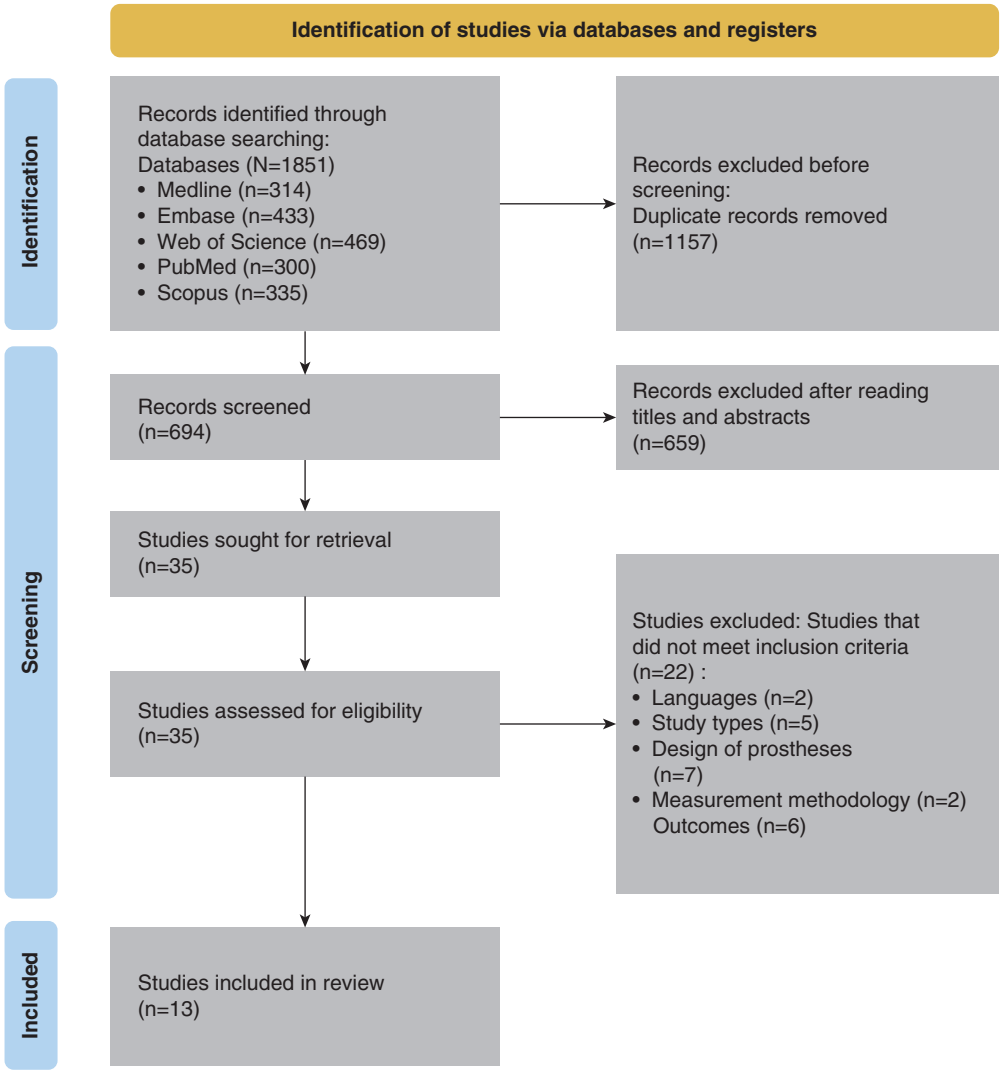

Figure 1. Flowchart illustrating literature search and selection process.

300 PubMed, and 469 Web of Science). Following the removal of 1157 duplicates, 694 records were screened, and 659 records were then excluded after reading titles and abstracts, leaving 35 articles eligible for full-text review. Following a comprehensive full-text review and application of the inclusion and exclusion criteria, a total of 13 in vitro studies were included in the final analysis (Table 2).

The quality assessment using the QUIN tool is summarized in Table 3. All included in vitro studies scored at least 50%, indicating acceptable methodological quality. Among them, 8 were rated as having a medium risk of bias,[5,9,10,23–25,27,28] and 5 as having a low risk.[17,18,26,29,30] Each included study provided explicit objectives, details of the comparison group, a clear explanation of the methodology, and detailed descriptions of the outcome measurement methods and results. In medium-risk studies, the risk of bias primarily resulted from inadequately specified or unreported details related to sample size calculation, sampling technique, randomization, operator or assessor calibration, and blinding.

All 13 included studies evaluated the marginal fit of FPDs, with none assessing internal fit (Table 2). Among them, the most common restoration type was a 3-unit FPD supported by 2 parallel implants.[5,9,10,17,18,23–25,27,29,30] Additionally, 1 study used FPDs supported by 3 implants,[28] while another generated 4-unit frameworks supported by 2 nonparallel implants.[26] Regarding fixation methods, 3 of these studies designed prostheses fixed directly to implants,[9,10,27] while the other 10 retained the frameworks via abutments using screws.[5,17,18,23–26,28–30] These variations in implant number, span length, and angulation may have partly affected the accuracy of fit assessment.

Regarding the dimensions of marginal misfit assessed, 10 measured only the vertical gaps, while 3 assessed both vertical and horizontal gaps.[5,28,30] Of these, 6 assessed marginal fit after both OST and AST,[23,24,26–28,30] while 4 performed measurements only after OST,[5,9,25,29] and 3 conducted only AST.[10,17,18] The techniques used to assess marginal fit in these studies included radiographic evaluation,[29] optical microscopy,[23] 3D confocal laser scanning microscopy (CLSM),[30] SEM,[10,27,28] stereomicroscopy,[9,17,18,24–26] and profile projection.[5] The precision of these techniques under different test conditions was ranked based on weighted average CV (Table 4), and the overall ranking is illustrated in Figure 2. When employing OST, radiographic evaluation showed the highest precision, with the lowest weighted average CV of 13.7%, followed by optical microscopy, 3D CLSM, SEM, and stereomicroscopy. Using a profile projector exhibited the greatest variability, with the highest weighted average CV of 70.7%, indicating substantial inconsistency and limited reliability. After AST, the optical microscopy demonstrated the greatest repeatability and precision with a weighted average CV of 20.5%, followed closely by 3D CLSM with a weighted average CV of 23.4%, while SEM and stereomicroscopy showed higher variability, suggesting lower precision. Compared with AST, optical microscopy showed slightly lower repeatability under OST. In contrast, 3D CLSM demonstrated comparable repeatability under both conditions, while SEM and stereomicroscopy exhibited greater repeatability under OST than AST, with stereomicroscopy showing the largest difference.

DISCUSSION

The null hypothesis that no difference would be found in the precision of measurement methods for assessing the fit of screw-retained implant-supported FPDs was rejected, as differences were observed among the various measurement techniques under different test conditions. For in vitro studies, a 3-unit framework supported by 2 parallel implants was the most frequently adopted configuration because of its simplified design, reduced experimental variability, and high reproducibility, though it does not fully represent clinical complexity. However, more complex configurations of FPDs with nonparallel implants, increased implants, or longer spans have been less assessed, although they may better reflect clinical variability and allow a more comprehensive evaluation of the fit.[26,28] Additionally, differences in fixation methods may have contributed to discrepancies during seating and evaluation. Metal frameworks fixed directly to implants involve fewer interfaces and require higher seating precision.[9,10,27] In contrast, frameworks fixed to implants via abutments can offer greater tolerance for implant angulation discrepancies and flexibility in material selection, making it easier to achieve clinically acceptable fit and esthetic outcomes.[11]

Most studies focused on measuring vertical gaps to assess the marginal fit, although the horizontal misfit has been reported to occur more frequently and may be more critical than the vertical misfit in implant-supported fixed prostheses.[14] Moreover, horizontal discrepancies are clinically important as they can generate uneven force distribution, leading to screw loosening, abutment stress, and even localized peri-implant bone loss.[28,30] In long-span or nonparallel implant-supported prostheses, relying solely on vertical gap measurements risks overlooking these complications, and misfit may go undetected.[16,30] Therefore, assessment combining vertical and horizontal gap measurement has been increasingly recognized as essential to provide more clinically relevant evidence on the marginal fit of implant-supported FPDs.[5,28,30]

Compared with marginal fit, internal fit plays a crucial role in stress distribution and the mechanical stability of implant-supported fixed prostheses. Neglecting

Table 2. Characteristics of included studies

Articles	Study Types	Sample Size (N)	Units/ Number of Implants	Fixation	Groups	Fit Assessment	Test	Measurement Technique	Results (μm)		Precision of Measurement Methods (CV, %)
									Marginal Fit	Internal Fit	
Oteiza-Galdón et al, 2020[23]	in vitro	33	3-unit, 2 implants (parallel)	Via abutments	Group I: Co-Cr Group II: Ti	Marginal fit (VG)	1. OST 2. AST	Optical microscope (magnification NP)	**1. OST:** Group I: 4.43 ±0.52 (A) 5.59 ±1.32 (B) Group II: 5.50 ±1.61 (A) 6.25 ±1.55 (B) **2. AST:** Group I: 4.13 ±0.63 (A) 4.41 ±0.93 (B) Group II: 5.1 ±1.02 (A) 4.81 ±1.24 (B)	N/A	**1. OST:** 22.36 ±7.49 **2. AST:** 20.53 ±4.32
Tonin et al, 2021[24]	in vitro	40	3-unit, 2 implants (parallel)	Via abutments	Group I: C^M Group II: C^M + LAS Group III: C^M + TIG Group IV: milling	Marginal fit (VG)	1. OST 2. AST	Stereomicroscope at ×50 magnification	**1. OST:** Group I: 20.35 ±10.10 (A) 64.31 ±24.81 (B) Group II: 25.38 ±11.47 (A) 45.96 ±17.99 (B) Group III: 27.03 ±12.13 (A) 61.36 ±27.70 (B) Group IV: 12.53 ±4.51 (A) 31.87 ±16.88 (B) **2. AST:** Group I: 21.73 ±13.56 Group II: 24.26 ±10.29 Group III: 27.09 ±11.35 Group IV: 10.17 ±5.47	N/A	**1. OST:** 43.94 ±5.76 **2. AST:** 50.13 ±9.85
Abu Ghofa et al, 2023[9]	in vitro	50	3-unit, 2 implants (parallel)	Directly to implants	Group I: C^M Group II: C^{ML} Group III: C^P Group IV: milling Group V: 3D printing	Marginal fit (VG)	OST	Stereomicroscope at ×40 magnification	Group I: 137.5 ±18.9 Group II: 116.7 ±17.0 Group III: 92.8 ±23.9 Group IV: 108.4 ±12.0 Group V: 74.2 ±20.5	N/A	18.56 ±7.57
Nakhaei et al, 2023[25]	in vitro	24	3-unit, 2 implants (parallel)	Via abutments	Group I: milling Co-Cr Group II: C^M Ni-Cr Group III: C^M + soldering Ni-Cr Group IV: cast-to Ni-Cr	Marginal fit (VG)	OST	Stereomicroscope at ×204 magnification	Group I: 27.90 ±18.48 Group II: 86.47 ±21.36 Group III: 71.89 ±32.38 Group IV: 69.77 ±40.49	N/A	48.50 ±18.11

Table 2 (*Continued*)

Articles	Study Types	Sample Size (N)	Units/ Number of Implants	Fixation	Groups	Fit Assessment	Test	Measurement Technique	Results (μm)		Precision of Measurement Methods (CV, %)
									Marginal Fit	Internal Fit	
Atsu et al, 2024[26]	in vitro	30	4-unit, 2 implants (nonparallel)	Via abutments	Group I: PEEK Group II: Zir Group III: Ti	Marginal fit (VG)	1. OST 2. AST	Stereomicroscope at ×100 magnification	**1. OST:** Group I: 70.9 ±19.6 Group II: 49.3 ±16.2 Group III: 91.3 ±24.2 **2. AST:** Group I: 23.7 ±4.6 Group II: 32.9 ±8.7 Group III: 52.5 ±10.6	N/A	**1. OST:** 29.00 ±3.39 **2. AST:** 22.01 ±3.86
Peixoto et al, 2024[17]	in vitro	40	3-unit, 2 implants (parallel)	Via abutments	Group I: C^M Co-Cr Group II: C^M + LAS Co-Cr Group III: C^M + TIG Co-Cr Group IV: milling Co-Cr Group V: milling Zir	Marginal fit (VG)	AST	Stereomicroscope at ×50 magnification	Group I: 6.64 ±4.68 (A) 7.86 ±11.75 (B) Group II: 8.03 ±10.35 (A) 16.15 ±1.92 (B) Group III: 6.12 ±3.32 (A) 6.80 ±5.00 (B) Group IV: 3.91 ±1.91 (A) 4.28 ±1.92 (B) Group V: 4.02 ±0.96 (A) 5.07 ±1.94 (B)	N/A	64.44 ±43.88
Batista et al, 2024[18]	in vitro	20	3-unit, 2 implants (parallel)	Via abutments	Group I: custom abutment Group II: mini-conical abutment	Marginal fit (VG)	AST	Stereomicroscope at ×50 magnification	Group I: 27.53 ±13.47 (A) 25.20 ±10.50 (B) Group II: 24.61 ±6.81 (A) 26.87 ±5.78 (B)	N/A	34.94 ±12.57
Nassar et al, 2023[10]	in vitro	30	3-unit, 2 Implants (parallel)	Directly to implants	Group I: C^{ML} Group II: milling Group III: 3D printing	Marginal fit (VG)	AST	SEM at ×800 magnification	Group I: 7.95 ±2.21 Group II: 3.22 ±0.75 Group III: 4.98 ±1.73	N/A	28.61 ±5.77
Del Monte et al, 2023[27]	in vitro	20	3-unit, 2 implants (parallel)	Directly to implants	Group I: milling Group II: 3D printing	Marginal fit (VG)	1. OST 2. AST	SEM at ×250 magnification	**1. OST:** Group I: 97.15 ±6.91 Group II: 106.91 ±20.42 **2. AST:** Group I: 73.96 ±6.14 Group II: 83.20 ±7.20	N/A	**1. OST:** 13.11 ±8.48 **2. AST:** 8.48 ±0.25

Table 2 (*Continued*)

Articles	Study Types	Sample Size (N)	Units/ Number of Implants	Fixation	Groups	Fit Assessment	Test	Measurement Technique	Results (μm)		Precision of Measurement Methods (CV, %)
									Marginal Fit	Internal Fit	
Rodrigues et al, 2024[28]	in vitro	15	3-unit, 3 implants (parallel)	Via abutments	Group I: milling Group II: 3D printing Group III: conventional chairside method	Marginal fit (VG & HG)	1. OST 2. AST	SEM (magnification NP)	**1. OST:** Group I: 13.22 ±7.64 (VG) 20.66 ±4.22 (HG) Group II: 110.41 ±33.98 (VG) 122.81 ±29.61 (HG) Group III: 10.23 ±2.34 (VG) 20.97 ±9.89 (HG) **2. AST:** Group I: 1.30 ±0.28 (VG) 20.37 ±4.05 (HG) Group II: 13.53 ±14.83 (VG) 55.35 ±23.68 (HG) Group III: 4.12 ±1.83 (VG) 15.15 ±6.05 (HG)	N/A	**1. OST:** 37.15 ±18.31 (VG) 30.57 ±14.49 (HG) **2. AST:** 58.52 ±45.70 (VG) 34.20 ±12.48 (HG)
El-Asfahani et al, 2023[29]	in vitro	32	3-unit, 2 implants (parallel)	Via abutments	Group I: closed-tray Group II: closed-tray Group III: open-tray Group IV: open-tray	Marginal fit (VG)	OST	Radiographs (calibrated, magnification NP)	Group I: 108.6 ±13.4 Group II: 96.9 ±14.1 Group III: 55.3 ±9.6 Group IV: 83.0 ±8.8	N/A	13.71 ±2.92
Tonin et al, 2025[30]	in vitro	50	3-unit, 2 implants (parallel)	Via abutments	Group I: C^M Co-Cr Group II: C^M + LAS Co-Cr Group III: C^M + TIG Co-Cr Group IV: milling Co-Cr Group V: milling Zir	Marginal fit (VG & HG)	1. OST 2. AST	3D CLSM at ×5 magnification	**1. OST:** Group I: 33.25 ±12.84 (VG) 337.63 ±77.87 (HG) Group II: 25.13 ±7.87 (VG) 276.90 ±39.19 (HG) Group III: 31.09 ±9.62 (VG) 274.30 ±40.98 (HG) Group IV: 40.23 ±13.97 (VG) 175.57 ±26.69 (HG) Group V: 48.53 ±6.86 (VG) 216.70 ±38.48 (HG) **2. AST:** Group I: 23.43 ±8.98 (VG) 291.17 ±40.32 (HG) Group II: 24.00 ±10.17 (VG) 237.28 ±23.2 (HG) Group III: 19.61 ±9.47 (VG) 258.33 ±39.73 (HG) Group IV: 40.95 ±12.89 (VG) 180.41 ±19.39 (HG) Group V: 51.01 ±5.80 (VG) 217.38 ±26.80 (HG)	N/A	**1. OST:** 29.73 ±9.12 (VG) 17.02 ±3.64 (HG) **2. AST:** 34.37 ±14.24 (VG) 12.42 ±2.27 (HG)

Table 2 (*Continued*)

Articles	Study Types	Sample Size (N)	Units/ Number of Implants	Fixation	Groups	Fit Assessment	Test	Measurement Technique	Results (μm)		Precision of Measurement Methods (CV, %)
									Marginal Fit	Internal Fit	
Fábrega et al, 2021[5]	in vitro	20	3-unit, 2 implants (parallel)	Via abutments	Group I: virtual abutment Group II: real abutment	Marginal fit (VG & HG)	OST	Profile projector at ×192 magnification	Group I: 50 ±24 (A) 30 ±38 (B) Group II: 35 ±27 (A) 42 ±13 (B)	N/A	70.69 ±41.91

A, implant A; AST, all-screws test; B, implant B; CLSM, confocal laser scanning microscope; C^{M}, casting (with manual pattern); C^{ML}, casting (with milled pattern); Co-Cr, cobalt chromium; C^{P}, casting (with printed pattern); CV, coefficient of variation; HG, horizontal gap; LAS, laser welding; N/A, not applicable; Ni-Cr, nickel-chromium; NP, not provided; OST, 1-screw test; PEEK, polyetheretherketone; PEKK, polyetherketoneketone; SEM, scanning electron microscope; 3D, 3-dimensional; Ti, titanium; TIG, tungsten inert gas welding; VG, vertical gap; Zir, zirconia.

Table 3. Risk of bias assessment for included studies by Quality Assessment Tool For In Vitro Studies (QUIN Tool)

Study	Criteria 1	Criteria 2	Criteria 3	Criteria 4	Criteria 5	Criteria 6	Criteria 7	Criteria 8	Criteria 9	Criteria 10	Criteria 11	Criteria 12	Total	Final Score	Risk of Bias
	Clearly Stated Aims/ Objectives	Detailed Explanation of Sample Size Calculation	Detailed Explanation of Sampling Technique	Details of Comparison Group	Detailed Explanation of Methodology	Operator Details	Randomization	Method of Outcome Measurement	Outcome Assessor Details	Blinding	Statistical Analysis	Presentation of Results			
Oteiza-Galdón et al, 2020[23]	2	0	0	2	2	0	0	2	0	0	2	2	12	50%	Medium
Tonin et al, 2021[24]	2	0	0	2	2	0	0	2	0	0	2	2	12	50%	Medium
Abu Ghofa et al, 2023[9]	2	0	0	2	2	1	0	2	2	0	2	2	15	63%	Medium
Nakhaei et al, 2023[25]	2	1	0	2	2	0	0	2	0	0	2	2	13	54%	Medium
Atsu et al, 2024[26]	2	2	1	2	2	0	0	2	2	0	2	2	17	71%	Low
Peixoto et al, 2024[17]	2	2	2	2	2	1	2	2	0	0	2	2	19	79%	Low
Batista et al, 2024[18]	2	2	0	2	2	2	0	2	2	0	2	2	18	75%	Low
Nassar et al, 2023[10]	2	0	0	2	2	2	0	2	2	0	2	2	16	67%	Medium
Del Monte et al, 2023[27]	2	0	0	2	2	0	2	2	0	0	2	2	14	58%	Medium
Rodrigues et al, 2024[28]	2	2	0	2	2	0	0	2	0	0	2	2	14	58%	Medium
El-Asfahani et al, 2023[29]	2	2	0	2	2	0	2	2	1	2	2	2	19	79%	Low
Tonin et al, 2025[30]	2	2	2	2	2	0	0	2	1	2	2	2	19	79%	Low
Fábrega et al, 2021[5]	2	0	0	2	2	0	0	2	0	0	2	2	12	50%	Medium

Table 4. Precision ranking of measurement techniques under different test conditions for assessing marginal fit

OST				AST			
Rank	**Techniques**	**Sample Size, Total (N)**	**Weighted Average CV (%)**	**Rank**	**Techniques**	**Sample Size, Total (N)**	**Weighted Average CV (%)**
1	Radiographs	32	13.7	Not assessed (no available studies)			
2	Optical microscope	33	22.4	1	Optical microscope	33	20.5
3	3D CLSM	100	23.4	2	3D CLSM	100	23.4
4	SEM	50	25.6	3	SEM	80	30.2
5	Stereomicroscope	144	32.8	4	Stereomicroscope	130	45.7
6	Profile projector	20	70.7	Not assessed (no available studies)			

AST, all-screws test; CLSM, confocal laser scanning microscope; CV, coefficient of variation; OST, 1-screw test; SEM, scanning electron microscope; 3D, 3-dimensional.

internal fit may seriously underestimate risks, since poor internal adaptation can lead to significant micromovements, uneven and potentially damaging load transfer to screws and abutments, and biological complications such as peri-implant bone resorption.[1,12] Without evaluating the internal fit, assessments of implant-supported fixed prosthesis reliability remain fundamentally incomplete. Nevertheless, none of the in vitro studies included in this review assessed internal fit for screw-retained implant-supported FPDs, highlighting the scarcity of such assessments.

The present review focused specifically on the test conditions and measurement techniques used, as they are key determinants of measurement reliability and study comparability. For test conditions, while OST may reveal misfits more clearly under controlled laboratory conditions,[1,2] AST better simulates the prosthesis under everyday function, where all screws are tightened.[10] Moreover, AST highlights whether the prosthesis can withstand long-term loading without complications such as screw loosening or framework strain.[10,17,18] Therefore, compared with dimensional discrepancies, measuring the induced stress and strain has been considered more representative for evaluating the degree of misfit after AST.[1] However, relying solely on AST may result in overestimating the apparent fit of a framework, since all screws are tightened during measurement. The combination of OST and AST can provide more comprehensive and clinically relevant evidence of the fit for screw-retained implant-supported FPDs.

Despite the present review focusing on precision, the choice of measurement technique also needs to account for clinical practicality. As a clinical method, radiographic evaluation has been widely applied because of its accessibility, high consistency, and practical ease of use.[1,29] In contrast, stereomicroscopy and SEM have been frequently used in the laboratory because of their high magnification and ability to provide detailed assessments.[9,10,17,18,24–28] Nevertheless, factors such as sensitivity to positioning errors and complex sample preparation may reduce measurement consistency, potentially affecting the reliability of fit evaluation.[1,9,10] Although profile projection has also been applied for measuring marginal gaps, the technique is highly sensitive to setup parameters, projection quality, and operator variability, leading to compromised precision.[5] Compared with these techniques, optical microscopy allows a relatively straightforward procedure, which may contribute to its good repeatability and high precision in measurement.[1,23] However, regardless of the precision of these 2D techniques, they remain limited in assessing 3D discrepancies and angular misfits. In contrast, 3D CLMS is nondestructive, capable of evaluating 3D geometry, and has been applied in dentistry for dental surface analysis.[30] Although Tonin et al[30] used 3D CLSM for fit assessment, they measured only horizontal (x-axis) and vertical (y-axis) misfit, which suggests that their results may reflect essentially 2D measurements rather than a truly comprehensive 3D assessment.

While CV allows comparisons of relative variability across techniques with different measurement scales, it can be influenced by low mean values, which may exaggerate variability for techniques producing small marginal gap measurements.[20] Therefore, a weighted

Test conditions	Ranking of techniques
OST	Radiographs>Optical microscope>3D CLSM>SEM>Stereomicroscope>Profile projector
AST	Optical microscope>3D CLSM>SEM>Stereomicroscope

Figure 2. Ranking of techniques used for marginal fit assessment. AST, all-screws test; CLSM, confocal laser scanning microscope; CV, coefficient of variation; OST, 1-screw test; SEM, scanning electron microscope; 3D, 3-dimensional.

average CV was calculated by incorporating sample sizes to provide a more representative assessment of precision across various techniques.[20,21] While a ranking of measurement methods was proposed based on these indicators (Fig. 2), variations in study protocols and different levels of risks of bias across the included studies suggest methodological limitations, making direct comparisons challenging. Study protocols varied across the included studies because of the persistent lack of standardization in fit assessment for screw-retained implant-supported FPDs.[15] Beyond test conditions and measurement techniques, substantial variability was also present in other aspects, including sample size, framework configuration, and measurement settings such as magnification, measurement sites, and number of repeated measurements. Moreover, certain techniques, including radiographic evaluation, 3D CLSM, and profile projection, were each used in only a single study, resulting in uncertainty regarding their relative precision in assessing the fit. Therefore, these sources of heterogeneity indicate that comparisons among the different measurement methods must be interpreted with caution.

The present review focuses on measurement methods that evaluated fit exclusively from a dimensional gap perspective, whereas other relevant fit-related outcomes, such as strain and stress distribution, were not addressed. Additionally, the results were derived from in vitro studies, with measurements performed before subsequent procedures such as veneering, thermal cycling, or mechanical loading, which may limit their clinical relevance. Future research should achieve consensus on clearly defined and standardized protocols for the fit assessment of screw-retained implant-supported FPDs. Also, the accuracy and precision of various measurement methods for assessing fit need to be evaluated in rigorously uniform and clinically relevant study designs.

CONCLUSIONS

Based on the findings of this systematic review, the following conclusions were drawn:

1. The techniques used for fit assessment included radiographic evaluation, optical microscopy, 3D CLSM, SEM, stereomicroscopy, and profile projection.
2. All evaluated techniques focused on assessing the marginal fit of FPDs, with none addressing the internal fit, in the studies included in this review.
3. Assessments were primarily performed by using OST or AST, with most measurement techniques demonstrating better repeatability under OST compared with AST.
4. Radiographic evaluation was the most precise technique under OST, whereas optical microscopy was the most precise under AST. 3D CLSM, SEM, and stereomicroscopy showed lower precision under both conditions, and the profile projection exhibited the greatest variability under OST.

REFERENCES

1. Pan Y, Tsoi JKH, Lam WYH, Pow EHN. Implant framework misfit: A systematic review on assessment methods and clinical complications. *Clin Implant Dent Relat Res*. 2021;23:244–258.
2. Abduo J, Bennani V, Waddell N, et al. Assessing the fit of implant fixed prostheses: A critical review. *Int J Oral Maxillofac Implants*. 2010;25:506–515.
3. Rutkunas V, Dirse J, Kules D, et al. Misfit simulation on implant prostheses with different combinations of engaging and nonengaging titanium bases. Part 2: Screw resistance test. *J Prosthet Dent*. 2024;131:262–271.
4. Katsoulis J, Takeichi T, Sol Gaviria A, et al. Misfit of implant prostheses and its impact on clinical outcomes. Definition, assessment and a systematic review of the literature. *Eur J Oral Implantol*. 2017;10:121–138.
5. Fábrega J, Ríos-Santos JV, Falcão C, Herrero-Climent M. A modified protocol for restorative implant abutment selection by using computer-aided design and computer-aided manufacturing technology. *J Prosthet Dent*. 2021;125:341–348.
6. Abdelrehim A, Etajuri EA, Sulaiman E, et al. Magnitude of misfit threshold in implant-supported restorations: A systematic review. *J Prosthet Dent*. 2024;132:528–535.
7. Ko KH, Huh YH, Park CJ, Cho LR. Effect of materials on axial displacement and internal discrepancy of cement-retained implant-supported prostheses. *J Prosthet Dent*. 2022;127:462–469.
8. Guichet DL, Caputo AA, Choi H, Sorensen JA. Passivity of fit and marginal opening in screw- or cement-retained implant fixed partial denture designs. *Int J Oral Maxillofac Implants*. 2000;15:239–246.
9. Abu Ghofa A, Önöral Ö. An assessment of the passivity of the fit of multiunit screw-retained implant frameworks manufactured by using additive and subtractive technologies. *J Prosthet Dent*. 2023;129:440–446.
10. Nassar HI, Fateen A. Accuracy of fit for cobaltchromium bar over two implants fabricated with different manufacturing techniques: An in-vitro study. *BMC Oral Health*. 2023;23:946.
11. Chen J, Guo J, Yang L, et al. Effect of different implant angulations on the biomechanical performance of prosthetic screws in two implant-supported, screw-retained prostheses: A numerical and experimental study. *J Prosthet Dent*. 2023;130:240.e1–240.e10.
12. Fakhr MWZF, Alansary H, Hassanien EEY. Internal fit and marginal adaptation of all-ceramic implant-supported hybrid abutment crowns with custom-milled screw-channels on Titanium-base: In-vitro study. *BMC Oral Health*. 2024;24:1073.
13. Son K, Lee S, Kang SH, et al. A comparison study of marginal and internal fit assessment methods for fixed dental prostheses. *J Clin Med*. 2019;8:785.
14. Kano SC, Binon PP, Curtis DA. A classification system to measure the implant-abutment microgap. *Int J Oral Maxillofac Implants*. 2007;22:879–885.
15. Thakur J, Parlani S, Shivakumar S, Jajoo K. Accuracy of marginal fit of an implant-supported framework fabricated by 3D printing versus subtractive manufacturing technique: A systematic review and meta-analysis. *J Prosthet Dent*. 2023;129:301–309.
16. Ayres AP, Cuschieri LA, Bianchi DM, et al. Advantages and drawbacks of different methods to measure marginal gaps in fixed dental prostheses: A scoping review. *J Dent*. 2024;151:105400.
17. Peixoto RF, Tonin BSH, Pinto-Fiamengui LMS, et al. Analysis of implant-supported cantilever fixed partial denture: An in vitro comparative study on vertical misfit, stress distribution, and cantilever fracture strength. *J Prosthodont*. 2024;33:584–592.
18. Batista JNS, Simionato AA, Faria ACL, et al. Evaluation of vertical misfit and torque loss of different abutments for Tri-channel type internal connection dental implants after mechanical cycling. *J Oral Implantol*. 2024;50:31–38.
19. Moher D, Liberati A, Tetzlaff J, Altman DG. Reprint-preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Phys Ther*. 2009;89:873–880.
20. Mocini E, Cammarota C, Frigerio F, et al. Digital Anthropometry: A systematic review on precision, reliability and accuracy of most popular existing technologies. *Nutrients*. 2023;15:302.
21. Wiebe N, Vandermeer B, Platt RW, et al. A systematic review identifies a lack of standardization in methods for handling missing variance data. *J Clin Epidemiol*. 2006;59:342–353.
22. Sheth VH, Shah NP, Jain R, et al. Development and validation of a risk-of-bias tool for assessing in vitro studies conducted in dentistry: The QUIN. *J Prosthet Dent*. 2024;131:1038–1042.
23. Oteiza-Galdón B, Martínez-González A, Escuder ÁV. Analysis of fit on implants of chrome cobalt versus titanium frameworks made by CAD/CAM milling. *J Clin Exp Dent*. 2020;12:e951–e957.

24. Tonin BSH, Peixoto RF, Fu J, et al. Evaluation of misfit and stress distribution in implant-retained prosthesis obtained by different methods. *Braz Dent J.* 2021;32:67–76.
25. Nakhaei M, Moraditalab A, Mottaghianfar A, Nodehi D. Comparison of the passivity between CAD/CAM implant frameworks and three different conventional techniques before and after applying veneering porcelain. *Avicenna J Dent Res.* 2023;15:103–108.
26. Atsu S, Erol U. Marginal fit and fracture resistance of polyetheretherketone, zirconia, and titanium implant-supported prosthesis frameworks for a partially edentulous arch after thermomechanical aging. *J Prosthet Dent.* 2024;131:273–280.
27. Del Monte S, Shahdad S, Taylor P. Passive fit analysis of laser-sintered, three-unit implant prostheses: An in vitro study. *Int J Prosthodont.* 2023;36:650.
28. Rodrigues TCM, Resende CCD, Moura GF, et al. Influence of fabrication method on the marginal fit of temporary restorations. *Braz Oral Res.* 2024;38:e063.
29. El-Asfahani IA, Ramdan AS, Agamy E. Accuracy of selective laser melted bar retaining mandibular implant-assisted overdenture: An in vitro comparison of different impression materials and techniques. *J Oral Implantol.* 2023;49:590–598.
30. Tonin BSH, Fu J, Peixoto RF, et al. An in vitro study using confocal laser scanning microscopy to evaluate the marginal misfits of different implant-supported frameworks. *J Prosthodont.* 2025;34:403–411.

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