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FIT OF LASER SINTERED METAL RESTORATIONS: A SYSTEMATIC REVIEW

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ABSTRACT

Objective: The aim of this study is to review all the published in vitro research on the fit of laser sintered metal copings compared to other fabrication techniques.

Materials and Methods: A comprehensive electronic search was performed through Google Scholar to combine the following key words: '3D printing', 'rapid prototyping', 'laser sintering', 'direct metal laser sintering', 'laser melting', 'metal coping', 'cobalt chromium coping', 'metal crown', 'cobalt chromium crown', 'internal fit' and 'marginal fit'. The search was limited to articles written in English. In addition, a manual search was also conducted through articles and reference lists retrieved from the electronic search and peer reviewed journals.

Results: A total of 284 articles were retrieved and only 17 met the specified inclusion criteria for the review. The selected articles had assessed marginal and/or internal fit of laser sintered metal copings against other fabrication techniques.

Conclusions: Laser sintered metal copings have a good marginal and internal fit within the clinically acceptable range suggested in the literature. Laser sintering procedure provides an efficient and rapid method for digitally designing and manufacturing complex metal structures for crowns and FPDs.

KEY WORDS: 3D printing- laser sintering- metal coping- internal fit – marginal fit.

INTRODUCTION

Metal-ceramic restorations are still extensively used as they showed excellent clinical performance and mechanical properties throughout the years. Their cost is relatively low compared to metal-free restorations and have simpler cementation procedures, in addition to their role in natural reproduction of lost dentition. In the fabrication of cast metal restorations, the lost wax casting technique is one of the most used methods. However, in recent

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years, new fabrication techniques, which are more efficient, began to be used instead of conventional ones.[1, 2]

Along with the CAD/CAM milling, a paradigm shift in the procedure for fabricating the metal coping has come into life with the introduction of 3D printing technology. 3D printing can be used for the fabrication of metal structures either indirectly by printing in burn-out resins or waxes for a lost-wax process, or directly in metal alloys.[3] The direct 3D printing of metal alloys - also known as laser sintering of metal alloys - allows the elimination of a major drawback of the lost wax technique: the casting shrinkage, easy fabrication of complex shapes, operation of an automatic system, and short working time due to elimination of the lost wax technique long procedures[4]. Because laser sintering is considered a new manufacturing technique, it requires extensive evaluation before it might be used to produce prostheses for clinical use.

The accurate fit is considered mandatory for a fixed restoration to achieve acceptable longevity.[5-7] A poor fit is responsible for 10% of prosthetic failures[8]. The fit of any restoration is determined by its marginal and internal fit. The ideal internal or marginal adaptation will result in minimal plaque accumulation and bone loss, less gingival irritation, less cement dissolution, less recurrent caries and less marginal discoloration. The purpose of this systematic review is to review the in vitro research on the fit of laser sintered metal copings compared to other fabrication techniques.

MATERIALS AND METHODS

This systematic review was conducted in accordance with the PRISMA statement[9]. The PRISMA flowchart summarizing the systematic review process is shown in figure 1.

Search strategy and selection criteria

The purpose of the search was to obtain all the articles on the fit of laser sintered metal copings following the inclusion criteria: Articles published in English, In-vitro studies, using one of 3D printing/additive manufacturing/laser sintering techniques in the direct construction of metal copings/crowns/FPDs and testing the internal and/or marginal fit accuracy. Electronic search was performed in the Google Scholar database using the following keywords: “3D printing” OR “rapid prototyping” OR “laser sintering ” OR “direct metal laser sintering” OR “laser melting” AND “metal coping” OR “cobalt chromium coping” OR “metal crown” OR “cobalt chromium crown” AND “internal fit” OR “marginal fit”. No publication year limit was used. The electronic search was supplemented by manual searching. In addition, the references of the selected articles were reviewed for possible inclusion.

Study selection and data extraction

Titles and abstracts of all studies identified in the electronic search were screened. Studies that did not meet the predefined inclusion criteria were excluded. All remaining studies were subjected to a full text review. Studies falling within the inclusion criteria were assessed and data were extracted. The primary outcome measures analyzed included the marginal and internal fit accuracy of crowns or FPDs constructed by additive manufacturing techniques compared to other techniques.

RESULTS

Study search

Initial database searching resulted in 284 studies, 1 additional study was identified through manual hand search. After duplicates removal, excluded studies from title and abstract, and assessing full text studies for eligibility, 17 studies[1,2,4,8,10-22] were included in this systematic review. Table 1 shows a summary of the studies included in this systematic review.

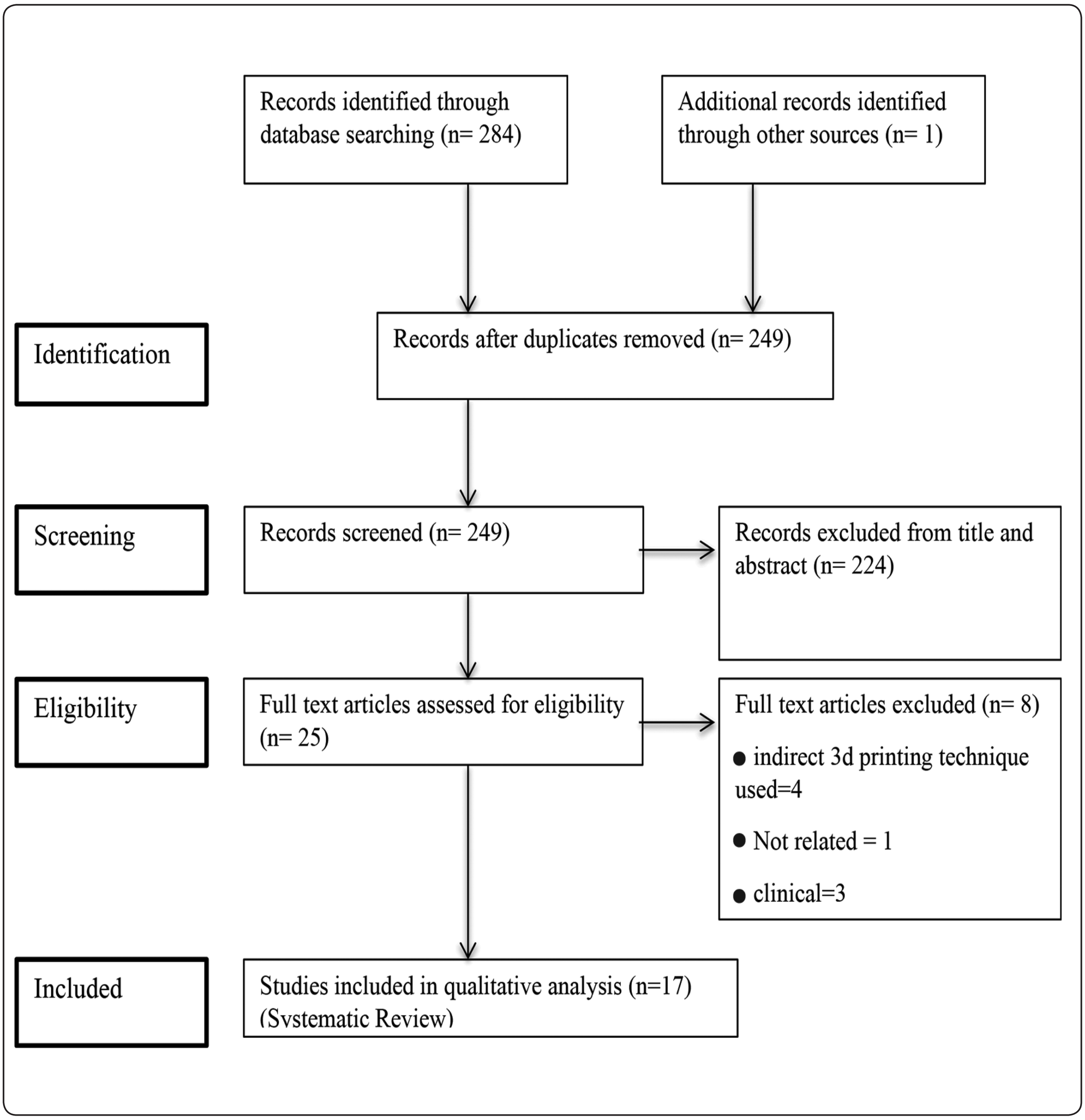

Fig. (1) : PRISMA flow chart of the systematic review

Description of studies

Of the included 17 articles, 6 articles[4,8,13,18,20,22] (35.3%) only assessed the marginal fit accuracy, one article[10] (5.9%) only assessed the internal fit accuracy and 10 articles[1, 2,11, 12,14-17,19, 21] (58.84%) assessed both the marginal and internal fit accuracy. 13 articles[1, 2, 4, 10, 12, 14-18, 20-22] (76.5%) used single crown frameworks, 3 articles[11,13,19] (17.6%) used fixed-partial-denture frameworks and only one article[8] (5.9%) used both single crown and fixed-partial-denture frameworks for the fit accuracy assessment.

Since this was the purpose of the systematic review, all the articles investigated the fit accuracy of laser sintered metal frameworks. Cobalt – Chromium (Co-Cr) was the material used in all the articles (100%) for laser sintering. 14 of them[1,2,8,10,11,13-15,17-22] (82.4%) used the direct metal laser sintering technique (DMLS) that is also known as selective laser melting (SLM) and 3 of them[4,12,16] (17.6%) used the selective laser sintering technique (SLS).

Different fabrication techniques were used for the comparison of the fit accuracy with the laser sintering of metal frameworks. The most common one was the lost wax method whether it used the conventional manual wax pattern[1,4,8,10-14,16-22], wax pattern milling using CAD/CAM technology [1,2,11,15,17] or 3D printing of wax/resin pattern[1,14]. Among other techniques, milling of Co-Cr metal frameworks using CAD/CAM technology was used in 7 articles[1,2,11,16,17,19,21]. Only one article[8] used CAD/CAM zirconia milling.

The selected articles show significant heterogeneity in terms of experimental methodology and sample size. The approaches used for the marginal and internal fit assessment were:

- Silicone replica approach[1,12,13,18-21]. Low-viscosity silicone impression material is injected in the fitting surface of the restoration. This step is followed by seating the restoration on the preparation. After the removal of metal framework, the thin layer of the low-viscosity material is stabilized by higher viscosity impression material to facilitate the handling. The silicone replica can then be sectioned and magnified.
- 3D replica approach[12,16]. The preparation is scanned with a dental scanner. After scanning, low-viscosity silicone impression material is injected in the fitting surface of the restoration in a manner similar to the conventional silicone replica technique and the restoration is seated on the preparation. After the removal of metal framework, the silicone impression material is kept on the preparation while a digital replica is made using a dental scanner. To 3-dimensionally measure the gap between the digital replicas, point cloud data are obtained from the digital replica files by using a dedicated program.
- Internal microscopic examination after cementation and sectioning of the specimen[2,8,10,11,14,15,17]. The metal framework is cemented to its corresponding preparation. After it sets, the metal framework along with the preparation are sectioned longitudinally and then examined microscopically. Some articles add colour to the cement before cementation[11,15,17] to be more visible under the microscope.
- External microscopic examination of the marginal area. It can be either done without cementation[2,4] or after using cement[14] or silicone pressure indicating paste[22].
- Silicone impression weighing approach[2,10]. Low-viscosity silicone impression material is injected in the fitting surface of the restoration that is then seated on the preparation. After the removal of metal framework, the thin layer of the low-viscosity material is removed and weighed using an analytical balance.
- Direct-sight approach[19]. The marginal fit is evaluated with direct-sight approach at a 90-degree angle on the tooth surface. Preparation is colored with a red marker so that the preparation border can be clearly seen.

TABLE (1) Descriptive summary and outcome for the included studies

Author and year	Type of restoration	Groups	Specimens per group	Testing method(s)	Outcome
Ucar et al 2009[10]	Crowns	* Laser sintered Co-Cr * Cast Co-Cr (conventional lost wax method) * Cast Ni-Cr (conventional lost wax method)	12	-Light body silicone weighting -Internal gap width (cement film) measurement 5 points.	-Significantly higher mean (SD) light-body silicone weights (P <.001) were observed in the laser-sintered Co-Cr alloy group (14.34 (1.67) mg) compared to the conventionally cast Ni-Cr alloy group (9.36 (1.97) mg) and Co-Cr alloy group (7.85 (1.19) mg). -Mean internal gap widths (SDs) were 58.21 (19.92) µm, 50.55 (25.1) µm, and 62.57 (21.62) µm, respectively, for the cast Ni-Cr and Co-Cr alloy groups and the laser-sintered Co-Cr alloy group. No significant difference was observed between the 3 groups for internal gap widths.
Ortorp et al 2011[11]	3-unit FPDs	* Cast Co-Cr conventional lost wax method (LW) * Cast Co-Cr using milled wax lost wax method (MW) * Milled Co–Cr (MC) * Laser sintered Co-Cr with direct metal laser sintering (DMLS)	8	Internal and marginal gap width (cement film) measurement: 11 points.	Best fit based on the means (SDs) in µm for all measurement points was in the DLMS group 84 (60) followed by MW 117 (89), LW 133 (89) and MC 166 (135). Significant differences were present between MC and DLMS (p < 0.05).
Kim et al 2013[12]	Crowns	* Laser sintered Co-Cr * Cast Co-Cr *Each group is divided into 2 subgroups: -Before porcelain application -After porcelain application	10	-Marginal gap width measurement 16 points (light body silicone replica technique) -Internal gap width measurements (3D replica technique)	The laser sintered group cores had higher values than the casting group cores, and the difference was statistically significant (P=. 045). The finished metal-ceramic crown gap values were also significantly higher in the SLS group compared to the casting group (P=. 023). A statistical significance in increase of marginal gap after firing in both Cast group (P=. 012) and laser sintered group (P=. 007), while only marginally significant or insignificant results were obtained for internal gap in Cast group (P=. 059) or SLS group (P>.05), respectively.

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Kim et al 2013[12]	Crowns	* Laser sintered Co-Cr * Cast Co-Cr *Each group is divided into 2 subgroups: -Before porcelain application -After porcelain application	10	-Marginal gap width measurement 16 points (light body silicone replica technique) -Internal gap width measurements (3D replica technique)	The laser sintered group cores had higher values than the casting group cores, and the difference was statistically significant (P=. 045). The finished metal-ceramic crown gap values were also significantly higher in the SLS group compared to the casting group (P=. 023). A statistical significance in increase of marginal gap after firing in both Cast group (P=. 012) and laser sintered group (P=. 007), while only marginally significant or insignificant results were obtained for internal gap in Cast group (P=. 059) or SLS group (P>.05), respectively.

Fig. (1) PRISMA flow chart of the systematic review

Author and year	Type of restoration	Groups	Specimens per group	Testing method(s)	Outcome
Kim et al 2013[13]	3-unit FPDs	* Laser sintered Co-Cr with direct metal laser sintering (DMLS) * Cast Ni-Cr conventional lost wax method (LW)	10	Using the light body film thickness technique, 3 readings: -Absolute marginal discrepancy (AMD) -Marginal gap (MG) -Internal gap (IG)	The mean values of AMD, MG, and IG were significantly larger in the DMLS group than in the LW group ($p < 0.001$). Means of AMD, MG and IG were 83.3, 80.0, and 82.0 µm in the LW group; and 128.0, 112.0, and 159.5 µm in the DMLS group, respectively. No significant difference between measurements for premolars and molars was found ($p > 0.05$).
Bhaskaran et al 2013[14]	Crowns	* Cast Co-Cr with inlay casting wax pattern (G1) * Cast Co-Cr using 3D printed resin pattern (G2) * Laser sintered Co-Cr with direct metal laser sintering (G3)	10	-Marginal gap width measurement (pressure indicating paste) -Internal gap width measurement (pressure indicating paste)	The mean vertical marginal gap of 45.36 µm for cast copings in (G1), 27.22 µm for cast copings in (G2) and 10.52 µm for copings obtained using DMLS technique (G3). The mean internal gap measurements of 39.97 µm for cast copings in (G1), 36.15 µm for cast copings in (G2) and 41.27 µm for copings obtained using DMLS technique (G3). Statistically significant difference is present between G1 and G2.
Harish et al 2014[15]	Crowns	* Cast Co-Cr using milled wax lost wax method * Laser sintered Co-Cr	10	Internal and marginal gap width (cement film) measurement	The mean internal and marginal gaps of Laser sintered metal copings are 107.6 and 102.15 µm respectively. The mean internal and marginal gaps for the conventional cast metal coping are 187.09 and 176.5 µm respectively. The p value < 0.001 was considered statistically significant.
Kim et al 2014[16]	Crowns	* Cast Co-Cr conventional lost wax method (LWC) * Milled Co–Cr using soft metal blocks (SMB) * Laser sintered Co-Cr with selective laser sintering (SLS)	10	Internal and marginal gaps width measurement (3D replica technique)	The SMB group exhibited the smallest mean gap, of 32.6 um; the mean gap of the SLS group was 47.3 µm; and that of the LWC group was 64.1 µm. Statistically significant differences were found among the groups ($P < .001$).

Table (1) : Descriptive summary and outcome for the included studies.

Author and year	Type of restoration	Groups	Specimens per group	Testing method(s)	Outcome
Sundar et al 2014[4]	Crowns	* Laser sintered Co-Cr with metal laser sintering (MLS) * Cast Ni-Cr conventional lost wax method (LW) *Each group is divided into 2 subgroups: -Before porcelain application -After porcelain application	20	-Marginal gap measurement. -Microleakage assessment after cementation.	The mean marginal fit of copings before and after ceramic addition in Group B (MLS) was better than the copings in Group A (LW) and was statistically significant ($P < 0.05$). The influence of ceramic firing had a significant ($P < 0.05$) increase in mean marginal gap in Group A (LW) but not in Group B (MLS). And the difference in mean microleakage between the groups was not statistically significant.
Xu et al 2014[18]	Crowns	* Laser sintered Co-Cr with direct metal laser sintering * Cast Co-Cr conventional lost wax method	18	Marginal gap width measurement (light body silicone replica technique)	The mean marginal gap width for the SLM fabricated crown group was 102.86 µm and for the cast crown group was 170.19 µm. The marginal gap widths differed significantly between the 2 groups.
Nesse et al 2015[19]	3-unit FPDs	* Cast Co-Cr conventional lost wax method * Milled Co–Cr * Laser sintered Co-Cr with selective laser melting (SLM)	10	-Internal gap width measurement (silicone replica technique) -The marginal fit evaluation with direct-sight technique (90-degree angle on the tooth surface x4.6 magnification)	Statistically significant differences were found in internal fit ($P < .001$). The mean measurement point within each group showed that the milled group had the best internal fit (95 µm) followed by the cast (116 µm) and SLM groups (156 µm). Statistically significant differences were also found in marginal fit among the groups.
Pompa et al 2015[8]	Crowns and 4-unit FPDs	* Cast Ni-Cr conventional lost wax method * Milled Y-TZP * Laser sintered Co-Cr with selective laser melting (SLM)	10 10	Internal and marginal gap width (cement film) measurement	The mean marginal discrepancy was 47.56 µm for the Ni-Cr alloy, 55.6 µm for YTZP, and 43.92 µm for the Co-Cr alloy. The mean internal gap was 54.11 µm for the Ni-Cr alloy, 74.73 µm for Y-TZP, and 58.76 µm for the Co-Cr alloy. Statistically significant differences ($P< 0.05$) were found in marginal and internal adaptations among the groups.

Author and year	Type of restoration	Groups	Specimens per group	Testing method(s)	Outcome
Zeng et al 2015[20]	Crowns	* Cast Co-Cr conventional lost wax method (CLW) * Laser sintered Co-Cr with selective laser melting (SLM)	15	Marginal gap width measurement (light body silicone replica technique) after the first, third, fifth, and seventh firing cycle	The mean marginal gap width values for SLM fabricated copings were 36 µm, 37 µm, 38 µm, and 38 µm after the first, third, fifth, and seventh firings, while the mean marginal gap width values for cast copings were 67 µm, 71 µm, 72 µm, and 73 µm at the same firing periods. A statistically significant difference was noted of the marginal gap width values of the 2 groups at all firing periods (P <. 05). The marginal gap width values of SLM copings were almost half that of the cast copings
Gunsoy and Ulosoy 2016[17]	Crowns	* Cast Co-Cr conventional lost wax method (CLW) * Cast Co-Cr using milled wax lost wax method (MWLW) * Milled Co–Cr (MCo–Cr) * Laser sintered Co-Cr with direct metal laser sintering (DLMS)	32 (16 molar and 16 premolar)	Internal and marginal gap width (cement film) measurement	Best fit according to all measurements was in DLMS both in premolar (65.84) and molar (58.38) models in µm. A significant difference was found between DLMS and the rest of fabrication techniques (P < 0.05). No significant difference was found between MCo-CR and MWLW in all fabrication techniques both in premolar and molar models (P > 0.05).
Kocaağaoğlu et al 2016[21]	Crowns	* Cast Co-Cr conventional lost wax method (C) * Milled Co–Cr using soft metal blocks (SM) * Milled Co–Cr using hard metal blocks (HM) * Laser sintered Co-Cr with selective laser sintering (LS) *Each group is divided into 2 subgroups: -Before porcelain application -After porcelain application	10	Marginal, axial, and occlusal gap measurement (silicone replica technique)	With regard to marginal and occlusal discrepancies, significant differences were found among the production techniques (*P*<. 001 and *P*<. 05, respectively). No significant differences in axial discrepancies were found among the groups (*P*>.05). Significant differences were found in the increase of marginal discrepancy after the application of veneering ceramic in the LS group (*P*=. 016). However, no significant differences in marginal discrepancy were found whether veneering ceramic was applied to copings before or after in the other groups (*P*>.05).

Author and year	Type of restoration	Groups	Specimens per group	Testing method(s)	Outcome
Kim et al 2017[2]	Crowns	* Cast Co-Cr using milled castable pattern resin wax method * Milled Co–Cr * Laser sintered Co-Cr with direct metal laser sintering (DMLS)	12	-Light body silicone weighting -Two dimensional vertical marginal gap width measurement - Internal gap width (cement film) measurement	The weight of the silicone material ranged from 0.005 g to 0.009 g. The lowest silicone weights were observed in the casting group. There were significant differences in the mean weight between the casting and the CAD/CAM milled groups. The mean two-dimensional vertical marginal gap. The laser sintered copings demonstrated the highest value, while the casting copings significantly exhibited the lowest vertical marginal gap ($p < 0.003$). The mean internal gap value was 65.9 µm in the casting group, 74.3 µm in the milled group, and 90.1 µm in the laser sintered group. The laser sintered group exhibited the highest average internal gap, which was significantly different to the casting and milled groups ($p < 0.0001$).
Sharma et al 2017[22]	Crowns	*Laser sintered Co-Cr with direct metal laser sintering (DMLS) * Cast Co-Cr conventional lost wax method (LW)	20	Marginal fit evaluated directly under the stereomicroscope	The mean marginal gap of DMLS group was 27.9 and LW group was 40.4 µm. Highly significant difference ($P>.05$) between the marginal mean of the DMLS group compared to LW group. The DMLS copings demonstrated superior marginal fit.
Kim et al 2018[1]	Crowns	* Cast Co-Cr conventional lost wax method (LW) * Cast Co-Cr using milled wax lost wax method (WB) * Milled Co–Cr using soft metal blocks (SMB) * Cast Co-Cr using printed wax lost wax method (µ-SLA) * Laser sintered Co-Cr with selective laser melting (SLM)	15	Marginal, axial and occlusal gap measurement (silicone replica technique)	The mean values of the marginal, axial and occlusal gaps were 91.8, 83.4, and 163 µm in the LW group; 94.2, 77.5, and 122 µm in the WB group; 60.0, 79.4, and 90.8 µm in the SMB group; 154, 72.4, and 258 µm in the m-SLA group; and 239, 73.6, and 384 µm in the SLM group, respectively. The differences in the marginal and occlusal gaps between the 5 groups were statistically significant ($P <. 05$).

DISCUSSION

Accurate marginal and internal fit is considered one of the major criteria for clinical success of fixed restorations. Marginal inaccuracies causing plaque retention can cause marginal gingival inflammation, gingival recession and formation of secondary caries below the margins of the crown[23] causing failure of restorations[24]. Thus, irrespective of any crown fabrication techniques, the marginal and internal fit of the coping is important for the success of the restoration.[15] Before making any attempt to assess such parameters, the acceptable gap dimensions should be known, however, there is no consensus on the clinically acceptable limits of marginal and internal gaps. According to American Dental Association (ADA) Specification No. 8, a gap width ranging between 25 to 40 µm has been suggested as a clinical goal[20]. Sulaiman et al[25] reported that 100 µm is an acceptable gap for clinical use. McLean and von Fraunhofer[26] on the other hand have suggested that 120 µm should be the limit for clinical use. Moldovan et al[27] reported that a gap of 200–300 µm is also acceptable. However, several researches consider the value of 120 µm proposed by McLean and von Fraunhofer to be the most suitable limit for clinical use.

There was a significant variation between the values obtained by the included studies even for the same system. These variations may be due to difference in fabrication process, difference in scanning technique or even difference in study designs: the shape of the study casts, the types of abutment teeth, and the measurement methods. Because of such variability, it was impossible to rank the available systems in terms of accuracy or to formulate a proper meta-analysis. However, almost all the measurements were well within the clinically acceptable range suggested by McLean and von Fraunhofer. There was an agreement between the studies that the used systems have the ability to yield restorations with a clinically acceptable fit.

Laser sintering versus lost wax

Nine studies found that laser sintered metal copings had better marginal and internal fit than the casted metal copings while six studies found the opposite. Casting is highly technique-sensitive, requiring qualified technicians, control of the wax pattern fabrication and investing procedure, and careful attention during the casting process. Many procedures are required to execute this process, which increases the possibility of mistakes affecting the accuracy and fit of copings made. According to Harish et al[15], fit accuracy can be compromised by shrinkage and stress relaxation of the inlay casting wax, high setting expansion of investment and high coefficient of thermal expansion of the molten alloy. Also the induction coil heating used melts alloy at higher temperature than its melting range, which may cause the alloy to lose its low melting point compositional elements making it more viscous and affecting its flow.

On the other hand, Laser Sintering of metal copings may avoid the distortions related to casting procedures. The CAD process of producing copings by laser sintering technique using automated scanning process and powerful CAD software offers many advantages such as complete control over coping thickness and design, margin placement and cement space maintenance as well as elimination of casting procedures.[14] Moreover, rapid solidification of cobalt chrome powder, which occurs in small sections, minimizes the chance of shrinkage of the alloy.[15]Also the composition of the alloy used may affect the final result. Bashkaran et al[14] stated that the composition of Co–Cr alloy used for laser sintering has lower molybdenum content compared to Co–Cr alloy used for conventional casting. Laser sintering of alloy is facilitated by the absence of such refractory metals that have higher melting range than cobalt and chromium. However, there are three main factors that could affect the fit accuracy of laser sintered metal coping: the precision of the scanner that reads the abutments, how the software can transform the scanning data into a 3D model in the computer, and the precision of the machine that will CAM the objects from the CAD data.[10,22]

Bashkaran et al[14] and Pompa et al[8] found mixed results in their studies. Marginal fit was better in the laser sintered groups while internal fit was better in the lost wax groups. According to Bashkaran, this could be because while scanning the master die and constructing three dimensional coping shell model image, the margin determination was done under manual adjustment while the external surface scanning of the master die was determined by the non uniform offsetting and shelling algorithm in the scanning system software which lead to those variable results.

Laser sintering versus milling

Eight of the selected studies compared laser sintering with CAD/CAM milling showing mixed results. Ortorp et al[11] found that laser sintered frameworks had significantly better marginal fit than milled framework. This was in agreement with Gunsoy and Ulosoy[17] and Pompa et al[8]; And in disagreement with Kim et al (2014)[16] and Kim et al (2018)[1]. This variability in results can be explained by the two possible factors related to the fit of restorations produced by CAD software: the skill of the technician using the software and the accuracy of the scanning process. According to Ortorp et al [11] and Kim et al[2], possible sources of error of the milling technique include the wear of milling instruments when milling such a hard material as Co–Cr and a change in the radius of the instruments during the milling procedure, which can reduce the milling precision. A change of the milling instruments at regular intervals is highly recommended in order to control this factor and reduce the risk of using burs with decreased diameters, in case the milling machine lacks the capacity to fully compensate for this phenomenon. Moreover, Vibrations during the milling process and resistance of the milling axis during preparation could also affect the accuracy of the milling procedure.

Effect of methodology

Several methods have been used to measure the fit accuracy of dental restorations in the selected articles. Among these methods, the Internal microscopic examination after sectioning and the silicone replica approach were used the most. In the Former approach, the specimen is applied to the abutment or model, fixed and cut, and the cross-section is observed using a digital microscope or by scanning electron microscopy. Measurements cannot be made from various points with these methods, and the biggest drawback is that the specimens and models are destroyed. In the silicone replica approach, the gap between the specimen and the abutment or the model is replicated by using light body silicone, and the silicone replica is cut so that the cross-section can be observed with a digital microscope. Although this technique is non-destructive, measurements cannot be made from various points[12]. Moreover, precise analysis is not possible since both these methods use 2D measurements and cannot meet the requirement proposed by Groten et al[28] of measuring the gap at a minimum of 50 points while evaluating the fit.

Two of the selected articles[12,16] used a new measurement method to overcome the limitations of these two earlier methods. These studies measured the gap 3-dimensionally and evaluated the fit by using a computer. This method overcomes the disadvantages of the two earlier methods because it is nondestructive, facilitates easy measurement; and permits measurement in the oral cavity in case of clinical study[16]. The accuracy and reliability afforded by 3-dimensionally analyzing gaps with a computer have been reported by previous studies.[29]. When using this method, meeting the requirement of measuring more than 50 points is possible for evaluating the fit of a single tooth. The limitation of this method is that the marginal discrepancy cannot be measured because the margin is not a face but a line, and accurate point cloud data are difficult to obtain from the digital replica; therefore it's more suitable to evaluate the internal rather than the marginal fit.[16]

CONCLUSIONS

Laser sintered metal copings have a good marginal and internal fit within the clinically acceptable range suggested in the literature. While further research is necessary to optimize the process parameters and clinical applications, the laser sintering procedure provides an efficient and rapid method for digitally designing and manufacturing complex metal structures for crowns and FPDs.

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