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Internal fit of lithium disilicate and resin nano-ceramic endocrowns with different preparation designs

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A B S T R A C T

Purpose: Investigation of different central cavity designs on internal fit of endocrowns fabricated from two materials.
Materials and methods: Forty maxillary premolars were endodontically treated and divided into 8 groups [n = 5]: LS10, LS6, LD10, LD6, ES10, ES6, ED10 and ED6 ("L" restored with Lava™ Ultimate [resin nano ceramic], "E" restored with IPS e.max® CAD [lithium disilicate], "S" shallow depth [3 mm], "D" extended depth [5 mm], "6"-degree and "10"-degree axial wall divergence). All restorations were fabricated using CEREC CAD/CAM system. Samples were tested for internal fit using CBCT imaging (Next Generation i-CAT scanner) before and after adaptation. Data was tabulated and statistically analyzed.
Results: Lava™ Ultimate showed significant better internal fit compared to IPS e.max® CAD endocrowns both before and after adaptation [$p = 0.007$ and 0.003, respectively]. Samples with 6-degree axial wall divergence showed significant better internal fit compared to those with 10-degree axial wall divergence before adaptation [$p = 0.041$].
Before adaptation, group LS6 showed the best internal fit [403.00 ± 115.30 μm] followed by LD6, LD10, ES6, ES10, ED10, LS10 and ED6. After adaptation, group LS10 showed the best internal fit [394.80 ± 21.17 μm], followed by LS6, LD10, ED6, LD6, ES6, ED10, and ES10.
Conclusion: Resin nano-ceramic endocrowns presented better internal adaptation compared to lithium disilicate endocrowns, regardless of the preparation design.

1. Introduction

Recently, endocrown was introduced for restoring endodontically treated teeth due to the use of minimally invasive preparations, with maximal tissue conservation. The preparation consists of a circular butt-joint margin with a central retention cavity inside the pulp chamber. This restorative approach has been shown to provide adequate function and esthetics, as well as biomechanical integrity of structurally compromised posterior non-vital teeth [1]. Endocrown is a monoblock restoration corresponding to the pulp chamber and morphologically shaped crown [2]. ***Bindl and Mörmann*** [3] suggested that this monoblock foundation utilizes the available surface in the pulp chamber to obtain stability and retention of the restoration through adhesive bonding. Endocrowns can be fabricated by different methods; one of these methods is milling of different available materials. The clinical success of bonded restorations is closely connected to their mechanical properties, efficient bonding, accurate adaptation and reasonable esthetics [4].

The fitting accuracy of a restoration produced using the CAD/CAM technique is influenced by the scanning process, software design, milling process and post-milling dimensional changes [5,6]. Considering the CAM process, the diameter and shape of the milling instrument can limit the machining of internal contours, which in turn affects the post milling accuracy and fit of the restorations [5–7].

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Different methods have been used to evaluate internal gap. Direct evaluation of sectioned tooth-restoration sample under a microscope is the basic technique for internal fit evaluation, but in this technique some data may be lost during sectioning procedure, and limited number of sections can be obtained [8]. Thus, non-destructive techniques were developed for sample preservation for added evaluation. Replica technique is the most widely used non-destructive technique, however it has limited number of 2D sections, the reproducibility of correct sectioning alignment is difficult, in addition, it lacks accuracy due to replica material peeling off the internal surface of the restoration.

Recently, 3-dimensional (3D) digital techniques were developed to produce 3D reconstructed images providing endless number of sections and points for linear measurements in different directions on 3D data sections, in addition, 3D mapping of internal gap can be previewed. 3D reconstructed images can be obtained using optical scanners, for example triple-scan technique [9], or x-rays, as in case of micro-CT and cone beam computed tomography (CBCT) allowing high resolution investigation of the internal gap between tooth preparation and restoration [10,11]. Micro-CT techniques allow 2D and 3D investigation of the internal gap within the range of a few micrometers at multiples sites and directions [10]. Thus, it provides a more realistic perception of the internal gap. However, it is not possible to perform an accurate analysis in cases where insufficient radiographic contrast exists. Therefore, to improve the contrast between the abutment, the restoration and the internal gap, the scanning procedure take place before cementation [12]. Also, micro-CT cannot be used for in vivo studies, due to high radiation dosage, unlike CBCT.

Due to the influence of different preparation design features on restoration serviceability, this study was conducted to test the influence of different preparation design features on restoration internal fit, where the null hypothesis is that different materials and preparation design features do not influence endocrown internal fit.

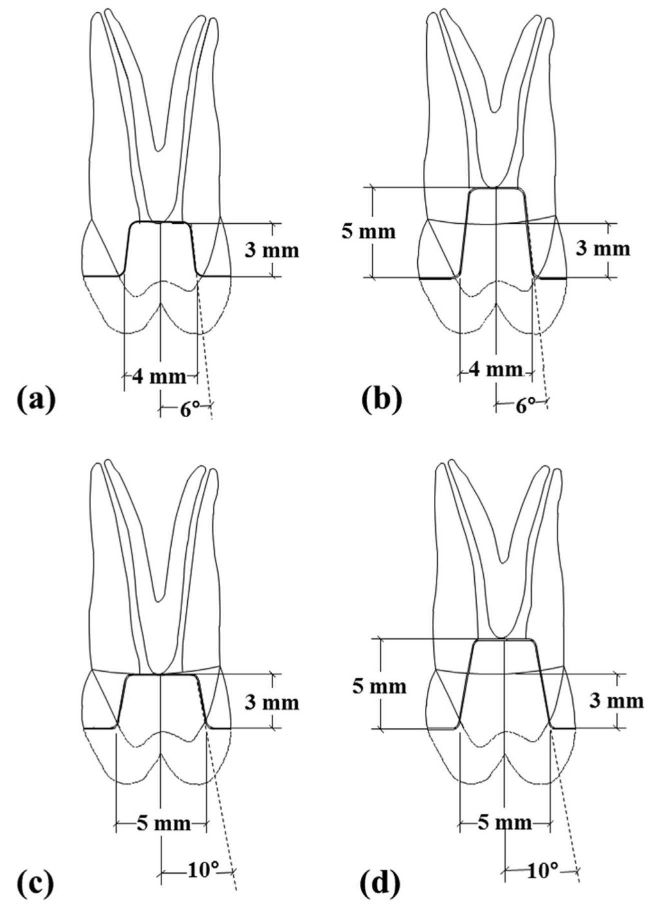

Fig. 1. Schematic drawings of 4 types of tooth preparation designs. Group I (S6) = 6° divergence angle, 3 mm depth. Group II (D6) = 6° divergence angle, 5 mm depth. Group III (S10) = 10° divergence angle, 3 mm depth. Group IV (D10) = 10° divergence angle, 5 mm depth.

2. Materials and methods

Forty human bifurcated maxillary first premolars, indicated for extraction due to periodontal problems or orthodontic treatment, were collected for this study. Teeth selection was performed according to the following criteria: (1) teeth were sound, non-carious and non-cracked, (2) teeth dimensions ranged from 9 to 10 mm bucco-palatally, and 7–8 mm mesio-distally, measured at the level of 3 mm above the cemento-enamel junction (CEJ), and (3) depth of the pulp chamber ranged from 5 to 7 mm measured from the central groove to the pulpal floor using a periodontal probe through the access cavity. Selected teeth were divided into 8 groups [n = 5]: LS10, LS6, LD10, LD6, ES10, ES6, ED10 and ED6 ("L" restored with Lava™ Ultimate[1] [resin nano-ceramic], "E" restored with IPS e.max® CAD[2] [lithium disilicate], "S" shallow depth [3 mm], "D" extended depth [5 mm], "6" degree and "10" degree axial wall divergence) (Fig. 1). A single operator performed endodontic treatment of all samples. Rotary Protaper® S1, S2, and F1 files[3] were used to prepare the canals to working length, respectively, in conjunction with X-Smart®.[3] Sodium hypochlorite (5%) was used for irrigation between different files. Obturation was accomplished using lateral condensation technique with Protaper® Gutta-percha points[3] size F1 and resin-based sealer (AD Seal®[4]).

A circular mold fabrication was suggested to allow positioning of all samples at equal distances from the center of rotation of the CBCT scanner; thus, providing a standardized image quality. Two plastic cylinders (3 cm height) with two different diameters (7 cm and 10 cm) were used as a mold for the acrylic resin base. These diameters were especially selected to allow mounting of teeth on the circumference of 8 cm circle representing the most accurately imaged layer by the CBCT scanner (iCAT Next Generation[5]) to provide mounting block of 15 mm bucco-lingual width and 25 mm occluso-apical height. To facilitate mounting of each sample separately, a putty rubber based condensation silicon (Ormadent putty C-silicone[6]) replica was prepared. Then, it was divided into ten even sectors to mount ten consecutive samples.

Mounting was performed with the aid of Amer's paralleling device. A high-speed contra-angled hand piece was attached to the paralleling device following Amer's methodology [13], so that a cylindrical stone (SR-13[7]), attached in the hand piece, was perpendicular to the fixed platform of the device, to allow mounting of teeth with the tooth long axis perpendicular to the floor at zero position. For mounting of a tooth, only one of the putty sectors was removed from the mold while the rest of the circular putty replicas were in their place between the two plastic cylinders.

[1] 3M ESPE, St Paul, MN, USA.
[2] Ivoclar Vivadent, Liechtenstein.
[3] Dentsply Maillefer, Switzerland.
[4] META, Korea.
[5] Imaging Sciences International, Inc., Hatfield, USA.
[6] Major, Italy.
[7] Mani Inc, Tochigi-Ken, Japan.

The space was lined with a thick layer of petroleum jelly (Vaseline[8]) to act as a separating medium. Then, auto-cured acrylic resin (Acrostone[9]) was mixed and poured to fill the space. Then, the roots of each sample were embedded to a level of 2 mm apical to the most apical buccal point of the CEJ, simulating the normal biological width.

All samples were decoronated perpendicular to their long axis, at a level 3 mm occlusal to the most occlusal point of the proximal CEJ, using a diamond wheel rotary cutting instrument (WR-13[7]) under copious water coolant. In this study, a mesio-occluso-distal (MOD) deep onlay cavity was prepared in all samples. For central cavity preparation with different divergence angles, an adjustable mobile base [13] was used to prepare both 6-degree and 10-degree divergence. The samples were prepared using a cylindrical diamond stone with rounded end (SR-13[7]) held perpendicular to the floor by the paralleling device while the sample was positioned on the inclined mobile base.

A single operator performed all optical impressions using Omnicam camera[10] in the intraoral camera mode. Restoration design procedures were accomplished using CEREC AC with software package 4.23 for all samples, using the "*Biogeneric Individual*" mode. Restoration design was accomplished with cement space = 80 μm, and instrument geometry and undercuts removal were considered. CEREC InLab MCXL[10] milling system was used for milling all the restorations, in both materials. After milling was completed, the remaining part of the sprue was finished using a finishing diamond wheel (DCB-Schleifer[11]). IPS e.max® CAD[2] endocrowns were distributed on IPS e.max® CAD crystallization tray[2] for crystallization. Crystallization was done using Programat® (P300)[2] following the manufacturer instructions.

The prepared sample blocks were arranged on the bite plate of CBCT machine in a circular pattern. Acquisition of CBCT images was accomplished using i-CAT Next Generation[5] scanner using same parameters for all samples. Invivo 5 Dental software[12] (version 5.1) was utilized for linear measurements. All sections and points represented in Fig. 2 and Fig. 3, respectively, were used for linear measurements. Internal gap assessment was done before and after fitting surface adjustments. The first group CBCT scans (Pre-seating scans) were done immediately after milling, without any adjustments in the intaglio surface. The second group of CBCT scans (Post-seating scans) was done with the same parameters of Pre-seating scans, after adjusting the intaglio surface of the endocrowns.

To identify areas requiring adjustment, a water-soluble pressure indicating paint (PICO-MARK®[13]) was used to identify pressure areas, which were removed by a finishing green diamond point (DCB-Schleifer[11]) until complete seating was achieved. The target of adaptation was defined as the point when clinically acceptable marginal adaptation was achieved, or no more improvement of marginal gap was detectable for two investigators using sharp explorer at different marginal points. Samples were then cleansed with alcohol moistened cotton pellet followed by post-seating scan.

Data was tabulated and statistically analyzed using IBM[14] SPSS[15] version 20.0. Statistical analysis of the results was performed using 3-way analysis of variance (ANOVA) to evaluate: (1) The influence of central cavity depth on the adaptation/internal gap of the endocrown restoration to the prepared dentinal wall. (2) The influence of central wall divergence on the adaptation/internal gap of the endocrown restoration to the prepared dentinal wall. (3) The influence of material type on the adaptation/internal gap of the endocrown restoration to the prepared dentinal wall. (4) The influence of various interactions between them on the adaptation/internal gap of the endocrown restoration to the prepared dentinal wall. Statistical significance was set at ≤ 0.05.

3. Results

3-way ANOVA test revealed significant better internal fit in case of Lava™ Ultimate compared to IPS e.max® CAD endocrowns both before and after adaptation [$p = 0.007$ and 0.003, respectively]. Samples with 6-degree axial wall divergence showed significant better internal fit compared to those with 10-degree axial wall divergence before adaptation [$p = 0.041$] (Table 1).

Resin nano-ceramic endocrown restorations displayed significantly smaller average internal gap compared to lithium disilicate endocrown restorations both before adaptation (494.50 ± 120.46 μm and 600.80 ± 131.99 μm, respectively) and after adaptation (422.55 ± 44.72 μm and 476.00 ± 56.91 μm, respectively). Before adaptation, the average internal gap was greater in teeth with a 6-degree divergence angle (508.60 ± 154.80 μm) than in teeth with a 10-degree divergence angle (586.70 ± 103.48 μm), which was reversed after adaptation, where the average internal gap in teeth with 10-degree divergence angle was 448.15 ± 54.95 μm, while that of 6-degree divergence angle was 450.40 ± 61.00 μm. There was no significant difference in the internal gap with different central cavity depths. Internal fit before adaptation was greatest in groups LS10 and ED6 (634.6 ± 47.7 μm and 634.2 ± 151 μm, respectively), and smallest in group LS6 (403.0 ± 115.3 μm). While internal fit after adaptation was greatest in group ED10 (489.2 ± 41.52 μm) and smallest in group LS10 (394.8 ± 21.17 μm).

Regarding IPS e.max® CAD endocrowns, 2-way ANOVA revealed that interactions of investigated preparation design variables had no statistically significant influence on internal fit both before and after adaptation [$p = 0.778$ and 0.823, respectively]. On the other hand, regarding Lava™ Ultimate endocrowns, 2-way ANOVA revealed that cavity axial wall divergence significantly influenced the internal fit before adaptation in case of 3 mm central cavity depth (S) [$p = 0.004$], whereas there was slight influence in case of 5 mm central cavity depth (D) [$p = 0.777$]. Interactions of investigated preparation design variables had statistically significant influence on internal fit of Lava™ Ultimate endocrowns before adaptation, and a slight influence after adaptation [$p = 0.004$ and 0.141, respectively] (Fig. 4).

4. Discussion

In this study, it was assumed that the preparation design would not affect the internal fit. However, due to the scanning accuracy of 3-dimensional scanners, the geometry of the prepared cavity may pose an effect on the internal fit. In this study, internal fit methodology was based on the methodology of ***Seo et al.*** [10] and ***Karakaya et al.*** [14], who obtained sections of 1 mm thickness, by sectioning their samples mesio-distally along a line passing through the center of the restoration. Moreover, in this study, sections were obtained in both mesio-distal and bucco-lingual directions. Since, ***Seo et al.*** [10] found a statistical significant difference between internal gap measurements taken on the mesio-distal views and those on bucco-lingual views. Furthermore, measurements were done at several points representing axial walls, angles and horizontal walls, as they also found that there is significant difference in internal gap mean values at these different

8 EVA, Egypt.
9 Acrostone, Egypt.
10 Sirona, Bensheim, Germany.
11 Komet, Germany.
12 Anatomage, San Jose, CA, USA.
13 Renfert, Germany.
14 IBM Corporation, NY, USA.
15 SPSS, Inc., an IBM Company, USA.

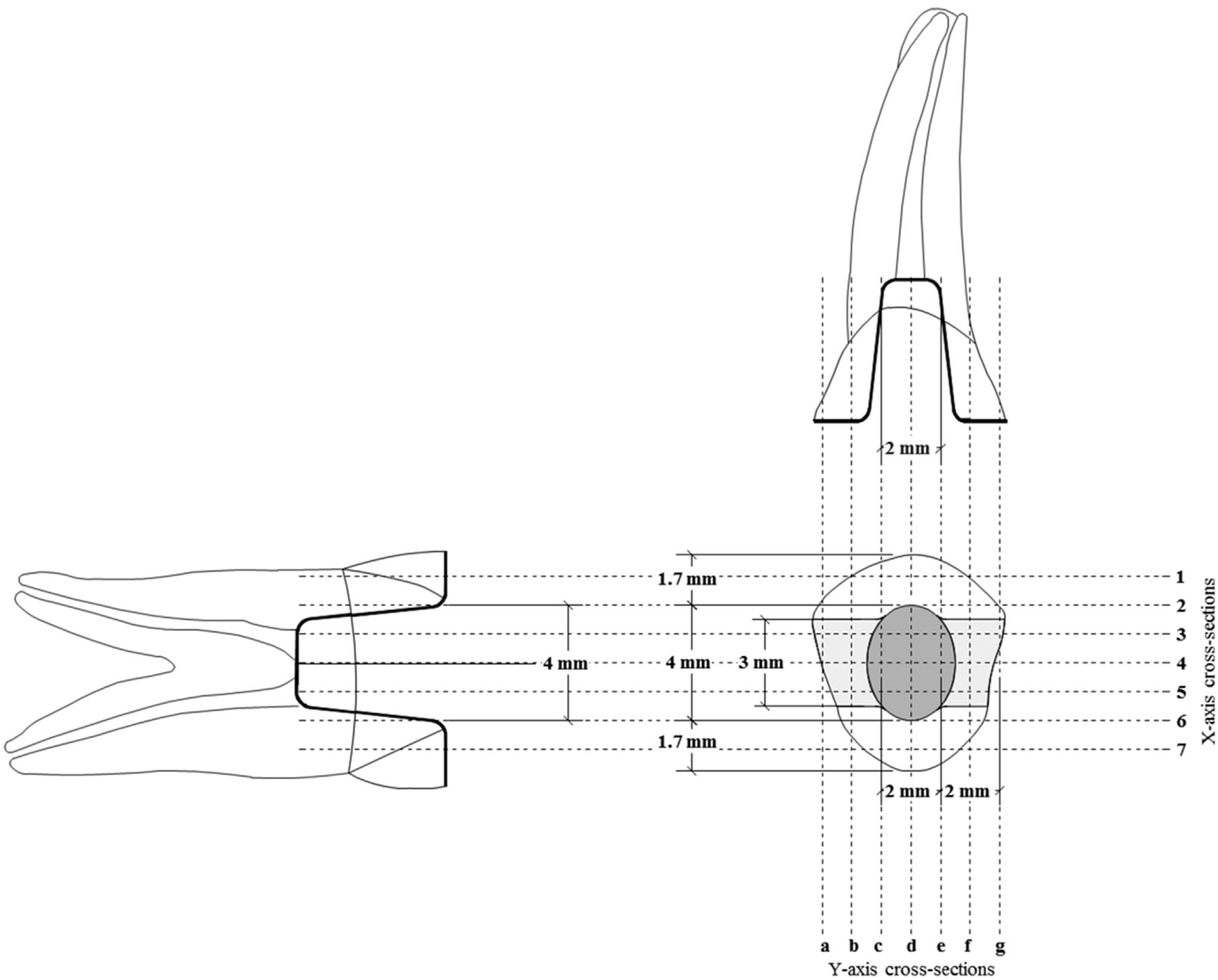

Fig. 2. Schematic drawing of endocrown preparations used in this study, showing bucco-lingual and mesio-distal sections. The bucco-lingual reference section was taken passing through buccal and palatal cusp tips of the endocrown restoration (Y-axis), the mesio-distal reference section was taken passing through the central groove of the endocrown restoration (X-axis); additional cross-sections were obtained bilaterally at 1 mm intervals.

locations. However, it is not possible to perform an accurate analysis in cases where insufficient radiographic contrast exists. Therefore, scanning procedure was done before cementation to improve the contrast between the abutment tooth, the ceramic restoration and the internal gap.

In this study, CBCT scans were used instead of micro-CT for internal gap measurements in an attempt to be closer to clinical situation. Since, micro-CT cannot be used for in vivo studies due to its high radiation level of exposure [15].

The null hypothesis was rejected. Ceramic systems investigated in the present study showed different levels of internal fit. Lava™ Ultimate endocrowns displayed smaller internal gaps compared to IPS e.max® CAD endocrowns, which was statistically significant regardless of cavity preparation design. This may be explained by the absence of post milling firing, in case of Lava™ Ultimate, that eliminates the incidence of any dimensional changes [16]. On the other hand, "IPS e.max® CAD" lithium disilicate ceramics undergo densification during crystallization process, which leads to 0.2% shrinkage, due to microstructure transformation, during which lithium disilicate crystals grow in a controlled manner, resulting in material relocation [17].

In another study by ***Borbaa et al.*** [12], they stated that other factors related to the processing method may be responsible for the observed difference in the internal fit level between the two systems. The two materials have different microstructures and mechanical properties, which may affect in different ways how they interact with the CAD/CAM burs. Lava™ Ultimate is less brittle compared to IPS e.max® CAD resulting in better milling quality and accuracy. Also, IPS e.max® CAD is milled in the soft stage, in which the material has low strength against chipping. These factors may promote better internal fit of the final restoration fabricated from Lava™ Ultimate over IPS e.max® CAD. The internal fit of both restorative materials has been significantly improved after adaptation.

Axial cavity walls prepared with different divergences, led to different internal fit values. Regardless of endocrown material, samples with 6-degree axial wall divergence displayed smaller internal gaps than those with 10-degree axial wall divergence. Alteration of axial cavity wall divergence revealed significant difference in internal fit. This may be explained by that the closer the geometry of the restoration to the geometry of the milling burs, the better the resulting internal fit.

Logically, increasing the axial cavity walls divergence would result in better internal fit, due to decreased frictional interference.

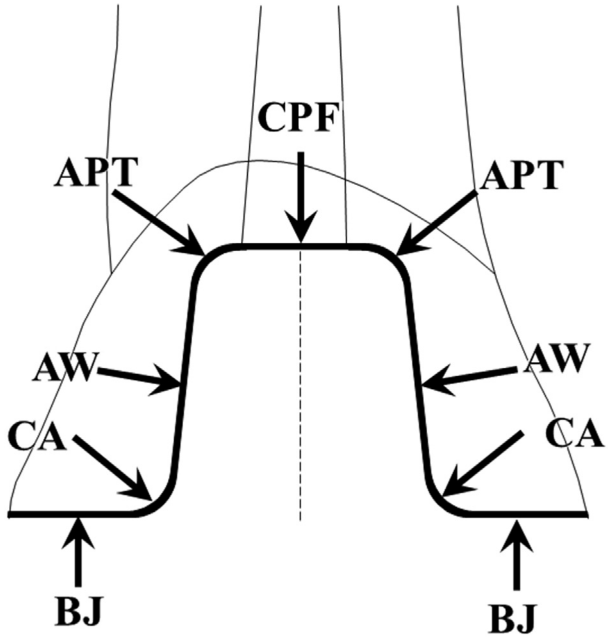

Fig. 3. Schematic drawing of endocrown preparation illustrating the measuring locations [BJ: butt-joint gap, CA: cavo-occlusal angle, AW: axial wall gap, APT: axio-pulpal transitional angle, CPF: center of pulpal floor].

However, this study result is consistent with the findings of ***Mou et al.*** [18] who achieved a better internal fit with abutment convergence angle of 12° than 20°. Also, ***Nakamura et al.*** [19] investigated the effect of different axial wall inclinations on internal adaptation of all-ceramic crowns, and found that abutments with smaller convergence angle displayed significantly smaller internal gaps. ***Nakamura et al.*** [20] stated that abutments with more parallel surfaces are easy in milling even with small occlusal convergence, thus achieving better internal fit.

Different investigated materials displayed different average internal gaps in response to changes in central cavity depth. In case of IPS e.max® CAD endocrowns, shallow central cavity resulted in smaller average internal gap than deep central cavity, whereas, in case of Lava™ Ultimate endocrowns, deep central cavity resulted in better internal fit than shallow central cavity. The disparity in study results may be explained by the compensation of the CAD/CAM system carried out, in case of lithium disilicate ceramics “IPS e.max® CAD”, to compensate for the subsequent densification shrinkage, which can also influence its internal fit. The success of this compensation depends on the homogeneity of the pre-crystallized lithium disilicate (IPS e.max® CAD) block and the software's ability to estimate the material shrinkage depending on the restoration design. On the other hand, Lava™ Ultimate resin nano-ceramics are milled to their final dimensions, which could be a positive factor for the restoration adaptation when compared to IPS e.max® CAD.

Central cavity depth variation didn't influence the internal fit significantly. Similar results were reported by ***Mou et al.*** [18], who found that when different preparation heights were used with both 12° and 20° convergence angles, there was no significant difference in the cement space. This may be due to the small difference between the investigated depth values. Thus, further research is required with a wider depth variation.

Limitations of the current study include the following: only one spacer thickness was evaluated. However, internal fit may be influenced by altering spacer thickness. Internal gap measurements were done before cementation, which neglects the influence of the luting procedure and cement type on the internal gap width. Internal gap measurements were done using CBCT, which may cause difficulty in comparison of results with other studies, however, not affecting results interpretation within the current comparative study. Internal gap linear measurements were taken using CBCT that has about 200 μm overestimation in comparison with micro-CT, as reported by ***Mangione et al***. [21]. That overestimation was also confirmed to apply to the current study samples through a pilot comparison of linear measurements of the marginal gap using CBCT and stereomicroscope. Great difference in radiodensity of both restorative materials may have affected the internal gap values.

5. Conclusion

Within the limitations of this study, the following conclusions were drawn:

1. Endodontically treated maxillary premolars restored with resin nano-ceramic endocrowns presented better internal adaptation

Table 1
3-way ANOVA of the 3 variables, endocrown material, central cavity depth and cavity axial wall divergence on the internal fit of the endocrown restoration before and after adaptation (The mean difference is significant at $p = 0.05$).

Source		Type III sum of squares	df	Mean square	F	Sig.
Material	Before adaptation	28569.025	1	28569.025	10.689	0.003
	After adaptation	112996.900	1	112996.900	8.359	0.007
Divergence	Before adaptation	50.625	1	50.625	0.019	0.891
	After adaptation	60996.100	1	60996.100	4.512	0.041
Depth	Before adaptation	1404.225	1	1404.225	0.525	0.474
	After adaptation	348.100	1	348.100	0.026	0.874
Material* Divergence	Before adaptation	4347.225	1	4347.225	1.627	0.211
	After adaptation	41088.100	1	41088.100	3.040	0.091
Material* Depth	Before adaptation	7645.225	1	7645.225	2.861	0.100
	After adaptation	29702.500	1	29702.500	2.197	0.148
Divergence* Depth	Before adaptation	2.025	1	2.025	0.001	0.978
	After adaptation	30140.100	1	30140.100	2.230	0.145
Material* Divergence* Depth	Before adaptation	570.025	1	570.025	0.213	0.647
	After adaptation	11902.500	1	11902.500	0.881	0.355

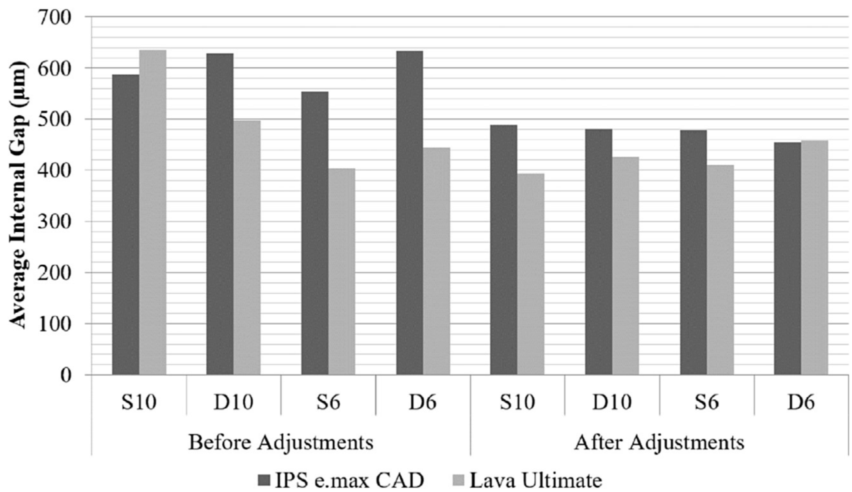

Fig. 4. Bar chart showing the influence of preparation design variables interaction on internal fit of IPS e.max® CAD and Lava™ Ultimate endocrowns before and after fitting surface adjustments ("S" shallow depth [3 mm], "D" extended depth [5 mm], "6" degree and "10" degree axial wall divergence).

compared to those restored with lithium disilicate endocrowns, regardless of the preparation design.

2. Endocrown preparation with smaller axial wall divergence provides better internal fit.
3. Central cavity depth is not influential on internal fit of investigated endocrown restorative systems.

Conflict of interest

Authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article. There has been no significant financial support for this study that could have influenced its outcome. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. All authors have approved the final article for publishing.

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