Influence of the Manufacturing Trinomial (Technology, Printer, and Material) on the Marginal and Internal Discrepancies of Printed Metal Frameworks for the Fabrication of Tooth-Supported Prostheses: A Systematic Review and Meta-analysis

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Purpose: The purpose of this systematic review and meta-analysis was to compare the influence of fabrication method (conventional, subtractive, and additive procedures) and manufacturing trinomial (technology, printer, and material combination) on the marginal and internal fit of cobalt-chromium (Co-Cr) tooth-supported frameworks. ***Materials and Methods:*** An electronic systematic review was performed in five data bases: MEDLINE/PubMed, Embase, World of Science, Cochrane, and Scopus. Studies that reported the marginal and internal discrepancies of tooth-supported Co-Cr additive manufacturing (AM) frameworks were included. Two authors independently completed the quality assessment of the studies by applying the Joanna Briggs Institute Critical Appraisal Checklist for Quasi-Experimental Studies. A third examiner was consulted to resolve lack of consensus. ***Results:*** A total of 31 articles were included and classified based on the evaluation method: manufacturing accuracy, the dual- or triple-scan method, stereomicroscope, optical coordinate measurement machine, microCT, profilometer, and silicone replica. Six subgroups were created: 3D Systems, Bego, Concept Laser, EOS, Kulzer, and Sisma. Due to the heterogeneity and limited data available, only the silicone replica group was considered for meta-analysis. The meta-analysis showed a mean marginal discrepancy of 91.09 µm (I^2 = 95%, $P < .001$) in the conventional group, 77.48 µm (I^2 = 99%, $P < .001$) in the milling group, and 82.92 µm (I^2 = 98%, $P < .001$) in the printing group. Additionally, a mean internal discrepancy of 111.29 µm (I^2 = 94%, $P < .001$) was obtained in the conventional casting group, 121.96 µm (I^2 = 100%, $P < .001$) in the milling group, and 121.25 µm (I^2 =99%, $P < .001$) in the printing group. ***Conclusions:*** Manufacturing method and selective laser melting (SLM) metal manufacturing trinomial did not impact the marginal and internal discrepancies of Co-Cr frameworks for the fabrication of tooth-supported restorations. *Int J Prosthodont 2024;37(suppl):s285–s307. doi: 10.11607/ijp.8830*

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Table 1 Boolean Search Strategy Used in Five Databases Explored

Database	MeSH terms and search terms
MEDLINE/PubMed	(Crown OR "complete coverage restoration" OR "tooth-supported restoration" OR "Dental Prosthesis"[Mesh] OR Framework) AND ("Metal printing" OR "additive Manufacturing" OR "Selective laser sintering" OR "Selective laser melting" OR "Electron beam melting" OR Cobalt-Chromium Alloys[Mesh]) AND (Casting OR milling OR "conventional procedures" OR dental casting investment[Mesh]) AND (accuracy OR trueness OR precision OR "marginal discrepancy" OR "marginal misfit" OR "internal discrepancy" OR "internal misfit" OR Adaptation, Dental Marginal[Mesh] OR Adaptation, Dental Internal[Mesh])
Embase, World of Science, Cochrane, and Scopus	"Crown" OR "complete coverage restoration" OR "tooth-supported restoration" OR "Dental Prosthesis" OR "Framework" AND "Metal printing" OR "additive Manufacturing" OR "Selective laser sintering" OR "Selective laser melting" OR "Electron beam melting" OR "Cobalt-Chromium Alloys" AND "Casting" OR "milling" OR "conventional procedures" OR "dental casting investment" AND "accuracy" OR "trueness" OR "precision" OR "marginal discrepancy" OR "marginal misfit" OR "internal discrepancy" OR "internal misfit" OR "Dental Marginal adaptation" OR "Dental Internal adaptation" NOT [medline]/lim AND [embase]/lim.

Metal-ceramic dental prostheses have been used extensively due to their excellent mechanical properties, long-term survival rates, and reduced manufacturing cost when compared with all-ceramic restorations.[1–5] While different noble and base metal dental alloys have been used to fabricate tooth-supported restorations, the higher cost of noble metals together with the high allergenic potential of Ni-Cr alloys have led to the widespread use of cobalt-chromium (Co-Cr) dental alloys.[6,7]

Additive manufacturing (AM) technologies allow the fabrication of Co-Cr frameworks[8,9] for both tooth-supported[10–12] and implant-supported prostheses.[13–15] Powder bed fusion technologies are the AM methods usually selected to process metals in dentistry. These technologies include selective laser sintering (SLS), selective laser melting (SLM), and electron beam melting (EBM).[8,16] The SLM method is the most broadly utilized technique due to its improved mechanical properties compared to SLS and its earlier development and higher accuracy compared to the EBM method.[17–21] It is critical to understand that the manufacturing trinomial selected (ie, the AM technology, printer, and material) and printing strategy (printing parameters and postprocessing methods) used impact the properties of the printed device.[22] Other factors such as the characteristics of the virtual design (thickness, sharp angles) can also impact the properties of the device being printed.[22]

The marginal and internal discrepancies are important parameters for the long-term survival of tooth-supported restorations.[23–25] While a consensus on the optimal maximum marginal discrepancy of a dental restoration is lacking, a marginal discrepancy ranging from 50 to 120 mm has been considered clinically acceptable.[26–28] Previous systematic reviews have analyzed the marginal and internal discrepancies of AM Co-Cr frameworks for the fabrication of tooth-supported restorations.[29–31] These studies reported that AM metal technologies produced tooth-supported restorations with similar marginal and internal discrepancy values compared to conventional methods.[29–31] However, these studies did not analyze the manufacturing trinomial tested and how these may impact the marginal and internal discrepancies of the AM Co-Cr frameworks.

The purpose of the present systematic review and meta-analysis was to evaluate the influence of fabrication method (conventional, subtractive, and additive procedures) and manufacturing trinomial (technology, printer, and material combination) on the marginal and internal fit of Co-Cr tooth-supported frameworks. The null hypotheses were that there would be no significant difference in the marginal and internal discrepancies of Co-Cr frameworks fabricated using different manufacturing methods (and that there would be no significant difference in the marginal and internal discrepancies of Co-Cr frameworks fabricated using different SLM manufacturing trinomials.

MATERIALS AND METHODS

Search Strategy

The PICOS question that outlined the search strategy was defined as follows:

- **P** (problem or population): teeth receiving a metal-ceramic (Co-Cr) tooth-supported restoration
- **I** (intervention): Co-Cr AM frameworks fabricated using SLM technology
- **C** (comparison): incorporated cast and milled technologies
- **O** (outcome): the marginal and internal discrepancies of the AM metal-ceramic tooth-supported restorations tested
- **S** (study type): in-vitro, animal, or clinical studies.

Five different databases were chosen to complete the search of articles, namely MEDLINE/PubMed, Embase, World of Science, Cochrane, and Scopus (Table 1). A manual search was also conducted in peer-reviewed

Table 2 The Joanna Briggs Institute Critical Appraisal Checklist for Quasi-Experimental Studies (Nonrandomized Experimental Studies)

Question		Answer
1	Is it clear in the study what is the "cause" and what is the "effect" (ie, there is no confusion about which variable comes first)?	Yes, no, unclear, or not applicable
2	Were the participants included in any comparisons similar?	
3	Were the participants included in any comparisons receiving similar treatment/care other than the exposure or intervention of interest?	
4	Was there a control group?	
5	Were there multiple measurements of the outcome both before and after the intervention/exposure?	
6	Was follow-up complete and, if not, were differences between groups in terms of their follow-up adequately described and analyzed?	
7	Were the outcomes of participants included in any comparisons measured in the same way?	
8	Were outcomes measured in a reliable way?	
9	Was appropriate statistical analysis used?	

journals specializing in prosthodontics or digital dentistry (*Journal of Prosthetic Dentistry, Journal of Prosthodontics, International Journal of Prosthodontics, Journal of Prosthodontic Research,* and *Journal of Dentistry*). The starting point of 1995 was selected because that was the year SLM technologies were first patented.[17–21] The systematic search was performed in September 2023.

Study Selection and Eligibility Criteria

All titles and abstracts were first assessed for the inclusion criterion of any study that reported the marginal and/or internal discrepancies of AM Co-Cr frameworks for the fabrication of tooth-supported restorations. The exclusion criteria included studies that performed ceramic veneering procedures without analyzing the marginal and internal discrepancies before applying the ceramic or investigations that applied ceramic on the Co-Cr frameworks. This systematic review conformed to Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.[32]

After evaluating the full text of the articles according to the previously defined inclusion and exclusion criteria, articles with the subsequent characteristics were considered ineligible: *(1)* review articles; *(2)* studies that evaluated the marginal and internal discrepancies of additively manufactured interim and/or all-ceramic restorations; *(3)* studies that evaluated the fit of AM metal frameworks for fabricating removable partial dentures; *(4)* studies that evaluated the fit of AM metal frameworks for fabricating complete denture bases; *(5)* studies that evaluated other mechanical properties on the AM metal-ceramic prostheses such as flexural strength, fracture resistance, and/or ceramic bond strength; and *(6)* studies that considered a different metal alloy such as Ni-Cr or titanium dental alloys.

Data-Collection Process

Two calibrated reviewers (M.R.L. and M.G.P.) independently collected the data from the selected articles into structured tables. Discrepancies were resolved by consensus and by consulting a third examiner (J.C.K.). Cohen's kappa values between examiners was 0.9804 ($P < .001$), indicating an excellent agreement between the examiners.

Risk of Bias Assessment of Individual Studies

The same two review authors independently evaluated the quality assessment of the studies by applying the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Quasi-Experimental Studies (nonrandomized experimental studies)[33] (Table 2). The third examiner (J.C.K.) was consulted to resolve any lack of consensus.

Measurements and Statistical Analysis

The marginal and internal discrepancy values reported on each included study were recorded in a spreadsheet document. However, due to the variability on the measurement method, only the studies that used the silicone replica technique were included in the meta-analysis.

For each study included that assessed the fit of the Co-Cr restorations using the silicone replica technique, the mean values and standard deviations (SD) of marginal and internal discrepancies of the Co-Cr frameworks fabricated using different manufacturing methods were extracted. For further analysis, the mean difference between cast and milled groups and between cast and AM groups were calculated using a random effects model. In order to obtain the 95% confidence intervals (95% CI) of the summary estimates, each of the study's estimates and standard errors were obtained. All statistical analyses were performed using R software. Level of statistical significance (alpha level) was based at 0.05. The 95% CI for the mean difference was then calculated by using the 95% confidence limits of the mean differences.

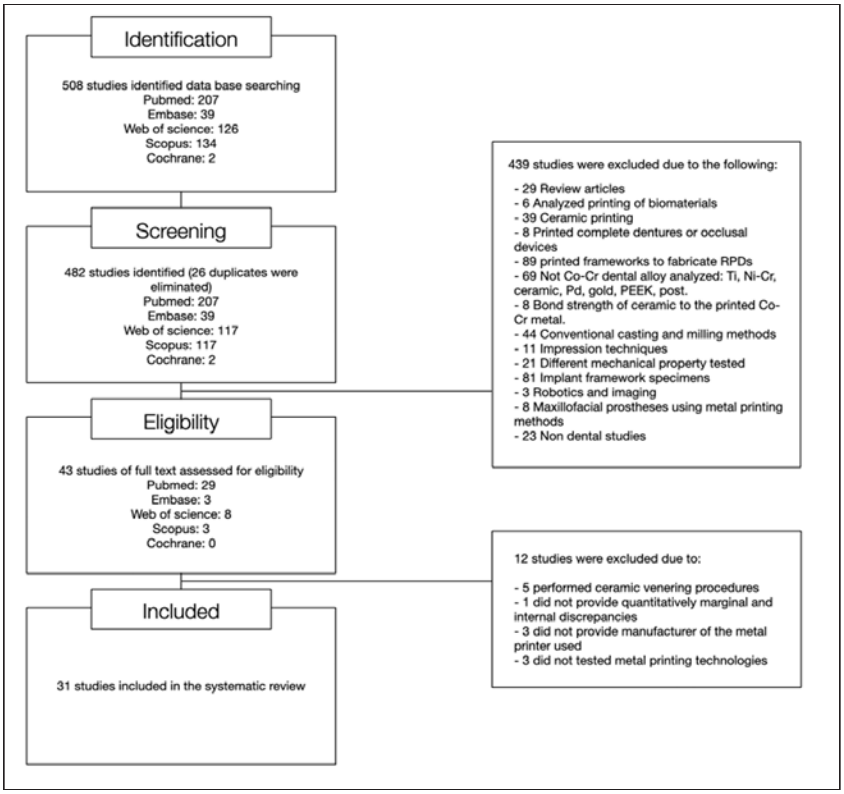

Fig 1 PRISMA flow chart of the study selection.

I-Squared (I^2) statistic and its associated P value was used to assess the heterogeneity between studies, which describes the variation in mean difference that is attributable to the heterogeneity of the studies.[34]

RESULTS

Study Selection

The search strategies employed yielded 508 studies. Twenty-six articles were duplicated. From the 482 articles, 43 were selected for full-text review (Fig 1). Afterward, 12 articles were excluded because 5 studies analyzed the marginal and internal discrepancy values after completing ceramic veneering procedures, 1 investigation did not provide the quantitatively measured marginal and internal discrepancies, 3 studies did not provide the manufacturer of the metal printer used to fabricate the specimens, and 3 studies did not test metal AM techniques. A total of 31 articles (30 in vitro[35–53,55–65] and 1 clinical[54]) were included in the present systematic review.[35–65]

Study Characteristics

The selected articles were classified based on the evaluation method used to assess the fit of the Co-Cr frameworks, namely manufacturing accuracy,[35,36] the dual-scan[37,38] and triple-scan method,[39] stereomicroscope,[40–45] optical coordinate measurement machine (CMM),[46] microCT,[47,48] profilometer,[49] and silicone replica technique.[50–65] Additionally, each group was subdivided into six subgroups based on the manufacturer used to fabricate the SLM Co-Cr frameworks, namely 3D Systems,[35,62] Bego,[51,54] Concept Laser,[37–39,41,42,47,48,52,56,58] EOS,[36,40,43–45,47,49–51,55,57,60,61,63–65] Kulzer,[53] and Sisma[59,62] (Tables 3 and 4).

Among the two included articles that analyzed the manufacturing accuracy of SLM methods for fabricating tooth-supported Co-Cr frameworks, one study tested Concept Laser[35] and the other study tested EOS.[36] Additionally, varying geometries were tested, namely onlay[36] and crown[35] restorations. Both studies digitized the specimens by using a laboratory scanner[35,36] and used a reverse engineering software program (Geomagic Control X35 or Geomagic Verify 202536 from 3D Systems) to analyze the volumetric discrepancies between the virtual design of the restoration and the digitized specimens by calculating the root mean square (RMS) error.[35,36] Bae et al[36] concluded that the manufacturing accuracy of the AM method tested was better than that of the milling technique analyzed. However, Ali Majeed and Hasan Jasim[35] reported that the metal printed specimens showed the same manufacturing accuracy as conventional casting procedures but better accuracy than subtractive methods. Due to the limited data available, a meta-analysis could not be performed.

Three included articles selected the dual-scan[37,38] or triple-scan[39] method to analyze the fit of the metal specimens. These three studies used Concept Laser to fabricate the specimens[37–39]; however, only one[38] of them reported the specific printer and Co-Cr powder used to fabricate the specimens. Although all studies considered a metal crown as the geometry tested,[37–39] the digitizing methods (intraoral,[37] laboratory,[38] or industrial scanner[39]) used to scan the tooth preparation or specimens varied. Additionally, the measurement method used to analyze the marginal and internal discrepancies differed. All studies reported marginal and internal mean discrepancies smaller than 120 µm[37–39] (see Tables 3 and 4). Due to the limited data available, a meta-analysis could not be performed.

Six studies analyzed the marginal and internal discrepancies of the

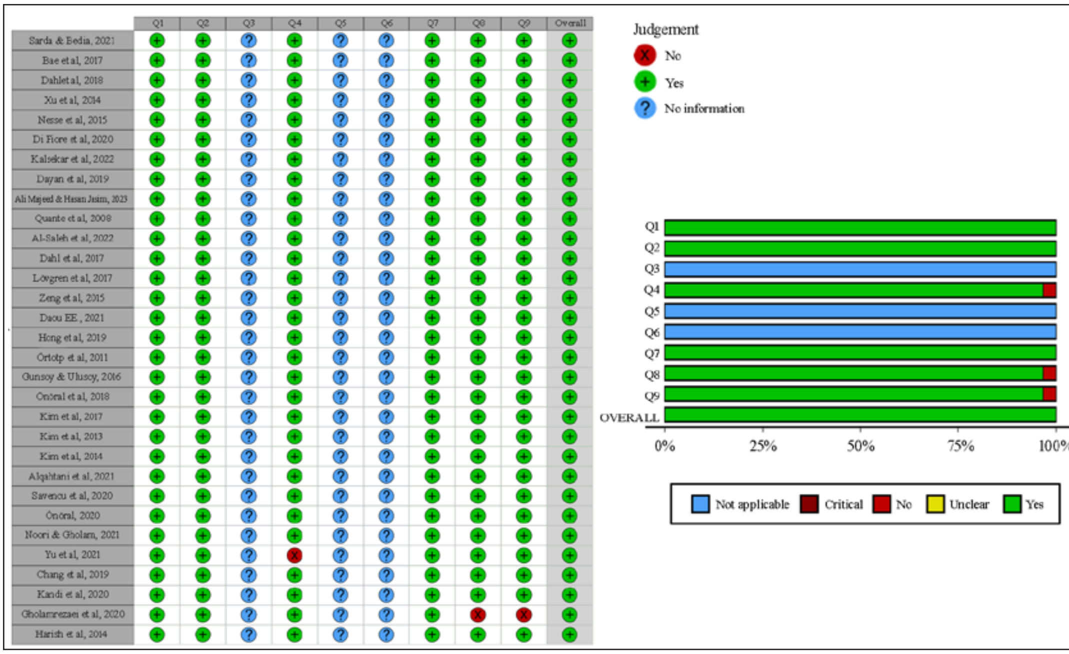

Fig 2 Evaluation results of the JBI Critical Appraisal Checklist for Quasi-Experimental Studies.

specimens using a stereomicroscope.[40–45] Two different SLM printer manufacturers were tested among the studies, namely EOS[40,43–45] and Concept Laser.[41,42] Among the studies that tested EOS, three of them used the same EOS printer (EOS EOSINT M270)[43–45] but different Co-Cr powders (not provided,[43] SP2,[44] and MP1[45] from EOS). Disparities on the printer and Co-Cr powder were also found between the two studies that used a Concept Laser manufacturing method[41,42] (see Table 3). Additionally, research methodology disparities were found among the studies, including geometry of the restoration tested (crown[41–45] or three-unit fixed dental prosthesis[40]), digitizing methods, and cement used (see Table 3). Except for one group of the Al-Saleh et al study (radial shoulder group with a mean 167 ± 28 µm), all studies reported marginal and internal mean discrepancies lower than 120 µm. Due to the limited data available, a meta-analysis could not be performed.

A unique in-vitro study used an optical CMM measurement method to assess the fit of the SLM Co-Cr four-unit fixed dental prosthesis specimens manufactured using an EOS printer[46] (see Table 3). The authors reported a mean ± SD marginal discrepancy of 25 ± 9 µm.[46] One reviewed study used a profilometer to analyze the marginal discrepancy of the Co-Cr crown specimens fabricated using an SLM EOS M270 printer and the powder Wirobond C+ from Bego[49] (see Table 3). The authors reported a mean ± SD marginal discrepancy of 67 ± 16 µm and an internal discrepancy of 10 ± 1 µm.[4] Due to the limited data available for the studies using optical CMM or profilometer, a meta-analysis could not be performed.

Two included in-vitro studies analyzed the marginal and internal discrepancies of the SLM Co-Cr specimens using microCT.[47,48] These studies selected two different SLM printer manufacturers, Concept Laser[47,48] and EOS.[47] Kim et al[47] compared two different metal manufacturing trinomials, one from Concept Laser and one from EOS. Results revealed that the EOS trinomial obtained better mean marginal discrepancy than the Concept Laser trinomial.[47] Alqahtani et al[48] did not describe the SLM printer used to manufacture the specimens. Both studies tested crown geometries, but one for a premolar[46] and one for a molar tooth preparation.[48] Due to the limited data available, a meta-analysis could not be performed.

A total of 16 reviewed articles measured the marginal and internal discrepancies using the silicone replica technique[50–65] with frameworks manufactured by 3D Systems,[62] EOS,[50,55,57,60,61,63–65] Bego,[51,54] Concept Laser,[52,56,58] Kulzer,[53] and Sisma[59,62] (see Table 4).

Quality Assessment of the Studies

The JBI Critical Appraisal Checklist for Quasi-Experimental Studies showed a 100% low risk of bias in all included articles for questions 1, 2, and 7 (Fig 2). Furthermore, the results to questions 4, 7, and 8 revealed 95% low risk and 5% critical risk of bias due to the Yu et al[37] study, which obtained an unclear risk of bias on question 4, and the Gholamrezaei et al[49] investigation, which obtained an unclear risk of bias on questions 7 and 8. Because there is no specific in-vitro study quality assessment tool, questions 3, 5, and 6 of the JBI were not applicable to the studies in the present systematic review.

Table 3 Study Characteristics of the Included Articles That Analyzed the Manufacturing Accuracy of Co-Cr Frameworks or Analyzed the Marginal and Internal Discrepancy Without Using the Silicone Replica Technique

Reference	Measurement method	Subgroup	Study type	Groups tested/methods
Ali Majeed and Hasan Jasim (2023)[35]	Manufacturing accuracy	3D Systems	In vitro	Digitizing methods of tooth preparation NP. Three groups: • Conventional casting of printed patterns (Printer NP, Asiga) • Milled Co-Cr • SLM Specimens scanned (T710, Medit) and superimposed with STL file used to manufacture the specimens. RMS error measured (Geomagic Control X, 3D Systems).
Bae et al (2017)[36]	Manufacturing accuracy	EOS	In vitro	Three groups: • Conventional casting of milled patterns • Milled Co-Cr • SLM Specimens digitized using LBS (D800, 3Shape) and compared with the reference STL file (Geomagic Verify 2025, 3D Systems) by computing RMS error.
Dahl et al (2018)[37]	Dual-scan technique	Concept Laser	In vitro	Tooth preparation digitized using IOS (Trios, generation NP, 3Shape). Six groups: • Conventional casting of handmade patterns • Milled presintered zirconia • Milled sintered zirconia • Milled LD • Milled Co-Cr • SLM
Yu et al (2021)[38]	Dual-scan technique Manufacturing accuracy	Concept Laser	In vitro	Four groups (four finish lines): • Chamfer 1-mm depth (135-degree finish line) • Feather edge • Shoulder lip • Chamfer with sharp line angles (SA) All specimens fabricated using SLM printer. Specimens digitized using LBS (E4, 3Shape) and aligned BF with reference STL file of crown design and abutment. Digital marginal and internal discrepancies computed and manufacturing accuracy (RMS).

Reference	SLM printer	Co-Cr powder	n	Specimens' geometry/ reference model	Results by group (mean ± SD)
Ali Majeed and Hasan Jasim (2023)[35]	ProX DMP 100, Concept Laser	NPZ	12	Crown, chamfer 0.5-mm depth Milled zirconia die	*Cast:* RMS 18 ± 4.04 µm *Milled:* RMS 44.40 ± 3.66 µm *SLM:* RMS 27.2 ± 2.73 µm
Bae et al (2017)[36]	EOSINT M270, EOS	EOS SP2 CoCr, EOS	10	NP STL file onlay geometry	*Cast:* RMS 116 ± 109 µm *Milled:* RMS 119 ± 112 µm *SLM:* RMS 113 ± 105 µm
Dahl et al (2018)[37]	NP	NP	3	Crown, chamfer Typodont tooth, CI	*Cast:* • Marginal discrepancy 49 ± 32 µm • Internal discrepancy 71 ± 26 µm in the buccopalatogingival direction • Internal discrepancy 47 ± 33 µm in the mesiodistal direction *Milled Co-Cr:* • Marginal discrepancy 44 ± 49 µm • Internal discrepancy 157 ± 98 µm in the buccopalatogingival direction • Internal discrepancy 122 ± 136 µm in the mesiodistal direction *SLM:* • Marginal discrepancy 63 ± 24 µm • Internal discrepancy 97 ± 40 µm in the buccopalatogingival direction • Internal discrepancy 112 ± 77 µm in the mesiodistal direction
Yu et al (2021)[38]	Mlab, Concept Laser	CT-AB Co-Cr D, Zhongkekang Technology Co.	10	STL file of crown with four different finish lines	*SLM:* Marginal and internal discrepancy, respectively: • Chamfer: 20 ± 2 µm and 40 ± 2 µm • 135-degree: 26 ± 2 µm and 40 ± 3 µm • Feather edge: 21 ± 3 µm and 39 ± 2 µm • Shoulder lip: 41 ± 4 µm and 47 ± 3 µm • Chamfer SA: 18 ± 2 µm and 45 ± 3 µm *SLM:* Manufacturing accuracy, margin and internal areas: • Chamfer: 6 ± 3 µm and 10 ± 1 µm • 135-degree: 6 ± 4 µm and 9 ± 3 µm • Feather edge: 11 ± 3 µm and 9 ± 2 µm • Shoulder lip: 17 ± 3 µm and 16 ± 3 µm • Chamfer SA: 7 ± 2 µm and 14 ± 3 µm

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Table 3 Study Characteristics of the Included Articles That Analyzed the Manufacturing Accuracy of Co-Cr Frameworks or Analyzed the Marginal and Internal Discrepancy Without Using the Silicone Replica Technique *(cont)*

Reference	Measurement method	Subgroup	Study type	Groups tested/methods
Dahl et al (2017)[39]	Triple-scan technique	Concept Laser	In vitro	Tooth preparation digitized with industrial scanner (Atos, GOM). Six groups: • Conventional casting • Milled presintered zirconia • Milled sintered zirconia • Milled LD • Milled Co-Cr • SLM
Örtorp et al (2011)[40]	Stereomicroscope analysis of cemented specimens	EOS	In vitro	Tooth preparation digitized using LBS (D640, 3Shape). Four groups: • Conventional casting handmade patterns (Wirobond C, Bego) • Conventional casting milled patterns • Milled Cr-Cr • SLM Specimens were cemented using composite resin cement. Longitudinal cuts for stereomicroscopic assessment.
Gunsoy and Ulusoy (2016)[41]	Stereomicroscope analysis of cemented specimens	Concept Laser	In vitro	Tooth preparation scanned using LBS (D700, 3Shape). Four groups: • Conventional casting handmade patterns • Conventional casting milled patterns • Milled Co-Cr • SLM Specimens were cemented using polycarboxylate cement (50-N load) and sectioned. Stereomicroscope, magnification X24, 17 measurement points.

Reference	SLM printer	Co-Cr powder	n	Specimens' geometry/ reference model	Results by group (mean ± SD)
Dahl et al (2017)[39]	NP	NP	3	Crown, chamfer in a CI Typodont tooth	*Cast:* • Marginal discrepancy 58 ± 23 µm • Internal discrepancy 66 ± 25 µm in the buccopalatogingival direction • Internal discrepancy 61 ± 35 µm in the mesiodistal direction *Milled Co-Cr:* • Marginal discrepancy 90 ± 78 µm • Internal discrepancy 130 ± 107 µm in the buccopalatogingival direction • Internal discrepancy 193 ± 199 µm in the mesiodistal direction *SLM:* • Marginal discrepancy 82 ± 37 µm • Internal discrepancy 97 ± 41 µm in the buccopalatogingival direction • Internal discrepancy 114 ± 65 µm in the mesiodistal direction
Örtorp et al (2011)[40]	NP	NP	8	Three-unit FDP (abutment PM and M), chamfer Dental stone cast	*Cast:* • Premolar abutment: Internal discrepancy 114 ± 92 µm • Molar abutment: Internal discrepancy 121 ± 80 µm *Milling:* • Premolar abutment: Internal discrepancy 163 ± 135 µm • Molar abutment: Internal discrepancy 169 ± 126 µm *SLM:* • Premolar abutment: Internal discrepancy 69 ± 58 µm • Molar abutment: Internal discrepancy 99 ± 58 µm
Gunsoy and Ulusoy (2016)[41]	M1, Concept Laser	NP	32	Crown, chamfer Printed casts	*Cast:* • Marginal discrepancy 84.55 ± 18.56 µm • Occlusal discrepancy 87.02 ± 19.24 µm • Axial discrepancy 99.54 ± 22.34 µm *Milled:* • Marginal discrepancy 84.18 ± 17.59 µm • Occlusal discrepancy 88.36 ± 19.13 µm • Axial discrepancy 91.84 ± 21.65 µm *SLM:* • Marginal discrepancy 51.60 ± 11 µm • Occlusal discrepancy 101.5 ± 20.74 µm • Axial discrepancy 61.9 ± 14.17 µm

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Table 3 Study Characteristics of the Included Articles That Analyzed the Manufacturing Accuracy of Co-Cr Frameworks or Analyzed the Marginal and Internal Discrepancy Without Using the Silicone Replica Technique *(cont)*

Reference	Measurement method	Subgroup	Study type	Groups tested/methods
Al-Saleh et al (2022)[42]	Stereomicroscope analysis of cemented specimens	Concept laser	In vitro	Tooth preparation digitized using LBS (Cercon Eye Scanner, DeguDent). Three groups (manufacturing method): • Conventional casting handmade patterns • Milled presintered Co-Cr • SLM Three subgroups (finish line): • Shoulder • Radial shoulder • Chamfer Stereomicroscopic assessment. Six measurement points.
Kalsekar et al (2022)[43]	Stereomicroscope analysis of cemented specimens	EOS	In vitro	Tooth preparation. Digitizing methods NP. Three groups: • Conventional casting handmade patterns • Conventional casting printed patterns (Printer NP, FormLabs) • SLM Specimens cemented (cement NP). 50-N load. Stereomicroscope (XTL 3400 E, Wuzhou). Magnification X20.
Kandi et al (2020)[44]	Stereomicroscope analysis of cemented specimens	EOS	In vitro	Tooth preparation of four-unit FDP scanned using LBS (Mapp300, Amann Girrbach). Four groups: • Milled zirconia • Pressed LD, milled pattern • Milled Co-Cr • SLM Specimens cemented (glass ionomer). 20N load. Stereomicroscope (XTL 3400 E, Wuzhou). Magnification X0. 4 measurement points.
Harish et al (2014)[45]	Stereomicroscope analysis of cemented specimens	EOS	In vitro	Tooth preparation digitized using LBS (Lava, 3M ESPE) Two groups: • Conventional casting milled patterns • SLM Specimens cemented (zinc phosphate). Stereomicroscope (Versamet 3, Union Opt). Magnification X20. 4 measurement points.
Di Fiore et al (2020)[46]	Optical CMM	EOS	In vitro	Tooth preparation of four-unit FDP scanned using LBS (Zfx Evolution, Zfx) One manufacturing method (SLM), measurements taken before and after ceramic veneering procedures using an optical CMM (OGP SmarScope, Quality Vision International). 30 measurement points.

Reference	SLM printer	Co-Cr powder	n	Specimens' geometry/ reference model	Results by group (mean ± SD)
Al-Saleh et al (2022)[42]	Mlab, Concept Laser	Starbond Easy Powder 30, Concept Laser	10	Crown, three finish lines Typodont teeth	*Cast:* Vertical discrepancy: • Shoulder: 125 ± 22 µm • Radial shoulder: 162 ± 30 µm • Chamfer: 163 ± 28 µm Horizontal discrepancy: • Shoulder: 94 ± 17 µm • Radial shoulder: 133 ± 21 µm • Chamfer: 89 ± 15 µm *Milled:* Vertical discrepancy: • Shoulder: 69 ± 14 µm • Radial shoulder: 59 ± 13 µm • Chamfer: 103 ± 18 µm Horizontal discrepancy: • Shoulder: 135 ± 14 µm • Radial shoulder: 115 ± 15 µm • Chamfer: 95 ± 18 µm *SLM:* Vertical discrepancy: • Shoulder: 105 ± 26 µm • Radial shoulder: 167 ± 28 µm • Chamfer: 168 ± 24 µm Horizontal discrepancy: • Shoulder: 138 ± 38 µm • Radial shoulder: 133 ± 21 µm • Chamfer: 117 ± 28 µm
Kalsekar et al (2022)[43]	EOSINT M270, EOS	NP	20	Crown, chamfer 1-mm depth Extracted human maxillary PM	*Cast handmade pattern:* Marginal discrepancy 216 ± 37 µm *Cast milled pattern:* Marginal discrepancy 101 ± 13 µm *SLM:* Marginal discrepancy 49 ± 13 µm
Kandi et al (2020)[44]	EOSINT M270, EOS	EOS SP2 CoCr, EOS	15	Crown, 90-degree shoulder Metal die, PM tooth preparation	*Milled Co-Cr:* Marginal discrepancy 109 ± 24 µm *SLM:* Marginal discrepancy 29 ±14 µm
Harish et al (2014)[45]	EOSINT M270, EOS	EOS MP1 CoCr, EOS	10	Crown, finish line NP Metal die	*Cast:* • Marginal discrepancy 177 ± 26 µm • Internal discrepancy 187 ± 11 µm *SLM:* • Marginal discrepancy 102 ± 17 µm • Internal discrepancy 108 ± 11 µm
Di Fiore et al (2020)[46]	EOSINT M270, EOS	EOS SP2 CoCr, EOS	28	Four-unit FDP Dental stone cast	Marginal discrepancy 25 ± 9 µm (before ceramic veneering procedures)

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Table 3 Study Characteristics of the Included Articles That Analyzed the Manufacturing Accuracy of Co-Cr Frameworks or Analyzed the Marginal and Internal Discrepancy Without Using the Silicone Replica Technique *(cont)*

Reference	Measurement method	Subgroup	Study type	Groups tested/methods
Kim et al (2017)[47]	MicroCT	EOS Concept Laser	In vitro	Tooth preparation scanned using LBS (D700, 3Shape). Eight groups: • Conventional casting (StarLoy C, DeguDent) printed pattern (Projet 3500 DPPro, 3D Systems) • Two milled Co-Cr • Two milled presintered Co-Cr • SLM EOS • SLM Concept Laser Silicone replica. 50-N load. MicroCT (SkyScan 1272, Bruker). Pixel size 4 μm.
Alqahtani et al (2021)[48]	MicroCT	Concept Laser	In vitro	Tooth preparation scanned using LBS (Cercon Eye Scanner, DeguDent) Four groups: • Conventional casting (Wirobond C, Bego) handmade pattern • Conventional casting (Wirobond C, Bego) printed (M-one, Makex) pattern • Milled presintered Co-Cr • SLM MicroCT (SkyScan 1173, SkyScan NV).
Gholamrezaei et al (2020)[49]	Profilometer	EOS	In vitro	Tooth preparation scanned using LBS (D810, 3Shape) Two groups: • Conventional casting handmade patterns • SLM Silicone used as a cement was removed and weighed; this was considered the internal fit. This data is provided in μm. Marginal discrepancy was assessed using a profilometer (Talyscan 150, Taylor Hobson)

BF = best fit; CI = central incisor; CMM = coordinate measurement machine; FDP = fixed dental prosthesis; IOS = intraoral scanner; LBS = laboratory scanner; LD = lithium disilicate; NA = not applicable; NP = not provided; M = molar; PM = premolar; RMS = root mean square; SD = standard deviation; SLM = selective laser melting; STL = standard tessellation language.

Table 4 Study Characteristics of the Included Articles That Analyzed the Marginal and Internal Discrepancy Using the Silicone Replica Technique

Reference	Measurement method	Subgroup	Study type	Groups tested/methods
Savencu et al (2020)[62]	Silicone replica	3D Systems Sisma	In vitro	Four groups: • Conventional casting printed (P4DDP, EnvisionTEC) patterns (Bellavest SH, Bego). Tooth preparation scanned using LBS (D700, 3Shape). • Milled Co-Cr. Tooth preparation scanned using LBS (Series 7, Dental Wings). • Two SLM methods. Tooth preparation scanned using LBS (Series 7). Silicone replica. Microscope (DM500, Leica). Magnification X20
Quante et al (2008)[54]	Silicone replica	Bego	Clinical study	28 patients receiving a metal-ceramic crown. Conventional impression. Digitizing methods of the definitive cast NP. Specimens fabricated with two alloys: Co-Cr and Au-Pt. Silicone replica on definitive cast before and after ceramic veneering procedures. 50-N loading. Digital photograph (DC 100; Leica), X15 magnification, 10 measurement points.

Reference	SLM printer	Co-Cr powder	n	Specimens' geometry/ reference model	Results by group (mean ± SD)
Kim et al (2017)[47]	EOSINT M270, EOS M1, Concept Laser	EOS SP2 CoCr, EOS Remanium Start SL CoCr, Concept Laser	10	Crown, PM metal die	*Cast:* Marginal discrepancy 70 ± 12 μm *Milled Co-Cr:* Marginal discrepancy 124 ± 32 μm *Milled pre-sintered Co-Cr:* Marginal discrepancy 56 ± 20 μm *SLM:* Marginal discrepancy: • EOS: 99 ± 27 μm • Concept Laser: 129 ± 29 μm
Alqahtani et al (2021)[48]	NP	Starbond Easy Powder 30, Scheftner GmbH	10	Crown, radial shoulder Typodont tooth, M tooth preparation	*Cast handmade pattern:* Marginal discrepancy 27 ± 9 μm *Cast milled pattern:* Marginal discrepancy 148 ± 30 μm *Milled presintered:* Marginal discrepancy 89 ± 21 μm *SLM:* Marginal discrepancy 27 ± 9 μm
Gholamrezaei et al (2020)[49]	EOSINT M270, EOS	Wirobond C+, Bego	5	Crown, round shoulder 0.5-mm depth Metal die	*Cast:* • Marginal discrepancy 133 ± 28 μm • Internal discrepancy 9 ± 1 μm *SLM:* • Marginal discrepancy 67 ± 16 μm • Internal discrepancy 10 ± 1 μm

Reference	SLM printer	Co-Cr powder	n	Specimens' geometry/ reference model	Results by group (mean ± SD)
Savencu et al (2020)[62]	PXS Dental, 3D Systems Mysint 100, Sisma	Starbond Easy Powder 30, Scheftner Both printers used the same powder	24	Crown, chamfer 1-mm depth Typodont, M tooth preparation	*Cast:* • Marginal discrepancy 96 ± 17 μm • Internal discrepancy 111 ± 26 μm *Milled:* • Marginal discrepancy 47 ± 6 μm • Internal discrepancy 58 ± 10 μm *SLM 3D Systems:* • Marginal discrepancy 62 ± 11 μm • Internal discrepancy 72 ± 21 μm *SLM Sisma:* • Marginal discrepancy 53 ± 13 μm • Internal discrepancy 69 ± 16 μm
Quante et al (2008)[54]	NP	Wirobond C+, Bego	28	Crown, chamfer depth NP	Before ceramic veneering procedures, Co-Cr alloy: Mean marginal discrepancy 93 μm Before ceramic veneering procedures, Co-Cr alloy: Mean internal (occlusal) discrepancy 252 μm

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Table 4 Study Characteristics of the Included Articles That Analyzed the Marginal and Internal Discrepancy Using the Silicone Replica Technique *(cont)*

Reference	Measurement method	Subgroup	Study type	Groups tested/methods
Zeng et al (2015)[51]	Silicone replica	Bego	In vitro	Tooth preparation scanned using LBS (D700, 3Shape). Two groups: • Conventional casting • SLM Silicone replica after 1, 3, 5, 7 firings. 50N load. Eight measurement points. Microscope (Stemi 2000C, Carl Zeiss)
Kim et al (2013)[60]	Silicone replica	EOS	In vitro	Tooth preparation scanned using LBS (D700, 3Shape). Two groups: • Conventional casting printed (Projet DP3000, 3D Systems) patterns (Bellabond Plus, Bego) • SLM Silicone replica. 50-N load. Eight measurement points. Microscope (KH 700, Hirox). Magnification X160
Kim et al (2014)[61]	Silicone replica	EOS	In vitro	Tooth preparation scanned using LBS (D700, 3Shape). Three groups: • Conventional casting handmade patterns (Bellabond Plus, Bego) • Milled presintered Co-Cr • SLM Silicone replica. 50-N load. Silicone digitized using the same LBS. 40,000 measurement points using a CAD program (CopyCAD, Delcam).
Xu et al (2014)[50]	Silicone replica	EOS	In vitro	Tooth preparation scanned using LBS (D700, 3Shape A/S). Two groups: • Conventional casting handmade patterns (Wirobond C+; Bego) • SLM Silicone replica. 50-N load. Eight measurement points. Microscope (Stemi 2000C, Carl Zeiss).
Önöral et al (2018)[55]	Silicone replica	EOS	In vitro	Tooth preparation scanned using IOS (Omnicam, Dentsply Sirona). Four groups: • Conventional casting milled patterns (Wirobond Easy, Bego) • Milled presintered Co-Cr • SLM Silicone replica. 50-N load. Eight measurement points. Microscope (Stemi 2000C, Carl Zeiss).
Chang et al (2019)[65]	Silicone replica	EOS	In vitro	Tooth preparation scanned using LBS (IScan L1, Imetric 3D). Three groups: • Conventional casting handmade patterns (Wirobond, Bego) • Milled Co-Cr • SLM Silicone replica. 50-N load. Silicone scanned using the same LBS.
Önöral (2020)[63]	Silicone replica	EOS	In vitro	Tooth preparation scanned using IOS (Omnicam, Dentsply Sirona). Three groups: • Conventional casting milled patterns (Wirobond easy, Bego) • Milled presintered Co-Cr • SLM Silicone replica. Eight measurement points. Stereomicroscope (S8 APO, Leica), magnification X80.
Sarda and Bedia (2021)[57]	Silicone replica	EOS	In vitro	Tooth preparation scanned using LBS (DS-EX, Shinning 3D). Three groups: • Conventional casting milled patterns (Wirobond-C, Bego) • Milled presintered Co-Cr • SLM Silicone replica. 50-N load. Four measurement points. Microscope (Model NP, Wuzhou), magnification X50.

Reference	SLM printer	Co-Cr powder	n	Specimens' geometry/ reference model	Results by group (mean ± SD)
Zeng et al (2015)[51]	NP	Wirobond C+, Bego	15	Crown, chamfer 1-mm depth Zirconia die	*Cast:* Marginal discrepancy 67 ± 42 μm, after 1 firing *SLM:* Marginal discrepancy 36 ± 11 μm, after 1 firing
Kim et al (2013)[60]	EOSINT M270, EOS	EOS SP2 CoCr, EOS	10	Three-unit FDP, chamfer 1.2-mm depth Typodont, M tooth preparation	*Cast:* • PM abutment: Marginal discrepancy 82 ± 7 μm • M abutment: Marginal discrepancy 82 ± 7 μm *SLM:* • PM abutment: Marginal discrepancy 131 ± 35 μm • M abutment: Marginal discrepancy 133 ± 40 μm
Kim et al (2014)[61]	EOSINT M270, EOS	EOS SP2 CoCr, EOS	10	Crown, chamfer 1.2-mm depth Metal reference die, M tooth preparation	*Cast:* Marginal discrepancy 64 ±14 μm *Milled presintered:* Marginal discrepancy 33 ± 5 μm *SLM:* Marginal discrepancy 47 ± 9 μm
Xu et al (2014)[50]	NP	NP	18	Crown, chamfer 1-mm depth Metal reference cast, PM tooth preparation	*Cast:* Marginal discrepancy 170 ± 66 μm *SLM:* Marginal discrepancy 103 ± 41 μm
Önöral et al (2018)[55]	EOSINT M270, EOS	EOS SP2 CoCr, EOS	15	3-unit FDP, chamfer 1-mm depth	*SLM:* Premolar: • Marginal discrepancy 79 ± 2 μm • Axial discrepancy 78 ± 1 μm • Axial-occlusal wall discrepancy 83 ± 4 μm • Occlusal discrepancy 137 ± 9 μm Molar: • Marginal discrepancy 82 ± 2 μm • Axial discrepancy 83 ± 3 μm • Axial-occlusal wall discrepancy 86 ± 4 μm • Occlusal discrepancy 150 ± 9 μm
Chang et al (2019)[65]	EOSINT M270, EOS	Wirobond, Bego	10	Crown, chamfer 1-mm depth Zirconia die, M tooth preparation	*Cast:* Marginal discrepancy 76 ± 61 μm *Milled:* Marginal discrepancy 116 ± 92 μm *SLM:* Marginal discrepancy 121 ± 98 μm
Önöral (2020)[63]	EOSINT M270, EOS	EOS SP2 CoCr, EOS	15	Three-unit FDP, chamfer 1-mm depth Typodont teeth, C and PM abutments	*Cast:* • C abutment: Marginal discrepancy 130 ± 10 μm • PM abutment: Marginal discrepancy 115 ± 6 μm *Milled presintered:* • C abutment: Marginal discrepancy 82 ± 4 μm • PM abutment: Marginal discrepancy 80 ± 3 μm *SLM:* • C abutment: Marginal discrepancy 85 ± 2 μm • PM abutment: Marginal discrepancy 81 ± 1 μm
Sarda and Bedia (2021)[57]	NP	EOS SP2 CoCr, EOS	10	Crown, chamfer 1-mm depth Metal die	*Cast:* Marginal discrepancy 88.44 ± 42.30 μm *Milled presintered:* Marginal discrepancy 61.13 ± 12.29 μm *SLM:* Marginal discrepancy 55.39 ± 15.15 μm

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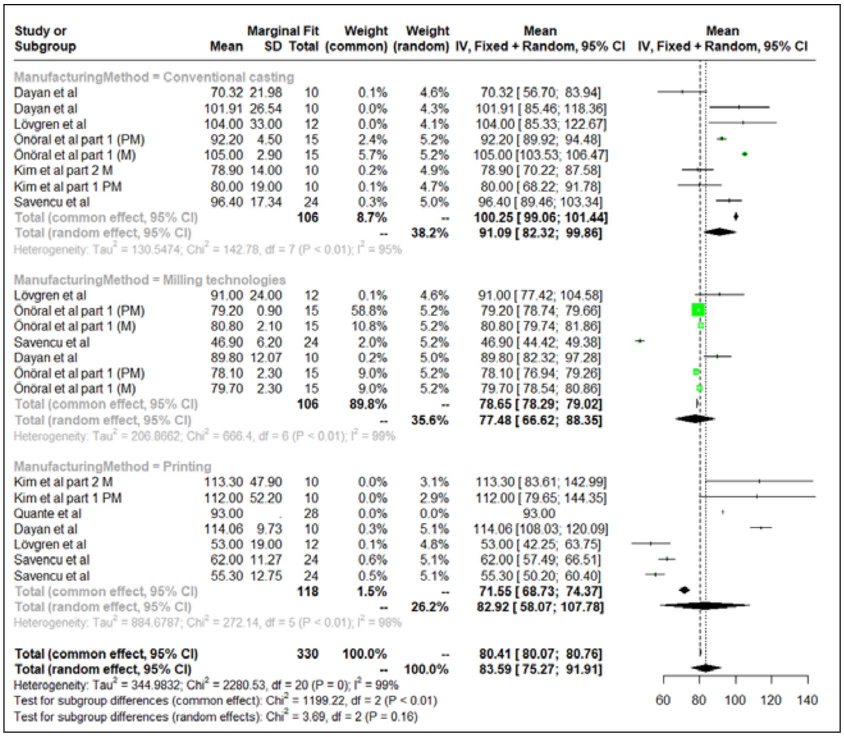
Table 4 Study Characteristics of the Included Articles That Analyzed the Marginal and Internal Discrepancy Using the Silicone Replica Technique *(cont)*

Reference	Measurement method	Subgroup	Study type	Groups tested/methods
Noori and Gholam (2021)[64]	Silicone replica	EOS	In vitro	Tooth preparation scanned using LBS (I3D, imes-icore). Three groups: • Conventional casting milled pattern • Milled presintered Co-Cr • SLM Silicone replica. 50-N load. Microscope magnification X200.
Lövgren et al (2017)[52]	Silicone replica	Concept Laser	In vitro	Tooth preparation scanned using LBS (Everest scan pro 4101, KaVo Dental). Three groups: • Conventional casting milled pattern (Wirobond C, Bego) • Milled Co-Cr • SLM Silicone replica. Stereomicroscope (DFC 420, Leica). Magnification X31, 9 measurement points.
Hong et al (2019)[56]	Silicone replica	Concept Laser	In vitro	Three groups: • Conventional casting handmade pattern (LunaCast, ACF) • Two groups SLM: different laser settings Specimens were tested with/without veneering procedures (independent samples). Silicone replica. 50-N loading. Microscope (SMZ1500, Nikon). Magnification X160, 8 measurement points.
Dayan et al (2019)[58]	Silicone replica	Concept Laser	In vitro	Tooth preparation digitized using LBS (D700, 3Shape A/S). Three groups: • Conventional casting handmade pattern (Wirobond C, Bego). Conventional impression. Stone casts. • Milled presintered Co-Cr • SLM Silicone replica. Stereomicroscope. Magnification X100, 12 measurement points.
Nesse et al (2015)[53]	Silicone replica	Kulzer	In vitro	Digitizing method of tooth preparation NP. Three groups: • Conventional casting milled pattern (Wirobond C, Bego) • Milled Co-Cr • SLM Visual assessment of fit: scale from 1 to 5. Two specimens from each group were used to analyze the internal discrepancy using SEM (Model NP, Zeiss).
Daou (2021)[59]	Silicone replica	Sisma	In vitro	Tooth preparation digitized using LBS (Ceramill Map 400, Amann Girrbach). Three groups: • Conventional casting milled pattern (Girobond nb, Amann Girrbach) • Milled presintered Co-Cr • SLM Silicone replica. 40-N loading. SEM (AIS2100C, Seron Technologies). Magnification X100 and X150, 18 measurement points. Before and after ceramic veneering.

Au = gold; C = canine; FDP = fixed dental prosthesis; LBS = laboratory scanner; LD = lithium disilicate; NA = not applicable; NP = not provided; PM = premolar; Pt = platinum; SD = standard deviation; SEM = scanning electron microscopy; SLM = selective laser melting.

Reference	SLM printer	Co-Cr powder	n	Specimens' geometry/ reference model	Results by group (mean ± SD)
Noori and Gholam (2021)[64]	EOS M100, EOS	EOS SP2 CoCr, EOS	15	Crown, chamfer depth NP Metal die, PM tooth preparation	*Cast:* Marginal discrepancy 23 ± 3 µm *Milled presintered:* Marginal discrepancy 19 ± 1 µm *SLM:* Marginal discrepancy 39 ± 3 µm
Lövgren et al (2017)[52]	Mlab, Concept Laser	Remanium Start SL CoCr, Dentaurum GmbH	12	Crown, chamfer 0.6-mm depth M metal die	*Cast:* • Marginal discrepancy 104 ± 33 µm • Chamfer discrepancy 163 ± 24 µm • Axial wall discrepancy 99 ± 15 µm • Occlusal discrepancy 140 ± 34 µm *Milled:* • Marginal discrepancy 91 ± 24 µm • Chamfer discrepancy 148 ± 27 µm • Axial wall discrepancy 94 ± 11 µm • Occlusal discrepancy 136 ± 27 µm *SLM:* • Marginal discrepancy 53 ± 19 µm • Chamfer discrepancy 120 ± 20 µm •- Axial wall discrepancy 79 ± 8 µm • Occlusal discrepancy 125 ± 30 µm
Hong et al (2019)[56]	M1, Concept Laser	Remanium Start CL CoCr, Dentaurum GmbH	10	Crown, chamfer 1-mm depth Metal die	*Cast nonveneered specimens:* Marginal discrepancy 56 ± 10 µm *SLM nonveneered specimens:* Marginal discrepancy 76 ± 10 µm and 75 ± 16 µm for SLM with large and small porosity, respectively
Dayan et al (2019)[58]	NP	Remanium Start CL CoCr, Dentaurum GmbH	10	Crown, chamfer 1-mm depth Typodont tooth, M	*Cast:* • Marginal discrepancy 70 ± 22 µm • Occlusal wall discrepancy 92 ± 21 µm *Milled presintered:* • Marginal discrepancy 90 ± 12 µm • Occlusal wall discrepancy 124 ± 15 µm *SLM:* • Marginal discrepancy 114 ± 10 µm • Occlusal wall discrepancy 166 ± 15 µm
Nesse et al (2015)[53]	NP	Cara Co-Cr SLM, Kulzer	10	Three-unit FDP, chamfer depth NP Typodont teeth	*Cast:* Mean internal discrepancy 116 µm *Milled:* Mean internal discrepancy 95 µm *SLM:* Mean internal discrepancy 156 µm SLM group obtained the lowest marginal and internal discrepancy values when compared with the other two groups.
Daou (2021)[59]	Mysint100, Sisma	Mediloy S-Co, Bego	20	Three-unit FDP, chamfer 1.2-mm depth Typodont teeth, PM and M abutments	Before veneering procedures *Cast:* marginal discrepancy 126 ± 17 µm *Milled presintered:* Marginal discrepancy 119 ± 22 µm *SLM:* marginal discrepancy 126 ± 29 µm



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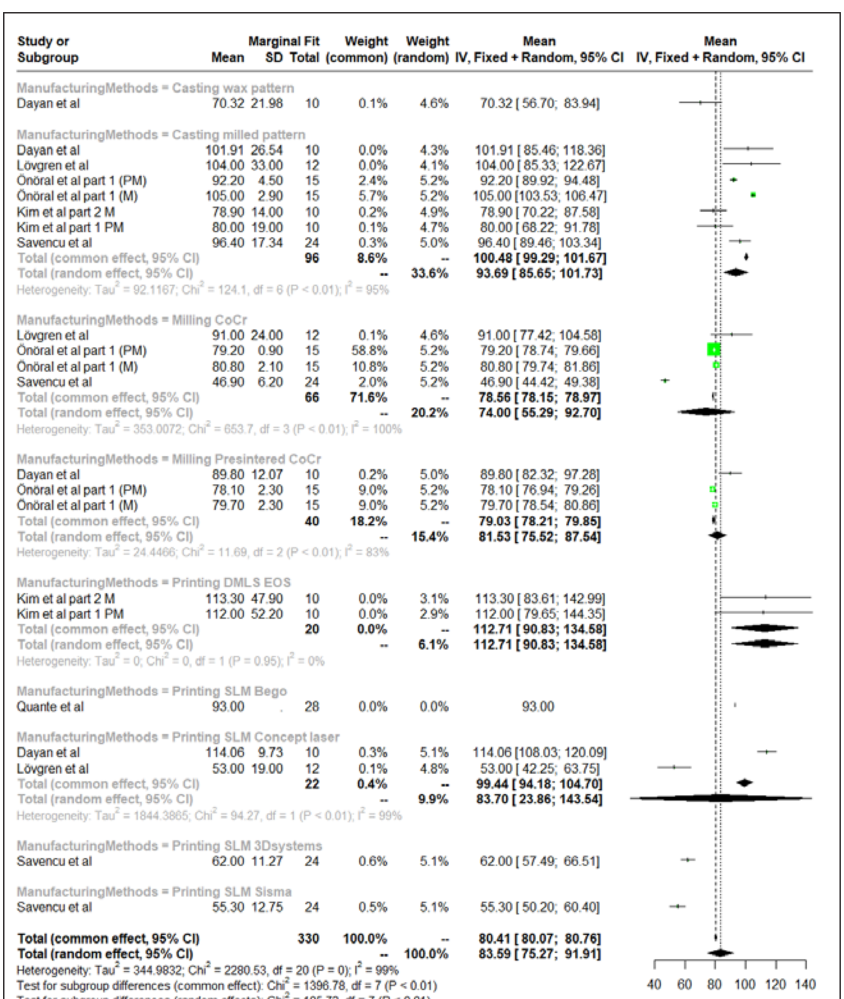

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Fig 3 *(a)* Forest plot of pooled studies included comparing the mean ± SD of the marginal discrepancy values of the cast, milled, and SLM AM Co-Cr tooth-supported frameworks measured using the silicone replica technique. *(b)* Forest plot of pooled studies included comparing the mean ± SD of the marginal discrepancy values of the cast, milled, and SLM AM subgroups.

Meta-analysis

In the silicone replica test group,[50–65] the marginal and internal discrepancies of conventionally cast, milled, and AM frameworks were compared. Considering the overall manufacturing methods, milling, and each SLM printing method, the following mean marginal discrepancies (Fixed+Random effect, 95% CI) were obtained: 91.09 µm ($I^2 = 95\%$, $P < .001$) in the conventional casting group, 77.48 µm ($I^2 = 99\%$, $P < .001$) in the milling group, and 82.92 µm ($I^2 = 98\%$, $P < .001$) in the printing group (z 3a). Additionally, when the marginal discrepancy was analyzed considering the two conventional (using handmade or CAD/CAM patterns), milling (presintered or sintered Co-Cr disks), and each SLM printing method (EOS, Bego, Concept Laser, 3D Systems, and Sisma), the conventional casting method using either a handmade or CAD/CAM pattern resulted in a mean marginal discrepancy (Fixed+Random effect, 95% CI) of 93.69 µm ($I^2 = 95\%$, $P < .001$). The milling led to a mean marginal discrepancy (Fixed+Random effect, 95% CI) of 81.53 µm ($I^2 = 83\%$, $P < .001$) when using a presintered

Co-Cr disk and 74.00 μm (I^2 = 100%, P < .001) when using a sintered Co-Cr disk. Lastly, the SLM AM method obtained a mean marginal discrepancy (Fixed+Random effect, 95% CI) of 112.71 μm when using an EOS printer, 93 μm when using a Bego printer, 83.70 μm (I^2 = 99%, P < .001) when using a Concept Laser printer, 62.00 μm when using a 3D Systems printer, and 55.30 μm when using a Sisma printer. Overall, SLM AM methods showed a mean marginal discrepancy (Fixed+Random effect, 95% CI) of 83.59 μm (I^2 = 99%, P < .001) (Fig 3b).

Regarding internal discrepancy analysis considering the overall manufacturing methods, milling, and each SLM printing method, a mean internal discrepancy (Fixed+Random effect, 95% CI) of 111.29 μm (I^2 = 94%, P < .001) was obtained in the conventional casting group, 121.96 μm (I^2 = 100%, P < .001) in the milling group, and 121.25 μm (I^2 = 99%, P < .001) in the printing group (Fig 4a). Furthermore, when the internal discrepancy analysis was performed considering the two conventional (using handmade or CAD/CAM patterns), milling (presintered or sintered Co-Cr disks), and each SLM printing method (EOS, Bego, Concept Laser, 3D Systems, and Sisma), the conventional casting method using either a handmade or CAD/CAM pattern obtained a mean internal discrepancy (Fixed+Random effect, 95% CI) of 114.09 μm (I^2 = 94%, P < .001). The milling technique led to a mean internal discrepancy (Fixed+Random effect, 95% CI) of 113.54 μm (I^2 = 88%, P < .001) when using a presintered Co-Cr disk and 127.46 μm (I^2 = 88%, P < .001) when using a sintered Co-Cr disk. Lastly, the SLM AM method resulted in a mean internal discrepancy (Fixed+Random effect, 95% CI) of 152.14 μm (I^2 = 0%, P = .064) when using an EOS printer, 252 μm when using a Bego printer, 146.38 μm (I^2 = 84%, P < .001) when using a Concept Laser printer, 72.40 μm when using a 3D Systems printer, and 69.30 μm when using a Sisma printer. Overall, SLM AM methods showed a mean internal discrepancy (Fixed+Random effect, 95% CI) of 117.41 μm (I^2 = 99%, P < .001) (Fig 4b).

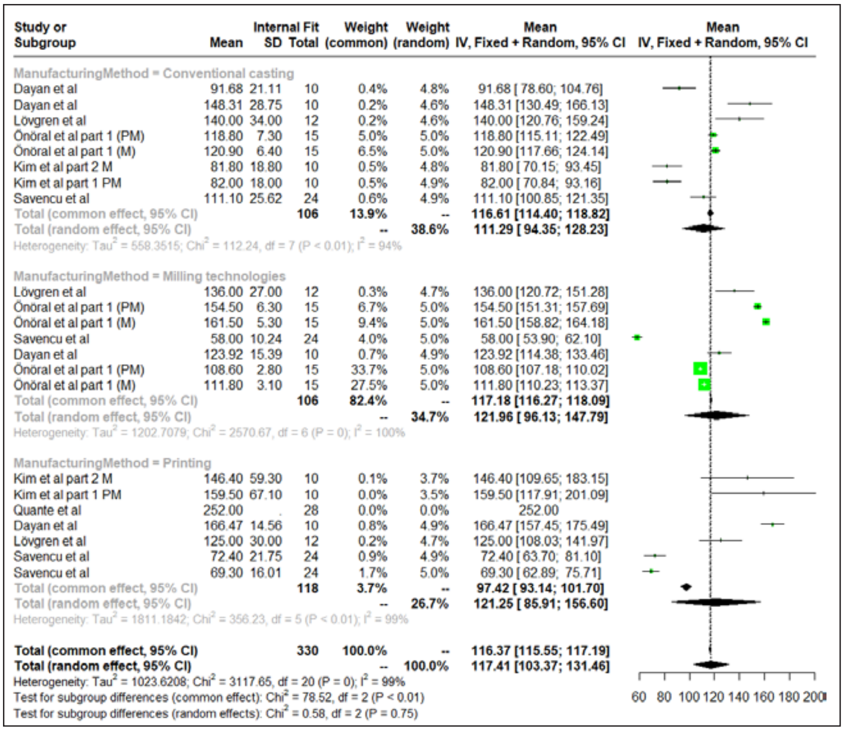
DISCUSSION

A total of 31 articles were included in the present systematic review. Among the review studies, seven measurement methods have been used to analyze the marginal and internal discrepancies of Co-Cr frameworks, namely manufacturing accuracy,[35,36] the dual-scan[37,38] and triple-scan method,[39] stereomicroscope,[40–45] optical CMM,[46] microCT,[47,48] profilometer,[49] and silicone replica technique.[50–65] Due to the heterogeneity and limited data available, only the silicone replica group[50–65] was considered for the meta-analysis. The results revealed that the manufacturing method did not impact the marginal and internal discrepancies of the Co-Cr frameworks. When analyzing the overall data considering three manufacturing methods, the marginal and internal discrepancies were lower than the 120-μm clinically acceptable threshold. However, when considering the subgroups of each manufacturing method, the milling-sintering, SLM-EOS, SLM-Bego, and SLM-Concept Laser subgroups led to a mean internal discrepancy higher than 120 μm. Additionally, inconclusive results and considerable heterogeneity was found in the meta-analysis. Therefore, the null hypothesis was accepted. Factors such as different manufacturing trinomial (metal printers and alloy composition); printing parameters such as layer thickness, scan speed, power laser, fabrication speed, and laser diameter; and postprocessing protocol of the AM metal could have contributed to the high heterogeneity. Therefore, the results should be interpreted carefully, and clinical recommendations can only be made after analyzing additional in-vitro and clinical studies.

The two included studies that analyzed the manufacturing accuracy of Co-Cr onlays and crowns fabricated using EOS or Concept Laser printers, respectively, reported contradictory results.[35,36] These studies reported that the SLM technologies analyzed showed better or worse manufacturing accuracy than subtractive methods. This may be explained by the use of different CAD design parameters on the virtual design of the restoration, manufacturing trinomial, printing parameters, postprocessing techniques, restoration geometry discrepancy, and disparities in the measurement method. Further studies are needed to assess the manufacturing accuracy of different SLM metal manufacturing trinomials, printing parameters, and postprocessing procedures for fabricating tooth-supported metal frameworks.

Three studies used the dual- or triple-scan method to evaluate the marginal and internal fit of SLM Co-Cr crown specimens.[37–39] Overall, all studies reported that marginal discrepancies were smaller than internal discrepancies.[37–39] Additionally, the reported misfit values were smaller than 120 μm, within the clinically acceptable marginal gap.[26–28] Even though three studies used the same metal printer manufacturer, the printer or Co-Cr powder were not disclosed. Therefore, it is unclear if the same manufacturing trinomial was tested. Furthermore, printing parameters and postprocessing methods were not described in all studies. Similarly, varying conventional and milling methods were considered in the studies. Hence, direct comparisons among these studies are challenging.

Six included studies used the stereomicroscope technique to assess the marginal and internal discrepancy of the Co-Cr tooth-supported frameworks.[40–45] Overall, these studies reported marginal and internal discrepancies smaller than 120 μm, within the clinically acceptable marginal gap.[26–28] Although only two SLM printer manufacturers (EOS and Concept Laser) were tested among these studies, methodology discrepancies (geometry and



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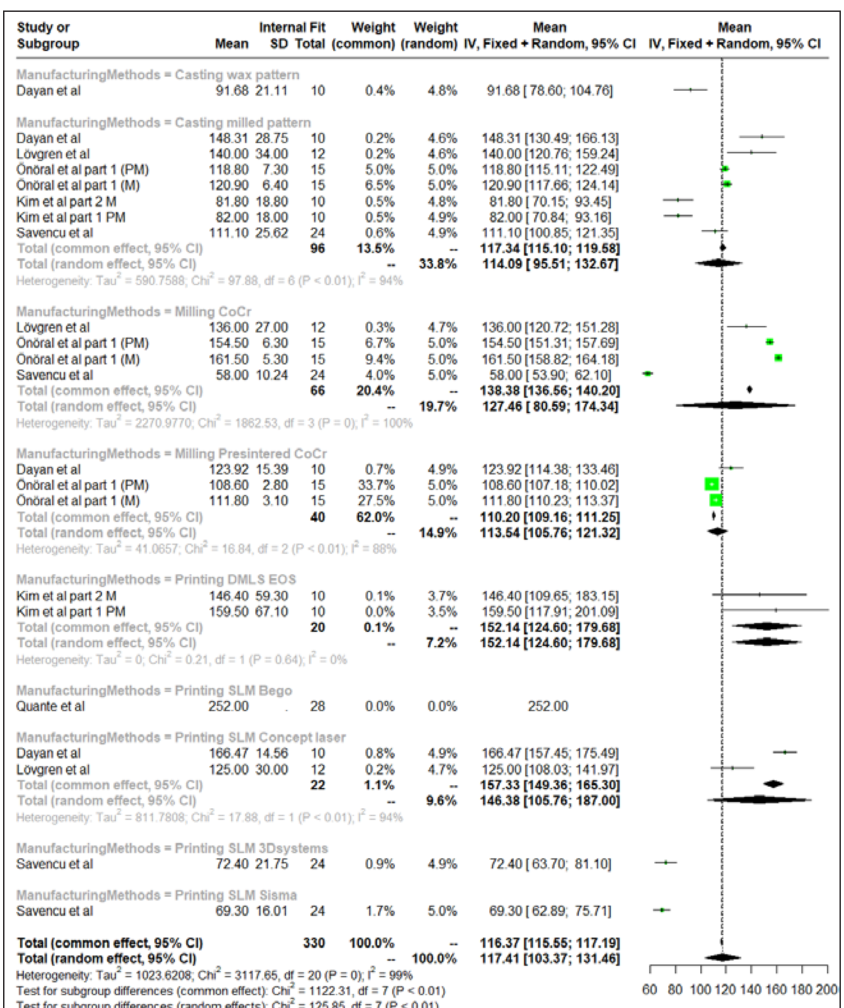

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Fig 4 *(a)* Forest plot of pooled studies included comparing the mean ±S D of the internal discrepancy values of the cast, milled, and SLM AM Co-Cr tooth-supported frameworks measured using the silicone replica technique. *(b)* Forest plot of pooled studies included comparing the mean ± SD of the internal discrepancy values of the cast, milled, and SLM AM subgroups.

extension of the framework, manufacturing techniques, cementation methods, number of measurement points, and magnification) were found among the studies, making direct comparison of the results difficult.

One in-vitro study used an optical CMM for measuring the marginal discrepancy of four-unit AM frameworks fabricated using an EOS trinomial before and after ceramic veneering procedures.[46] The authors reported a mean ± SD marginal discrepancy of 25 ± 9 µm before ceramic veneering methods.[46] This is the only study that used this measurement method; therefore, comparison with similar publications is not feasible. However, the marginal discrepancy reported is within the range of the reported data from the other included studies.

Two in-vitro studies used microCT to measure the marginal discrepancy when metal crowns were fabricated using conventional, milling, or SLM (EOS and Concept Laser) methods.[47,48] However, these studies reported different mean marginal discrepancy values, which may be explained by the discrepancies in the methodology used (manufacturing trinomial, printing strategy, postprocessing, geometry and thicknesses of the crown, number and location of the measurement points, microCT settings).

One in-vitro investigation used a profilometer to measure the marginal and internal discrepancies of metal crowns fabricated using SLM technology of an EOS printer (EOSINT M270) with the metal powder from another manufacturer (Wirobond C+ from Bego).[49] This is the only study that used this measurement method; therefore, comparisons with other studies are not possible. The mean marginal and internal discrepancies reported were lower than the clinically acceptable discrepancy of 120 µm.

Sixteen articles selected the silicone replica technique to assess the fit of the tooth-supported metal frameworks.[50–65] As previously described, the meta-analysis revealed no differences in the marginal and internal discrepancies of the Co-Cr tooth-supported frameworks fabricated using conventional, milling, and SLM methods. However, when analyzing different SLM methods tested, results demonstrated different fit values among the manufacturing trinomials assessed. However, the meta-analysis revealed no statistically significant differences among the manufacturing methods tested or manufacturing trinomials considered. Nonetheless, due to the heterogeneity of the data, generalization of the results should be avoided. Additional studies are needed to further evaluate the impact of manufacturing trinomial and printing strategy on the marginal and internal discrepancies of the AM tooth-supported frameworks. Additionally, the majority of the included studies did not report details regarding the printing strategy used to manufacture the specimens, such as print orientation, layer thickness, or postprocessing methods. Future research should include manufacturing details for better comparisons and analysis of the published data.

The present systematic review and meta-analysis included in-vitro and clinical studies that assessed the fit of Co-Cr frameworks for the fabrication of tooth-supported restorations. The included studies' publication dates ranged from 2008 to 2021, which introduces the factor of software and/or hardware development. This represents a limitation when comparing the data in the meta-analysis performed in the present investigation. Additionally, the exclusion criteria included ceramic veneering applications. Therefore, the metal-ceramic restorations were not completely finished. Further studies are needed for a better understanding of the impact of the AM technologies on the marginal and internal discrepancies of Co-Cr frameworks, with further analysis of the multiple variables of the manufacturing process. The clinical longevity and long-term complications of metal-ceramic prostheses whereby the metal framework is additively fabricated should be analyzed further in depth.

CONCLUSIONS

Based on the results of the present systematic review and meta-analysis, the following conclusions were drawn:

- The manufacturing method (conventional casting, subtractive, and additive manufacturing procedures) did not impact the marginal and internal discrepancies of Co-Cr frameworks for tooth-supported restorations.
- The manufacturing trinomial (SLM, printer, and Co-Cr alloy) did not impact the marginal and internal discrepancies of Co-Cr frameworks for tooth-supported restorations.

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