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SYSTEMATIC REVIEW

Marginal gap measurement of ceramic single crowns before cementation: A systematic review

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ABSTRACT

Statement of problem. Different instruments have been used to measure the marginal gaps of crowns in vitro. However, a comprehensive systematic review is lacking.

Purpose. The purpose of this systematic review was to evaluate the existing literature on the instruments used for the in vitro marginal gap measurement of ceramic single crowns before cementation and to determine whether the crown material and method of fabrication influenced the marginal gap.

Material and methods. The search was conducted in 2024 across the EBSCO Host, Scopus, PubMed, and Web of Science databases by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and predefined eligibility criteria. Eligible articles were screened to evaluate 6 instruments for measuring crown marginal gaps: direct view microscopy, scanning electron microscopy, impression replica, cross-sectioning, microcomputed tomography, and 3-dimensional (3D) superimposition. The normality of the data was assessed by using the Kolmogorov-Smirnov test, and the differences in mean marginal gap were statistically evaluated using the Welch ANOVA (α=.05).

Results. Ninety-two articles were included, with 77 documenting single measurement instruments and 15 using a combination of 2 or more measurement instruments. Direct view microscopy was the most used instrument and appeared in 31 (40%) of the studies. No significant differences in mean marginal gap (F=2.09, P=.077) were found across the 6 measurement instruments. Across all studies, excluding those using 3D superimposition, the mean ±standard deviation number of marginal gap measurements per crown was 34.3 ±50.6. Among the 77 studies using a single measurement instrument, 64 used computer-aided design and computer-aided manufacturing (CAD-CAM) technology to fabricate the crowns. CAD-CAM crowns had a mean ±standard deviation marginal gap of 78.9 ±28.6 µm (n=64) compared with 71.6 ±29.5 µm (n=13) for crowns manufactured using conventional methods. Zirconia and lithium disilicate were the most researched materials. Zirconia crowns recorded a mean ±standard deviation marginal gap of 69.4 ±34.2 µm for 972 crowns, which was significantly different (P=.045) from lithium disilicate with a mean ±standard deviation marginal gap of 92.2 ±42.5 µm for 602 crowns.

Conclusions. Direct view microscopy was the most used marginal gap measurement instrument for ceramic single crowns before cementation, and CAD-CAM was the most used crown fabrication method. No significant differences in mean marginal gap were found among the 6 marginal gap measurement instruments. (J Prosthet Dent 2025;133:1145-1156)

The marginal gap is the measurement between the axial wall of the prepared tooth and the intaglio surface of the restoration at the margin.[1] Ahead of esthetics and fracture resistance, the marginal fit of the restoration has been considered the most critical factor in the clinical success of crowns.[2–4] An accurate marginal fit reduces the risk of hypersensitivity because of microleakage and reduces plaque accumulation, whereas a lack of accurate marginal fit can result in periodontal disease, caries leading to pulpitis, and an increased thickness of cement exposed to the oral environment leading to increased water absorption and marginal leakage.[3,5,6] Multiple factors have been reported to influence the marginal fit of a dental restoration, including the preparation design, location of the preparation finish line, restorative material, fabrication method, and impression material and technique.[7]

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Clinical Implications

CAD-CAM crowns demonstrated slightly larger mean marginal gaps compared with crowns fabricated using conventional methods. Zirconia crowns demonstrated a significantly smaller mean marginal gap than lithium disilicate crowns.

A widely accepted historical maximum clinical marginal gap has been reported to be 120 μm,[8] sourced from data using polyether rubber films applied to a variety of restorations seated in vivo and measured in vitro. More recent studies have considered that clinically acceptable gaps were smaller, including ≤100 μm,[9,10] ≤90 μm,[11] and ≤75 μm.[12] Conversely, acceptable marginal gaps reported in ceramic restorations ranged from 7.5 to 206.3 μm, with the included studies characterized by a range of different ceramic materials, different fabrication methods, and different measurement instruments.[13–15] A consensus on the ideal marginal gap is lacking.[16]

Marginal gap measurements are generally made at arbitrarily selected locations and conveniently extrapolated to assume and represent the overall crown marginal gap.[1,2,17] Making approximately 50 measurements has been proposed as the minimum number of marginal gap measurements per crown, but the recommendation was based on calculating arithmetic means in a limited sample size with a view to minimizing the impact on the measurement error.[18] The minimum number of measurements relates to gap variation and intended precision, which is similar to the statistical power analysis required to predict sample sizes required for hypothesis testing.[18] Currently, a consensus on the number of measurements required to provide an optimal and clinically relevant conclusion on the accuracy of the marginal adaptation of crown restorations is lacking.[19–21]

The main instruments for measuring marginal gaps can be broadly categorized into 2-dimensional (2D) or 3-dimensional (3D) and destructive (DE) or non-destructive (ND) methods. The instruments include direct view microscopy (2D, ND), scanning electron microscopy (3D, ND), impression replica (2D, ND), cross-sectioning (2D, DE), microcomputed tomography (3D, ND), and 3D superimposition (3D, ND). Each instrument has its own advantages and limitations. There are conflicting and limited reports comparing the accuracy of different crown marginal gap measurement instruments.[22] Schmalz et al[22] reported that scanning electron microscopy was more accurate than light microscopy, while Groten et al[23] reported no significant difference between the 2 instruments, although scanning electron microscopy provided more realistic observations. However, these studies are now somewhat outdated. Several reviews have explored crown marginal gap assessment and factors influencing its use,[7,13,16,24–27] but a systematic evaluation of the influence of different measurement instruments on marginal gap values is lacking.[11]

The aim of this study was to systematically evaluate the existing literature on the instruments used for the in vitro marginal gap measurement of ceramic single crowns before cementation. Additionally, the study sought to determine whether factors such as the material used for crown fabrication and the number of marginal gap measurements made influence the final outcomes. The null hypothesis was that the instruments used for marginal gap measurement would have no significant effect on the overall marginal gap.

MATERIAL AND METHODS

This systematic review was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The inclusion criteria focused on in vitro studies assessing marginal gaps in complete coverage, ceramic single crowns before cementation. Studies had to specify the instruments used for marginal gap assessment, including the number of measurements made. Only original articles with cross-sectional or longitudinal experimental designs using digital or conventional procedures for ceramic crown fabrication were considered. If studies measured marginal gaps both before and after cementation, only measurements made before cementation were analyzed, provided the same instrument was used throughout. Additionally, in studies evaluating the quality of ceramic materials through heat press, sintering, or glazing, only the marginal gap values of the finished ceramic prosthesis were included.

The exclusion criteria eliminated in vivo studies of complete coverage, ceramic single crowns, as well as virtually fabricated and evaluated crowns without a physical component. Studies that relied on manual estimation of marginal gaps through visual or tactile assessments or those that measured intaglio fit without assessing marginal gaps were also excluded. Partial coverage crowns, such as inlays and onlays, fixed partial dentures, and 1-piece endodontic crowns were not considered. Crown types that included base metal, gold alloys, stainless steel, or metal-ceramic were excluded.

Data were retrieved from the Scopus, PubMed.gov, EBSCOHost Dentistry Oral Sciences Source, and Web of Science (WoS) databases. Web of Science captured the following databases, with translations in English when necessary: Web of Science Core Collection, Current Contents Connect, Derwent Innovations Index, KCI-Korean Journal Database, MEDLINE, Russian Science Citation Index, SciELO Citation Index. The searches were conducted in

June 2024, with no restrictions on the publication date of the articles. Specific language and field restrictions were applied to Scopus and Web of Knowledge searches to show only English research on material sciences within dentistry and healthcare.

The search process was independently conducted by 2 reviewers (J.D., T.H.F.). Interrater reliability was measured using the Cohen kappa (κ) coefficient. Keyword-based logic grids, Boolean logic, and individual searches of published bibliography were performed.[28] The search methods are described in Supplemental File 1 (available online).

An a-priori search was conducted using the manuscript title and research question with a generative artificial intelligence (AI) model (Consensus AI; Consensus Inc) to determine the data items and summary measures to be extracted. Duplicates were removed, and manuscripts were screened using a systematic review screening platform (Covidence.org; Veritas Health Innovations Ltd). This platform ensured complete agreement and conflict resolution between the reviewers before allowing eligible manuscripts to advance through the screening process. Translation of eligible foreign articles was performed with the assistance of a deep learning language model (Co-pilot; Microsoft Corp). Due to the specific nature of the included studies, most key research was published across a limited number of journals and publishing bodies. As such, all papers were included to provide a broad narrative overview without critically appraising for biases, which might have resulted in the exclusion of otherwise eligible papers.

The following parameters were measured: instrument(s) used for crown marginal gap, number of crowns tested in each investigation, ceramic material used for crown fabrication, method of crown fabrication, type and material of the tooth or die underlying the prepared crown, number of marginal gap measurements per crown, mean range of marginal gap measurements (in μm) in any direction, and mean marginal gap (in μm, rounded to the nearest whole number). The normality of the data was assessed using the Kolmogorov-Smirnov test. While the overall data were normally distributed, the distribution of studies was not homogeneous across the measurement methods. Therefore, the Welch ANOVA was used to evaluate the mean marginal gap differences across the studies (α=.05). The influence of the number of measurement points across different instruments was assessed using Pearson correlation analysis of individual measurement instruments.

RESULTS

Ninety-two articles were included for evaluation after systematic screening. The process and results are summarized in the PRISMA flowchart (Fig. 1). Table 1 details the individual measurement methodologies and mean marginal gaps reported for ceramic crowns before cementation (n=77). The most used instrument for marginal gap measurement was direct view microscopy representing 31 (40%) of the 77 studies included followed by the impression replica instrument (17%). The scanning electron microscopy measurement instrument yielded the lowest mean ±standard deviation marginal gap of 64.0 ±22.6 μm, based on a mean of 19 measurements per crown. This was followed by direct view microscopy, which reported a mean ±standard deviation marginal gap of 68.3 ±29.5 μm from a mean of 27.6 measurements per crown. No significant differences in mean marginal gap (F=2.09, *P*=.077) were found across the 6 measurement instruments. Table 2 presents the mean ±standard deviation marginal gaps reported for ceramic crowns before cementation, assessed using various combinations of measurement instruments (n=15). The distribution of measurement instruments across manuscripts, categorized by year of publication, is illustrated in Figure 2.

The number of measurements made per crown using a single measurement instrument is detailed in Table 1. These measurements were divided into direct view microscopy,[2,14,17,20,29–55] scanning electron microscopy,[4,18,56–59] impression replica,[60–72] cross-sectioning,[5,73–76] microcomputed tomography,[77–87] and 3D superimposition.[88–98] The mean ±standard deviation number of marginal gap measurements made per crown across all studies using a single measurement instrument (except 3D superimposition) was 34.3 ±50.6. The correlation between measured marginal gaps and the number of measurements per crown was assessed for each measurement instrument individually, followed by Welch ANOVA (Table 2). The 3D superimposition method measured spatial volumetric overlap and not points. Studies with unspecified parameters were excluded from correlation analyses. No significant correlations were observed across the number of marginal gap measurements and the resultant marginal gap values with variances adjusted for robust analyses (Equality of means, *P*=.178).

CAD-CAM technology was used to fabricate crowns in 64 of the 77 studies that used a single measurement instrument. Across all measurement instruments, the mean ±standard deviation marginal gap for crowns fabricated using CAD-CAM (n=64) was 78.9 ±28.6 μm compared with conventional methods (n=13) of 71.6 ±29.5 μm.

Among the included studies, 27 used only zirconia as the crown material, resulting in a mean ±standard deviation marginal gap of 69.4 ±34.2 μm for 972 crowns. In contrast, 21 studies using only lithium disilicate reported a mean ±standard deviation marginal gap of 92.2 ±42.5 μm for 602 crowns, a significant difference

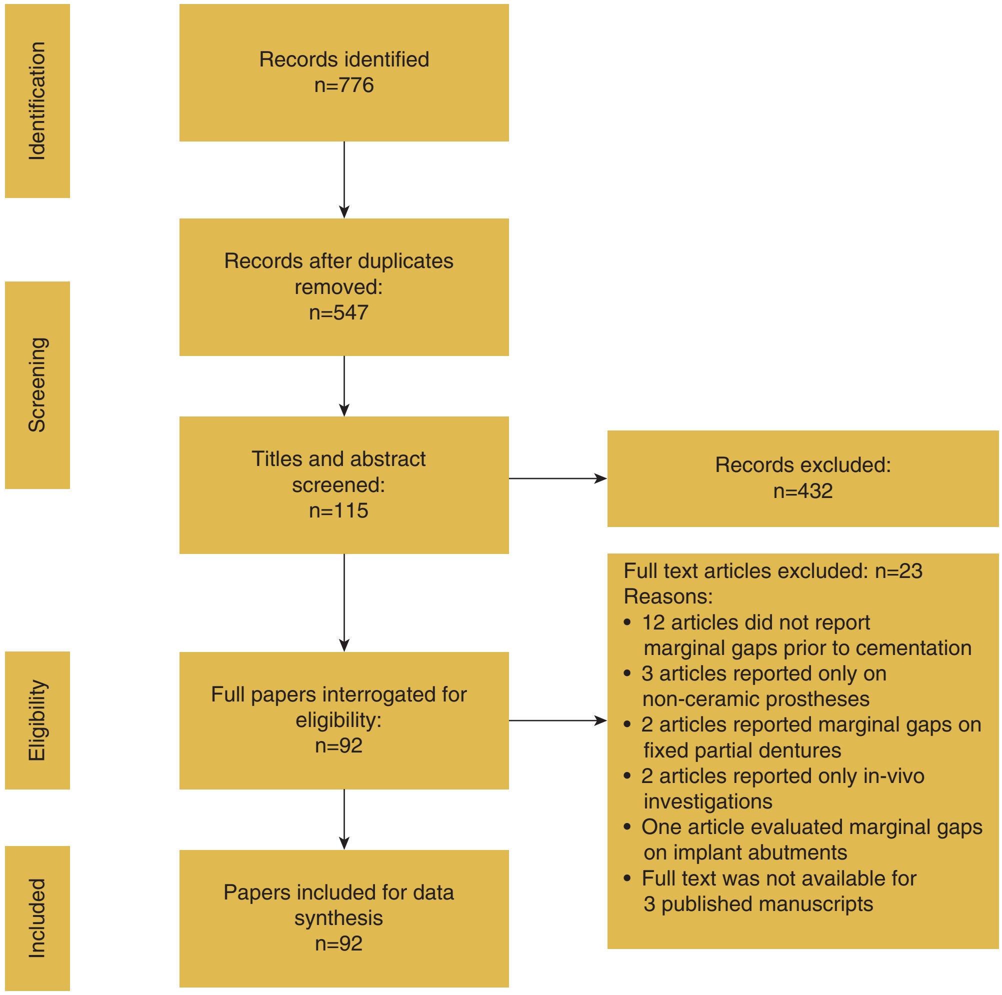

Figure 1. PRISMA flowchart showing search results. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

(F=4.27, *P*=.045) (Table 3). Eight studies that used ceramic to fabricate 351 crowns found a mean ±standard deviation marginal gap of 87.4 ±26.1 µm, whereas 3 studies used In-Ceram Alumina for 130 crowns reported a mean ±standard deviation marginal gap of 63.3 ±15.0 µm. Eighteen studies that fabricated 609 crowns from a combination of zirconia, lithium disilicate, ceramic, and In-Ceram Alumina reported a mean ±standard deviation marginal gap of 86.0 ±56.7 µm. The mean number of crowns included per study was 34.6, which varied from impression replica (50.2) to 3D superimposition (26.0).

The 3 main types of abutment teeth used in the crown fabrication process were metal or alloy dies (n=15), human teeth (n=17), and typodont teeth (n=42). The mean ±standard deviation marginal gap for each abutment tooth type was 74.9 ±60.5 µm, 76.1 ±44.8 µm, and 85.1 ±33.8 µm, respectively. Ten studies that fabricated crowns for 472 incisors reported a mean ±standard deviation marginal gap of 81.0 ±32.1 µm, 8 studies for 240 premolars reported 66.8 ±27.6 µm, and 48 studies for 1505 molars found a mean ±standard deviation marginal gap of 86.9 ±47.9 µm.

The results from studies that used multiple measurement instruments[5,23,99–111] in a single workflow are tabulated in Table 4. Because of the combined instrument measurement methodologies, it was not possible to separate the data into individual instrument measurements that permitted comparative analysis. Therefore, the data were not included in the main analysis.

DISCUSSION

This systematic review evaluated the existing literature on the instruments used for in vitro marginal gap measurement of ceramic single crowns before cementation. No significant differences in mean marginal gap were found among the 6 marginal gap measurement instruments; therefore, the null hypothesis that the instruments used for marginal gap measurement would have no significant effect on the overall marginal gap

Table 1. Individual measurement methodologies and mean marginal gaps reported on single ceramic crowns before cementation (n=77)

Measurement Instrument	No. of Studies	Author, Year	Number of Crowns Tested	Crown Material	Method of Crown Fabrication	Underlying Crown Preparation Material	Tooth form Measured	Number of Marginal Gap Measurements per Crown	Mean Range of Marginal Gap Measurements (in µm) in Any Direction	Mean Marginal gap (in µm, Rounded to Nearest Whole Number)
Direct view microscopy	31	Loetzerich, 2023	12	Zirconia	CAD-CAM	Plastic model teeth	Maxillary molar	240	120 to 127	124
		Nasir, 2023	48	Zirconia	CAD-CAM	Human teeth	Maxillary first premolars	16	16.36 to 25.16	21
		Mohaghegh, 2022	30	Zirconia	CAD-CAM	Die of metal or alloy	Unspecified	18	48.18 to 51.35	50
		Su, 2022	24	Lithium disilicate	CAD-CAM	Plastic model teeth	Mandibular first molar	12	63.73 to 107.41	86
		Tan, 2022	24	Lithium disilicate	CAD-CAM	Plastic model teeth	Mandibular first molar	12	100.4 to 101.08	101
		Taha, 2022	24	Zirconia	CAD-CAM	Human teeth	Maxillary first premolar	16	80 to 120	100
		Zhang, 2021	24	Lithium Disilicate	CAD-CAM	Plastic model teeth	Mandibular first molar	16	61 to 117	89
		Akhlaghian, 2021	40	Zirconia	CAM	Die of metal or alloy	unspecified	12	42 to 109	76
		Mohaghegh, 2020	30	Zirconia	CAD-CAM	Die of metal or alloy	Unspecified Molars	18	42.3 to 62.9	53
		Kwong, 2020	24	Lithium disilicate	CAD-CAM	Plastic model teeth	Mandibular molar	12	63.73 to 88.64	76
		Sadid-Zadeh, 2020	12	Lithium disilicate	CAD-CAM	Plastic model teeth	Unspecified Molars	12	59.7 to 123.7	92
		Sadid-zadeh, 2019	12	Lithium disilicate	Heat press, CAD-CAM	Plastic model teeth	Unspecified molars	14	77.2 to 113.3	95
		Elrashid, 2019	30	Lithium Disilicate	Lost wax, CAD-CAM	Plastic model teeth	Maxillary first molar	8	26.8 to 38.8	33
		Tabesh, 2018	24	Lithium disilicate	CAD-CAM	Plastic model teeth	Mandibular molar	12	77.84 to 109.26	94
		Hamza, 2017	30	Zirconia	CAD-CAM	Die of metal or alloy	Unspecified	8	19.4 to 39.3	29
		Kale, 2017	6	Zirconia	CAD-CAM	Plastic model teeth	Maxillary first molar	144	9.79 to 85.51	38
		Kale, 2016	15	Zirconia	CAD-CAM	Plastic model teeth	Maxillary first molar	8	53 to 85	69
		Al-Zubaidi, 2015	32	Zirconia, Lithium disilicate	CAD-CAM	Die of metal or alloy	Maxillary first molar	16	73.55 to 162.34	118
		Abdel-Azim, 2015	30	Lithium disilicate	CAD-CAM	Plastic model teeth	Maxillary central incisor	4	89.6 to 112.3	101
		Alhavaz, 2015	40	Zirconia	Copy milling, CAD-CAM	Plastic model teeth	Mandibular molar	16	56.87 to 136.12	96
		Jalali, 2015	24	Zirconia	CAM	Human teeth	Mandibular premolars	12	71.59 to 80.68	76
		Jalalian, 2015	20	Lithium Disilicate	CAD-CAM	Die of metal or alloy	premolar	10	32.01 to 35.24	33
		Shetty, 2014	32	Zirconia	Copy milling	Human teeth	Maxillary first premolars	2	12.34 to 142.8	78
		Asavapanumas, 2013	36	Lithium disilicate	Lost wax	Plastic model teeth	Maxillary central incisor	12	38.3 to 70.0	54
		Sakrana, 2013	30	In-ceram, Zirconia	Copy milling	Human teeth	Mandibular first premolars	12	83.50 to 84.94	84
		Hamza, 2013	40	Zirconia, lithium disilicate	CAD-CAM	Die of metal or alloy	Mandibular second molar	8	14 to 86.1	50
		Yucel, 2013	80	In-ceram	Lost wax, CAM	Die of metal or alloy	Maxillary incisor	80	21.5 to 74.6	48
		Borges, 2012	90	Lithium disilicate, alumina	Lost wax	Bovine teeth	Maxillary incisors	16	66.2 to 83.13	75
		Rus, 2011	40	In-ceram, ceramic	CAD-CAM	Human teeth	Mandibular first molar	10	8.67 to 29.98	19
		Okutan, 2006	32	Zirconium silicate	Lost wax	Human teeth	Mandibular molar	64	32.7 to 33.0	33
		Pera, 1994	9	In-ceram, alumina	Slip casting	Plastic model teeth	Incisor, canine, premolar	16	21.67 to 27.50	25
		Overall	944 crowns tested; mean marginal gap measured=68.26 ±29.51 µm							
Scanning electron microscopy	6	Halici, 2018	60	In-ceram, lithium disilicate, zirconia	CAM	Plastic model teeth	Maxillary central incisor, maxillary first molar	52	28.29 to 114.16	71
		Yus, 2018	30	zirconia	CAD-CAM	Die of metal or alloy	Maxillary molar	12	8.94 to 22.42	16
		Alqahtani, 2017	60	Lithium disilicate	CAD-CAM	Die of metal or alloy	Mandibular first molar	12	60.2 to 111.1	86
		Cetik, 2017	60	zirconia	CAD-CAM	Plastic model teeth	Maxillary first molar	8	59 to 79	69
		Groten, 2000	10	In-ceram	Copy milling	Die of metal or alloy	Maxillary central incisor	230	30 to 97	64
		Ringke, 1995	40	In-ceram	Copy milling	Die of metal or alloy	Maxillary incisor and premolar	54	1 to 154	78
		Overall	260 crowns tested; mean marginal gap measured=64.0 ±22.58 µm							

Table 1 *(Continued)*

Measurement Instrument	No. of Studies	Author, Year	Number of Crowns Tested	Crown Material	Method of Crown Fabrication	Underlying Crown Preparation Material	Tooth form Measured	Number of Marginal Gap Measurements per Crown	Mean Range of Marginal Gap Measurements (in µm) in Any Direction	Mean Marginal gap (in µm, Rounded to Nearest Whole Number)
Impression replica	13	Ibrahim, 2024	36	Zirconia	CAD-CAM	Plastic model teeth	Maxillary molar	48	67 to 137	102
		Alves, 2023	45	Lithium disilicate	CAM	Die of metal or alloy	Unspecified	12	63 to 74	69
		Ozsurmeli, 2021	60	Zirconia	CAM	Human teeth	Mandibular first molar	20	31.13 to 56.83	44
		Al Hamad, 2019	40	Lithium Disilicate	CAD-CAM	Human teeth	Peg-shaped maxillary lateral incisor	6	125.46 to 135.59	131
		Praca, 2018	40	Zirconia	CAD-CAM	Human teeth	Premolars and Molars	32	45.90 to 117.59	82
		Mejia, 2017	70	Zirconia	CAD-CAM	Plastic model teeth	Maxillary incisor	12	42.1 to 58.2	50
		Sinhori, 2017	20	Lithium disilicate	CAD-CAM	Plastic model teeth	Maxillary molar	24	96.28 to 305.38	200
		Renne, 2015	80	Lithium disilicate	CAD-CAM	Plastic model teeth	Maxillary incisor	8	36.6 to 104	70
		Shim, 2015	40	Ceramic	CAD-CAM	Plastic model teeth	Maxillary second molar	16	20 to 160	90
		Tidehag, 2014	45	Ceramic	Heat press, CAD-CAM	Plastic model teeth	Maxillary first molar	38	107 to 128	118
		Renne, 2012	75	Ceramic	CAD-CAM	Plastic model teeth	Maxillary molar	16	38.5 to 90.1	64
		Zhang, 2011	30	Lithium Disilicate, In-Ceram, alumina	Direct layering,Slip casting,CAD-CAM	Human teeth	Maxillary premolar	12	41.1 to 71.7	56
		Iwai, 2008	72	Zirconia	CAD-CAM	Die of metal or alloy	Mandibular first molar	35	20.7 to 142.1	81
		Overall	653 crowns tested; Mean marginal gap measured=89.0 ±40.41 µm							
Cross sectioning	5	Cin, 2023	20	Zirconia	CAD-CAM	Plastic model teeth	Mandibular first molar	13	29 to 75	52
		Pei, 2021	18	Ceramic	CAM	Human teeth	Third molars	Unspecified	106.5 to 116.1	111
		ArRejaie, 2018	30	Ceramic, Zirconia	CAD-CAM	Die of metal or alloy	Maxillary first molar	7	112.5 to 160.7	273
		Habib, 2018	100	Zirconia	CAD-CAM	Plastic model teeth	Mandibular first molar	8	46.93 to 101.65	74
		Nakamura, 2000	30	Alumina, Ceramic	Copy milling	Plastic model teeth	Maxillary central incisor	5	30 to 130	80
		Overall	198 crowns tested; Mean marginal gap measured=118.0 ±89.16 µm							
Microcomputed tomography	11	Tamam, 2023	28	Ceramic	CAD-CAM	Plastic model teeth	Mandibular second molar	114	12.9 to 146.7	80
		Kojima, 2022	3	Lithium disilicate	CAD-CAM	Plastic model teeth	Mandibular first molar	20	45 to 170	108
		Kale, 2020	48	Zirconia	CAD-CAM	Human teeth	Maxillary molar	8 (CBCT)	15.44 to 38.75	27
		Tabata, 2020	32	Ceramic, Lithium Disilicate	CAD-CAM	Human teeth	Third molars	120	75 to 113	94
		Vag, 2020	24	Lithium disilicate	CAM	Human teeth	Maxillary molar	Unspecified	169 to 224	197
		Vasiliu, 2020	32	Ceramic, zirconia	CAD-CAM	Plastic model teeth	Maxillary premolar	18	81.3 to 90.5	86
		Alammari, 2019	48	Zirconia reinforced Lithium Disilicate	CAD-CAM	Plastic model teeth	unspecified	140	50.09 to 63.15	57
		Mosharraf, 2019	10	Zirconia	CAD-CAM	Plastic model teeth	Maxillary first molar	50	50.4 to 78.6	64.5
		Silveira, 2017	10	Lithium disilicate	CAD-CAM	Human teeth	Third molars	20	60 to 62	61
		Yildirim, 2017	48	Ceramic, Lithium Disilicate	CAD-CAM	Unspecified	Mandibular first molar	160	91.5 to 155.5	124
		Mously, 2014	40	Ceramic	Heat press, CAD-CAM	Plastic model teeth	Mandibular first molar	12	30.8 to 55.2	43
		Overall	323 crowns tested; mean marginal gap measured=85.59 ±46.48 µm							

Table 1 *(Continued)*

Measurement Instrument	No. of Studies	Author, Year	Number of Crowns Tested	Crown Material	Method of Crown Fabrication	Underlying Crown Preparation Material	Tooth form Measured	Number of Marginal Gap Measurements per Crown	Mean Range of Marginal Gap Measurements (in µm) in Any Direction	Mean Marginal gap (in µm, Rounded to Nearest Whole Number)
3D superimposition	11	Bin Lee, 2023	20	zirconia	CAD-CAM (Stereolithography)	Plastic model teeth	Maxillary molar	Volumetric spatial overlap	54.99 to 176.98	116
		Kim, 2023	30	Lithium disilicate	CAD-CAM	Plastic model teeth	Maxillary first molar	Volumetric (triple scan method)	66.01 to 123.46	95
		Faruqi, 2022	6	Zirconia, lithium disilicate	Lost wax	Plastic model teeth	Maxillary central incisor	Volumetric spatial overlap	15 to 259	137
		Yuan Li, 2022	10	Zirconia, lithium disilicate	Self-glazed, conventional milling	Human teeth	Mandibular first molar	Volumetric spatial overlap	78.07 to 81.40	80
		Son, 2021	45	Ceramic	CAD-CAM	Plastic model teeth	Unspecified	Volumetric (triple scan method)	60 to 100	80
		Rong Li, 2021	10	Zirconia	CAD-CAM	Unspecified	Maxillary first molar	Volumetric (triple scan method)	49.4 to 60.8	55
		Wang, 2021	10	Alumina, Zirconia	CAD-CAM (Stereolithography)	Plastic model teeth	Maxillary first molar	Volumetric spatial overlap	62 to 109	86
		Rong Li, 2019	5	Zirconia	CAM (Stereolithography)	Plastic model teeth	Maxillary molar	Volumetric spatial overlap	151.45 to 187.71	170
		Liang, 2018	60	Ceramic	Conventional, CAD-CAM	Plastic model teeth	Maxillary and mandibular incisors, premolars and molars	Volumetric spatial overlap	110 to 115	113
		Boitelle, 2016	60	Zirconia	CAD-CAM	Plastic model teeth	Maxillary first molar	Volumetric (triple scan method)	54.32 to 66.56	60
		Anadioti, 2014	30	Lithium Disilicate	CAD-CAM	Plastic model teeth	Unspecified Mandibular molar	Volumetric spatial overlap	40 to 89	65
		Overall	286 crowns tested; mean marginal gap measured=96.09 ±35.21 µm							

Table 2. Analyses of different measurement instruments in assessing mean ±standard deviation marginal gap (n=77)

	Mean ±SD (μm)	Number of Marginal Gap Measurements per Crown		F-stat (Adjusted df)	P*
		ρ	P of ρ		
Direct view microscopy	68.26 ±29.51	.132	.479	2.084 (5)	.077
Scanning electron microscopy	64.0 ±22.58	.08	.880		
Impression replica	89.0 ±40.41	.243	.423		
Cross sectioning	118.0 ±89.16	−.355	.645		
Micro-computed tomography	85.59 ±46.48	.486	.155		
3D superimposition	96.09 ±35.21	-	-		

df, degree of freedom; ρ, correlation coefficient; SD, standard deviation.
* Significant at $P<.05$; Welch 1-way ANOVA. Pearson correlation coefficient.

was not rejected. The most used marginal gap measurement instrument for ceramic single crowns before cementation was direct view microscopy followed by impression replica then μCT and 3D superimposition. Direct view microscopy has the advantages of convenience, practicality, ease of use, and low cost. Cross sectioning was the least used instrument presumably because of concerns with the accuracy of measurement and specimen destruction. The lack of use of scanning electron microscopy may be associated with its cost and equipment availability.

The scanning electron microscopy instrument yielded the lowest mean marginal gap measurement. However, the lack of overarching studies assessing and comparing the accuracy of different measurement instruments inhibited meaningful interexperimental comparisons. Clinicians and researchers are therefore left with the marginal gap findings from individual studies to either established and accepted norms (120 μm),[8] clinical guidelines where <80 μm is difficult to detect,[12] more recent guidelines, or individual preferences.[19] Generally, smaller is considered better in the context of large reported marginal gap ranges.[55] Further complicating rationalizing the scientific literature, some research has proposed that the adhesive luting of materials to tooth substrate may reduce the importance of the marginal gap.[27] The optimal marginal gap for ceramic single crowns has not yet been established.

Table 3. Subgroup analyses of marginal gaps (μm) for lithium disilicate (n=21) and zirconia-based (n=27) crowns from studies using single measurement instrument (n=77)

	Mean Square	F Stat	P*
Between groups	6161.43	4.265	.045*
Within groups	1444.57		

SD, standard deviation.
* Significant at $P<.05$; Welch One-way ANOVA.

The mean number of crowns included per study across all included studies was 35, and the mean number of measurements made per crown was 34, with most included studies falling short of the suggested 50 measurements.[18] In the absence of any explanation in the included research, convenience rather than scientific reasoning appears to be the prime reason. A key component of future research is to define an appropriate number of specimens and measurements per specimen rather than justify by reference to previous studies.

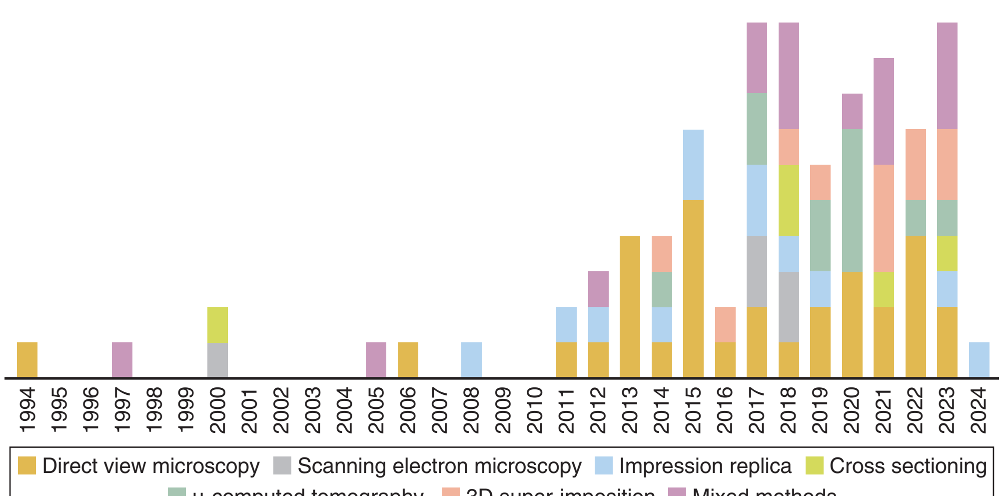

Figure 2. Distribution of measurement instruments across manuscripts categorized by year.

Table 4. Mean marginal gaps reported on ceramic single crowns before cementation following assessment through combinations of measurement instruments (n=15)

Author, Year	Measurement Instrument	Number of Crowns Tested	Crown Material	Method of Crown Fabrication	Underlying Crown Preparation Material	Tooth form Measured	Number of Marginal Gap Measurements per Crown	Range of Marginal Gap Measurements (in µm) in Any Direction
El-Ashkar, 2023	Impression replica + microscopy +triple scan method	16	Zirconia-reinforced lithium disilicate	CAD-CAM	Plastic model teeth	Mandibular first molar	78	119.4 to 133.8 in Impression replica 83.7 to 120.2 in triple scan method 85.9 to 99.5 in microscopy
Fasih, 2023	impression replica + triple-scan	20	zirconia	CAD-CAM	Human teeth	Maxillary central incisor	8	54 to 65
Sun, 2023	Microscopy + impression replica	30	Zirconia	Gel deposition, CAD-CAM	Human teeth	Mandibular first molar	96	30 to 65
Ferrairo, 2021	Impression replica +MicroCT	10	Lithium disilicate	CAD-CAM	Plastic model teeth	Mandibular first molar	12	48.2 to 90.6 in Impression replica 91.8 to 133 in microCT
Khamverdi, 2021	microscopy + impression replica	12	zirconia	CAD-CAM	Human teeth	Posterior teeth (unspecified)	8	203.62 to 241.07
Urapepon, 2021	Cross sectioning +impression replica	20	Zirconia	CAD-CAM	Plastic model teeth	Maxillary second premolar	6	53 to 119
Piras, 2020	MicroCT+Microscopy	30	Lithium disilicate, zirconia	CAM	Plastic model teeth	Mandibular first molar	84 in MicroCT and 24 points in microscopy	75 to 129 in MicroCT, 54 to 75 in microscopy
Wenhao Li, 2018	microscopy + optical coherence tomography	32	Lithium disilicate	CAD-CAM	Human teeth	Maxillary third molars	48	59.48 to 59.55
Boitelle, 2018	impression replica + triple scan	60	Zirconia	CAD-CAM	Plastic model teeth	Maxillary first molar	8	59 to 64
Mostafa 2018	MicroCT + volumetric spatial overlap	45	Lithium disilicate	CAD-CAM	Plastic model teeth	Maxillary premolar	20	33.3 to 54.1
Shamseddine, 2017	Impression replica + scanning electron microscopy	20	Lithium disilicate	Lost wax, CAM (stereolithography)	Plastic model teeth	Maxillary canine	40	105.1 to 126.2
Habib, 2017	Cross sectioning + scanning electron microscopy	40	Zirconia	CAD-CAM	Human teeth	Third molars	5	199.5 to 214.46
Seelbach, 2012	profilometry +microscopy	20	Ceramic	CAD-CAM	Die of metal or alloy	Maxillary molar	50	30 to 48
Nakamura, 2005	microscopy + impression replica	28	Ceramic	Conventional milling	Plastic model teeth	Maxillary first premolar	Unspecified	42 to 59
Groten, 1997	Microscopy + Scanning Electron Microscopy	30	In-ceram	Copy milling	Steel die	Maxillary central incisor	124 to 138	18.3 to 25.1

CAD-CAM was the dominant crown fabrication procedure, but it did not result in a significantly better mean marginal gap compared with conventional methods. Zirconia and lithium disilicate were the most researched materials, with zirconia demonstrating a significantly better mean marginal gap compared with lithium disilicate, which remains a debated topic.[63,112] A wide variety of technologies and techniques are available for fabricating ceramic crowns. Sanchez et al[16] analyzed 7 in vitro studies and observed no differences in the marginal adaptation of lithium disilicate crowns produced through CAD-CAM and pressing procedures, both of which demonstrated clinically acceptable accuracy.[16] Smaller marginal gaps in lithium disilicate crowns produced using conventional heat press methods have been reported compared with crowns made using CAD-CAM technology.[25] Intraoral scanning produced crowns with a smaller marginal gap compared with impression scanning and cast scanning, although this appeared to depend on the scanners and milling units used.[39,113] Moderate risks of bias were noted across all studies largely because of variations in cement space considerations during CAD-CAM fabrication.[15,33] Irrespective of the CAM process, ceramic materials produced through CAM are susceptible to shrinkage, which is counteracted by controlled oversizing in CAD before printing, leading to marginal gap variations.[26] Consequently, crowns fabricated using CAD-CAM technology exhibit a wide range of marginal adaptation.[11]

The present research was limited to the in vitro measurement of ceramic single crowns before cementation. The large number of experimental variables, crown fabrication techniques and different measurement instruments limited the statistical analysis as evidenced by the large variations in means that were offset by equally large standard deviations. As one example, 3D superimposition measured volume and not points; therefore, a marginal gap distance measurement was not obtainable. It was not possible to analyze the data in studies that used multiple measurement instruments. The data for pressed and milled lithium disilicate restorations and for different types of zirconia restorations were pooled as separation would have further complicated the classification and limited the analysis. Future studies should focus on standardizing the method of measurement to facilitate determining the accuracy of results that may not depend on the instrument used and to advance the measurement of marginal gaps in vivo. The present research serves as a point of reference for future studies.

CONCLUSIONS

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

1. Direct view microscopy was the most frequently used instrument, yet no significant differences were found in mean marginal gap compared with the other measurement instruments.
2. CAD-CAM technology was the predominant crown fabrication method. However, crowns produced via CAD-CAM exhibited slightly larger mean marginal gaps compared with crowns fabricated using conventional methods.
3. The mean number of marginal gap measurements per crown was 34.3. The substantial variability highlighted inconsistencies in measurement practices across studies.
4. Zirconia and lithium disilicate were the most researched materials. Zirconia crowns demonstrated a significantly smaller mean marginal gap than lithium disilicate crowns.

APPENDIX A. SUPPORTING INFORMATION

Supplemental data associated with this article can be found in the online version at doi:10.1016/j.prosdent.2025.01.007.

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James Dudley: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Roles/Writing - original draft, and Writing - review and editing. **Taseef Hasan Farook:** Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Validation, Visualization, Roles/Writing - original draft, and Writing - review and editing.

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