

RESEARCH AND EDUCATION

## Effect of layer thickness on the marginal and internal adaptation of laser-sintered metal frameworks



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The long-term clinical success of fixed prostheses is closely associated with the adaptation of restorations.<sup>1-4</sup> Increased marginal discrepancy initiates a series of events involving cement dissolution, plaque accumulation and bacterial growth, and secondary caries or periodontal disorders.<sup>5-9</sup> Therefore, optimum marginal and internal adaptation should be established between the restoration and prepared tooth structure.<sup>7-9</sup> Although the clinically acceptable marginal discrepancy value varies among authors,<sup>4,5,10-16</sup> most agree that marginal discrepancy values of greater than 120  $\mu\text{m}$  are not clinically acceptable.<sup>4,5,10-13</sup> Moreover, a consensus on the optimum cement film thickness is lacking.<sup>17</sup> Previous studies have provided material-specific recommendations.<sup>18-20</sup> Marginal discrepancy can be evaluated by using different methods,<sup>21</sup> with direct microscopic evaluation, sectioning, and the replica method being the most common.<sup>21,22</sup>

The excellent mechanical properties of metal-ceramic restoration have continued the popularity and success of this treatment option.<sup>23,24</sup> The conventional lost-wax

method has been used for fabricating metal-ceramic restorations for many years<sup>25</sup>; however, this method is associated with some disadvantages such as multiple technique-sensitive steps and the development of casting imperfections.<sup>1</sup> In recent years, computer-aided design and computer-aided manufacturing (CAD-CAM)

### ABSTRACT

**Statement of problem.** Laser sintering is commonly used for fabricating metal-ceramic restorations. The layer thickness of the sintering process may affect restoration adaptation. However, limited information is available regarding its impact.

**Purpose.** The purpose of this in vitro study was to compare the marginal and internal adaptation of laser-sintered cobalt-chromium single crown frameworks sintered with layer thicknesses of 25 and 50  $\mu\text{m}$ .

**Material and methods.** Thirty resin dies that represented prepared single molar abutment teeth were prepared by using a 3-dimensional printer and were divided into 3 groups ( $n=10$ ) according to the method used for fabricating metal frameworks: group C, metal frameworks fabricated by using the lost-wax method (control); group L25, metal frameworks fabricated by using direct metal laser melting with a layer thickness of 25  $\mu\text{m}$ ; and group L50, metal frameworks fabricated by using direct metal laser melting with a layer thickness of 50  $\mu\text{m}$ . After fabricating the metal frameworks, 15 vertical marginal discrepancy measurements were made in each axial region (mesial, distal, buccal, and lingual) using a stereomicroscope. Next, all the specimens were sectioned from the midline, and 5 internal discrepancy measurements were made in each internal region (inner marginal, axial, and occlusal). The data were analyzed statistically by using 1-way ANOVA, the Tukey honestly significant difference, and Tamhane T2 tests ( $\alpha=.05$ ).

**Results.** The highest marginal and internal discrepancy values were obtained for metal frameworks in group C, and these values were significantly different ( $P<.001$ ) from those obtained for metal frameworks in the other 2 groups. No significant difference was observed in the marginal and internal discrepancy values of metal frameworks in groups L25 and L50.

**Conclusions.** These results indicate that layer thickness does not affect the adaptation of laser-sintered metal frameworks, yet both sintering parameters yielded significantly lower mean marginal discrepancy values than the cast group. (J Prosthet Dent 2019;121:922-8)

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## Clinical Implications

Processing parameters of laser sintering should be clearly defined before the fabrication stage. Reduction of the layer thickness of the sintering process may not significantly improve the marginal and internal adaptation of metal frameworks.

systems have been increasingly used because of their high accuracy and standard quality.<sup>26,27</sup> The CAD-CAM systems used in dentistry at present can be classified into subtractive manufacturing systems (such as milling) and additive manufacturing systems (such as laser sintering).<sup>28,29</sup>

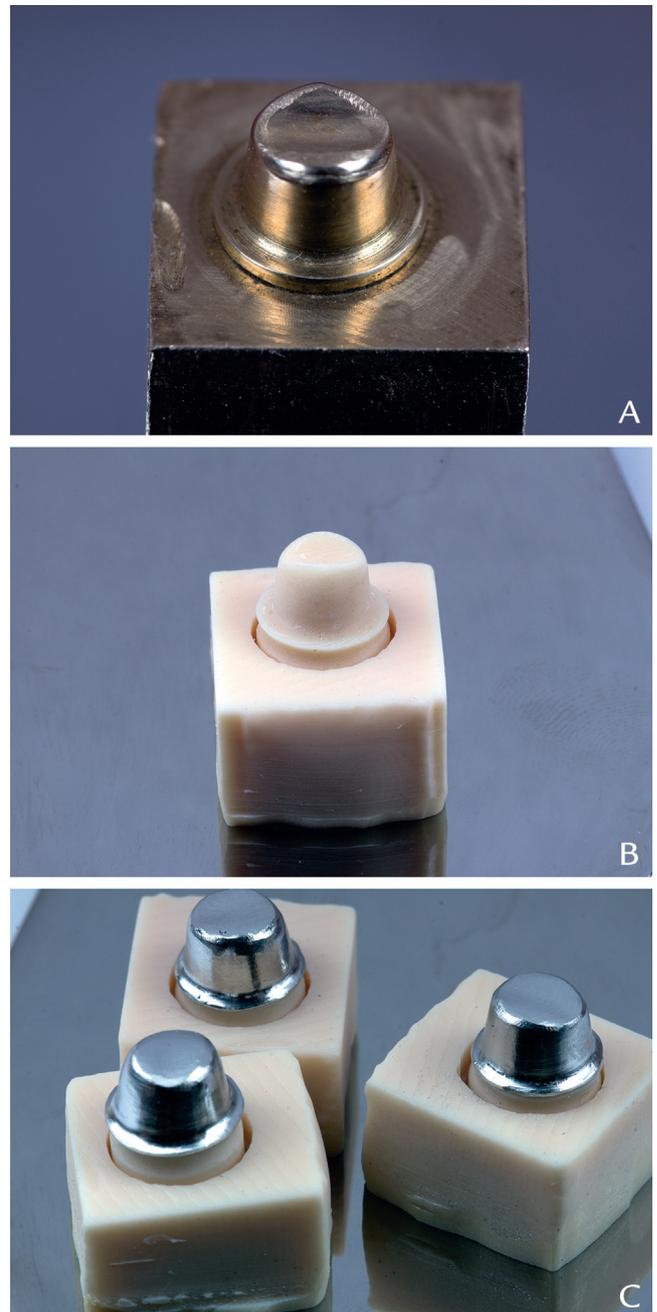
Laser sintering systems have been increasingly used for fabricating metal-based prostheses.<sup>30</sup> These systems transform CAD data into 3-dimensional (3D) complex structures by using a laser source that consolidates powdered material layer by layer.<sup>31-33</sup> Metal powders can be sintered by using direct metal laser sintering (DMLS), which involves the partial melting of metal powders or direct metal laser melting (DMLM), which involves the complete melting of metal powders.<sup>29,32</sup> The complete melting of metal powders produces a structure with high density (approximately 99.8%).<sup>29,32</sup> Several DMLS and DMLM machines for dental applications are available, including EOSINT M270; EOS GmbH (DMLS), M1; Concept Laser GmbH (DMLM), and MYSINT 100; Sisma SpA (DMLM).<sup>29,30</sup>

In the laser sintering process, the thickness of the sintering layer plays a significant role in determining the mechanical features of the metal structures produced.<sup>34,35</sup> However, this parameter is mostly determined by the dental laboratories. Reducing the layer thickness enhances mechanical properties, whereas increasing it beyond a certain point causes major problems such as impaired surface finish, reduced accuracy, and decreased mechanical properties.<sup>29,36-41</sup> The sintering layer thickness can be set within a range of 20 to 100  $\mu\text{m}$ ; however, this may be limited by the capacity of laser sintering machines.<sup>29,35,42</sup>

The present in vitro study compared the marginal and internal adaptation of laser-sintered cobalt-chromium (Co-Cr) frameworks with layer thicknesses of 25 and 50  $\mu\text{m}$ . The study hypothesis was that metal frameworks sintered with a layer thickness of 25  $\mu\text{m}$  showed improved marginal and internal adaptation.

## MATERIAL AND METHODS

The sample size was determined by performing a power analysis (G\*Power 3.1.9.3.), and the effect size was found to be 8.98 at 99% power.



**Figure 1.** Fabrication of master models and frameworks. A, Bronze metal die model. B, Resin die model. C, Metal frameworks.

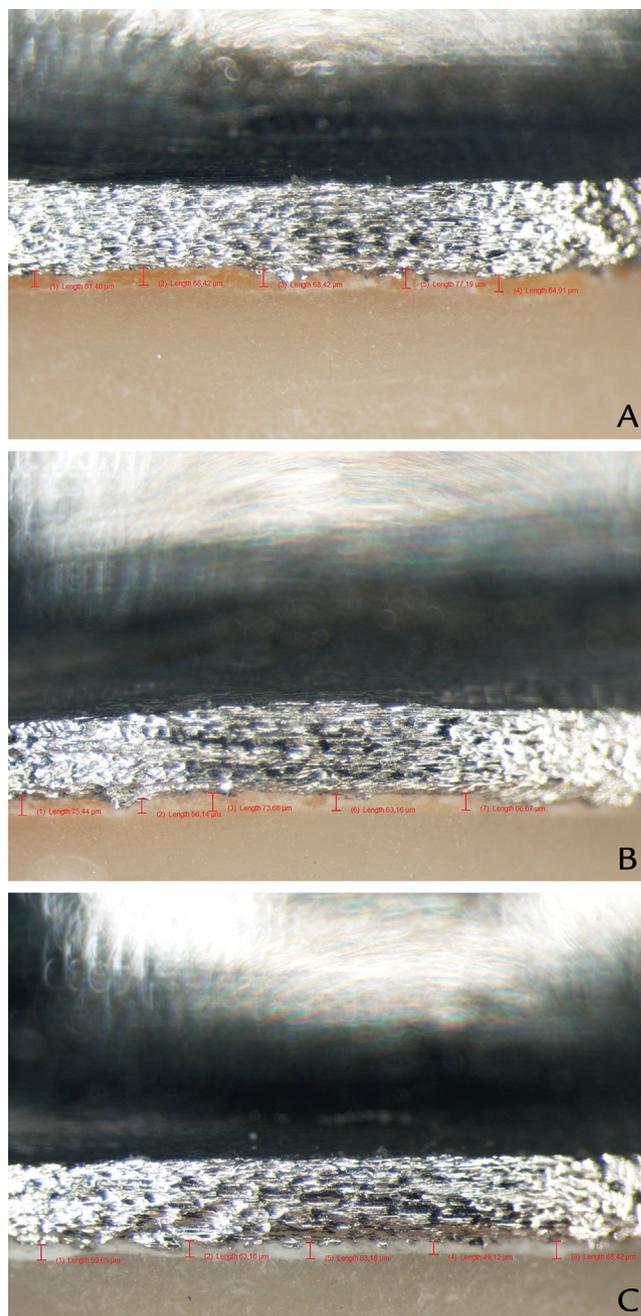
A master bronze metal die (Fig. 1) representing a prepared mandibular first molar tooth (rounded shoulder finish line with 1.2-mm width and 6-degree axial convergence) was fabricated by using a computer numerically controlled machine (Deckel Maho DMC 1035; DMG Mori). The master die was scanned with a 3D desktop scanner (AutoScan-DS200+; Shining 3D Tech). In all, 30 resin die (Fig. 1) models (E-Model; EnvisionTEC GmbH) were fabricated by using a 3D printer (VIDA; EnvisionTEC GmbH). The resin die models were divided

into 3 groups (n=10) according to the method used for fabricating metal frameworks (Fig. 1): group C, metal frameworks fabricated by using the lost-wax method (control); group L25, metal frameworks fabricated by using DMLM with a layer thickness of 25  $\mu\text{m}$ ; and group L50, metal frameworks fabricated by using DMLM with a layer thickness of 50  $\mu\text{m}$ .

The resin die models in group C were scanned by using the 3D scanner. The 3D design of the metal frameworks (Exocad; Exocad GmbH) was completed by setting the film thickness at 30  $\mu\text{m}$ <sup>18</sup> and the framework thickness at 0.5 mm. Wax patterns (Press-E-Cast; EnvisionTEC GmbH) of the metal frameworks were fabricated by using the 3D printer and were invested with phosphate-bonded investment (Maruvest Speed; Megadental GmbH). The casting rings were completely filled by the vacuum-mixed investment mixture and allowed to set for 20 minutes. After wax elimination, they were cast in an induction-heated centrifugal casting machine (INF-2010; Mikrotek Dental) from a Co-Cr dental alloy (Starbond CoS; S&S Scheftner GmbH). After cooling, the cast specimens were deinvested and airborne-particle abraded by using 110- $\mu\text{m}$  aluminum oxide ( $\text{Al}_2\text{O}_3$ ) particles (Cobra; Renfert GmbH) at a pressure of 400 kPa.

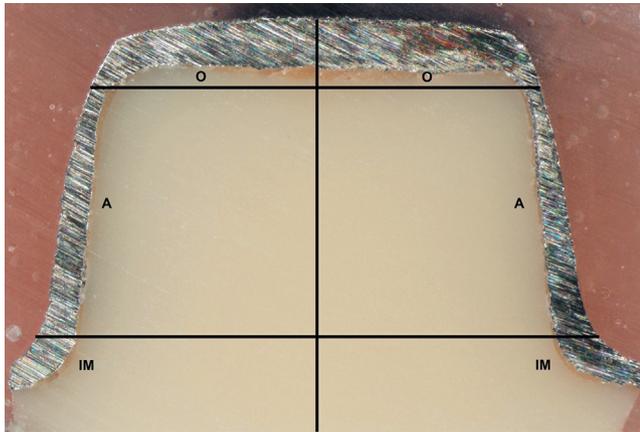
In groups L25 and L50, the resin dies were scanned by using the 3D scanner, and the metal frameworks were designed by using the same parameters (film thickness: 30  $\mu\text{m}$ <sup>18</sup> and framework thickness: 0.5 mm). In group L25, the metal frameworks were sintered with a layer thickness of 25  $\mu\text{m}$  from the Co-Cr dental alloy powder (Starbond CoS Powder 30; S&S Scheftner GmbH) by using a DMLM machine (SLM 100; ReaLizer GmbH), and the manufacturing was completed in 5.5 hours. In group L50, the metal frameworks were sintered with a layer thickness of 50  $\mu\text{m}$  from the same Co-Cr alloy powder (particle size range: 5  $\mu\text{m}$  to 30  $\mu\text{m}$ ) and by using the same DMLM machine, and the manufacturing was completed in 2.5 hours. After the sintering process, the laser-sintered metal frameworks were annealed according to the manufacturer's instructions (temperature range: 450°C to 980°C) in a preheating furnace (Magma; Renfert GmbH) for 2.5 hours to relieve thermal stress.

After the fabrication was complete, the adaptation of the metal frameworks was controlled in terms of exposed metal surface by using an addition-polymerizing precision impression material (Panasil initial contact light; Kettenbach GmbH). The metal frameworks were cemented on the resin dies with a self-adhesive resin cement (RelyX U200 Clicker; 3M ESPE) under a standard 150-N load by using a dynamometer stand. Then, 4 points were marked on 4 corners of each abutment tooth in a crosswise manner to separate the mesial (M), distal (D), buccal (B), and lingual (L) sides. Next, 15 vertical marginal discrepancy measurements (from the framework margin to the finish line) were recorded at equal



**Figure 2.** Stereomicroscope view of marginal discrepancy measurements. A, Lost-wax. B, DMLM with 25- $\mu\text{m}$  layer thickness. C, DMLM with 50- $\mu\text{m}$  layer thickness (original magnification  $\times 40$ ). DMLM, direct metal laser melting.

intervals in each axial region by using a stereomicroscope (SZX16; Olympus) at  $\times 40$  magnification (Fig. 2). The stereomicroscope had an integrated digital camera system (DP73; Olympus) synchronized with microimaging analysis software (Stream Basic; Olympus Soft Imaging Solutions GmbH). Measurements were made to an accuracy of 1  $\mu\text{m}$ . An arithmetic mean of 60 measurements was used as the mean vertical marginal discrepancy value



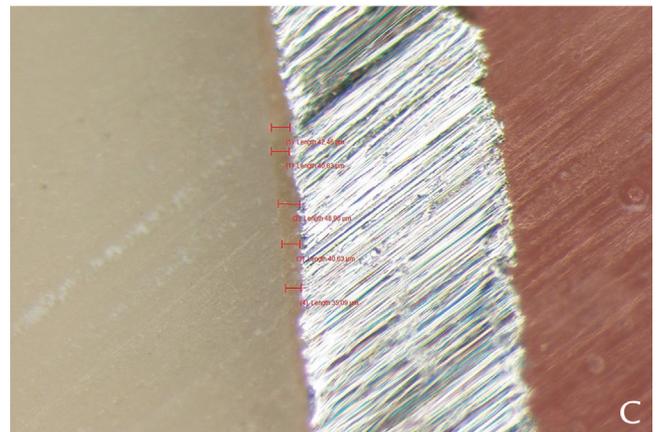
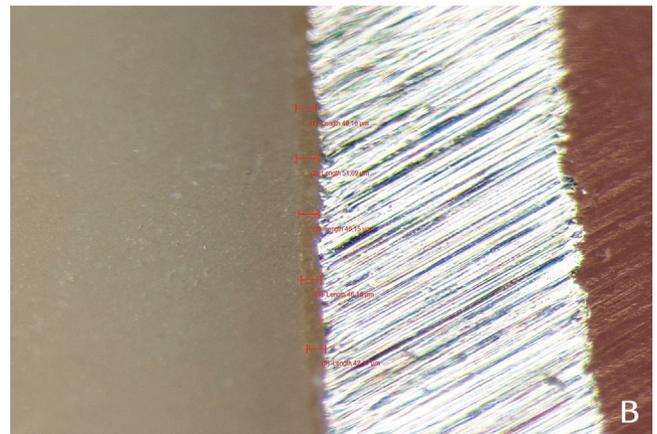
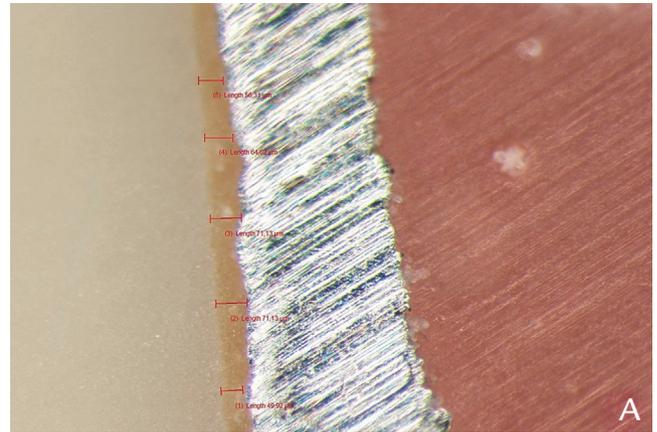
**Figure 3.** Stereomicroscope view of internal measurement regions. A, Axial; IM, Innermarginal; O, Occlusal (original magnification  $\times 10$ ).

of each abutment tooth.<sup>12</sup> The dies were removed from the master models, and the specimens were embedded in acrylic resin (Paladent; Kulzer GmbH) and sectioned centrally in a mesiodistal direction by using a low-speed precision saw (IsoMet 1000; Buehler Ltd).<sup>27</sup> Each half of the specimen was used for evaluating internal discrepancy. Three internal regions were evaluated for each section: inner marginal (IM), axial (A), and occlusal (O) (Fig. 3).<sup>43</sup> Five internal discrepancy measurements were recorded in each region on both the M and D sides by using the stereomicroscope at  $\times 80$  magnification (Fig. 4). An arithmetic mean of 60 measurements was used as the mean internal discrepancy value of each abutment tooth.<sup>44</sup>

In all, 60 marginal and internal discrepancy measurements were recorded for each specimen.<sup>45</sup> Data were analyzed with statistical software (IBM SPSS Statistics, v21.0; IBM Corp). Differences among the groups were evaluated by using 1-way ANOVA, the Tukey honestly significant difference for marginal discrepancy (when variances were homogeneous), and Tamhane T2 tests for internal discrepancy (unequal variances) ( $\alpha=.05$ ).

## RESULTS

Results of the 1-way ANOVA test showed a significant difference in marginal discrepancy ( $df=2$ ,  $F=18$ ,  $P<.001$ ) and internal discrepancy ( $df=2$ ,  $F=84$ ,  $P<.001$ ) values between the control and DMLM groups. However, the results of multiple comparisons (Tables 1 and 2) did not show any significant difference in marginal discrepancy ( $P=.900$ ) and internal discrepancy ( $P=.384$ ) values between groups L25 and L50. Mean, minimum, and maximum marginal and internal discrepancy values and standard deviations are shown in Tables 1 and 2. The control group showed higher mean marginal discrepancy ( $77 \pm 10 \mu\text{m}$ ) and internal discrepancy ( $73 \pm 9 \mu\text{m}$ ) values than both the DMLM groups.



**Figure 4.** Stereomicroscope view of internal discrepancy measurements. A, Lost-wax. B, DMLM with 25- $\mu\text{m}$  layer thickness. C, DMLM with 50- $\mu\text{m}$  layer thickness (original magnification  $\times 80$ ). DMLM, direct metal laser melting.

## DISCUSSION

The results of this in vitro study indicate that the layer thickness of sintering has no effect on the marginal and internal adaptation of metal frameworks. Reducing the layer thickness increases the adaptation of metal frameworks. Therefore, the study hypothesis that metal frameworks sintered with a layer thickness of 25  $\mu\text{m}$

**Table 1.** Marginal discrepancy values ( $\mu\text{m}$ )

(I) Group	(J) Group	P	95% Confidence Interval		Mean ( $\mu\text{m}$ )	$\pm\text{SD}$	Min. ( $\mu\text{m}$ )	Max. ( $\mu\text{m}$ )
			Lower Bound	Upper Bound				
C	L25	<.001	9	26	77	10	67	100
	L50	<.001	10	28				
L25	C	<.001	-26	-9	59 <sup>a</sup>	6	49	70
	L50	.900	-7	10				
L50	C	<.001	-28	-10	58 <sup>a</sup>	8	46	73
	L25	.900	-10	7				

C, lost wax; L25, laser sintering with 25- $\mu\text{m}$  layer thickness; L50, laser sintering with 50- $\mu\text{m}$  layer thickness; SD, standard deviation. <sup>a</sup>Mean difference significant at  $P<.05$  level.

would improve marginal and internal adaptation was rejected.

Marginal discrepancy values of greater than 120  $\mu\text{m}$  are not clinically acceptable.<sup>4,5,10-13</sup> In the present study, the mean marginal discrepancy value was less than 120  $\mu\text{m}$  for all the metal frameworks. Although the laser-sintered specimens showed lower marginal discrepancy values than the control specimens, this difference may not be clinically significant. Furthermore, marginal discrepancy values were only measured for the metal frameworks, and subsequent porcelain firing may affect marginal discrepancy.<sup>21</sup> Therefore, greater accuracy should be achieved while fabricating metal frameworks.

Resin-based cements are associated with advantages such as excellent bonding properties, insolubility in oral fluids, and considerable strength under compressive load.<sup>18</sup> In the present study, the metal frameworks were sectioned to evaluate the internal discrepancy, and sectioning was conducted under water irrigation and a standard 2.9-N load. All the metal frameworks were cemented with a self-adhesive resin cement. Wu and Wilson<sup>18</sup> evaluated the optimal thickness of a cement film for resin-based cements and reported that at least a 30- $\mu\text{m}$  luting space is required. Therefore, the film thickness of all the specimens was set at 30  $\mu\text{m}$  in the present study. The International Organization for Standardization standard 4049:2009 recommends that the film thickness of polymer-based luting materials should not be greater than 50  $\mu\text{m}$ .<sup>46</sup> In the present study, the mean internal discrepancy value for both the DMLM groups was less than 50  $\mu\text{m}$ , indicating that both the sintering parameters were sufficient in terms of internal adaptation.

DMLM is based on the principle of powder-bed fusion. The layer thickness of sintering is defined by the amount of powder distributed to the melt surface in these systems.<sup>41</sup> Previous laser sintering machines could work with a layer thickness of 50 to 80  $\mu\text{m}$ . Laser sintering systems, which work with a layer thickness of approximately 20  $\mu\text{m}$ , have been introduced for dental applications.<sup>35</sup> Laser penetration depth is an important factor in this evolution. A thicker layer of powder is more difficult

**Table 2.** Internal discrepancy values ( $\mu\text{m}$ )

(I) Group	(J) Group	P	95% Confidence Interval		Mean ( $\mu\text{m}$ )	$\pm\text{SD}$	Min. ( $\mu\text{m}$ )	Max. ( $\mu\text{m}$ )
			Lower Bound	Upper Bound				
C	L25	<.001	19	36	73	9	62	93
	L50	<.001	22	38				
L25	C	<.001	-36	-19	46 <sup>a</sup>	4	40	52
	L50	.384	-2	6				
L50	C	<.001	-38	-22	43 <sup>a</sup>	2	40	46
	L25	.384	-6	2				

C, lost wax; L25, laser sintering with 25- $\mu\text{m}$  layer thickness; L50, laser sintering with 50- $\mu\text{m}$  layer thickness; SD, standard deviation. <sup>a</sup>Mean difference significant at  $P<.05$  level.

to completely melt, and unconsolidated parts between the layers may weaken the structure.<sup>47</sup> Therefore, the layer thickness of sintering could affect the quality and mechanical strength of the final product.<sup>34,35</sup> Increasing the sintering layer thickness beyond a certain level decreases process accuracy and impairs surface finish,<sup>29,36,37,39-41</sup> whereas decreasing the layer thickness by up to 20  $\mu\text{m}$  increases process accuracy.<sup>34,35</sup> However, decreasing the layer thickness to less than 20  $\mu\text{m}$  may increase porosity within the structure,<sup>34</sup> and decreasing the layer thickness usually increases the manufacturing time.<sup>41</sup> The powder material is swept onto the build surface by a metal, ceramic, or polymer-coated bar, which is called the rake, in powder-bed fusion systems. The layer thickness dictates the division of a structure into layers, and the smaller layer thickness increases the number of passes of the rake and slows down the deposition rate, hence increases the manufacturing time.<sup>41</sup>

The film thickness and rheological behavior of a cement agent should be considered in dental studies evaluating the adaptation of restorations.<sup>18-20</sup> The present study compared the marginal and internal discrepancy values of metal frameworks with sintering layer thicknesses of 25 and 50  $\mu\text{m}$  and showed no significant difference between the 2 parameters. Although reduced accuracy is associated with increased sintering layer thickness in the engineering literature,<sup>36,37,39-41</sup> hydrostatic pressure and film thickness of a cement agent may provide constant discrepancy values irrespective of the accuracy of the manufacturing system.<sup>18</sup> The present in vitro study did not record marginal and internal discrepancy values before cementation. Therefore, additional studies should be performed to evaluate marginal and internal discrepancy values before and after cementation to obtain more comprehensive results.

Direct microscopy and sectioning are commonly used for evaluating marginal discrepancy.<sup>4,5,15,21</sup> Direct microscopy is a straightforward, fast, and reproducible method but is less accurate. In contrast, sectioning is a challenging method but provides sensitive results.<sup>22</sup> In

the present study, marginal discrepancy was evaluated by performing direct microscopy, and internal discrepancy was evaluated after sectioning. Scanning electron microscopy may increase the accuracy of measurement. However, Groten et al<sup>16</sup> reported no significant difference in marginal discrepancy measurements obtained from light microscopy and scanning electron microscopy. In the present study, marginal discrepancy measurements were obtained by using a stereomicroscope and by considering the number of measurements per specimen.

In studies evaluating marginal discrepancy, the power of the statistical analysis is influenced by the sample size and number of measurements obtained per specimen.<sup>21</sup> The number of measurements per specimen required for obtaining precise results is unclear, and no specific evidence is available regarding the same. However, Groten et al<sup>45</sup> reported that approximately 50 measurements are required to obtain clinically relevant information. Therefore, 60 measurements per specimen were obtained in the present study.

In the present study, only 1 type of laser sintering machine and dental alloy were used for fabricating the metal frameworks. Moreover, only 1-unit metal frameworks were evaluated in the present study. Different results may be obtained by using fixed partial dentures. Moreover, several factors affect the survival of restorations. However, the microstructural and mechanical properties of the metal frameworks were not evaluated in the present study. Therefore, additional studies should be performed to determine the effects of sintering layer thickness on laser-sintered restorations.

## CONCLUSIONS

Based on the findings of this *in vitro* study, the following conclusions were drawn:

1. The layer thickness of sintering did not affect the adaptation of the metal frameworks.
2. The mean marginal discrepancy value was less than 120  $\mu\text{m}$  in all the groups.
3. The mean internal discrepancy value was less than 50  $\mu\text{m}$  in both the DMLM groups.
4. Because no significant difference was observed between the 2 sintering parameters, a sintering layer thickness of 50  $\mu\text{m}$  may be recommended for fabricating thin margins of laser-sintered dental restorations.

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## Noteworthy Abstracts of the Current Literature

### Effects of alumina-blasting pressure on the bonding to super/ultra-translucent zirconia

Aung SSMP, Takagaki T, Lyann SK, Ikeda M, Inokoshi M, Sadr A, Nikaido T, Tagami J  
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**Objectives.** Translucent zirconia has brought the advantages such as less tooth preparation, biological compatibility, high strength, good mechanical properties, and less antagonist wear. This study's aim was to elucidate how clinically relevant surface treatments; alumina-abrasion and priming effect on bond strength of Y-PSZ in three different translucency grades after long-term water storage.

**Material and methods.** Three highly translucent Y-PSZ grades were ground flat with #600-grit SiC paper. Four different surface treatments (untreated, alumina blasting at 0.1 MPa or 0.2 MPa or 0.4 MPa) and two resin cements (PANAVIA V5 and PANAVIA SA CEMENT PLUS AUTOMIX) were tested. The bonded specimens were stored in water for 1 day, 30 days and 150 days and tensile bond strength (TBS) were measured with universal testing machine at a crosshead speed of 2 mm/min (n=10). The surface roughness (Sa) measurement and surface morphology analysis without alumina-blasting pressure (untreated) and with alumina-blasting pressures (0.1 MPa, 0.2 MPa and 0.4 MPa) for three different zirconia grades were evaluated with 3D-Laser Scanning Confocal Microscope.

**Results.** Different alumina-blasting pressures and different storage periods affected the bonding of resin cement to translucent zirconia. The Weibull moduli increased in some groups after 150 days storage. After 1 day and 30 days storage, 0.4 MPa alumina-blasting pressure provided superior bond strength, however, after 150 days, 0.2 MPa gave reliable and stable bond strength.

**Significance.** Alumina-blasting pressure of 0.2 MPa was the most effective for reliable and durable bonding performance to translucent zirconia after long-term water storage.

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