

SYSTEMATIC REVIEW

Marginal and internal fit of CAD-CAM inlay/onlay restorations:
A systematic review of in vitro studies



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ABSTRACT

Statement of problem. Different parameters can influence the adaptation of computer-assisted design and computer-assisted manufacturing (CAD-CAM) inlay/onlay restorations. However, systematic reviews to identify and discuss these parameters are lacking.

Purpose. The purpose of this systematic review was to summarize the scientific literature investigating all parameters that can influence both the marginal and internal adaptation of CAD-CAM inlay/onlay restorations.

Material and methods. An electronic search was conducted by 2 independent reviewers for studies published in English between January 1, 2007 and September 20, 2017 on the PubMed/MEDLINE, Scopus, and Web of Science databases and in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. Factors investigated in the selected articles included the type of CAD-CAM system, virtual space parameters, version of the software, type of block, luting procedure, type of restoration, sample size and aging procedure, evaluation method, and number of measurement points per specimen.

Results. A total of 162 articles were identified, of which 23 articles met the inclusion criteria. Nine studies investigated adaptation with different restorative materials, 2 evaluated adaptation according to the type of preparation design, 9 compared adaptation before/after thermomechanical loading, and 2 before/after cementation, 1 study investigated marginal adaptation based on whether the optical scan was made intraorally or extraorally, 1 compared adaptation with 5 and 3 axis CAM systems, and 1 assessed adaptation with 4 different intraoral scanners. The risk of bias was high for 7, medium for 15, and low for 1 of the studies reviewed. The high level of heterogeneity across the studies excluded meta-analysis.

Conclusions. Most of the studies reported clinically acceptable values for marginal adaptation. The performance of a CAD-CAM system is influenced by the type of restorative material. A nonretentive cavity preparation exhibited better adaptation than a retentive preparation. Most studies showed that thermomechanical loading affected the quality of marginal adaptation. Cementation increased marginal discrepancies. No statistically significant difference was found for marginal fit of onlays between intraoral and extraoral optical scans using a stone die. The number of milling axes, the type of digital camera, and the region measured were statistically significant in relation to marginal/internal adaptation. Values of adaptation recorded failed to reproduce the preestablished spacer parameters in the software. Clarification is needed concerning adaptation according to the type of preparation design, the type of material, the choice of intrinsic parameters for the CAD process, the type and shape of milling instruments, and the behavior of the material during milling. Adaptation of CAD-CAM inlay/onlays should be evaluated under clinical conditions. (*J Prosthet Dent* 2019;121:590-7)

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Clinical Implications

Practitioners should be aware that the type of cavity preparation, the choice of the restorative material, the optical scan, and the parameters related to the CAD process may influence the adaptation of inlay/onlay restorations.

Computer-assisted design and computer-assisted manufacturing (CAD-CAM) and intraoral digital scanners have become popular as alternatives to conventional impression making and casting methods, especially with the introduction of a new range of digitalization tools and scanners.¹⁻³ The fabrication process comprises scanning the abutment tooth, designing the prosthesis, and milling the restoration in a centralized milling center or with a laboratory or chairside process.⁴ The potential for CAD-CAM to enhance prosthesis accuracy is based on the omission of several fabrication steps, and CAD-CAM may offer similar or better results than conventional methods.⁵ Inlay/onlay restorations represent a more conservative approach than complete coverage crowns and can be made with less retention form because of advances in the quality of luting procedures.⁶ In addition, polymerization shrinkage for indirect composite resin restorations is limited to the cement space.⁷ The performance of CAD-CAM inlay/onlays is satisfactory with a success rate of 88.7% for ceramics over a period of 10 years⁸ and 84.78% for composite resins over a period of 5 years.⁹

Current materials used for inlay/onlay restorations are glass-ceramic blocks and composite resin blocks. Glass-ceramics include feldspathic porcelain (Mark II; VITA Zahnfabrik), leucite-reinforced ceramics (Empress CAD; Ivoclar Vivadent AG, Initial LRF Block; GC Dental Products), lithium disilicate (e.max CAD; Ivoclar Vivadent AG), and zirconia-lithium monosilicate-reinforced glass-ceramic blocks (Suprinity; VITA Zahnfabrik, Celtra Duo; Dentsply Sirona).¹⁰ CAD-CAM technology has enabled the use of new composite resin blocks with dispersed fillers (Lava Ultimate; 3M ESPE, CERASMART; GC Dental Products) and a polymer-infiltrated ceramic network material (Enamic; VITA Zahnfabrik).¹⁰⁻¹³ These new materials are polymerized under high pressure and high temperature. Therefore, this process yields higher mechanical and biological properties than conventionally polymerized composite resins.^{12,13} Moreover, these new composite resin blocks have improved resistance to fracture and machinability due to a low elastic modulus close to dentin.^{12,14-16}

Several factors affect the longevity of an indirect restoration, including the quality of the marginal and internal adaptation. Poor marginal adaptation can lead to

Table 1. PubMed/MEDLINE search methodology

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((fit[Text Word] OR gap[Text Word] OR internal[Text Word] OR marginal[Text Word] OR adaptation[Text Word] OR accuracy[Text Word] OR discrepancy[Text Word]) AND (resin[Text Word] OR composite[Text Word] OR ceramic[MeSH Terms]) AND (CAD [Text Word] OR computer-aided[Text Word]) AND (inlay*[MeSH Terms] OR onlay*[Text Word])
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microleakage, dissolution of the luting cement, secondary caries, and gingival inflammation.¹⁷⁻²⁷ In addition, poor internal fit can increase cement thickness, alter retention, affect occlusion, reduce the fracture resistance of the restorations, and also result in poor marginal fit.^{9,27,28} Marginal and internal adaptation is of particular importance for inlay/onlay restorations, as their margins are exposed to mechanical, physical, and thermal stresses.

The authors are unaware of a systematic review describing marginal and internal adaptation of CAD-CAM inlay/onlay restorations. Thus, the purpose of this study was to review *in vitro* studies and especially those in relation to CAD-CAM technology which can influence both marginal and internal adaptation of these restorations.

MATERIAL AND METHODS

The protocol for this systematic review (CRD42017076069) was registered in the international prospective register of systematic reviews (<https://www.crd.york.ac.uk/PROSPERO/>). This systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.²⁹ An electronic search was performed, using 3 electronic databases (PubMed/MEDLINE, Scopus, and Web of Science) for studies published between January 1, 2007 and September 20, 2017. A search strategy was prepared for each database using 4 levels: level 1 considering the adaptation quality, level 2 considering the type of material, level 3 considering CAD-CAM technology, and level 4 considering the type of restoration. The search strategy included the following medical subject headings (MeSH): ‘Ceramic’, ‘Inlay*’, and the following text words: ‘fit’, ‘gap’, ‘marginal’, ‘internal’, ‘adaptation’, ‘discrepancy’, ‘resin’, ‘composite’, ‘CAD’, ‘computer-aided’, and ‘onlay’. The PubMed/MEDLINE search is presented in Table 1. Inclusion criteria included articles published in English concerning *in vitro* studies, with only inlay and/or onlay (partial-coverage crown) restorations, and evaluating marginal and/or internal fit in micrometers or in percentage of continuous margin (%gap free) on natural or artificial teeth. Interim CAD-CAM blocks, implant abutments, reviews, abstracts, short communications, books, and animal studies were excluded. Initially, 2 independent reviewers (A.G., D.S.) reviewed titles and abstracts. After considering the inclusion and exclusion criteria, full texts were selected for both reading and final selection. All differences in choices between the 2 authors were analyzed by a third reviewer (H.A.), and

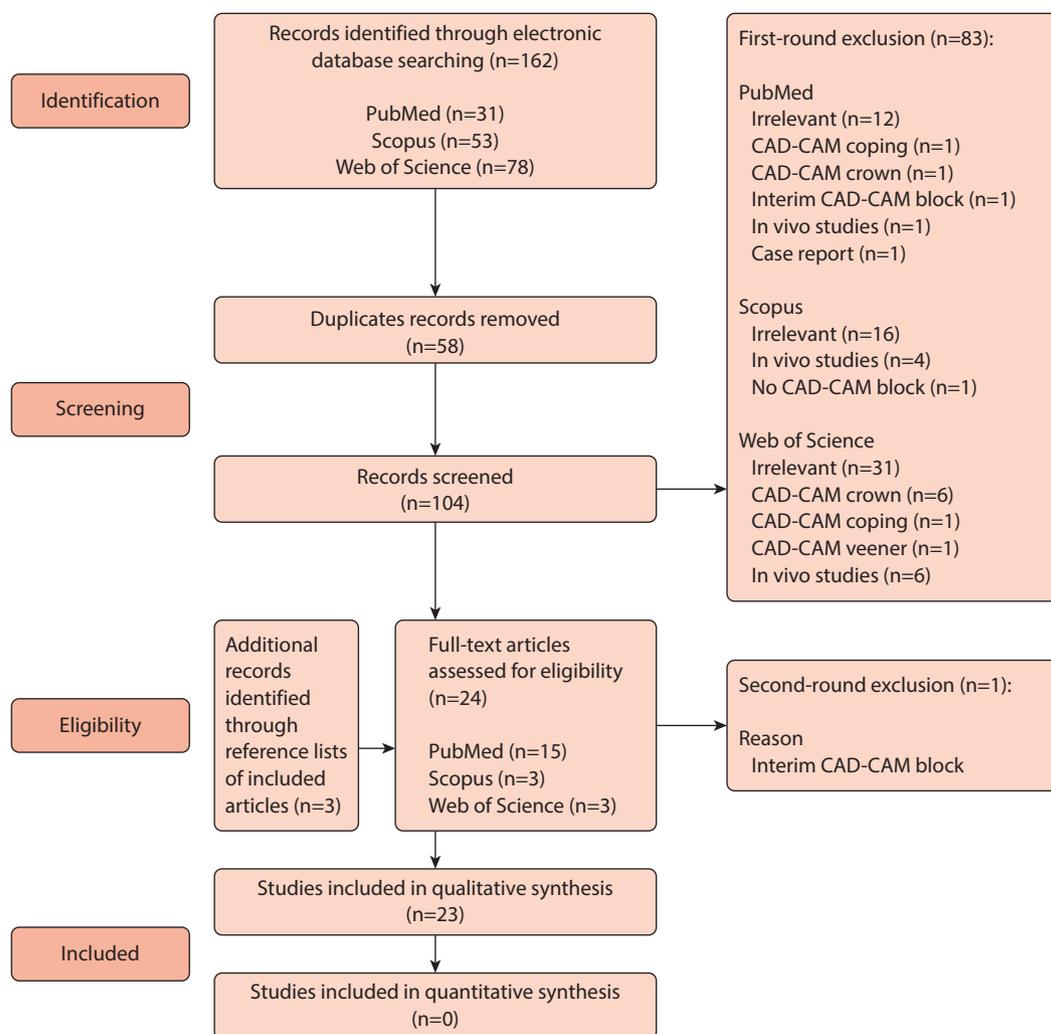


Figure 1. PRISMA flow diagram of literature search and selection process. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

agreement was established through discussion. The factors extracted from the selected studies and subsequently analyzed were, in order, authors and years, CAD-CAM systems, virtual space parameters, versions of software, types of block, types of restoration, sample size and aging procedures, numbers of measurement points per specimen, marginal and/or internal fit recorded, luting procedures, and evaluation methods. Because of the high degree of heterogeneity in terms of different studies and methodologies, a meta-analysis was not appropriate.

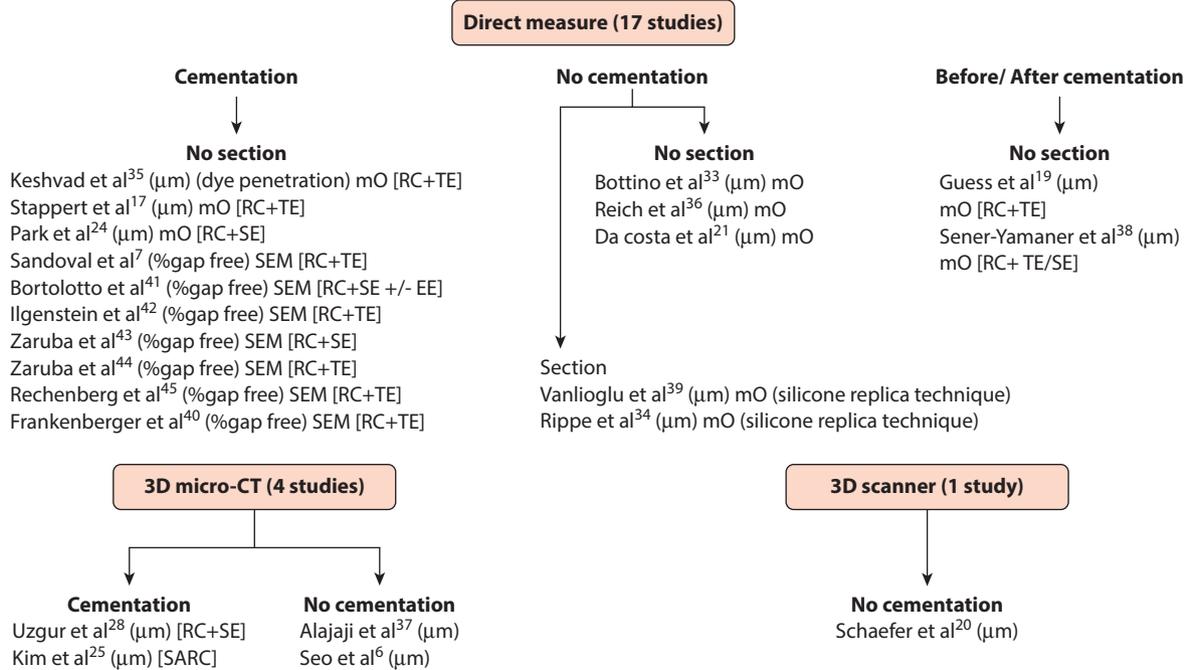
Two authors (A.G., D.S.) independently evaluated the risk of bias of each included study using an adaptation of the methods applied in 2 previous systematic reviews of in vitro studies.^{30,31} Descriptions of the following parameters were used to assess each article's risk of bias (Supplemental Table 1, available online): randomization of the teeth for experimental groups, blinding of the operator, number of measurement points per specimen (>50, according to Groten et al³²), presence of a control

group, statistical analysis carried out, gap measurement by a single operator, and luting space parameter specified. A "yes" was assigned where the parameter was reported in the text and a "no" if the information was absent. The risk of bias was classified according to the sum of "yes" received as follows: 1 to 3=high, 4 to 5=medium, 6 to 7=low risk of bias.

RESULTS

The electronic search identified 162 articles, 31 from PubMed/MEDLINE, 53 from Scopus, and 78 from Web of Science databases. After duplicated articles had been removed and the inclusion and exclusion criteria considered, 23 articles remained.^{6,7,17,19-21,24,25,28,33-46} Details of the search strategy are presented in a flow diagram (Fig. 1). The parameters recorded for all included studies are described in Supplemental Tables 2, 3 (available online) and Figure 2.

MARGINAL FIT (22 studies)



INTERNAL FIT (13 studies)

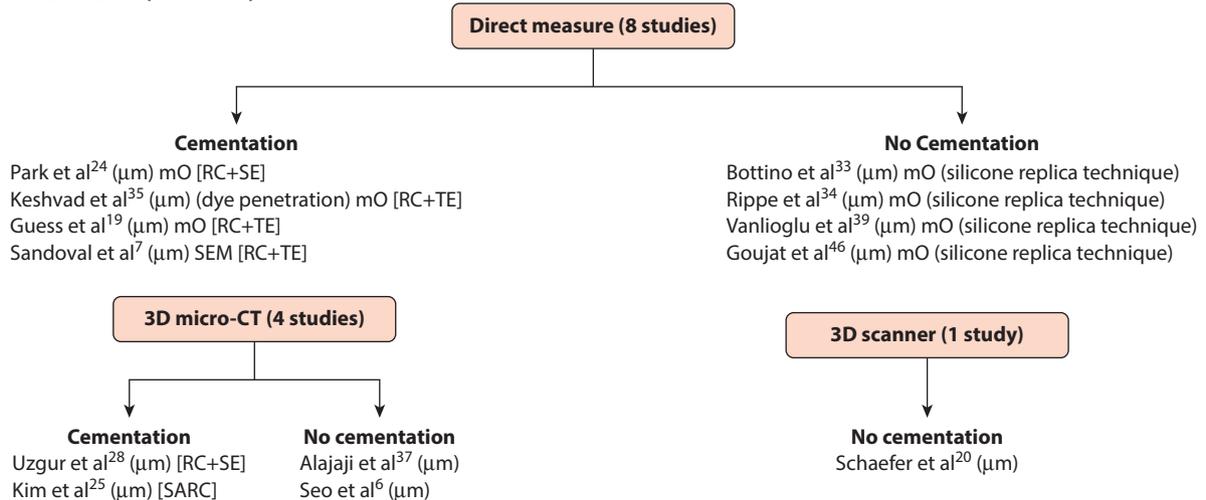


Figure 2. Type of methodology used for evaluation of marginal/internal fit CAD-CAM inlay/onlays. CAD-CAM, computer-assisted design and computer-assisted manufacturing; EE, enamel etch; mO, optical microscopy; SARC, self-adhesive resin cement; SEM, scanning electron microscopy; RC+SE, resin cement+self-etch; RC+TE, resin cement+total etch.

The values for the marginal fit of the studies selected ranged between 36 μm³⁵ and 222.5 μm,³³ and the values for the internal fit ranged between 23 μm³⁵ and 406.5 μm.⁶ The %gap-free unit values for marginal fit ranged between 43%⁷ and 92%⁴⁰ in dentin and 51%⁴¹ and 98.4%⁴² in enamel; the values for the internal fit ranged between 71%⁷ and 89%⁷ in dentin. Marginal fit was calculated between the restoration border and the preparation margin. When the specimens were sectioned, the marginal gap⁴⁷ was evaluated and 2 studies^{34,37} also considered the absolute marginal discrepancy⁴⁷; thus,

some restorations can be either overextended or under-extended. Overextension, which is the less favorable situation, may lead to plaque accumulation.

Nine articles evaluated marginal and internal fit with different restorative materials^{24,28,33,34,38,41,42,44,46} and 5 articles^{24,33,34,42,46} showed that the performance of a CAD-CAM system relative to marginal/internal fit was influenced by the type of restorative material. For marginal fit, 3 studies^{28,38,41} found no differences between a polymer-based and a glass-ceramic material, whereas 3 others showed significantly better adaptation for

polymer-based materials,^{33,42} more specifically at the cervical margin.³⁴ For internal fit, 3 studies^{28,34,46} demonstrated no significant difference between the 2 types of material, whereas 2 showed a significantly better adaptation for the polymer-based material^{33,42} but, for Bottino et al,³³ only on the pulp wall. When 2 polymer-based blocks were compared, 1 study showed a significant difference for internal fit⁴⁶ and 1 showed a significant difference for both marginal and internal fit.²⁴

Two studies reported that a more retentive preparation resulted in a higher overall internal gap⁶ and a higher overall internal/marginal gap²⁵ than a non-retentive preparation. Two studies evaluated marginal adaptation before and after cementation^{19,38} and concluded that resin cement with either self or total etch³⁸ and with total etch only¹⁹ increased marginal discrepancies. In these 2 studies, the adhesive was not light polymerized before the restorations were seated.

Nine studies evaluated the quality of the marginal adaptation in micrometers^{17,19} or in % of continuous margin^{7,40-45} after aging. A significant reduction of continuous margin appeared after thermomechanical loading (TML) in 6 studies,^{7,40,41,43-45} whereas 2 did not show a statistically significant difference for marginal adaptation before/after TML^{17,19} and 1 found that TML can significantly improve marginal adaptation.⁴²

One study²⁰ compared 4 digital cameras (iTero, cara TRIOS, CEREC AC with Bluecam, and Lava COS) and concluded that differences among acquisition systems were statistically significant. iTero provided the best adaptation for marginal fit and CEREC AC with Bluecam provided the best adaptation for internal fit. Direct digitalization was preferred in 15 studies^{6,7,20,21,24,25,28,34,36,39-42,44,46} and indirect digitalization was used in 8 studies.^{17,19,33,35,37,38,43,45} Only 1 study investigated adaptation whether the optical scan was made intraorally or extraorally from a gypsum die and found no statistically significant difference between the 2 techniques.²¹ One study demonstrated that a 5-axis milling machine provided a better occlusal marginal gap and better axial internal gap than a 3-axis milling machine.³⁷

The number of measuring points per specimen, when specified, ranged between 6³⁴ and 600³⁷ for marginal fit and 7³⁵ and 320²⁴ for internal fit. Some studies gave only a mean marginal/internal gap value,^{19,28,35} while others gave the mean corresponding values of each region,^{17,21,24,33,34,37-39} or at best, values of each reference point selected.^{6,25,36,46}

Seven studies^{6,24,25,33,34,38,46} showed that the region measured was statistically significant in relation to marginal/internal adaptation. These studies used an ANOVA test followed by a Tukey test except 1 study which used a Dunnett T3 test.²⁵ For marginal fit, only 1 study³⁸ gave values for the gingival, axial, and occlusal area in a direct measurement and showed that the larger gaps were obtained at the gingival margin. For

internal fit, Rippe et al³⁴ showed that the highest values of gap were obtained on the pulp wall, regardless of the type of materials. Furthermore, 4 studies in which values were recorded at each reference point showed that the larger gaps were obtained on the pulp and angle wall.^{6,24,25,46}

Among the 23 studies selected, 3 specified the "luting space" value^{33,34,46} and 8 specified both "luting space" and "adhesive gap" values in the software.^{6,21,24,25,28,36-38} The choice of the "luting space" value was set between 30 and 140 μm and the "adhesive gap" value was set between 20 and 50 μm . All studies demonstrated that the values of adaptation recorded failed to reproduce the preestablished spacer parameters, with larger spacing showing throughout.

DISCUSSION

No consensus has been reached for a marginal discrepancy value that is clinically acceptable.²⁷ Some authors have suggested it to be lower than 100 μm ^{21,37,48,49} but others felt that a gap lower than 120 μm ^{22,27,50-52} is a suitable threshold value. Most of the studies reported marginal gap values within this range (<120 μm). For internal adaptation, values between 70 μm and 120 μm have been proposed.^{27,53} Studies reported that an internal gap of 50 μm to 100 μm could result in the most favorable resin cement performance.⁵⁴⁻⁵⁶

To evaluate marginal/internal fit, a 2D analysis can be performed, but a limited number of measuring points and sections are possible. Therefore, results may not be representative of the whole fit of the restoration.^{35,57-60} 3D analysis as microcomputed tomography^{25,54,56,61-65} and the triple-scan protocol^{20,59,66-69} can be used to evaluate marginal and internal fit. These 2 techniques provide multiple point measurements,^{6,20,25,28,67,70} which cannot be achieved with a 2D measurement. Hence, they can be considered to have high validity and reliability.^{20,67,68} A recent study showed that a triple-scan protocol produced a smaller marginal fit than the replica method with less data dispersion.⁶⁸

The range of restorative CAD-CAM material can influence the marginal and internal adaptation of a restoration.^{61,63,71,72} This review showed that the performance of a CAD-CAM system relative to marginal/internal fit inlay/onlay restorations is influenced by the type of restorative material. Low hardness and modulus of elasticity have been shown to result in a greater amount of material being removed during grinding.⁷³ Conversely, other studies have reported that less brittle materials have lower edge chipping, better machinability,⁷⁴ and better adaptation.^{33,34} The type of milling instrument and its behavior according to the microstructure and the composition of the material should be further investigated.^{61,75} In addition, removal of the material induces

vibrations and mechanical loads, which can reflect on the surface dimensions and shape of the restoration.⁷⁵

Inlay/onlays have a more complex geometry than crowns. This parameter is fundamental in explaining variations of adaptation in some areas and between a nonretentive and a retentive inlay/onlay preparation.^{6,19,25,70} The type of milling device could affect the results of adaptation,^{2,23,37,70,71,76} especially if the restoration has a complex shape, deep groove regions, and internal angles. When 2 different milling units were compared with the same scan system and CAD software, 4-axis milling units presented a lower accuracy of fit than 5-axis units,^{23,76} more particularly in occlusal marginal gap and axial internal gap.³⁷ With a 5-axis unit, steep walls, small angles, and undercuts can be machined from different directions.^{2,70} The rotary instrument size and shape of the milling unit can influence the adaptation of a restoration.^{2,4,25,61,67,70,77} Overmilling of any surface details less than the diameter of the milling rotary instrument will result in a less accurate restoration,^{2,70} especially at the line angles of the preparation.^{56,66} A small diameter of 0.6 mm should be used when complex shapes are milled,⁷⁷ as for inlay/onlay restorations.

The complex geometry of an inlay/onlay restoration can also influence the accuracy of the intraoral scan.^{25,61,70} Furthermore, the technology used by the scanner itself can influence the accuracy of the restoration,^{4,20,78-81} whereas few studies have shown any difference.^{5,68} Another influencing parameter is the luting space setting in the software. Almost 50% of the studies selected did not specify the virtual space parameter. It was shown that cement space settings had a statistically significant effect on the marginal fit of CAD-CAM restorations^{22,26,68} As the marginal fit improved, the cement space decreased.²² In addition, studies on crowns have also demonstrated that marginal and internal accuracy failed to reproduce the preestablished spacer parameters.^{82,83} Unlike direct digitalization, indirect digitalization needs a conventional impression with elastomeric materials to produce a gypsum cast. This methodology may thus lead to several potential sources of error because of dimensional deformations along the process chain.^{18,84-86} While Da Costa et al²¹ did not find a statistically significance difference for the marginal fit of onlays, 4 studies on crowns reported that direct digitalization demonstrated a better adaptation than indirect digitalization.^{18,81,86,87}

This review had limitations. The high heterogeneity of the included studies prevented quantitative analyses of the data. Some parameters have been discussed based on few studies or even one, and although 23 studies were included, only one¹⁹ presented a low risk of bias according to the study quality assessment criteria used. Therefore, any general conclusions need to be drawn cautiously.

In vitro studies evaluating the adaptation of inlay/onlays are scarce compared with studies on crowns. Clarification is needed concerning adaptation of inlay/onlays according to the type of preparation design, the type of material, the choice of intrinsic parameters for the CAD process, the type and shape of milling instruments, and the behavior of the material during milling. In vivo studies for inlay/onlays are even fewer⁸⁸⁻⁹² and used the United States Public Health Service criteria to assess the quality of marginal adaptation. Moreover, the internal adaptation was not evaluated. In vivo, the replica technique can be used, and a 3D digital capture in 3 steps has recently been proposed to offer a more comprehensive assessment of restoration fit than a methodology in 2 dimensions.⁵⁹

CONCLUSIONS

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

1. Most of the studies reported a clinically acceptable range for marginal adaptation (<120 µm)
2. The performance of a CAD-CAM system relative to marginal/internal fit is influenced by the type of restorative material.
3. A nonretentive cavity preparation exhibited better adaptation than a retentive preparation.
4. Most studies showed that TML affected the quality of marginal adaptation. Cementation increased marginal discrepancies.
5. No statistically significant difference was found for the marginal fit of onlays between an intraoral and extraoral optical scan using a gypsum die.
6. Five-axis milling machines produced restorations with better fit than 3-axis milling machines.
7. The adaptation of a partial-coverage restoration depended on the digital scan technique used.
8. The region measured was statistically significant in relation to marginal/internal adaptation, with larger gaps at the gingival margin and on the pulp and angle wall.
9. For most studies, the values of adaptation recorded failed to reproduce the preestablished spacer parameters in the software, with larger spacing showing throughout.

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Supplemental Table 1. Quality assessment and risk of bias considering aspects reported in [Material and Methods](#) section

Author, Year of Publication	Teeth Randomization	Blinding of the Operator	Number of Measurement Point (>50) per Specimen for Marginal Fit	Control Group	Statistical Analysis Carried Out	Gap Measurement by a Single Operator	Luting Space Parameter (μm)	Risk of Bias
Bottino et al (2015) ³³	Yes	No	No	Yes	Yes	No	Yes	Medium
Rippe et al (2017) ³⁴	Yes	No	No	Yes	Yes	No	Yes	Medium
Park et al (2016) ²⁴	No	No	No	Yes	Yes	No	Yes	High
Uzgur et al (2016) ²⁸	No	No	No	Yes	Yes	No	Yes	High
Guess et al (2014) ¹⁹	Yes	No	Yes	Yes	Yes	Yes	Yes	Low
Alajaji et al (2017) ³⁷	No	No	Yes	Yes	Yes	Yes	Yes	Medium
Da Costa et al (2010) ²¹	No	No	No	Yes	Yes	Yes	Yes	Medium
Kim et al (2015) ²⁵	Yes	No	No	Yes	Yes	No	Yes	Medium
Stappert et al (2008) ¹⁷	No	No	Yes	Yes	Yes	No	No	High
Seo et al (2009) ⁶	Yes	No	No	Yes	Yes	No	Yes	Medium
Sener-Yamaner et al (2017) ³⁸	Yes	No	No	Yes	Yes	No	Yes	Medium
Schaefer et al (2014) ²⁰	No	No	No	Yes	Yes	No	No	High
Goujat et al (2017) ⁴⁶	No	No	No	Yes	Yes	No	Yes	High
Keshvad et al (2011) ³⁵	Yes	No	No	Yes	Yes	Yes	No	Medium
Reich et al (2008) ³⁶	Yes	No	No	Yes	Yes	Yes	Yes	Medium
Vanlioglu et al (2012) ³⁹	No	No	No	Yes	Yes	No	No	High
Frankenberger et al (2013) ⁴⁰	No	Yes	NA	Yes	Yes	Yes	No	Medium
Sandoval et al (2015) ⁷	Yes	Yes	NA	Yes	Yes	Yes	No	Medium
Bortolotto et al (2007) ⁴¹	Yes	No	NA	Yes	Yes	No	No	High
Ilgenstein et al (2015) ⁴²	Yes	No	NA	Yes	Yes	Yes	No	Medium
Zaruba et al (2013) ⁴³	Yes	No	NA	Yes	Yes	Yes	No	Medium
Zaruba et al (2014) ⁴⁴	Yes	Yes	NA	Yes	Yes	Yes	No	Medium
Rechenberg et al (2010) ⁴⁵	Yes	Yes	NA	Yes	Yes	Yes	No	Medium

NA, not applicable.

Supplemental Table 2. Data collected from studies evaluating marginal/internal fit (μm)

Author, Year of Publication	CAD-CAM System	Space Parameters μm	Software Version	Type of Block	Restoration/ Sample Size/ Aging	Number of Measuring Points per Specimen	Mean Internal Fit $\mu\text{m} \pm\text{SD}$ or (95% CI)	Mean Marginal Fit $\mu\text{m} \pm\text{SD}$ or (95% CI)
Bottino et al (2015) ³³	CEREC MC XL	Luting space 80	NS	Enamic (EN); VITA Mark II (VM)	Inlay/20 (10x2)	16 (marginal); NS (internal)	EN: 124 \pm 18 to 130.1 \pm 26; VM: 210.6 \pm 75 to 137.8 \pm 40	EN: 163.1 \pm 53 to 159.6 \pm 36; VM: 222.5 \pm 46 to 208.9 \pm 54
Rippe et al (2017) ³⁴	Lava COS CEREC	Luting space 45, luting space 40	NS	e.max CAD (EM); Lava Ultimate (LU)	Inlay/30 (10x3)	6 (marginal); 19 (internal)	EM: 66.7 \pm 19.9 to 207.2 \pm 61.3; LU: 76.7 \pm 24.6 to 233.8 \pm 80.5	EM: 171.8 \pm 56.6 to 177.8 \pm 68.9; LU: 105.9 \pm 40.3 to 145.3 \pm 106.5
Park et al (2016) ²⁴	CEREC Bluecam	Luting space 140, adhesive gap 20	4.0	Lava Ultimate (LU); Exp Resin Comp. (ERC)	Onlay/10	NS (marginal); 320 (internal)	LU: 90.76 \pm 8.35 to 186.54 \pm 10.52; ERC: 118.86 \pm 11.25 to 222.50 \pm 10.38	LU: 48.72 \pm 4.07; ERC: 55.27 \pm 6.40
Keshvad et al (2011) ³⁵	CEREC inLab	NS	NS	ProCAD	Inlay/25(marginal); 10(internal)	12 (marginal); 7 (internal)	23 \pm 9	36 \pm 11
Guess et al (2014) ¹⁹	CEREC InLab 3D	NS	3.01	e.max CAD	Onlay/8-24 (marginal); 16 (internal)/TMF	400-500 (marginal); 66 (internal)	103.37 (96.66-110.08)	50.09 (47.18-52.99) to 54.05 (52.26-55.84)
Reich et al (2008) ³⁶	CEREC 3D MC XL	Luting space 40, adhesive gap 20	3.0	CEREC blocs	Onlays/16	385	–	70 \pm 32 (60-79) to 94 \pm 30 (78-110)
Uzgun et al (2016) ²⁸	3 shape	Luting space 40, adhesive gap 20	NS	e.max CAD (EM); Enamic (EN); CERASMART (CER)	Inlay/30 (10x3)	NS	EM: 60.58 (9.22); EN: 77.53 \pm 12.13; CER: 54.85 \pm 6.94	EM: 67.54 \pm 10.16; EN: 84.09 \pm 3.94; CER: 95.18 \pm 10.58
Alajaji et al (2017) ³⁷	E4D	Luting space 100, adhesive gap 25	NS	e.max CAD	Inlay/30	600 (marginal); 240 (internal)	104.98 \pm 14.05 to 216.81 \pm 34.34	51.08 \pm 12.46 to 79.93 \pm 19.41 [AMD 58.75 \pm 9.95 to 99.83 \pm 16.68]
Da Costa et al (2010) ²¹	CEREC 3D	Luting space 50, adhesive gap 50	NS	VITA Mark II	Onlay/12	12	–	91 \pm 19.71 to 147.5 \pm 25.88
Kim et al (2015) ²⁵	CEREC 3 Bluecam CEREC MC	Luting space 30, adhesive gap 20	3.85	Empress CAD	Retentive (R)-none retentive (NR) onlay/16 (8x2)	R: 16 (marginal), 76 (internal); NR: 16 (marginal), 66 (internal)	R: 160 \pm 37.8 to 306.8 \pm 52.7; NR: 135 \pm 80.5 to 235.9 \pm 53.2	R: 82.6 \pm 29.9 to 142.6 \pm 54.2; NR: 81 \pm 39.7 to 93.3 \pm 37.1
Stappert et al (2008) ¹⁷	CEREC 3	NS	NS	ProCAD	Onlay/16/TML	450	–	Luted: 27.5 \pm 36.2 to 68.9 \pm 23.03; aged: 51.4 \pm 11.34 to 94 \pm 37.7
Seo et al (2009) ⁶	CEREC 3D	Luting space 30, adhesive gap 30	3.05	ProCAD	Onlay/60(20x3)	20 (marginal); 61-105 (internal)	50.5 \pm 46.5 to 406.5 \pm 176.1	35.4 \pm 32.2 to 128.4 \pm 69.5
Sener-Yamaner et al (2017) ³⁸	CEREC 3D MC XL	Luting space 30, adhesive gap 30	4.2.1	e.max CAD (EM); Lava Ultimate (LU)	Inlay/40 (20x2)	18	–	EM: 56.75 \pm 17.69 to 107.53 \pm 17.58; LU: 60.74 \pm 16.02 to 109.45 \pm 14.03
Schaefer et al (2014) ²⁰	iTero (ITE), TRIOS (TRI), CEREC (CBC), Lava (COS)	NS	NS	e.max CAD	Onlay/20 (4x5)	NS	ITE: 92 \pm 9 (81-104); TRI: 106 \pm 7 (117-139); CBC: 84 \pm 16 (63-104); COS: 92 \pm 10 (80-105)	ITE: 90 \pm 14 (71-108); TRI: 128 \pm 9 (117-139); CBC: 146 \pm 17 (125-167); COS: 109 \pm 11 (96-123)
Vanlioglu et al (2012) ³⁹	NS	NS	NS	e.max CAD	Onlay/20	40	132.77 \pm 31.32 to 196.49 \pm 31.32	112.14 \pm 15.64 to 119.65 \pm 38.16
Goujat et al (2017) ⁴⁶	CEREC 3D MC XL	Luting space 120	4.3	e.max CAD (EM); Enamic (EN); Lava Ultimate (LU); CERASMART (CER)	Inlay/60 (15x4)	9	EM: 122 \pm 35 to 217 \pm 46; EN: 119 \pm 55 to 234 \pm 51; LU: 158 \pm 79 to 231 \pm 51 CER: 127 \pm 39 to 205 \pm 40	–

AMD, absolute marginal discrepancy; CAD-CAM, computer-assisted design and computer-assisted manufacturing; CI, confidence interval; NS, not specified; SD, standard deviation; TMF, thermomechanical fatigue; TML, thermomechanical loading.

Supplemental Table 3. Data collected from studies evaluating marginal/internal fit (%gap free)

Author, Year of Publication	CAD-CAM System	Space Parameters μm	Software Version	Type of Block	Restoration/ Sample Size/Aging	Number of Measuring Points per Specimen	Mean Internal Fit (Marginal Quality-%Gap Free) % \pm SD or (95% CI) After Aging	Mean Marginal Adaptation (Marginal Quality-%Gap Free) % \pm SD or (95% CI) After Aging
Frankenberger et al (2013) ⁴⁰	NS	NS	NS	Empress CAD	Inlay/48 (8 \times 6)/TML	—	—	Dentin 92 \pm 7
Sandoval et al (2015) ⁷	CEREC 3D	NS	3.10	Empress CAD	Inlay/32 (8 \times 4)/ML	—	Dentin 71 \pm 29 to 89 \pm 14	Dentin 43 \pm 32 to 63 \pm 15; enamel 62 \pm 6 to 63 \pm 15
Bortolotto et al (2007) ⁴¹	CEREC 3D	NS	2.60	VITA Mark II (VM) Paradigm (P)	Inlay/24 (12 \times 2)/TML	—	—	Enamel VM: 51 \pm 10.5 to 66.2 \pm 10.3; P: 58.8 \pm 14.6 to 80.2 \pm 14.3
Ilgenstein et al (2015) ⁴²	CEREC Bluecam	NS	4.03	VITA Mark II (VM); Lava Ultimate (LU)	Onlay/48 (24 \times 2)/TML	—	—	Enamel VM: 69.8 (61.4-78.1); LU: 98.4 (97.2-99.6)
Zaruba et al (2013) ⁴³	CEREC 3D	NS	3.60	VITA Mark II	Inlay/40 (10 \times 4)/TML	—	—	Dentin 75.6 \pm 6.6; enamel 87.8 \pm 4.3 to 90 \pm 6.4
Zaruba et al (2014) ⁴⁴	CEREC	NS	3.80	Empress CAD (EM); Paradigm (P)	Inlay/40 (10 \times 4)/TML	—	—	Dentin (P): 79.8 \pm 27, EM: 79.9 \pm 16.1; enamel P: 73.8 \pm 17.2, EM: 85.6 \pm 8.8
Rechenberg et al (2010) ⁴⁵	CEREC	NS	2.70	VITA Mark II	Inlay/40 (6 \times 8)/TML	—	—	Dentin 57.0 \pm 17 to 89.9 \pm 4.9; enamel 54.7 \pm 11.9 to 72.5 \pm 6.1

CAD-CAM, computer-assisted design and computer-assisted manufacturing; CI, confidence interval; ML, mechanical loading; NS, not specified; SD, standard deviation; TML, thermomechanical loading.