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Marginal misfit of heat-pressed milled wax-pattern and CAD/CAM crowns and its effect on stress distribution in implant-supported rehabilitations

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Aim: To compare the marginal fit of lithium disilicate CAD/CAM crowns and heat-pressed crowns fabricated using milled wax patterns, and evaluate its effect on stress distribution in implant-supported rehabilitation. **Methods:** A CAD model of a mandibular first molar was designed, and 16 lithium disilicate crowns (8/group) were obtained. The crown-prosthetic abutment set was evaluated in a scanning electron microscopy. The mean misfit for each group was recorded and evaluated using Student's t-test. For *in silico* analysis, a virtual cement thickness was designed for the two misfit values found previously, and the CAD model was assembled on an implant-abutment set. A load of 100 N was applied at 30° on the central fossa, and the equivalent stress was calculated for the crown, titanium components, bone, and resin cement layer. **Results:** The CAD/CAM group presented a significantly ($p=0.0068$) higher misfit (64.99±18.73 μm) than the heat-pressed group (37.64±15.66 μm). *In silico* results showed that the heat-pressed group presented a decrease in stress concentration of 61% in the crown and 21% in the cement. In addition, a decrease of 14.5% and an increase of 7.8% in the stress for the prosthetic abutment and implant, respectively, was recorded. For the cortical and cancellous bone, a slight increase in stress occurred with an increase in the cement layer thickness of 5.9% and 5.7%, respectively. **Conclusion:** The milling of wax patterns for subsequent inclusion and obtaining heat-pressed crowns is an option to obtain restorations with an excellent marginal fit and better stress distribution throughout the implant-abutment set.

Keywords: Dental materials. Dental marginal adaptation. Dental prosthesis, implant-supported. Microscopy, electron, scanning. Finite element analysis.

Introduction

The marginal misfit of dental restorations has been associated with clinical failures. It is commonly related to microleakage, caries, margin staining, debonding, and restoration fracture[1-3]. In addition, the misfit between the crown and implant-abutment set can lead to biofilm and food accumulation, which could result in peri-implant complications[4]. Some studies have reported that marginal misfit can influence the stress distribution around restorations, where a thick cement layer increases the stress in itself and is harmful to the longevity of the restoration[1,2]. A 120 μm misfit was considered as a minimum clinically acceptable value in the past, and the current studies still consider this value as a reference even with the higher accuracy of the current techniques and devices[3,5,6].

Technology devices such as computer-aided design/computer-aided manufacturing (CAD/CAM) systems have been successfully used to improve restorative procedures in the dental field. This technology offers faster and more practical procedures to obtain ceramic restorations compared to the conventional manual method[3,7] because it allows a chairside digital workflow without the need for physical models[8]. A clinical study[9] assessing implant-supported single crowns in the posterior region showed that the use of the CAD/CAM technique produced crowns with excellent adaptation in relation to interproximal and occlusal contacts, without the need for adjustments.

Another option for fabricating dental restorations is the heat-press technique (HPT)[3,7,10,11], where a tooth is waxed-up, invested in refractory material, and heated in an oven[3,7,12]. The space created by wax elimination is filled with a ceramic ingot that is heat-pressed to obtain the restoration[12,13]. The waxing-up procedure can be handmade (conventional method), or computer-aided designed and milled in wax blocks[10-12]. Milling restoration directly from ceramic blocks decreases one step compared to milling those in wax blocks, which needs to be invested and heat-pressed. However, some studies report that the latter procedure is related to the production of a better fit than the former[7,10,14,15]. Furthermore, when several restorations are made, the milling process directly from single ceramic blocks could be slow to obtain a large number of restorations because of its hardness[15]. In contrast, milling from a wax block is faster, and the investment of the restorations for pressing can be made with several restorations at the same time[16].

CAD/CAM restorations have the advantage of good accuracy and a computer-controlled process that can provide well-defined and fitted margins[17]. In practice, the milled edges of thin crowns on hard materials can produce defects in their margins which worsens their fit and produce stresses in that region, which could lead to restoration of failure[14,18]. A possible solution would be a combination of CAD/CAM and HPT. From a digital design, a crown can be milled in a wax block[10,12]. Since wax presents a soft surface with low hardness, it is an easy material to be milled and consequently to produce high margin accuracy restorations[18,19]. This wax crown can be invested to create a ceramic restoration by HPT afterwards[16,20].

Different commercial presentations of the same material are available sometimes[21]. One of these materials is lithium disilicate, a glass-ceramic material that has been well studied; however, it is still controversial whether the material provides better edge stability and marginal fit[7,22]. Currently, this material is available in blocks for CAD/CAM or ingots for HPT to furnish all market demand[3,7]. Although many studies have compared the marginal fit of lithium disilicate CAD/CAM crowns to those made by HPT, the wax patterns of the HPT are often produced manually by dental technician[7,12]. As all manual labor, reproducibility is a factor that can compromise the comparison between such techniques[7]. However, this problem can be solved by a controlled milling process[23]. Additionally, the stress distribution in lithium disilicate implant-supported single crowns manufactured by the two techniques remains unclear, and its influence on the implant components and bone is still unclear. The objective of the present study was to compare the marginal fit of lithium disilicate CAD/CAM crowns and heat-pressed crowns fabricated using milled wax patterns and evaluate its effect on stress distribution in implant-supported rehabilitation.

Material and Methods

In vitro analysis

Using a CAD software (Ceramill Mind; Amann Girrbach, Koblach, Vorarlberg, Austria) a mandibular first molar (height, 10.6 mm; buccal-lingual width, 10.8 mm; mesio-distal width, 11.4 mm) was designed over a universal prosthetic abutment (4.5 diameter, 6 mm height, 2.5 mm collar height). The relief adopted followed the standard of the software used, which is 0.05 mm. From this CAD, sixteen crowns were milled, eight from lithium disilicate blocks (IPS E.max CAD; Ivoclar), and eight from a wax block (Odontofix; Ribeirão Preto, São Paulo, Brazil). The crowns were milled under irrigation using a 5-axis milling unit (Ceramill Motion 2 5X; Amann Girrbach, Koblach, Vorarlberg, Austria) using a new bur for each group. For the heat-pressed group, the wax-up was invested with a phosphate-bonded universal investment (IPS PressVest Premium; Ivoclar Vivadent) and after heat pressing with a lithium disilicate ingot (IPS E.max Press; Ivoclar Vivadent) in a furnace (Programat P310, Ivoclar Vivadent) according to the manufacturer's instructions. The crowns were sputter-coated with gold for evaluation using a scanning electron microscope (SEM) (JSM-5600LV, Jeol, Boston, Massachusetts, USA)[24].

The crown was fixed with carbon adhesive tape from the occlusal surface to the base of the prosthetic abutment and positioned perpendicular to the stub. To avoid bias, the crowns were evaluated exactly in the way they were manufactured, without any kind of adjustment. The measurement was standardized on the center of the buccal, lingual, mesial, and distal faces with a zoom of 550x[24,25]. Four measures were made in each face with a distance of approximately 50 μm between them, and a mean of misfit was obtained for each crown (Figure 1).

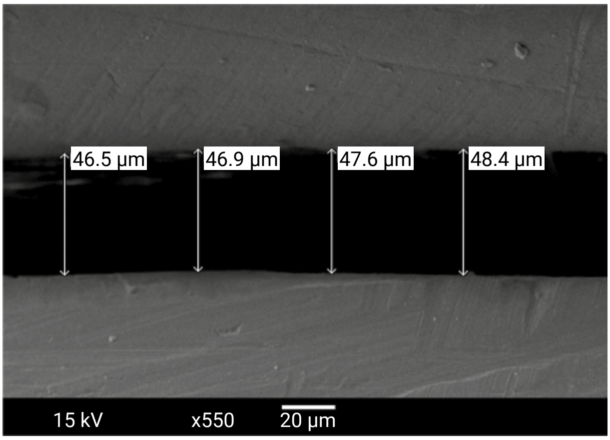

Figure 1. Measurement of the gap existing between the crown and the prosthetic abutment.

Normal data distribution was confirmed by the Shapiro-Wilk test and homogeneity by Levene's test. The mean misfit between the CAD/CAM and heat-pressed groups was evaluated by Student's t-test. Statistical analysis was performed using the SAS system release 9.3 (SAS Institute Inc., Cary, NC, USA), and a significance level of 5% (α=0.05) was adopted.

In silico analysis

The same mandibular first molar CAD model used for milling the crowns was exported to SolidWorks software (SolidWorks 2013; Dassault Systèmes Solidworks Corp). The crown was assembled in a universal prosthetic abutment (4.5 mm width × 2.5 mm collar height × 6 mm height), which was screwed in a 4 mm width x 11 mm height morse taper implant (Intraoss, Itaquaquecetuba, São Paulo, Brazil). Both universal prosthetic abutment and implant CADs were supplied by the manufacturer (Intraoss). The implant was inserted into a jaw segment with cortical and cancellous bones. A virtual cement thickness was designed for the two values found previously in the marginal fit evaluation to form the two experimental models (Figure 2). The two models were exported to the Ansys Workbench software for mathematical analysis (Ansys Workbench 15.0; Canonsburg, PA, USA). A 0.6 mm tetrahedral mesh was generated after 5% convergence analysis. The elastic modulus and Poisson's ratio of each material were used in the simulations (Table 1).

Table 1. Material properties used in finite element models.

Material	Elastic modulus (GPa) (E)	Poisson's ratio (δ)
Lithium disilicate[26]	95	0.20
Resin cement[27]	18.3	0.33
Titanium[28]	110	0.35
Cortical Bone[28]	13.6	0.26
Cancellous bone[28]	1.36	0.31

A load of 100 N was applied at 30° to the central fossa. The maximum principal stress (σ_{max}) was calculated for the prosthetic crown, von Mises stress (σ_{vM}) for titanium components (implant and prosthetic abutment), and maximum shear stress (τ_{max}) for bone (cancellous and cortical) and resin cement layer[26,28]. The results were evaluated qualitatively by the stress distribution and quantitatively by the peak stress (MPa) generated in each model. All models were assumed to be homogeneous, isotropic, and linearly elastic.

Results

The mean misfit for the heat-press group was 37.64 ± 15.66 μm, statistically different ($p = 0.0068$) from the CAD/CAM group, which presented a mean of 64.99 ± 18.73 μm. These values were used to simulate the cement thickness in the finite element analysis (FEA) (Figure 2).

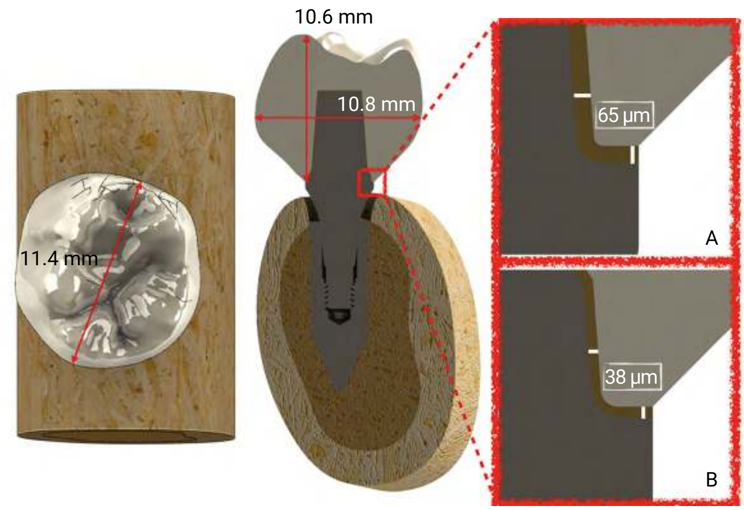

Figure 2. Occlusal and sectional schematic view showing the crown dimensions and cement thickness used in the CAD/CAM (A) and heat-pressed milled wax-pattern (B) groups.

The FEA results (Table 2) revealed an important influence of the cement thickness on the stress distribution in the two studied models. The most substantial difference occurred in the crown and cement layer, where the model restored with the lowest cement thickness (heat-press group) presented a decrease of 61% in the σ_{max} of the crown and 21% in the τ_{max} of the cement, both compared to the CAD/CAM group, restored with the highest cement thickness layer (Figure 3).

Table 2. Peak stress (MPa) and difference between groups after load.

Component	CAD/CAM	Heat-press	% stress
Crown (σ_{max})	132	51	*61%
Cement layer (τ_{max})	21.2	16.7	*21%
Prosthetic abutment (σ_{vM})	302	258	*14.5%
Implant (σ_{vM})	152	165	#7.8%
Cortical bone (τ_{max})	29.9	31.8	#5.9%
Cancellous bone (τ_{max})	11.4	12.1	#5.7%

(*) Stress decrease. (#) Stress increase.

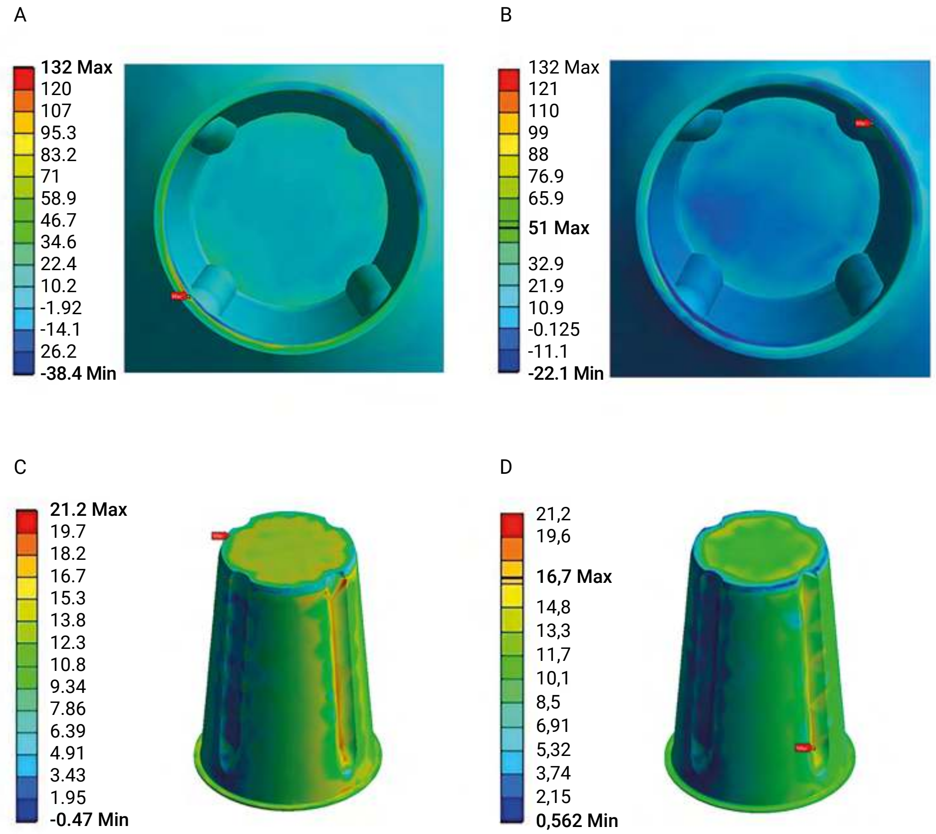

Figure 3. Stress distribution in the crown (σ_{max}) and cement layer (τ_{max}). Cervical view of the crown restored with a 65 µm (A) and 38 µm (B) cement layer showing the stress peak on the inner face. Isometric view of the cement layer with 65 µm (C) showing the stress peak on the occlusal face, and 38 µm (D) with the stress peak on the axial face.

The 38-µm cemented thickness model presented a decrease of 14.5% and an increase of 7.8% in the σ_{vM} for the prosthetic abutment and implant, respectively, compared to the 65-µm cemented thickness model (Figure 4). For the cortical and cancellous bone, a slight increase in τ_{max} occurred with a decrease in the cement layer thickness of 5.9% and 5.7%, respectively (Figure 5).

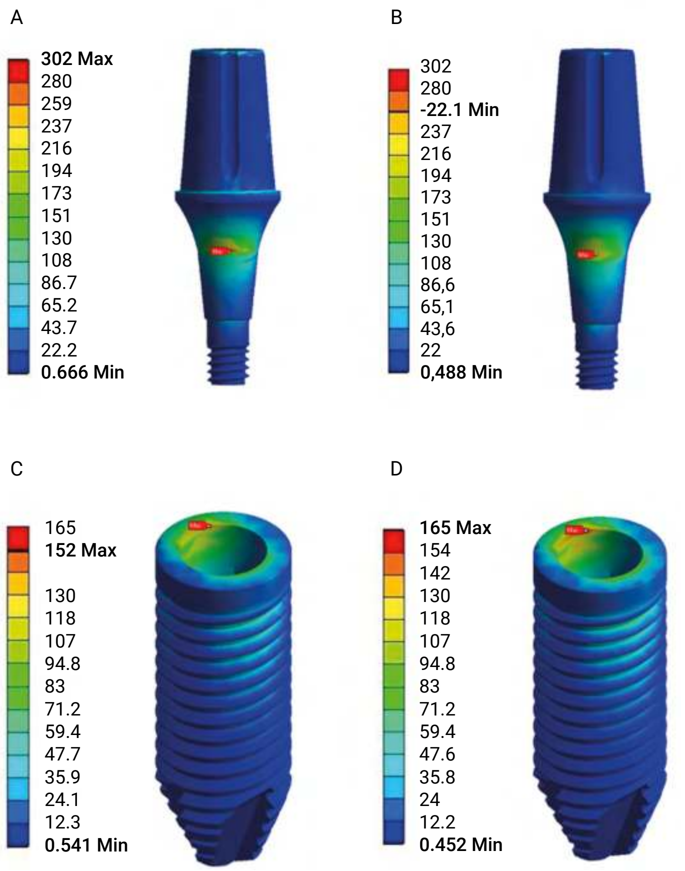

Figure 4. Stress distribution in the prosthetic abutment and implant (σ_{vM}). Vestibular view of the prosthetic abutment of the model restored with a 65 μm (A) and 38 μm (B) cement layer showing the stress peak on the prosthetic abutment collar. Isometric view of the implant of the model restored with a 65 μm (C) and 38 μm (D) cement layer showing the stress peak on the corresponding abutment collar level.

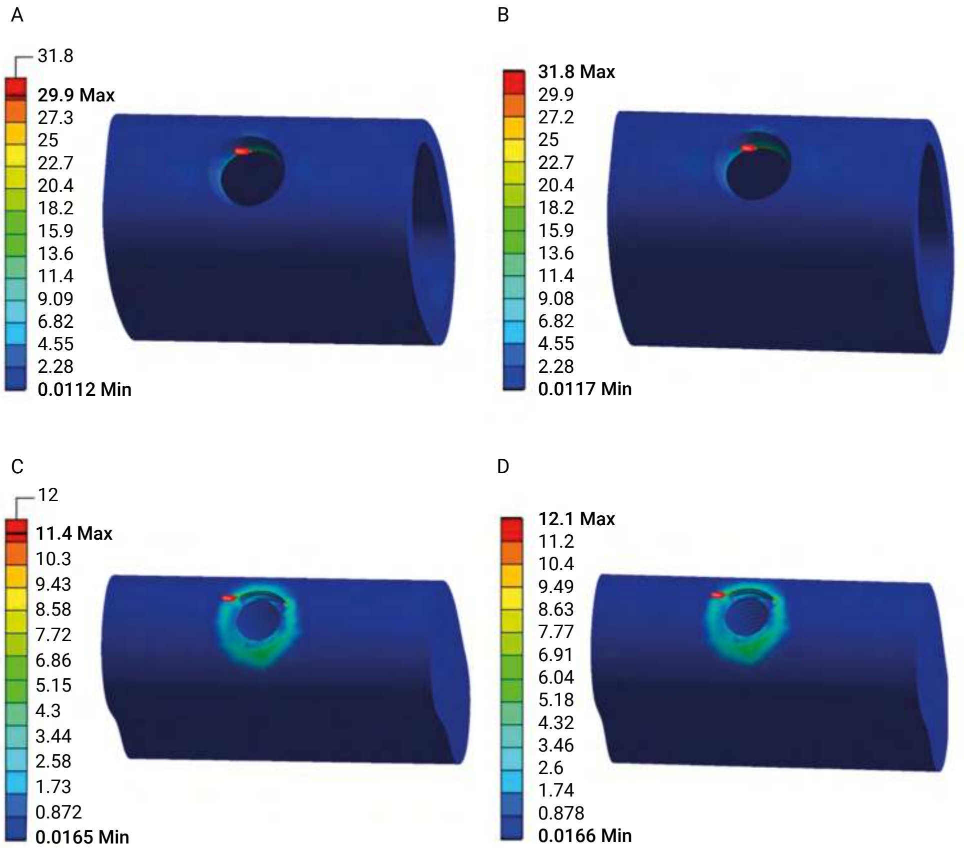

Figure 5. Stress distribution in the cortical and cancellous bone (τ_{max}). Exterior view of the cortical bone of the model restored with a 65 μm (A) and 38 μm (B) cement layer showing τ_{max} in the cervical inferior area at the buccal portion. Exterior view of the cancellous bone of the model restored with a 65 μm (C) and 38 μm (D) cement layer showing τ_{max} at buccal region.

Discussion

The concerns related to the study of restoration marginal fit have been addressed for many years[29]. Whenever a new material or technique arises, some studies resort to this methodology[18]. The concern about poorly fitting restorations is justifiable. Several studies have shown that a poor fit can cause many problems in the restoration such as cement dissolution, microleakage, and lower fracture strength[7,18,23,30]. Clinically acceptable values of 120 μm were established many years ago, regardless of the material and technique that are likely capable of generating better adjustment values than those reported in the past as acceptable[5,23]. Thus, this study evaluated, through *in vitro* and *in silico* analysis, the marginal fit and stress distribution of implant-supported rehabilitations restored with lithium disilicate crowns manufactured by CAD/CAM and the heat-pressed technique.

Regardless of the technique used for crown manufacture, the present study found values lower than 120 μm for both groups. This finding is supported by most studies related to the marginal fit of this material[7,13,18,31]. However, the result of a better fit to the heat-pressed group in this study is controversial[12]. Some others consider that the CAD/CAM process, owing to its high accuracy, produces the best values for the marginal fit of the restorations[12,13,30]. However, these studies do not consider chipping that may occur at the margin of the thin restorations during the milling process, which could lead to higher misfit values[18,19].

One of the most accepted theories for the best fit of the heat-pressed group is precisely the fact that it was made based on a milled wax pattern, which combined the high accuracy of the CAD/CAM system with the easy milling from wax, causing less occurrence of cervical defects on them[12,18,19]. Usually, the inaccuracies of the restoration fit occur in techniques where the manual skill of the technician is indispensable, as in the conventional lost-wax method, to fabricate porcelain fused to metal crowns[12]. Although marginal fit problems are minimized with CAD/CAM restorations, when compared to manual techniques, the final fit quality of restoration will further depend on the type of material milled[18,19]. The ease of how a material is milled depends directly on its hardness, which together with fracture toughness will be responsible for the final restorations edge quality[19]. The greater the hardness and the lower the material fracture toughness, the greater will be the difficulty of milling and achieving a good quality margin[18,19].

The difference between the two cement layers, although statistically significant, could not be clinically relevant because such a small difference found could not present different behaviors in the clinical environment. However, FEA seems to show a relevant influence of the cement layer on the stress behavior through rehabilitation, mainly for the crown and the cement itself. This stress distribution difference, over time, could lead to different fatigue behaviors with different failure load[32]. It is possible that the lower cement thickness in the heat-pressed group, as it presented the lowest stress value, would take longer to fail, which could decrease the chance of failure due to crown debonding when compared to the CAD/CAM group. It can also be seen that when a thicker cement layer is used, the stress peak in the crown is 2.5 times higher. This suggests that thinner cement layers favor the stress distribution throughout the crown ad cement layer and at the same time do not compromise in a relevant way the adjacent structures, such as the prosthetic abutment, implant, and bone, as the heat-pressed group showed only slightly higher values of stress for that component. Moreover, it is better for rehabilitation that the highest stress concentration is in the titanium components; ceramic restorations, due to their brittleness index, are more vulnerable to chipping[33] than prosthetic abutments and implants that are ductile and therefore withstand a certain level of plastic deformation before failure[34]. Hence, the higher stress in the ceramic crown could increase the possibility of crown chipping/fracture over time[1,35] and increase the risk of infiltration and solubility of the cement layer.

Although the heat-pressed group showed better results in both evaluations, this study had some limitations. This includes the absence of a mechanical test that allows the identification of the failure modes of the rehabilitation tested in the FEA, as it is numerical theoretical analysis. In addition, the lack of evaluation of the axial and occlusal discrepancies, since it is not possible to visualize the interior of the crown-prosthetic abutment set using the SEM, as the assessment restricted only to the margin of the restoration. Hence, further *in vitro* studies in this regard are needed to validate the results of the FEA, and to assess the internal misfit of the crowns.

Despite these limitations, it is worth remembering that although one technique has excelled the other, even the worst result can be considered as a good performance, being approximately half of what is considered clinically acceptable[5]. Therefore, it is up to each dentist and prosthetic technician to consider which procedure would work better in the workflow of their office or laboratory[15].

In conclusion, both methods achieved marginal misfit values within the clinically acceptable limits. The milling of wax patterns for subsequent inclusion and obtaining heat-pressed crowns is an option to obtain restorations with an excellent marginal fit and better stress distribution throughout the rehabilitation.

Conflicts Of Interest

The authors state no conflicts of interest.

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