THE EFFECT OF DIGITAL DIE SPACER ON THE MARGINAL FIT OF CAD PRESSED LITHIUM DISILICATE COMPLETE COVERAGE COPINGS: AN SEM ASSESSMENT

A Thesis

by

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ABSTRACT

The purpose of this *in vitro* study was to evaluate the marginal fit of pressed IPS e.max copings fabricated from a computer-aided designed and milled PMMA acrylic resin burnout coping of various cement spacer thicknesses. Three groups of ten PMMA acrylic burnout copings were designed and milled utilizing computer-aided software for a total sample size of thirty copings. Each group differed only by the die-spacer parameters indicated within the design software. Group 1, Group 2, and Group 3 were digitally designed with 25, 40, and 60 μm of die-spacer respectively.

All acrylic resin copings were pressed with IPS e.max lithium disilicate and adhesively bonded to thirty identical epoxy resin dies. Cross-sections of each specimen were obtained and viewed with a scanning electron microscope. Direct measurements were obtained at five pre-determined locations and data analyzed using statistical analysis software.

An analysis of variance (ANOVA) followed by a Mann-Whitney test was used to indicate significant differences between groups ($p \leq 0.017$). A statistically significant difference was found between groups for each measured location: buccal margin ($p=0.005$), buccal-axial ($p=0.013$), mid-occlusal ($p=0.030$), lingual-axial ($p=0.022$), lingual margin ($p=0.005$).

When 60 μm of die spacer was utilized in the fabrication of the milled acrylic resin coping, the definitive bonded ceramic coping yielded the best marginal fit. Cement thickness was greatest, and marginal fit was poorest when 25 μm of die spacer was utilized. Observed differences between groups can be attributed to the utilization of acrylic resin patterns in the fabrication of pressed IPS e.max copings.

The obtained results suggest that appropriate die spacer parameters indicated within computer-aided design software are critical in the fabrication of clinically acceptable indirect restorations.

DEDICATION

This work is dedicated to my wife, Annica. I thank you for your patience and grace throughout this process. You have allowed me the opportunity to pursue a career that I genuinely enjoy “showing up for” every day. I love you today and every day.

To my parents, James and Gina. I cannot express in words my gratitude for all that you have provided for me. I have enjoyed sharing each milestone with you both. Without either of you, none of them would have been possible.

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1. INTRODUCTION AND LITERATURE REVIEW

The marginal fit of complete coverage restorations has been extensively studied and continues to remain a topic of research due to its clinical relevance. Proper adaptation of a fixed restoration is the cornerstone of fixed prosthodontics and intimate marginal fit of an indirect restoration to the tooth preparation is of great importance with regards to the prognosis and longevity of the restoration.

Schwartz et al. evaluated unserviceable crowns and fixed partial dentures to determine causes of restoration failures [1]. Of the restorations evaluated, caries was the most frequent cause for failure at 36.8% followed soon after with 11.3% of restorations failing as a result of defective margins. This study, although dated, correlates the relationship between crown success and marginal fit of the restoration. Walton et al. updated Schwartz's study by following similar parameters and subsequently reported comparable results. Their findings indicated that the primary cause for crown failures was due to caries [2]. In a more recent literature review completed by Goodacre et al., clinical complications in fixed prosthodontics were examined. The most common complications associated with conventional fixed partial dentures were caries, which accounted for 18% of abutments. Caries accounted for 0.4% of single crown complications according to this review [3].

Silness and Hegdahl demonstrated that a marginal discrepancy results between the cervical margin of the crown and the margin of the prepared tooth due to the presence of luting material [4]. They continue by stating that this exposed cement layer represents a weak link as it is subject to dissolution, potentially resulting in recurrent caries. Orstavik evaluated the attachment of *Streptococcus sanguis* to dental crown cements under *in vitro* conditions and demonstrated that cements do in fact serve as a suitable substrate for bacterial adhesion [5]. The aforementioned findings substantiate the need to minimize marginal gaps due to a clear correlation between marginal misfit and bacterial ingress.

Another potential influence on marginal adaptation is the cement film thickness and the use of die spacer during fabrication of the restoration in the laboratory. Campagni et al. stated that cast restorations do not seat completely when cemented [6]. He went on to present techniques to improve the seating of castings including venting, mechanical grinding, carving of the wax patterns, etching with aqua regia, electrochemical milling, and die spacing. Of these available techniques, die spacer provided the most uniform and consistent method of obtaining cement space. Carter describes the application of die-spacer to a die as a means to produce an oversized die for wax pattern fabrication [7]. Olivera determined that the use of die spacer uniformly applied to a stone die, except in the region 0.5 mm coronal to the finish line, improved the marginal fit of the cemented castings evaluated [8].

The relationship between cement space and its effects on marginal fit of definitive cast restorations have been well reported. Eames et al. was an early proponent of the use of die-spacing material, stating that the problem of incomplete crown seating can best be handled with multiple coats of die-spacer [9]. It was demonstrated by Eames and others, that when zinc phosphate cement was used on a preparation with 10 degrees of convergence, a decrease in elevation of the cemented crown was observed from 143 microns to 45 microns when die-relief was utilized. Wang et al. were in agreement stating that the seating discrepancy during crown cementation decreased dramatically when die spacer was used during the fabrication of cast crowns [10].

Numerous authors have proposed reasons for this phenomenon as well as potential solutions to overcome the common occurrence of incompletely seated restorations. Jorgenson was an early investigator to report on the effects that zinc phosphate cement had on marginal openings of cast restorations [11]. Jorgenson's filtration process phenomenon stated that during cementation of the crown onto the tooth preparation there is accumulation of cement at the occlusal surface. Furthermore, hydrodynamic pressure increases upon cementation preventing the solid phase of the cement from escaping [11]. As Behrend would claim, a ring of cement is inevitable at the margin and the restorative dentist must accept the presence of this cement line [12]. The result is an incompletely seated crown restoration with marginal discrepancies. Windeler provided another plausible explanation for marginal misfits stating that the occlusal discrepancy was a result of excess cement that exceeded the available space within the casting [13]. Windeler's equation is unique in that it accounts for both film thicknesses as well as the geometry of the tooth preparation.

Cement thickness must be taken into consideration with regards to its influence on the marginal misfit of indirect restorations. In clinical practice, a significant range in film thicknesses have been reported and determined to be acceptable. Variation in film thickness can be attributed to the various particle sizes of the cements available. ADA

Specification No. 8 states that the film thickness of type I zinc phosphate luting cement should not exceed twenty-five micron [14]. Various luting and bonding agents are utilized in practice with the more commonly used cements being classified either as a resin-modified glass-ionomer, self-etch resin, or adhesive resin cements. Even with the more current bonding agents available, it still remains a challenge to obtain an effective and long-lasting marginal seal [15]. According to Van Meerbeek, the loss of marginal integrity and the successive microleakage that is noted over time is mainly a result of residual stresses by polymerization shrinkage and thermal dimensional changes [16]. Toman compared zinc phosphate cement and resin cement with regards to microleakage of all-ceramic crowns. In this *in vitro* study it was concluded that luting with an adhesive cement decreased microleakage compared with zinc phosphate [15].

Since marginal misfit of restorations is a common finding associated with indirect restorations, the restorative dentist is left to determine how much misfit is acceptable, if any. Holmes et al. described the lack of adequate fit as being potentially harmful to both the tooth and peridontium [17]. He proposed useful terminology that serves well in describing “fit” of any dental restoration. He stated that the fit of a casting is best defined in terms of the misfit measured at various points. It is the angular combination of the marginal gap and the extension error, overextension or underextension, which results in the absolute marginal discrepancy [17].

With regards to measuring marginal gaps, Groten et al. outlined general guidelines on how to perform gap measurements on crowns *in vitro* or *in vivo*. Based on his report, fifty measurements along the margin of a crown are required for clinically relevant information about gap size [18]. This quantifiable number was the first to be reported as a minimum requirement, and is in contrast to other studies in which fewer measurements were obtained.

Christensen provided some of the earliest published data on acceptable margins as it related to cast gold inlay restorations. He evaluated the marginal adaptation of visually accessible and inaccessible gold inlay margins by use of an explorer [19]. Of the restorations evaluated by clinicians, it was determined that the range of acceptable margins was from 2 to 51 µm for clinically visible margins. For inaccessible margins, it was found that 119 µm were acceptable.

Mclean and von Fraunhofer assessed the marginal fit of gold inlays, full gold crowns, metal-ceramic and aluminous porcelain jacket crowns by evaluating the effects cement film thickness *in vivo*. Cement film thickness was measured at different regions of each restoration. For the metal-ceramic specimens, a range from 26 to 138 µm of film thickness was obtained depending on the measured site. It was determined in this study that if these restorations were constructed such that the marginal gap was less than 120 µm, it was deemed a successful restoration [20].

In a separate study by Holmes, he measured the marginal fit of castable ceramics, Dicor, and compared it to that of type III gold crowns. The absolute marginal discrepancies were measured at the facial, lingual, mesial, and distal surfaces by examination of cross sections of cemented castings. The mean values of absolute marginal discrepancy for all locations ranged from 35 to 73 µm for the Dicor crowns [21]. Although Dicor all-ceramic restorations are not routinely used any longer, Holmes offered early data regarding marginal fit of all-ceramic restorations. This provided for an acceptable standard by which more modern all-ceramic materials could be compared.

Nakamura et al. reported on the marginal and internal fit of CAD/CAM Vita Mark II ceramic crowns. In this study, luting space settings of 10, 30, and 50 μm were tested. It was determined that for crowns milled with 50 μm of luting space, better marginal fit was obtained following cementation [22]. In a similar *in vitro* study, Iwai et al. examined the influence of cement space on the adaptation of zirconium dioxide ceramic copings. Results indicated that the 60 μm cement space group exhibited statistically smaller marginal discrepancies compared to the other tested groups of 10 and 30 μm of die spacer [23].

According to Giordano, conventional feldspathic porcelains are composed primarily of SiO2 (silica, 64%) and Al2O3 (alumina, 18%) with various amounts of K2O (potash) and Na2O (soda) [24]. Kelly stated that these predominantly glassy ceramics provided high esthetic results however were relatively weak [25]. He further described the moderately-filled glassy ceramics, which contained primarily feldspathic glass but also contained fillers such as leucite, a crystalline mineral that provided a moderate increase in strength [25]. The ability to bond porcelain to a rigid metal framework to increase functional predictability was the rationale for the early ceramo-metal restoration [26]. Over time there has been improvement in both the alloy substrates and the veneering porcelains utilized which has yielded both durable and esthetic metal-ceramic restorations [27].

All-ceramic materials have gained wide acceptance by the dental community in its applications for partial and full coverage indirect restorations. Culp states that it has become a challenge to the dental restorative team to provide patients with high-strength restorations without compromising esthetics [28]. The evolution of ceramic systems over time has yielded more predictable restorative options available to today's restorative practitioner. Early all-ceramic options included Dicor, In-ceram, and IPS Empress ceramics [27]. The primary disadvantage with the glass-ceramic options according to Culp, has been the relatively lower flexural strength of these materials [28]. Lithium disilicate is a glass-ceramic that offers ideal esthetic properties with increased flexural strength. With a flexural strength that can exceed 360 Mpa, this material consists of approximately 70% volume of lithium disilicate crystals that are crystallized in a glassy matrix [29]. The IPS e.max lithium disilicate is composed of quartz, lithium dioxide, phosphor oxide, alumina potassium oxide, and other components [29]. IPS e.max restorations in particular are currently a popular material of choice for inlay, onlay and full coverage crown restorations. High flexural strength, a wide range of esthetic properties, and relatively low materials cost allow for its versatility and acceptance by practitioners. Another advantage of this material is its ability to be pressed using the lost-wax hot pressing techniques. Holden et al. demonstrated that all-ceramic restorations fabricated via the pressed technique exhibited clinically acceptable marginal openings when compared to conventional cast restorations [30]. Reich measured cement thickness under lithium disilicate crowns and concluded that the marginal accuracy lies below the clinically acceptable 120 μm [31].

Die spacer can be manually applied on the master die during crown fabrication or, with the use of computer-aided design it can be indicated digitally within the designing software during the digital creation of the restoration. While manufacturer recommendations suggest a painted die spacer thickness of 18-22 μm for all-ceramic single crown restorations [32], there is limited data regarding the effects that various die spacer thicknesses have on the marginal fit of cemented full coverage lithium disilicate restorations. Furthermore, there are limited studies that evaluate the use of digital die spacer with use of computer-aided design software in the fabrication of ceramic restorations. As the utilization of CAD/CAM all-ceramic restorations continues to become more commonplace, it is prudent to evaluate the marginal fit of these restorations specifically as it relates to the die spacer parameters set within the designing software. The aim of this study was to evaluate the marginal fit of pressed IPS e.max restorations fabricated from a computer-aided designed and milled acrylic burnout coping. Various die spacer amounts would be tested in order to evaluate its influence on the fit of the final restoration. The cemented restorations would be examined with a scanning electron microscope to measure absolute marginal gaps at five pre-determined locations. The null hypothesis was that there would be no difference in the marginal fit of IPS e.max copings fabricated with 25, 40 or 60 μm of die spacer.

2. MATERIALS AND METHODS

Three groups of ten PMMA acrylic burnout copings were designed and milled utilizing computer-aided software for a total sample size of thirty copings. Each group differed only by the die-spacer parameters indicated within the design software. Group 1, Group 2, and Group 3 were digitally designed with 25 μm, 40 μm , and 60 μm of die-spacer respectively. These copings were then used to fabricate monolithic pressed lithium disilicate (IPS e.max Press) restorations, which were then adhesively bonded to standardized epoxy resin dies. The bonded crown-die specimens were sectioned in a buccal-lingual direction. Cross-sectioned samples were prepared and examined with a scanning electron microscope (SEM). Marginal misfits were assessed for each specimen and measurements were made at five points for statistical analysis.

2.1 Master Die Fabrication

An ivorine mandibular first molar was prepared for an all-ceramic complete crown preparation according to Ivoclar IPS e.max recommendations using a round-end tapered diamond bur (5856, Brasseler USA, Savannah, GA). A uniform reduction of 1.5 mm was prepared at the occlusal and axial surfaces. 1.0 mm reduction was completed at the gingival margin ensuring that rounded internal line angles were obtained. Preparation height was 4 mm with a total occlusal convergence of 12°. An impression of the master die was made using high-strength silicon material and a high-heat epoxy resin (Viade

Products Inc., Camarillo, CA) was poured into the impression to obtain thirty identical dies.

2.2 Crown Fabrication

The dies were divided into three groups differing only in the amount of die spacer indicated in microns: 25 μm Group, 40 μm Group, and 60 μm Group. Each group consisted of ten specimens each.

2.2.1 Fabrication of acrylic burnout copings

Utilizing the validated workflow within the scanning software (Straumann® Cares® Visual 8.0) a new order was created for each respective group. On the order prescription, tooth #30 was selected as the tooth to be scanned, and the material selected was the Polycon® cast a filler-free resin PMMA. The master die was inserted onto the scanning cylinder and scanned with the Straumann® Cares® Scan CS2 system. The margin of the scanned master die was located manually within the software. Die parameters for Group 1 were set to allow for 25 μm of die spacer beginning 0.5 mm from the finish line. Die parameters for Group 2 were set to allow for 40 μm of die spacer beginning 0.5 mm from the finish line. Die parameters for Group 3 were set to allow for 60 μm of die spacer beginning 0.5 mm from the finish line. For all groups, cement space was set to 0.00 μm and a uniform thickness of the coping was set to 1.00

mm. Each prescription was duplicated to allow for the fabrication of 10 identical Polycon® cast copings per group.

2.2.2 Fabrication of pressed restorations

Once Polycon® cast acrylic resin copings were received, each coping was seated onto a master die for each respective group. 2.5x magnification was used to visually inspect that margins were closed circumferentially prior to spruing and investing. It was confirmed that all copings seated completely onto its respective master die, and no adjustment of the acrylic coping was necessary. Each acrylic coping was sprued with a 4-mm long, 10-gauge sprue wax. Two copings were sprued per 100 gram investment ring (IPS Silicone Ring). Care was taken to ensure that each sprue was attached at a 45° angle to the base of the investment ring. Sprued copings were invested with a phosphate-bonded investment (IPS PressVEST Speed, Ivoclar Vivadent). Following a 45 minute set time, the investment was removed from the plastic ring and placed in the preheating furnace (Apollo II Whip Mix, Louisville, KY) for an additional 45 minutes at 1562°F. After completion of the preheating cycle, one high-translucency IPS e.max Press ingot was inserted into the investment followed by placement of a disposable plunger. The loaded investment was immediately placed in the center of the hot press furnace (Vario Press 300 Zubler USA Inc., Irving, TX) and the press program was initiated as recommended by the manufacturer. Following pressing and cooling, crowns were divested using polishing beads at 60 psi for gross removal of investment material and 25 psi for fine removal of investment material. Sprues were removed with an aluminum-oxide separating disc (Keystone Industries, Gibbstown, NJ) with irrigation. Each crown was fitted to its respective master die taking care to keep adjustments at a minimum. Complete seating of the restoration onto the master die was confirmed visually with 2.5x magnification and with an explorer tip (EXPL-5/6, Brasseler USA, Savannah, GA) prior to bonding.

2.3 Crown Cementation

All thirty pressed crown restorations were steam cleaned (Touchstream, Kerr Dental Laboratory Products, Orange, CA) and dried prior to bonding procedures in order to remove any residual debris. The same bonding protocol was carried out for each restoration of all groups and began with pre-treatment of the ceramic crowns. The intaglio surface of each crown was acid etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 seconds. The etchant was removed with water and dried with an oil-free air syringe. The intaglio surfaces were then silanated with a universal primer (Monobond Plus, Ivoclar Vivadent) for 60 seconds and allowed to air dry. Each master epoxy resin die was steam cleaned to remove residual debris and dried with on oil-free air syringe. A self-adhesive universal resin cement (RelyX Unicem Clicker, 3M ESPE) was dispensed onto a mixing pad. The equal amounts of catalyst and base were mixed with a spatula into a homogenous paste avoiding the incorporation of air bubbles. A thin layer of cement was applied to the intaglio surface of the crown with a microbrush and seated onto its respective die using a standardized force of 50N. Excess cement was removed from the margin region and light polymerization was performed for 10 seconds at each side of the die (mesial, lingual, buccal, and distal) using a LED Dental Curing Light (Demi, Kerr Co., Orange, CA). The specimen was left undisturbed for 5 minutes to allow for complete cement polymerization.

2.4 Preparation of Specimens for SEM Analysis

The distal surface of the crown-die specimen was embedded in a block of light curing acrylic (Triad® VLC, York, PA) and light polymerized for 3 minutes. Each sample was sectioned along the long axis in a buccal-lingual direction with a low speed, water-cooled diamond sectioning saw (Buehler Isomet Low-speed Saw; Lake Bluff, Illinois). Each sectioned sample was marked in order to distinguish the specimens from one another. All samples were separated into their respective groups prior to SEM analysis.

2.5 SEM Analysis and Measurement of Marginal Misfit

Scanning electron microscopy was conducted at the Texas A&M University Baylor College of Dentistry in the Department of Biomedical Sciences Microscopy Core Facility. The instrument used was a JEOL 6010LA (JEOL Inc., Tokyo, Japan) with scanning electron imaging (SEI) backscatter electron (BSE) and electron dispersive spectroscopy (EDS) modes. Images were taken at 5 kV with magnification for imaging set at 30x.

Each specimen was individually positioned and stabilized with the cross-sectioned surface facing upward. Working distance was determined based upon the total height of the scanning plate and the specimen. Once the areas of interest were located, measurements were made at five specific locations to include the buccal margin (B), buccal-axial surface (BA), mid-occlusal surface (MO), lingual-axial surface (LA), and lingual margin (L).

2.6 Statistical Analysis

Data was analyzed using a statistical software (SPSS 19.0, SPSS Inc., Chicago, IL). The Kruskal-Wallis test explored differences between the three groups (25 μm, 40 μm, 60 μm) for the five different locations (B, BA, MO, LA, L). The significance level was set at $p \leq 0.05$. When a difference was detected, a post-hoc analysis was performed using the Mann-Whitney test. The significance level was adjusted for multiple comparisons using the Bonferroni formula and was set at $p \leq 0.017$.

3. RESULTS

From the observed findings it was noted that when 60 μm of die spacer was utilized, it yielded the best marginal fit of the bonded restoration. Cement thickness was greatest, and marginal fit was poorest, when 25 μm of die spacer was utilized. The mid-occlusal site yielded the greatest cement thickness for all groups tested.

The cement thickness data (mean, standard deviation, median interquartile range, minimum and maximum values) for the three groups according to location are shown in Table 1. The marginal fit improved for all measured locations, except for the lingual-axial location, as die spacer thickness increased from 25 μm to 60 μm. Only at the lingual-axial surface was marginal fit better for the 25 μm group than both the 40 μm and 60 μm groups. When 60 μm of die spacer was utilized, marginal fit of the bonded IPS e.max restoration was found to be within the clinically acceptable range. Furthermore, it was observed that the mid-occlusal sites had the greatest cement thicknesses when compared to all other measured locations for groups tested.

Table 2 shows a statistically significant difference was found between the groups for each location: buccal margin (p=0.005), buccal-axial (p=0.013), mid-occlusal (p=0.030), lingual-axial (p=0.022), lingual margin (p=0.005).

Tables 3, 4, and 5 indicate differences between each group specifically. Table 3 shows a significant difference at the buccal margin (p=0.008) and the lingual-axial surface (p=0.010) when comparing the 25 μm group and the 40 μm group. Greater cement thickness was found in the 25 μm group for both locations. Table 4 shows that when the 25 μm group and the 60 μm group were compared to each other, significant differences were found at the following surfaces: buccal margin (p=0.005), buccal-axial (p=0.006), mid-occlusal (p=0.008), and the lingual margin (0.005). Greater cement thicknesses were found in the 25 μm group. There was no significant difference observed at the lingual-axial surface between these groups. Table 5 shows that when the 40 μm group and the 60 μm group were compared, only the lingual margin was found to be significantly different (p=0.005), with greater cement thickness observed in the 40 μm group.

4. DISCUSSION

The aim of this study was to evaluate the marginal fit of pressed IPS e.max copings fabricated from a computer-aided designed and milled PMMA acrylic resin burnout coping of various cement spacer thicknesses. Marginal fit and intimate adaption of the crown to the tooth is of significant importance with regards to the success and survival of indirect restorations. In the present study CAD/CAM technology was used to design and mill an acrylic resin burnout coping that was then used to press an IPS e.max coping. Commonly, die spacing parameters are pre-determined within the software, however it does allow the user to manually change these settings. Critical evaluation of how die spacer settings influence marginal fit of copings is necessary in order to appropriately indicate a die spacer thickness that will yield the most ideal marginal fit of the definitive restoration.

This study found a significant difference in the marginal fit of pressed IPS e.max copings that were digitally designed with 60 μm of die spacer compared to those fabricated with 25 or 40 μm of die spacer. The copings fabricated with 60 μm of die spacer demonstrated the least cement thickness and the smallest marginal discrepancies following SEM analysis. Therefore, the null hypothesis that there would be no difference in the marginal fit of IPS e.max copings fabricated with 25, 40, or 60 μm of die spacer was rejected. Upon visual inspection with 2.5x magnification and an explorer, marginal discrepancies were clearly evident for the 25 μm group samples and less obvious for the 60 μm group. These subjective findings supported the objective measurements obtained with the SEM. It was determined that all copings from the 25 μm group were clinically unacceptable due to the significant marginal discrepancies present. This indicates that a die spacer thickness of 25 μm was insufficient based on the present study.

The most probable cause for the differences observed between groups can be attributed to the fabrication process of the IPS e.max coping. The current Ivoclar IPS e.max press instruction manual outlines a protocol for direct wax patterns only, and does not provide recommendations for acrylic resin patterns as was utilized in this study. It is understood that waxes and acrylic resins differ in their degree of contraction and expansion as well as the temperatures at which this occurs. It is therefore likely that user recommendations for wax patterns are not appropriate for acrylic resin patterns when pressed with IPS e.max lithium disilicate. Vojdani et al. determined that the absolute marginal discrepancy for a coping obtained from a CAD/CAM acrylic resin pattern was significantly greater than a coping obtained from a conventional wax pattern. This brings to light the potential marginal and internal discrepancies that might be present in restorations made from acrylic resin patterns and validates findings of the present study. Furthermore, unlike the IPS e.max CAD technique, the press technique entails additional procedural steps to include investing, burnout of the acrylic resin pattern, and pressing that may have influenced the obtained results.

Results obtained in this study are further substantiated by those reported in previous studies that evaluated the influence of this “digital die spacer” on the marginal and internal fit of CAD/CAM restorations [22, 23]. This study is in agreement that die spacer in the range of 60 μm yielded more clinically acceptable marginal discrepancies than those groups with less die spacer.

These findings provide useful information regarding the applications of CAD/CAM technology and the active role that the practitioner or technician needs to assume in the digital design of restorations. These results suggest that pre-determined manufacturer settings often times need to be altered by increasing the die spacer amount when milled acrylic resin patterns are being fabricated. If insufficient spacer is used, it can be assumed that clinically unacceptable marginal fit of the final restoration may result.

One limitation of this study was the need for the operator to relieve the intaglio surface of all IPS e.max copings prior to cementation, primarily at the axial surfaces. Minimal adjustments were made, and only adjustments to achieve complete seating of the coping were performed. Although this introduced a potential for error, it did demonstrate that dimensional changes do in fact occur during the investing and pressing process of the acrylic resin pattern. A subjective finding was that fewer adjustments were necessary for the 60 μm group than for the other respective groups.

Additionally, only five measurements were obtained per sample and not the recommended fifty measurements as reported by Groten [18]. This may be another limitation of this study. Although fifty measurements may be ideal, the ability to reliably standardize fifty measurement locations per sample is questionable. In addition, measurements were only made from buccal-lingual cross-sectional samples. With an increased sample size, mesial-distal samples could have been obtained and may have provided more detailed information regarding marginal fit of pressed IPS e.max restorations.

One last potential limitation of the study was that that the master epoxy resin dies themselves were directly scanned with the Straumann® Cares® Scan CS2 system and not a master stone die obtained from an impression of the master epoxy resin die, as would be the more conventional method. The epoxy resin master die was true to form and therefore did not have any expansion, as would be the case if a stone master die had been scanned. This still however is clinically relevant in that with current intraoral scanning systems available, the prepared tooth can be directly scanned and a CAD/CAM restoration can be fabricated all within the digital workflow. This therefore would negate the need for a master stone die.

New and evolving CAD/CAM technology will continue to demand research to provide the highest levels of evidence. Within CAD/CAM software systems there is the capability to manipulate numerous design parameters. It is prudent for future studies to evaluate how manipulation of these various parameters influence the design, fit and overall success of indirect restorations. Such future studies will in turn provide useful recommendations for the CAD/CAM production of dental restorations.

Results obtained from this study bring to light the active role that both the practitioner and the laboratory technician must maintain throughout the design and fabrication process CAD/CAM restorations. Active communication and participation is critical such that specific design parameters can be altered in order to obtain individualized restorations with ideal form and function.

In summary, pressed copings digitally designed with 60 μm of die spacer were shown to have better marginal fit and the least amount of cement thickness when compared to copings digitally designed with 25 or 40 μm of die spacer. The obtained results demonstrated a significant difference and suggest that appropriate die spacer parameters are critical in the fabrication of a clinically acceptable restoration. Furthermore, IPS e.max press recommendations are needed for acrylic resin patterns as they are likely different than those for wax patterns.

5. CONCLUSIONS

Within the limitations of this *in vitro* study, the following conclusions can be drawn:

1. IPS e.max crowns pressed from CAD/CAM acrylic burnout copings with 25, 40, and 60 μm of die spacer required adjustment of the intaglio surface prior to cementation.
2. Pressed IPS e.max copings made with 60 μm die spacer had improved marginal fit and decreased cement thicknesses compared to copings made with 25 and 40 μm die spacer.
3. Pressed IPS e.max copings made with 25 μm die spacer were clinically unacceptable.

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APPENDIX A

Figure 1: Preparation of master epoxy resin die.

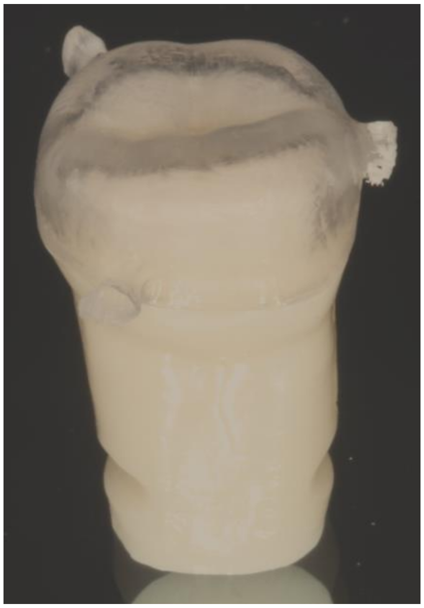

Figure 2: Polycon® cast coping seated onto master epoxy resin die prior to pressing.

Figure 3: Pressed IPS e.max copings immediately following divestment.

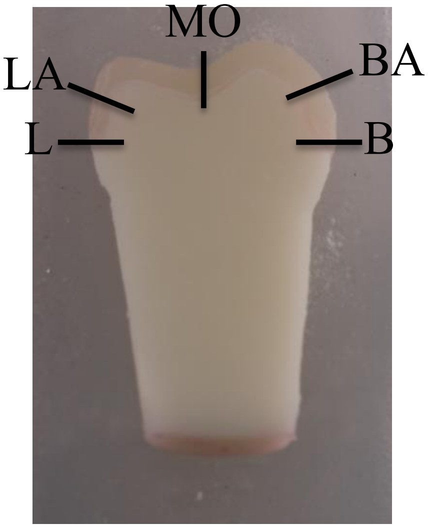

Figure 4: Cross-sectioned sample embedded in acrylic for SEM analysis with indicated measurement locations. (L) Lingual (LA) Lingual-axial (MO) Mid-occlusal (BA) Buccal-axial (B) Buccal.

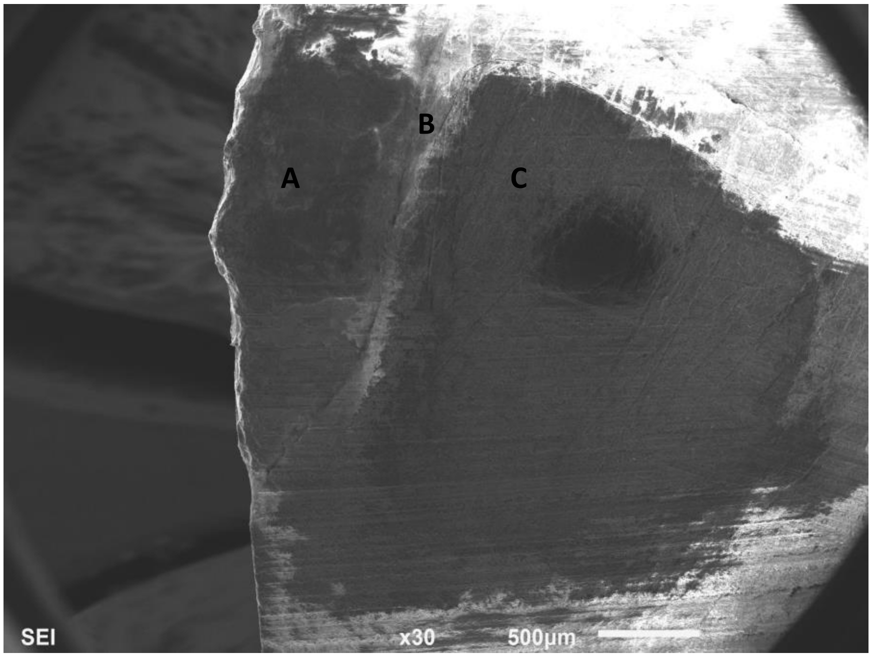

Figure 5: SEM image of buccal margin of specimen from Group 1 depicting (A) IPS e.max coping (B) cement and (C) epoxy resin die.

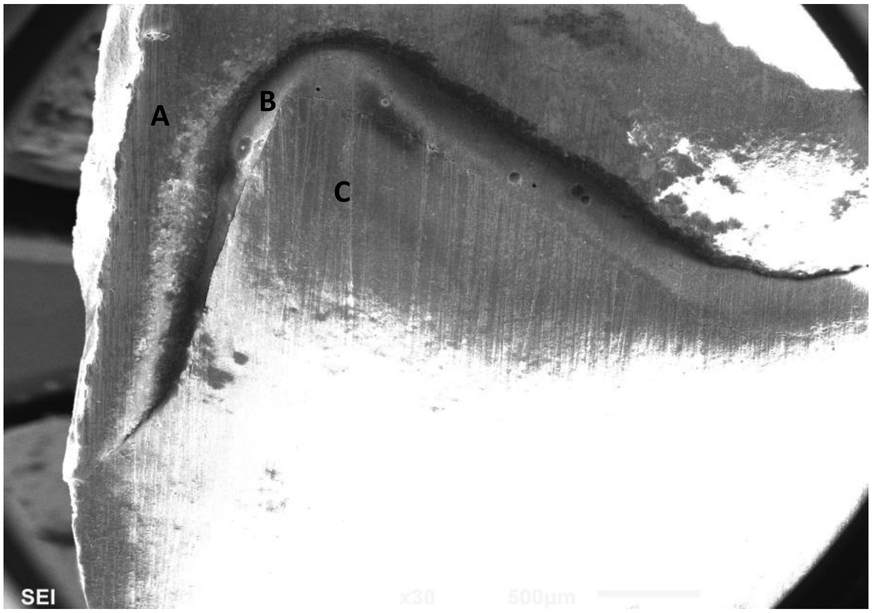

Figure 6: SEM image of buccal margin of specimen from Group 3 depicting (A) IPS e.max coping (B) cement and (C) epoxy resin die.

APPENDIX B

Table 1. Descriptive statistics examining the cement thickness (µm) for the 3 groups (25, 40 & 60 µm) according to location (Buccal margin, Lingual margin, Mid-occlusal, Buccal axial, Lingual axial).

	Buccal margin			Lingual margin			Mid-occlusal			Buccal axial			Lingual axial		
	25 µm	40 µm	60 µm	25 µm	40 µm	60 µm	25 µm	40 µm	60 µm	25 µm	40 µm	60 µm	25 µm	40 µm	60 µm
Mean	171	113	108	159	147	85	213	203	163	127	105	88	82	134	128
SD[a]	54	23	50	51	41	44	35	46	31	26	30	14	13	45	52
Median	166	109	130	158	136	75	204	208	163	129	99	86	84	136	122
Minimum	90	70	0	86	80	21	150	120	113	97	61	60	62	72	49
Maximum	276	140	160	250	205	176	260	267	213	165	151	103	98	225	232
IR[b]	67	26	70	76	76	59	52	84	55	48	44	20	25	62	70

a. Standard Deviation

b. Interquartile Range

Table 2. Inferential statistics using the Kruskal-Wallis Test to explore differences between the 3 groups (25, 40 & 60 µm) according to location.

	Buccal margin	Lingual margin	Mid-occlusal	Buccal axial	Lingual axial
Chi-Square	10.412	10.725	6.991	8.619	7.615
df	2	2	2	2	2
Significance* ($P \leq 0.05$)	P=0.005*	P=0.005*	P=0.030*	P=0.013*	P=0.022*

Table 3. Inferential statistics using the Mann-Whitney Test to explore differences between 2 groups (25 & 40 µm) according to location.

	Buccal margin	Lingual margin	Mid-occlusal	Buccal axial	Lingual axial
Mann-Whitney U	8	43	48	27	11
Wilcoxon W	36	98	103	82	47
Z	-2.637	-0.529	-0.151	-1.739	-2.577
Significance* ($P \leq 0.017$)	P=0.008*	P=0.597	P=0.880	P=0.082	P=0.010*

Table 4. Inferential statistics using the Mann-Whitney Test to explore differences between 2 groups (25 & 60 µm) according to location.

	Buccal margin	Lingual margin	Mid-occlusal	Buccal axial	Lingual axial
Mann-Whitney U	13	13	15	9	15
Wilcoxon W	68	68	70	45	51
Z	-2.798	-2.797	-2.647	-2.754	-2.221
Significance* (P≤0.017)	P=0.005*	P=0.005*	P=0.008*	P=0.006*	P=0.026

Table 5. Inferential statistics using the Mann-Whitney Test to explore differences between 2 groups (40 & 60 µm) according to location.

	Buccal margin	Lingual margin	Mid-occlusal	Buccal axial	Lingual axial
Mann-Whitney U	31	13	25.5	23	47
Wilcoxon W	59	68	80.5	59	102
Z	-0.39	-2.797	-1.853	-1.51	-0.227
Significance* (P≤0.017)	P=0.696	P=0.005*	P=0.064	P=0.131	P=0.821