Verification for Implant Supported Dental Prostheses: Evaluation of Gap Distance and Polymerization Time

BY

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THESIS

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I dedicate this thesis to my family who has encouraged me to pursue specialty training in Prosthodontics and a Masters of Science degree.
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<tr>
<td>FDP</td>
<td>Fixed Dental Prosthesis</td>
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<td>ISFDP</td>
<td>Implant Supported Fixed Dental Prosthesis</td>
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<td>SD</td>
<td>Standard Deviation</td>
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<td>TCE</td>
<td>Thermal Coefficient of Expansion</td>
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SUMMARY

One of the essential elements of fabricating an implant supported fixed dental prosthesis is the accurate transfer of intraoral implant position to a working laboratory cast. Incorrect verification of the implants can lead to an ill-fitting, non-passive framework of incorrect orientation over the abutments or on the implant fixtures (Eckert et al 2010, Duyck and Naert 2002, Hjamarsson et al. 2010, Eliasson et al. 2010). This non-passive fit will result in complications such as screw loosening, screw fracture, or damage of the dental implants (Jemt 1997).

Recent literature investigated the effect of splinted and non-splinted impression techniques on the accuracy of fit of fixed implant prostheses in edentulous patients (Papaspyridakos et al., 2011). It has been suggested that splinted impression copings lead to a more accurate working cast than the non-splinted technique (Papaspyridakos et al. 2011, Vigolo et al. 2003, Filho et al 2009). However, many authors do not address the technique used to section the assembly to relieve residual stresses or the amount of time allowed for polymerization to occur prior to the removal of the verification jig from the implant fixtures. The purpose of this in vitro study was to determine if the width of added polymerizing pattern resin between implant analogs and time to polymerization affects accuracy in the verification of implant location when connecting impression copings for a simulated fixed implant prosthesis.

A master model was fabricated using two Dentsply/AstraTech implant replicas at the same height embedded in Fuji Rock (GC Europe, Belgium). The replicas
were spaced 17mm apart from the most inner portion. AstraTech implant pick-ups (open tray impression copings) were attach to the replicas and torqued to a value of 10 Ncm. A prefabricated GC resin (GC America, IL, USA) acrylic cylinder with the standardized dimensions of 16mm (+/- 0.1mm) length and 5mm in diameter was attached to implant impression pick-ups using the Nealon technique (Nealon, 1952) with GC pattern resin on a standardized Teflon jig. The assembly was allowed to polymerize for 24 hours before testing. Measurements using an optical projector microscope (Nikon, Japan) with a movable table and digital display, capable of making measurements to 1μm, was made of each assembly after 24 hours at 8 points between impression copings.

Eighty specimens were fabricated in total. Specimens were separated into eight different sample groups with 10 specimens in each group: polymerization for 17min for 1mm, 3mm, and 5mm vertical gap distances; polymerization of 17min for 1mm horizontal gap distance; polymerization for 17 min of a 1mm 45 degree diagonal gap distance; and 3, 10, and 17 minute polymerization time for a 3mm vertical gap distance. Each specimen was sectioned as determined by the sample group using a miniature table saw of standardized width. The two segments were then placed on the master model and torqued to 10 Ncm. GC pattern resin was added to the specified gap using the Nealon technique and allowed to polymerize for the predetermined test time. Impression copings with the newly luted GC pattern resin cylinder were removed from the master model and measured. Post-luting measurements were compared to initial, pre-luting measurements for each specimen and calculations were made to determine
amount of distortion observed. Statistical analysis was performed using paired t-test.

The pair t-test revealed a trend towards statistically significant changes comparing the post-variable measurements to the pre-variable measurements for the 1mm, 3mm, and 5mm vertical gap distances (p=0.29, p=0.06 and p=0.02 respectively). There was no statistically significant change associated with the luting orientation of the gap distance or time to polymerization for a 3mm vertical gap distance.

The results of this study are consistent with other studies in literature suggesting that the gap distance should be minimized to reduce the amount of polymerization shrinkage associate with autopolymerizing resin. Within the confines of this study, the authors can conclude that the gap distance should be confined to less than 1mm to minimize the distortion when verifying implant location and splinting for final impression. Orientation and direction of the gap distance has no significant effect on the distortion. Polymerization time of 3 minutes, as per manufacturer instruction, is acceptable for accuracy, as increased polymerization time did not result in any less distortion for a 3mm vertical gap distance.
1. INTRODUCTION

1.1 Background

One of the essential elements of fabricating an implant supported fixed dental prosthesis is the accurate transfer of intraoral implant positioning to a working laboratory cast. Incorrect verification can lead to an expensive, ill-fitting, non-passive framework over the abutments or the fixtures. A non-passive fit will lead to complications such as rocking of the prosthesis, screw loosening, screw fracture, and damage of the dental implants (Jemt, 1997). The passively fitting prosthesis was one that was introduced by Branemark and his colleagues to address the osseous support provided by osseointegrated dental implants (Branemark et al., 1977). Unlike natural teeth, which may move up to 100um due to the surrounding periodontal ligament, an implant has limited movement in the range of 10um (Assif et al. 1996). According to some authors, osseointegrated dental implants cannot accommodate distortion or misfit at the implant-abutment interface (Karl et al. 2004). Although a completely passive prosthesis on implants is unlikely (Karl et al. 2004), authors like Jemt (1996) and Monteiro (2010), suggest that a certain level of tolerance is acceptable. Investigators have attempted to obtain the “ideal” or “passive” prosthesis but inaccuracy of the components, machining tolerances, preload, and flexure in the mandible has contributed to the misfit potential (Wee et al. 1999). Although, there is a certain degree of misfit potential built into the implant fixtures, implant companies are unable to disclose this proprietary information. Regardless, the
misfit must be minimized to obtain “passivity” in the restoration. Recent literature investigated the effect of splinted and non-splinted impression techniques on the accuracy of fit for fixed implant prosthesis in edentulous patients (Papaspyridakos 2011). The investigators found that the splinted impression technique generates a more accurate master cast compared to its non-splinted counterpart. Many authors agree that the splinted technique does improve accuracy but they do not address the technique used to section the assembly to relieve residual stresses of the polymerizing resin or the amount of time allowed for polymerization to occur (Vigolo 2003, Filho 2009). The purpose of this in vitro study was to determine if the width of added polymerizing pattern resin between implant analogs and time to polymerization affects accuracy in the verification of implant location when connecting impression copings for a simulated fixed implant prosthesis.

1.2 **Significance**

The significance of this study is to aid in the development of a clinical protocol for implant verification technique. This study further identifies the amount of distortion due to polymerization shrinkage of autopolymerizing resin on the implant system. Lastly, the amount of distortion identified may aid in the development of implant systems that allow for increased tolerance and still maintain “passivity” and ideal connection.
1.3 **Specific Aims**

The specific aim of this study is to determine whether the width of added polymerizing pattern resin between implants impression copings and time to polymerization affects the accuracy in the verification of implant location. Five different gap distances and luting orientations of polymerizing pattern resin were evaluated: 1mm, 3mm, and 5mm vertical gap distances; 1mm diagonal gap distance; and 1mm horizontal gap distance. Three different polymerization times were evaluated for a 3mm vertical gap distance: 3 minutes, 10 minutes, and 17 minutes. The three-minute polymerization time was utilized as per manufacturer instruction for GC pattern resin (GC America). The seventeen-minute polymerization time was also used because studies indicate that most of the polymerization shrinkage occurs by the 17 minute time point (Mojon et al. 1990).

1.4 **Hypothesis**

The alternative hypothesis in this investigation is that impression copings luted together using GC pattern resin will have residual stresses from polymerization shrinkage resulting in distortion of the implant replica location. This distortion is directly proportional to the amount of fresh material required to bridge the connection and inversely proportional to the time allowed for the resin to polymerize. Furthermore, diagonal and horizontal samples will have statistically significant less distortion in the x-direction.
The null hypothesis in this study is that there are no statistically significant differences with respect to amount of fresh material and time to polymerization between sample groups.
2. REVIEW OF LITERATURE

2.1 Accuracy of Implants and Misfit

Dental implants have been used successfully in the treatment of partial and complete edentulism (Branemark 1977). Many authors have suggested that the implant supported fixed dental prosthesis (ISFDP) should fit passively on the implant fixture (Branemark 1977, Jemt 1996). The lack of passivity would increase the chances of complications to the osseointegrated implant and prosthesis. A natural tooth can move up to 100um due to its surrounding periodontal ligament and can tolerate a small degree of misfit for tooth-borne FPDs (Assif, 1996). An osseointegrated implant however, has limited movement of 5-10um (Assif, 1996). The process of taking an impression, attaching analogs, and pouring a stone cast to replicate the intraoral condition introduces error that may lead to misfit of 20um to 180um of the prosthesis (Spector, 1990). This misfit may further lead to inadequate seating of the prosthesis, uneven force distribution, prosthetic screw loosening, screw fracture, and catastrophic prosthesis failure (Albrektsson 1986).

A study by Binon et al. in 1995, looked at the machining accuracy and consistency of implants, abutments, and analogs by determining a composite score and rotational discrepancy. The author found that there is significant variation in machining accuracy and consistency. The length and diameters can differ by 10-80um from their ideal length and diameter; the rotational discrepancy
ranged from 1.4 to 10.1 degrees. The composite score for implants ranged from 0.014 to 0.151, with the greatest accuracy coming from the smaller value. The authors concluded that there is significant variation with respect to different implants and different manufacturing batches. Overall, close tolerances can be obtained and as technology improves, inaccuracies will continue to decrease.

Another study by Ma et al. (1997) looked at the machining tolerances between Nobel Biocare implant components (abutments, gold cylinders, impression copings, and abutment replicas). The authors found that the measured tolerances between implants and their components ranged from 22um to 100um. Ma et al. further advised that machining tolerances should be “included in future studies of accuracy because it is an inherent characteristic of the component itself.”

Karl et al. in (2004) provided an in vitro study on the passive fit of ISFDP. The objective in the authors’ study was to quantify the strain of various screw-retained and cement-retained fixed partial dentures (FPD) or fixed dental prosthesis (FDP). The authors in this study used three ITI implant abutments and two pontics anchored in a straight-line configuration. String gauges were mounted close to the implants and on the pontics sites, and the developing strains were recorded during screw fixation and cementation. The authors in the study found that there was a considerable amount of strain, with no significant difference between the type of prostheses, cement versus screw retention. The authors concluded, ‘an absolute passive fit of superstructure is not possible using
conventional clinical and laboratory procedures as clinical fit-evaluation methods often do not detect “hidden” inaccuracies.’

Dias et al 2012, evaluated the implant-abutment microgap and bacterial leakage in five external-hex implant systems. The authors in this study inoculated samples with E.coli to determine bacterial leakage and subsequently found that only one of the five implant systems had 25% bacterial infiltration into the microgap. All systems had average gaps less than 3um with misfit values ranging from 0-18.4um in discrete areas of the junction between the implant and abutment. This demonstrates that there is a tight fit with respect to the manufactured implants and abutments to prevent bacterial infiltration and misfit levels in the 0-18um range.

A study by Eliasson et al. 2010 evaluated the precision of fit of milled titanium implant frameworks on Branemark external hex and Nobel Replace internal connection systems. The authors fabricated test frameworks for master models and used a contact type coordinate measuring machine to compare differences in distortion in three axes. The authors found that the maximum distortion in arch width and curvature was fewer than 71 and 55 um respectively for all frameworks. The Nobel Replace frameworks demonstrated a higher range of misfit values of 71um while the external hex Branemark implants demonstrated a range of 25um. The level of misfit range in the vertical z-axis was 10-11um for both implant types. The most significant misfit was in the x- and y- directions. The authors concluded from the study that no framework had a
passive fit but all measured frameworks presented levels of fit that were clinically acceptable.

The level of acceptable vertical misfit has not reached a consensus but most are in the range of 30 to 150 um (Jemt et al. 1995). According to literature, a vertical gap of 50-100 um is what is clinically detectable by the human eye (Riedy et al. 1997). Authors like Hobkirk (1995) and Chesire (1996) have demonstrated that variable tightening of the prosthetics screws contributes to the variable vertical gap observed in studies.

A study by Jemt in 1996 evaluated the in vivo fit of implant-supported prostheses in the edentulous jaw by using the master cast replicas and the intraoral implants as references. The authors surveyed seven maxillary and 10 mandibular casts and prostheses. When the master casts were used as a reference, the average 3D distortion was 37um and 75um for mandibular and maxillary prosthesis, respectively. When the intraoral implants were used as a reference, the distortion was 90um and 111um, respectively. The distortion ranged from as little as 9um to as much as 296um. The authors concluded that prostheses connected to osseointegrated implants could demonstrate distortions between the framework and the implants of up to several hundred microns (Jemt, 1996).

The ideal or passive fitting framework is something to strive for. According to the literature above, there is a substantial range of errors in the manufacturing of implant components, fit of different components, and the techniques used to create working models. According to Karl et al (2004), an absolute passive fitting
prosthesis is not possible with our current clinical and laboratory techniques. However, the misfit of the implant, abutment, and prosthetic components must be minimized to prevent stresses to the implant and prosthetic components and future clinical complications associated with the patients.

2.2 **Open versus Closed Tray Impression Techniques**

There are two impression techniques commonly used to fabricate a working laboratory cast: open tray, pick-up type impression copings and closed tray, transfer impression copings. The former is designed so that the impression coping is embedded or “picked-up” in the impression material while the latter is initially screwed down to the implant and must be “transferred” from the implant to the final impression after setting of the impression material. The open tray is also known as a direct impression coping and closed tray is also known as indirect. The impression determines the position of the implant in an occlusal-gingival, mesial-distal, and facial-lingual orientation and thus orients the implant position in relation to the other implants, the dentition, and the anatomical structures.

A systematic review was published in 2008 by Lee et al. regarding the accuracy of implant impressions techniques and examined the clinical factors affecting implant impression accuracy. An electronic search was performed and 41 articles were selected for review. The articles selected were all in vitro studies. Seventeen studies compared the accuracy between splint and non-splint techniques, 7 advocated using the splinting technique, 3 advocated the
non-splinting technique, and 7 reported no difference. Fourteen studies compared the accuracy of open versus closed tray techniques. The authors found that 5 studies demonstrated more accurate impressions with the open tray/pick-up technique while two reported more accurate impressions with the closed tray/transfer technique. Seven reported no difference. The authors found that the number of implants affected the open versus closed tray technique, as well as the splint/non-splint comparison. For cases where there were three or fewer implants, most studies showed no difference between the open tray and closed tray techniques. For cases with four or more implants, more studies demonstrated higher accuracy with the open tray technique.

Another aspect in the Lee et al. article comparison involved straight versus angled implants. The authors found that two studies reported higher accuracy with the straight implants while two reported that angulation had no significant effect on impression accuracy. Finally, the authors concluded that there was no difference between the use of Poly-vinyl siloxane (addition silicone) and polyether impression material.

A consideration of the open tray impression technique is the location and angulation of the implants. A study by Sorrentino et al. 2010, evaluated the accuracy of implant impression made with different materials, lengths of impression copings, and angled implant position using an open tray impression technique. The authors concluded that that the “presence of undercuts negatively affects the precision of the impression. The angulation of the implants may cause strains in the impression, probably because of higher forces required
for impression removal. In the presence of non-paralleled implants, the use of addition silicons resulted in more accurate casts.”

Carr (1991), compared open (direct) versus closed (indirect) impression techniques to develop a working cast for a five implant mandibular cast. The comparison was made using a dental cast framework fitted to the master cast. Differences were measured between each group and the master cast. The author found that the direct technique produced a more accurate working cast and that inaccuracies in the indirect technique were correlated with the non-parallel implants (greater than fifteen degrees) and deformed the impression material.

Based on the literature, the open tray (direct) technique is more widely considered as accurate when taking final impressions. The inaccuracies of the closed tray, indirect, transfer technique lies with the angulations of implants and the number of implants that must be impressed as well as increased chance of mobility in the impression material.

2.3 Splinted versus Non-Splinted Techniques

A study by Assif et al. 1992 looked at the effects of splinted and non-splinted impression techniques using different impression materials and impression copings. The authors in this study fabricated Duralay resin (Duralay, Reliance Dental) doughnuts on five impression copings, allowed it to set for 24 hours, and maintained a 1mm space between the copings. Fifteen minutes before the impression was taken, the doughnuts were luted together. The first
group utilized the open-tray splinted technique with alginate impression material in a stock tray. The second group utilized the same open tray luting technique with use of polyether impression material in a custom tray. The third group utilized square transfer (open tray) copings with polyether impression material in a custom fabricated acrylic tray. The last group utilized a closed tray technique. The accuracy of the impression was assessed manually and under a microscope. The authors concluded that the most accurate and reliable impression procedure used acrylic resin to splint the impression copings. There was no significant difference between the impressions of the splinted copings using polyether or alginate impression material. The authors further state that if the splinting technique is being utilized, the impression material and tray design can be modified as needed for soft tissue recording, material stability, and convenience. The splinting technique in this study was significantly better than both the open and closed tray techniques. The authors further concluded that impression copings embedded in the impression material is more accurate. The majority of specimens fabricated using the closed tray technique were deemed unacceptable.

A study by Filho et al. 2009, evaluated different splinting techniques for implant impressions. The authors in this study compared four different techniques involving floss and autopolymerizing acrylic. The first group involved a direct technique with square copings without joining with autopolymerizing resin; the second involved square copings splinted with dental floss and autopolymerizing acrylic resin; the third group involved copings splinted with floss
and autopolymerizing resin that were connected then sectioned and then splinted again; and the last group involved square copings splinted with a prefabricated acrylic resin bar as described by Dumbrigue (2000). The group without splinting demonstrated the most deviation from the control and there was a decrease in the amount of error from group two to four. The authors concluded that splinting of impression copings is indicated for implant impressions, with the prefabricated acrylic resin bar presenting the most accurate splinting technique.

Vigolo et al. 2003 evaluated the accuracy of 3 different impression techniques to obtain a working cast for the fabrication of a passively fitted prosthesis. A machined metal model with six implants and abutments and a corresponding, passively fitting, matching metal template were fabricated. A total of forty-five impressions were made and divided into 3 groups: group 1, non-modified impression copings; group 2, impression copings joined together with autopolymerizing acrylic resin before the impression procedure; group 3, particle abraded impression copings with impression adhesive. The impressions were poured. Then the metal template was placed onto the poured model and visually inspected for misfit and rocking by a single, blinded examiner. An optical scanner was also used to determine the positional accuracy of the abutments. The authors concluded that the accuracy of the master cast could be achieved by splinting the impression copings using autopolymerizing acrylic resin.

Another study by Vigolo et al. in 2004 evaluated the accuracy of three different impression techniques. A reference acrylic resin model with four internal connection implants was fabricated. Forty-five polyether impressions
were taken, with fifteen impressions in each group. The first group used non-modified, square, open-tray impression copings; the second group used square, open-tray impression copings joined together with autopolymerizing acrylic resin; and the third group used square, open-tray impression copings that had been airborne-particle abraded and coated with impression adhesive. The impressions were poured in ADA type IV stone and the position of the implant replica heads were evaluated by a single blinded, calibrated examiner using a profile projector. Vigolo et al. found that there was improved accuracy of the working cast when the impression copings were joined together with resin compared to the airborne particle abraded and non-modified copings for internal connection implants.

Papaspyridakos et al. 2011 provided a comparative study on the effect of splinted and non-splinted techniques on the accuracy of fit for a complete arch ISFDP. This clinical study included thirteen edentulous arches rehabilitated with a complete arch ISFDP. The implants were placed using a computer-guided, prosthetically driven approach. Splinted and non-splinted pick up impressions were made of each arch to generate two different casts. An intraoral verification jig was fabricated to make an index cast, which served as the control group. All patients were rehabilitated using one-piece, full arch, zirconia prosthesis. These prostheses were fitted on the generated index cast and casts made from the splinted and non-splinted techniques. The authors found that twelve of the thirteen splinted casts had accurate fit while only six of the thirteen of the non-splinted casts had accurate fit. The framework fit accurately on the control
group. The authors concluded that there is a statistically significant improvement in the accuracy of casts generated using the splinted impression technique compared to the non-splinted technique for a complete-arch, one-piece ISFDP.

Papaspyridakos et al. 2012 compared the three-dimensional accuracy of splinted and non-splinted impression coping techniques to a control cast and its corresponding verification jig and prosthesis. The authors also determined the maximum level of clinical undetectable misfit allowed in a prosthesis. Implant casts from twelve edentulous jaws restored with CAD/CAM zirconia implant supported fixed dental prosthesis were included. Intraoral acrylic jigs were used to fabricate index casts. Two casts were generated using the splinted and non-splinted techniques. The implant positioning on each casts were determined using optical scanning acquisition. Computer software was used to superimpose the scanning datasets from the splinted and non-splinted groups compared with the intraoral jig casts. The authors in this study found that the splinted technique generated the most accurate master cast compared to the casts using the non-splinted technique. This translates into improved accuracy and passivity when using the splinted technique. The authors also concluded that for external connections, the implant misfit ranged from 59 to 72um and considered this the maximum discrepancy resulting in an acceptable clinical fit with a one piece implant supported fixed complete dental prosthesis.

Based on the above recently published in vitro and in vivo literature, authors advocate the use of the open tray splinted technique to improve the
accuracy of the working laboratory cast for the fabrication of an implant-supported fixed dental prosthesis.

2.4 **Techniques for Splinting**

There are different splinting techniques discussed in the literature (Assif 1996, Dumbrigue 2000, Lee 2011, Tiossi, 2012). Some authors have splinted impression copings together using autopolymerizing or light polymerizing resins, while others have splinted the copings to the impression tray. A study by Assif et al. (1996) evaluated the accuracy of implant impression techniques by comparing the splinting of transfer copings with autopolymerizing acrylic resin to splinting transfer copings directly to a custom tray. The control group only used impression material to orient the transfer copings. The accuracy of these techniques was measured against a master framework fabricated on the original master cast. The fit of the framework on the working casts were tested using strain gauges. The authors found that the autopolymerizing acrylic resin splinting technique of the transfer coping in the impression technique was significantly more accurate than the other techniques.

Dumbrigue et al. (2000), looked at prefabricating acrylic resin bars for splinting implant transfer copings. The rational behind prefabricating resin bars is to minimize the resin polymerization shrinkage upon connection to the impression copings. This technique involved mixing and syringing GC pattern resin into a drinking straw, allowing it to set for 24 hours, and then cutting the resin bar to the required length for luting. This technique was adopted in part in this present study to minimize the polymerization shrinkage of the initial set up.
Lee et al. 2011 used open tray (direct) square impression copings splinted with different materials and techniques to determine its accuracy. The first group was splinted with autopolymerizing resin utilizing the sectioning process to allow for compensation of polymerization shrinkage; the second involved splinting without sectioning; the third group involved a primary impression with impression plaster and a secondary impression with polyether; the fourth group had impression coping splinted with impression plaster; and the final group splinted the impression copings with polyvinylsiloxane (PVS) bite registration material. The authors concluded from this study that splinting impression copings with autopolymerizing resin following compensation of shrinkage by the sectioning process and impression plaster use could enhance the accuracy of the master cast.

A study by Tiossi et al. in 2012, evaluated the vertical misfit of a cast implant supported prosthesis. The authors fabricated three nickel-chromium frameworks. The first specimen was cast in one piece; the second was casted in one piece, sectioned diagonally and laser welded; and the last was cast as sectioned segments and laser welded. The authors in this study determined that casting diagonally sectioned frameworks and sectioning a one-piece framework lowers the observed misfit levels.

Overall, studies have utilized many different types of materials to splint impression copings. Most advocated the use of an autopolymerizing resin with sectioning to compensate for material shrinkage as it has been demonstrated to
achieve the best accuracy. The last study by Tiossi reinforces the concept that splinting improves accuracy of the prosthesis.

2.5 **Material Selection for Verification**

Mojon et al. in 1990, investigated the effect of polymerization shrinkage on index and pattern acrylic resins. The purpose of the study was to evaluate the dimensional change of two self-curing acrylic resins. Early volumetric changes were evaluated using a diatometer and linear changes were evaluated using an inductive transducer. Ten cylindrical specimens, 8mm long and 6mm in diameter, were created for each group. The testing began at 17 minutes, due to the lack of hardness of the material, and continued for 24 hours. The authors concluded that after twenty-four hours, the volumetric shrinkage was 7.9% for the Duralay resin and 6.5% for Palavit G resin. The investigators in this study found that 80% of the change occurred at 17 minutes at room temperature with shrinkage increasing as the proportion of powder in the mixture was decreased. Ninety-five percent of the shrinkage occurred mainly in the first 3 hours with minimal shrinkage after 24 hours.

A study performed by De La Cruz in 2002, looked at different materials for the verification of implants. The investigators in this study compared the dimensional accuracy of three different resin verification materials to both open and closed try impression techniques. Thirty verification jigs were fabricated, with 10 specimens per group: (Group 1) Jig fabricated with GC pattern resin; (Group 2) Jig fabricated with Duralay resin; (Group 3) Jig fabricated with Triad
gel resin. Twenty standard impressions were taken: (Group 4) Impression: closed tray technique and (Group 5) Impression: open tray technique. The master model stone base and experimental stone base from the five groups were measured using a travelling microscope to determine the implant location. Within the confines of this study, the authors determined that Duralay jigs significantly exhibited greater distortion than the open and closed tray impressions and triad gels had a significant horizontal distortion. The authors concluded that verification jigs were not significantly more accurate than closed tray impressions.

Assif et al in 1999, performed a study evaluating the accuracy of implant impression splinted technique with different materials. The authors in this study looked at autopolymerizing acrylic resin (Duralay), dual-cure acrylic resin, and impression plaster. A metal implant master cast was created with an implant metal framework. A total of fifteen impressions were taken. The impressions after placement of the implant analog and pouring were analyzed against the implant metal framework using strain gauges. Statistical analysis revealed that there was a statistically significant difference between the autopolymerizing resin to the dual cure resin and the impression plaster to the dual cure resin. There was no difference between the autopolymerizing resin and the impression plaster. The authors concluded that as a splinting material, autopolymerizing acrylic resin and impression plaster were significantly more accurate than the dual-cure acrylic.
Authors have also advocated splinting utilizing old burs. Avila et al. 2012, examined the effect of splinting using burs in the accuracy of two implant impression techniques. The authors in this study fabricated a master cast with four parallel implant abutment analogs and a passive metal framework. Two groups with five casts were fabricated: group 1 – squared impression copings with no splint and group 2 – splinted squared impression copings using metal drill burs and pattern resin. Impressions were made using polyvinylsiloxane utilizing the open tray technique. The authors found that there was a statistically significant difference between the two test groups. Within the confines of the study, the splinted method using the drill burs yielded more accurate results than the non-splinted counterpart.

Papazian et al. 1998, described a technique utilizing 1.5mm thick aluminum strips that are luted to the implant components prior to impression making. The use of two aluminum strips creates a metal framework that is rigid and difficult to distort. The aluminum strips are luted using Zapit adhesive, a cyanoacrylate, or autopolymerizing resin. The authors stated that this technique is more accurate than the wire bending technique, as it does not have elastic memory from the wire bending. The added benefit of this technique is that it limits the amount of polymerization shrinkage to the connection portions when using autopolymerizing resin and has increase rigidity due to the thickness of two aluminum strips.

Other investigators also compared autopolymerizing acrylic resins to bite registration addition silicone and bite registration polyether (Hariharan, 2010).
These investigators concluded that impressions made with the splinted technique using polyether bite registration material were the closest to the master model followed by autopolymerizing resin. The authors further concluded that the differences between the test groups were statistically similar to each other and consistent with that of the current literature.

A recent study by Yamamoto et al 2010, evaluated the accuracy of four impression techniques for osseointegrated implants with or without acrylic resin splinting. A master model was fabricated with three implant analogs. Two impression materials, irreversible hydrocolloid and PVS, and two transfer techniques were used, splinted and non-splinted indexed impression copings. The authors found that irreversible hydrocolloid demonstrated the largest misfit and that the splinted impression copings generated a smaller marginal gap than the non-splinted technique, irrespective of the material used. The authors also reported that there was no significant different between the irreversible hydrocolloid with splinting, PVS without splinting, and PVS with splinting. One thing to note is that the standard deviation (SD) was three times lower in the PVS with splinting group and its mean was closer to the reference. Although the authors could not report a statistical significance, the evidence suggests that splinting with PVS reduces the variance and produces an accurate impression of the reference.

Literature has suggested that many different types of materials can be used to splint impression copings prior to final impression and also to verify implant location. Verification jigs and final impressions have been fabricated
using aluminum strips, old burs, bite registration material, cyanoacrylate, dual-cure resin, triad gels, and autopolymerizing resin. Most studies have concluded that the use of autopolymerizing resin generated the most accurate impression and working casts. Even with its polymerization shrinkage, pattern resin can be manipulated in a way that allows for splinting of impression copings and accurate verification of implant location for a working cast.
3. METHODOLOGY

This study was designed to evaluate two aspects of implant verification using autopolymerizing acrylic resin:

1. Gap Distance
2. Polymerization Time

3.1 Study Design Overview: Gap Distance

The design of the Gap Distance study can be visualized in Fig.1. Fifty specimens were fabricated using the method described in section 3.5. These specimens were placed on a custom fabricated measurement jig (Appendix B) and measurements were made from 4 points on the first open tray (direct, pick-up) impression coping to the corresponding 4 points on the second impression coping using a Nikon Profile Projector V-12 (Nikon, Japan) (Fig.3). These initial measurements serve as the pre-test measurements. The fifty specimens were then divided into 5 gap distance test groups: 1mm vertical gap distance, 3mm vertical gap distance, 5mm vertical gap distance, 1mm 45 degree diagonal gap distance, and 1mm horizontal gap distance. The specimens were sectioned according to the assigned sample group and luted on the master model using fresh GC pattern resin for the predetermined time of 17 minutes. Following polymerization, test specimens were then transferred to the measurement jig and measurements were taken at the indicated 8 points.
3.2 **Study Design Overview: Polymerization Time**

The design of the Polymerization Time study can be visualized in Fig.2. Thirty specimens were fabricated using the method described in section 3.5. These specimens were placed on the measurement jig and measurements were made from 4 points on the first open tray (direct, pick-up) impression coping to the corresponding 4 points on the second impression coping using a Nikon Profile Projector V-12 (Nikon, Japan). These initial measurements serve as the pre-test measurements. The thirty specimens were then divided into 3 polymerization time test groups with a vertical gap distance of 3mm for all sample groups: 3-minute polymerization time, 10-minute polymerization time, and 17-minute polymerization time. The specimens were then luted on the master
model using the Nealon technique for the predetermined time and allowed to rest for 24 hours on a flat laboratory bench prior to measurement. Following polymerization of 24 hours, test specimens were then transferred to the measurement jig and measurements were taken at the indicated 8 points.

Figure 2 - Study Design: Polymerization Time
3.3 Master Model Fabrication

A single master model was fabricated with two Dentsply/Astra Tech 3.5/4.0 diameter implant analogs spaced 20.5mm apart from the center and equal in height (Fig. 3). To ensure the accuracy of the master model, a standardization jig made from Teflon was fabricated using CAD/CAM technology. Two tapering holes on the standardization jig were placed 22.5mm apart to allow for the precise fit of two open tray impression copings connected to the analogs. This allowed for the impression copings to be spaced 17mm from the inner edge of one coping to the other. Type IV dental stone, Fuji Rock (GC America, USA), was then mixed using manufacturer specification and poured on a vibrating plate to embed the analogs (Fig. 4). The master model was allowed to set for 1 week prior to specimen fabrication and testing.
3.4 **Acrylic Cylinder Fabrication**

Acrylic cylinders 5mm in diameter were fabricated using a standardized Teflon fabrication jig with a cylindrical hole 5mm in diameter and 17mm in length. GC pattern resin was mixed in a flexible silicone dappen dish at a 1:1 polymer to monomer ratio. The GC pattern resin was then loaded into a plastic monojet syringe. The contents were syringed into the Teflon cylinder jig and allowed to set for 24 hours (Fig.5). After the determined setting time, the pattern resin cylinder was pushed out of the fabrication jig using an aluminum push-out pin and table (Fig.6). The pattern resin cylinders were then trimmed to 16 mm +/- 0.1mm using a diamond coated sectioning disk (Fig. 7) and verified using a Neiko digital caliper (Neiko, USA) accurate to 0.02mm. The specimens were trimmed to a length of 16mm +/- 0.1mm to allow the cylinder to fit between the impression copings with sufficient space for luting using the Nealon technique (Nealon, 1952).
Figure 5 - Fabrication of GC Pattern Resin Cylinder in Teflon Fabrication Jig.

Figure 6 - GC Pattern Resin Cylinder on Aluminum Table with Push-out Pin.

Figure 7 - Fabricated GC Pattern Resin Cylinders.
3.5 Fabrication of Test Specimens

The standardization jig was placed onto the implant analogs in the master model. Impression copings were attached to the analogs and torqued to 10 Ncm. The standardization jig was fabricated with a half cylindrical cut out to rest the pre-fabricated resin cylinder in the designed location between the two impression copings spaced 17mm apart (Fig.8). The resin cylinder was connected to both impression copings using autopolymerizing resin of the same material, GC pattern resin, utilizing the Nealon technique as described in the literature (Nealon, 1952). The specimens were allowed to autopolymerize for 24 hours prior to initial measurements and testing (Fig. 9a). This process was repeated for 80 of the specimens tested. The 1mm horizontal test group in the Gap Distance study required lengthwise sectioning of the resin cylinder to 75% of the length, or 12mm, prior to luting to the impression copings (Fig.9b). After initial measurement of the horizontal specimens, two vertical sections 5mm apart were made to allow for testing in the horizontal direction (Fig.9c). All other steps involved with the fabrication of the horizontal specimens were consistent with the remaining test group samples.
Figure 8 - Specimen Fabrication. Prefabricated Pattern Resin cylinder resting on the standardization jig.

Figure 9a - Test Specimen on Master Model.

Figure 9b - Horizontal Gap Specimen.
3.6 **Experimental Method**

**Measurement Calibration**

A standard 3mm gage block (National Institute of Standards and Technology) of known length was chosen for investigator calibration. A 3mm gage block was placed on the Nikon Profile Projector microscope V-12 (Nikon, Japan) at 20x magnification capable of making measurements to 1um. A total of six measurements were made of the known length. The measurement accuracy of the investigator was determined to be 1um+/-1.2um. All measurements for this calibration exercise were made at 22 degree Celsius.

**Measurements**

All eighty specimens were fabricated as described in section 3.5. The specimens were placed on a custom fabricated measurement apparatus oriented with the pre-polymerized resin cylinder parallel to the horizontal plane. The measurement apparatus with the specimen in place was then mounted to the Nikon Profile Projector microscope and screwed down to prevent movement.
while measurements were made (Appendix B). The Nikon Profile Projector provided data in x- and y- coordinates. These coordinates were in the units of microns (um). The digital coordinate system was zeroed on a reference point on the measurement apparatus. To ensure that the specimens were placed in the same position for both the pre- and post-measurement, coordinates were taken at the bottom left ledge of the first impression coping. This coordinate confirmed that the specimen was in the correct orientation. The microscope was zeroed again and co-ordinates were taken at the 4 points in the horizontal view with the bottom left serving as the coordinates (0,0) (Fig.3, Fig.10). The measurement apparatus was then rotated to the top view, as seen in Fig.3. The microscope was zeroed on an edge of the measurement apparatus, which served as the reference point for the top view. Coordinates were taken of a point on the bottom left and zeroed again. Four measurements were taken at the intersect of the edges of the impression coping (Fig.11). This was repeated for all 80 specimens.
Figure 10 - Specimen set up for Measurement from the Side View. Specimen is mounted to the measurement apparatus that is fixed to the moveable table of the Nikon microscope.

Figure 11 - Specimen set up for Measurement from the Top View.
The samples were divided as follows: 50 for the Gap Distance study and 30 for the Polymerization Time study.

**Gap Distance Study**

Fifty specimens were utilized for the Gap Distance study divided into 5 different sample groups: 1mm vertical gap distance, 3mm vertical gap distance, 5mm vertical gap distance, 1mm 45 degree diagonal gap distance, and 1mm horizontal gap distance (Fig.12-16). Two custom sectioning jigs were fabricated for the experiment. The first allowed for accurate cuts in the vertical direction (Fig.17); the second allowed cuts in the diagonal and horizontal directions (Fig.18). After baseline measurements were taken, the specimens were fixed to the cutting jig via flat-ended brass screws and sectioned to the predetermined gap distance on a miniature table saw. The table saw blade had a width of 0.38mm. Two custom fabricated measurement blocks held the jig in place for each test group and the specimen was passed through the blade twice to obtain the correct gap distance. One block allowed for the section on the left side while the other cut the resin again from the right (Fig.19). The width was then checked using calibrated standardized Gage Blocks (National Institute of Standards and Technology) while still fixed to the cutting jig to confirm gap distance (Fig.20).
Figure 12 - Gap Distance Study - 1mm Vertical Gap Distance

Figure 13 - Gap Distance Study - 3mm Vertical Gap Distance
Figure 14 - Gap Distance Study - 5mm Vertical Gap Distance

Figure 15 - Gap Distance Study - 1mm Diagonal Gap Distance
Figure 16 - Gap Distance Study - 1mm Horizontal Gap Distance

Figure 17 - Specimen Fixed to the Vertical Cutting Jig.
Figure 18 – Specimen fixed to the diagonal cutting jig.

Figure 19 – Specimen on Cutting Table. Specimen fixed to vertical cutting jig on the miniature table saw with the right cutting block in place.
After the specimens were sectioned to the predetermined gap distances and orientations, the specimens were placed back on the master model and torqued to 10 Ncm (Fig.21). Fresh GC pattern resin was added to the gap using the brush-on or Nealon technique (Nealon, 1952). Each specimen was allowed to polymerize for 17 minutes after which they were removed from the master model. The specimens were then placed on the measurement apparatus and post-test variable measurements were taken and recorded as described above.
Polymerization Time Study

Thirty specimens were divided into 3 polymerization time test groups at a vertical gap distance of 3mm: 3-minute polymerization time, 10-minute polymerization time, and 17-minute polymerization time (Fig. 22). The identical sectioning protocol for the 3mm vertical gap distance group as described above was applied to these 30 specimens. The specimens were sectioned at a distance of 3mm, torqued to 10 Ncm, and luted on the master model for the predetermined time. After the predetermined time elapsed, the specimens were removed and allowed to rest for 24 hours on a flat laboratory bench top prior to measurement. After the 24-hour polymerization period, the specimens were transferred to the measurement jig and measured as described above. The experimental procedure for both the Gap Distance and Polymerization Time studies were performed at a room temperature of 19-23 degrees Celsius.

Figure 22 - Polymerization Time Study - 3mm vertical gap distance closed with GC pattern resin and allowed to polymerize for 3, 10, and 17 minutes.
3.7 **Statistical Analysis**

Statistical software (R-Project) and Microsoft Excel 2010 were used for statistical analysis. Co-ordinate data measured during experimentation were expressed as micron (um) lengths. Preliminary test for significance measured the difference from the ideal 90-degree rectangle using trigonometry and Pythagorean theorem (Appendix A). Calculations of the error from ideal were performed for the pre-variable measurements and the post-variable measurements. Statistical analysis was performed on the data collected for the post-variable measurements compared to the pre-variable measurements using the paired T-test. Once statistical significance was determined from the preliminary measurements, a comparison of the difference between pre- and post-variable measurements was determined to reveal the amount of change per group and in which direction the change occurred for the statistically significant data. The values were reported as a measurement in microns and a percent shrinkage of the total 17mm distance between the impression copings. A power analysis was also performed to determine the number of specimens required to achieve significance. For all statistical analysis in this study, significance levels reported were at p<0.05.
4. RESULTS

4.1 Initial Test for Significance – Change in Error from Ideal Scenario

Prior to isolating the observed experimental changes into its component lengths from different views, an overview of whether or not the data was statistically significant was determined.

Pre-test variable sum of errors for 80 specimens involved in vertical gap distances and polymerization time were calculated using the Pythagorean theorem and trigonometry as a baseline (Appendix A, Fig.23 - Variable 0). Post-test variable sum of errors were calculated and reported in Figure 23 for the following gap distances: 1mm vertical gap (Variable 1), 3mm vertical gap (Variable 2), and 5mm vertical gap (Variable 3). Post-test variable sum of errors were also calculated for the Polymerization Time Study at a 3mm gap distance: 3-minute polymerization time (Variable 4), 10-minute polymerization time (Variable 5), and 17-minute polymerization time (Variable 6). The values are illustrated as boxplots in Fig. 23. This method of evaluating the change in error from the ideal scenario normalizes all specimens and determines the magnitude of error from the ideal positioning of the coordinate points.
Pre-variable sum of errors were also calculated using the Pythagorean theorem and trigonometry for 30 specimens involved in the orientation aspect of the Gap Distance study (Fig. 24 – Variable 0). It is important to note that the same data set was used for the 1mm Vertical gap in both the vertical gap distance and luting orientation comparisons. Post-variable sum of errors were calculated for the following orientations: 1mm vertical gap (Fig. 24 -Variable 1), 1mm 45 degree diagonal gap (Variable 2), 1mm horizontal gap (Variable 3).
The difference between the post-test variable error and pre-test variable error was taken to determine the amount of changed observed after subjecting the specimens to the test variables of gap distance, gap orientation, and polymerization time (Fig. 25-26). Comparing the sum of error data of test variable groups 1-3 (Vertical Sections) in Fig. 25, demonstrates that there is an increase in the amount of error observed when increasing the gap distance from 1mm to 5mm. The mean error value of the group increases when comparing the different vertical sample groups, as depicted by the solid black line in the
boxplots. Statistical analysis was performed using the paired t-test on the pre- and post-variable data. The results indicated no statistical significance for 1mm and 3mm vertical gaps (p=0.06, p=0.92 respectively) but a statistically significant difference for the 5mm gap distance (p=0.02). Comparing the data of test variables 4, 5, and 6 indicated no statistical significance for the 3-minute, 10-minute, and 17-minute polymerization times (p=0.19, p=0.45, p=0.54, respectively).

Figure 25 – Difference in Error: Pre-Variable to Post-Variable
A comparison of the results was also performed on the luting orientation aspect of the gap distance study. Figure 26 illustrates the difference in error for the 1mm vertical gap distance, 1mm 45-degree diagonal gap distance, and 1mm horizontal gap distance. Statistical analysis performed on this grouping indicated that there is no statistically significant difference with respect to the prescribed luting orientation of the sample (p=0.06, p=0.96, p=0.47, respectively).

Based on the results of this preliminary analysis, statistical significance was observed for a larger vertical gap distance (5mm). Polymerization time of
3, 10, and 17 minutes and luting orientation of the 1mm gap width did not reveal a statistically significance difference among samples.

4.2 **Change in Length – Comparing Post-Test Variable Measurements to Pre-Test Variable Measurements.**

The investigators in this study further evaluated the amount of change that occurred after sectioning and luting of samples with different gap distances. As discussed in section 4.1, statistically significant data was observed when the vertical gap distance increased. The measurement comparisons are illustrated in the schematic in Fig. 27. The distance measurements of all specimens in a test group were first averaged to develop a pre-test mean for the following: 1) Side View: Top Horizontal Measurement, 2) Side View: Bottom Horizontal Measurement and 3) Top View: Horizontal Measurement (Fig. 27). A post-test variable mean was also calculated for the same three measurements. The difference between the post-test mean and the pre-test mean determined the amount of change observed for the test group. The difference between the means is also expressed as a percentage of the overall acrylic length of seventeen millimeters. The top view measurements are longer due to a collar design on the top rung of the Dentsply/Astra Tech impression copings. Significance levels were also reported (Table 1).
Figure 27 – Schematic of the Measurement Points on the Test Specimen.

## Table I

### VERTICAL GAP DISTANCE COMPARISON

<table>
<thead>
<tr>
<th>Variable</th>
<th>Location of Measurement</th>
<th>Pre-Test Mean (SD)</th>
<th>Post-Test Mean (SD)</th>
<th>Change in Mean (SD)</th>
<th>% Change in Length</th>
<th>Significance Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1mm Vertical Gap Distance</td>
<td>Top View Horiz.</td>
<td>26.044mm (0.035mm)</td>
<td>26.054mm (0.049mm)</td>
<td>0.010mm (0.049mm)</td>
<td>0.06%</td>
<td>p=0.24</td>
</tr>
<tr>
<td></td>
<td>Top Horiz.</td>
<td>25.882mm (0.073mm)</td>
<td>25.873mm (0.099mm)</td>
<td>-0.009mm (0.099mm)</td>
<td>0.05%</td>
<td>p=0.29</td>
</tr>
<tr>
<td></td>
<td>Bottom Horiz.</td>
<td>25.889mm (0.060mm)</td>
<td>25.889mm (0.084mm)</td>
<td>0.000mm (0.084mm)</td>
<td>0%</td>
<td>p=0.91</td>
</tr>
<tr>
<td>3mm Vertical Gap Distance</td>
<td>Top View Horiz.</td>
<td>26.030mm (0.017mm)</td>
<td>26.081mm (0.032mm)</td>
<td>-0.012mm (0.032mm)</td>
<td>0.07%</td>
<td>p=0.11**</td>
</tr>
<tr>
<td></td>
<td>Top Horiz.</td>
<td>26.860mm (0.064mm)</td>
<td>25.838mm (0.082mm)</td>
<td>-0.022mm (0.082mm)</td>
<td>0.13%</td>
<td>p=0.06**</td>
</tr>
<tr>
<td></td>
<td>Bottom Horiz.</td>
<td>25.877mm (0.056mm)</td>
<td>25.861mm (0.082mm)</td>
<td>-0.016mm (0.082mm)</td>
<td>0.09%</td>
<td>p=0.01*</td>
</tr>
<tr>
<td>5mm Vertical Gap Distance</td>
<td>Top View Horiz.</td>
<td>26.036mm (0.042mm)</td>
<td>26.010mm (0.056mm)</td>
<td>-0.027mm (0.056mm)</td>
<td>0.16%</td>
<td>p=0.001*</td>
</tr>
<tr>
<td></td>
<td>Top Horiz.</td>
<td>25.850mm (0.072mm)</td>
<td>25.832mm (0.100mm)</td>
<td>-0.018mm (0.100mm)</td>
<td>0.11%</td>
<td>p=0.03*</td>
</tr>
<tr>
<td></td>
<td>Bottom Horiz.</td>
<td>25.882mm (0.073mm)</td>
<td>25.858mm (0.084mm)</td>
<td>-0.023mm (0.084mm)</td>
<td>0.14%</td>
<td>p=0.002*</td>
</tr>
</tbody>
</table>

* Denotes statistical significance. ** Denotes approaching statistical significance.
Results demonstrated that there is an average change ranging from 0 to 10um or 0-0.06% of the overall length for the 1mm vertical gap distance. There is no statistically significant change for the 1mm vertical gap distance for all measurement view points (p=0.24, p=0.29, p=0.91).

The 3mm vertical gap distance demonstrated that the bottom horizontal measurement has a statistically significant (p=0.01) change from the pre-mean value. The top view horizontal measurement and top horizontal values were not statistically significant but approach statistical significance (p=0.11, p=0.06, respectively). The overall observed change for the 3mm vertical gap distance ranges from 12um to 22um or 0.07-0.13% of the overall length.

The 5mm vertical gap distance demonstrated a statistically significant change from pre- to post-variable testing for all measurements (p=0.001, p=0.03, p=0.002) with changes ranging from 18um to 27um or 0.11-0.16% of the overall length.

All test groups demonstrated a decrease in distance due to polymerization shrinkage except the top view horizontal measurement of the 1mm vertical gap distance.
5. DISCUSSION

5.1 Findings of this Study

The purpose of this study was to evaluate the effect of gap distance and polymerization time on the verification of implant location on a working cast for implant supported fixed dental prostheses. The gap distance aspect of the investigation was accomplished by designing a model that tested different vertical gap distances (1mm, 3mm, 5mm) and luting orientations (vertical, horizontal and diagonal). The polymerization time aspect was evaluated at three different time points, 3-minute, 10-minute and 17-minute, all at a constant gap distance of 3mm.

The findings of the vertical gap distance study revealed that there was no statistically significant difference between pre- and post-test variable measurements in the 1mm vertical gap group with respect to the top view, top horizontal view, and the bottom horizontal view (p=0.24, p=0.29 and p=0.91, respectively). The average change, although not statistically significant, was in the range of 10um or 0-0.06% change of the 17mm length. The 3mm vertical gap distance group revealed a statistically significant difference between the pre- and post-test values in the bottom horizontal measurement (p=0.01). The top horizontal measurement and top view measurements had p-values approaching statistical significance (p=0.06 and p=0.11, respectively). A power analysis was performed for this test group and revealed that at a sample size of n=17, statistical significance would be obtained for the 3mm vertical gap distance. The
overall change due to the 3mm of fresh autopolymerizing resin was in the range of 12 to 22um or 0.07-0.13% change in length. Lastly, the 5mm sample group for all distances measured, top view, top horizontal, and bottom horizontal distances, demonstrated statistical significance with p-values of p=0.001, p=0.03, p=0.002, respectively. The amount of change observed in the 5mm group was between 18 to 27um or 0.11-0.16% change. The data is consistent with the shrinkage properties of autopolymerizing acrylic resin. As the amount of fresh polymerizing resin increases, the amount of distortion and shrinkage is observed.

The changes for all sample groups observed was of a negative value leading to an inward movement of the impression copings due to the polymerization shrinkage of the autopolymerizing GC pattern resin. In the top view of the 1mm vertical gap distance, the investigators in this study identified an average of 10um expansion. This may be due to outliers skewing the results or error in measurement. Since the sample size was limited to n=10, one specimen can greatly affect the results, especially dealing with micron distance measurements. Another factor to note is that the standard deviation is well above the value of change observed. An increase in sample size will aid in decreasing the variance and improve the accuracy and power of the study. Measurement error throughout experimentation and material property error also play a large role in the observed data.

Only one measurement was utilized for the top view. Since there were only two points of measure, it can be considered as a straight line between the two points. Both measurements would have yielded the same length, as one
impression coping rotates about the other. The top and bottom horizontal measurements from the side view were an attempt at investigating whether or not the impression copings changed uniformly or non-uniformly. This was an interest to the investigators because the autopolymerizing resin was luted towards the top of the impression coping. From the data, the investigators in this study cannot conclude whether or not there is uniform shrinkage of the top and bottom horizontal measurements. There is an average of 5-6um of difference between these measurements. In the 3mm vertical gap distance, the bottom horizontal value is smaller than the top horizontal value but reversed for the 5mm vertical gap distance. It can be speculated that the change is most likely uniform but further testing is required to confirm this hypothesis. During experimentation of the larger vertical gap distances, a significant amount of material distortion from the fresh autopolymerizing resin was observed due to the effects of gravity. Although the investigators are uncertain as to whether or not there is more shrinkage at one extreme or the other, it is possible that there is more residual stress near the bottom of the resin cylinder resulting in more shrinkage of the bottom horizontal value due to the effects of gravity on the fresh luting resin.

The orientation of the 1mm gap distance was also compared in this investigation. The study compared a 1mm vertical gap distance with a 1mm diagonal gap distance at a 45 degrees angle and a 1mm horizontal gap distance. From the initial test results, there appeared to be no statistically significant difference between the different luting orientations (p=0.06, p=0.96, p=0.47, respectively). The range of the observed change was between 7-10um,
consistent with the 1mm vertical gap distance shown in Table 1. This result indicated that the orientation does not play a significant role in the distortion of the assembly. All orientations would work equally well in the clinical and laboratory setting. For easy of use, a vertical or diagonal section should be utilized.

The findings with the polymerization time study demonstrated no statistical significance for the 3-minute, 10-minute, and 17-minute polymerization times (p=0.19, p=0.45, p=0.54, respectively) at a gap distance of 3 mm. The amount of shrinkage was in the range of -12-22um. This indicates that the manufacturer recommended protocol of 3 minutes is sufficient for the majority of the polymerization to occur. The recommended wait time of 17min for 80% of the polymerization shrinkage to occur as described by Mojon (1990) may be both unnecessary and unrealistic in the clinical situation. Although no statistical significance was found in this study, further analysis may yield significance when increasing the sample size or decreasing the gap distance. As mentioned above increasing the sample size to n=17 would demonstrate statistical significance for the 3mm gap distance. This may be the sample size required to observe significance for the polymerization time study as well. However, an observed significance using the 3mm vertical gap distance may be observed with an increased sample size due to the fact that it is a 3mm vertical gap distance, not necessarily due to the effects of polymerization time. Further experimentation of polymerization time may be required with the use of a 1mm vertical gap as no statistical significance was observed with this vertical gap distance.
5.2 **Standard Deviation and Repeatability of the Specimens**

The standard deviation of the data collected in Table 1 demonstrated a large value compared to the overall change in the sample. The reported standard deviations range from 20 to 100um. There are several explanations for why there is a large variation. Firstly, the experiment was performed in a non-temperature controlled room. The room temperature from the beginning to the end of the experiment ranged from 19-23 degrees Celsius. This change in temperature from the pre-test to post-test specimens, as well as between specimens and samples may result in varying lengths and distortions. The thermal coefficient of expansion (TCE) of autopolymerizing acrylic is between 70-81 x 10^{-6}/°C (Powers, 2006). A change in 5 degrees using the formula

\[
\frac{(l_{\text{final}} - l_{\text{original}})}{l_{\text{original}} \times (\theta_{\text{final}} - \theta_{\text{original}})} = \alpha
\]

where \( l \) equals length, \( \alpha \) equals the TCE, could affect the sample length by as much 7um or 0.04% in length, assuming a 17mm acrylic bridging distance between the impression copings. If the pre-test variable measurement was taken at a warmer temperature than the post-test variable measurement, a greater amount of shrinkage due to the test variable compounded by the effects of the temperature on the acrylic material itself would be observed.

Secondly, there was variability in the repeatability of measurements. Specimens throughout the experiment were selected randomly and measured twice to determine consistency in the measuring protocol. Although the investigator was calibrated using a known length, the shape of the calibration tool was not the same shape as the actual impression coping. Specimens were
measured as per Appendix A and B. A distance between a reference point on the measurement jig and the specimen was first determined. This served the purpose of verifying that the specimen was correctly placed on the measurement jig and microscope. The reference points for most pre-test and post-test specimen were consistent with variations of 0-4um. However, some specimens did vary greater than 10um. Although the reference point is not a major concern in the actual measurement of the specimen itself due to the zeroing at the starting point, it does demonstrate an inconsistency with a few specimens throughout experimentation and potentially contributing to the observed variance.

The repeatability of the specimen measurements once it has been correctly orientated in the measurement apparatus also contributes to the variation. Eight specimens throughout the experiment were randomly selected for repeat measurement. The variability in the measurement was slightly greater than the investigator calibration aspect of the experiment in section 3.6. The variability in the repeat measurement ranged from 0-6um when the specimens were re-measured; most samples differed approximately 0-2um from the first measurement. This is consistent with the initial calibration test. Overall, this measurement error contributed to the standard deviations observed in the experiment. The reason for this measurement error is partially explained by the design of the impression copings. Measurements were made based on the reflective machined surface from the top view and the densest and flattest edge of the impression coping from the side view. Although the measurement points and sides were distinct, if the focal point of the microscope was on a different
aspect of the coping, it would change the measurements upwards of several microns. Similarly from the top view, the machined surface observed under 20x magnification was distinct with irregularities. Points of irregularity on the sides of the impression copings resulted in difficulty in measurement consistency. The investigators attempted to measure from the most outer aspect of the coping, but this measurement could be altered based on the irregularities, light reflection from the machined surface and also the angulations of the impression copings.

Another point of mention regarding measurement error originates from wear of the Dentsply/AstraTech analogs on the master model and measurement jig. Since a single measurement jig with one analog was utilized, as well as only 1 master model, wear of the components could have resulted in rotation of the impression copings on both of the apparatuses. Rotations of the impression copings would further change the orientation of the measurement points and would have also resulted in increased variance observed in the test data. As described earlier, the investigators focused on the flat sides of the impression copings from the side view measurements. A rotation of the impression coping would have changed where the densest and flattest aspect would be located and would result in an increased measurement error.

The large standard deviations in this investigation could be explained by the difficulties in measuring the lengths between the irregularly shaped impression copings at a micron level. The wear of the implant components, rotation of the impression copings, thermal coefficient of expansion of acrylic due
to differing temperatures, and repeatability of measurements all contribute to the large standard deviations observed in the results of the study.

5.3 **Limitations of the Study**

There are several limitations in this study that must be addressed. Firstly, the sample size (n=10) is considered to be small for each test group. A single exaggerated specimen would skew the result in one direction or another. However, n=10 did yield statistically significant data with respect to the vertical gap distance aspect of the study. As previously mentioned, a sample size of n=17 would have lead to an increased power, as well as yielded statistical significance with respect to the 3mm gap distance. This increase in sample size may also determine whether or not polymerization time yields statistically significant data at the 3mm vertical gap distance. However, as stated earlier, a statistical significance for the polymerization time of a 3mm gap may be due to the vertical gap distance itself and not due to the tested polymerization time. A 1mm vertical gap should be utilized for the polymerization time test at the n=10 sample size as it demonstrated insignificance with respect to the gap distance.

A second limitation of this study is the inconsistency of GC pattern resin mixing and the Nealon technique consistency. Although a single investigator performed the experiment, it is difficult to ideally recreate the exact amount of monomer to polymer ratio used. The amount of monomer to polymer does affect the amount of shrinkage observed (Dumbrigue, 2000). With an increase in the amount of monomer, there is an increased tendency for more shrinkage.
Another potential limitation is the wear of the analogs on the master model and the analog on the measurement apparatus. The torquing effect of the impression copings to 10 Ncm could have worn away the internal facets of the analog as the study progressed. This would have altered the rotational orientation of the impression copings, resulting in a skewed luting of the two sections.

A last potential limitation of this study was the orientation of the specimen on measurement jig. If the specimen was not oriented parallel to the microscope table, a forshortening effect would have been observed. As the non-fixated impression coping moves towards or away from the lens, the impression copings would have appeared closer together, giving rise to an increase in the magnitude of observed change.

5.4 **Clinical Implications**

This study aimed to aid in the development of a protocol for the verification of implant supported fixed dental prosthesis using GC pattern resin as the luting material. This study demonstrated that when using an autopolymerizing resin, the clinician would tend to see a degree of polymerization shrinkage based on the amount of fresh polymerizing resin used to bridge the gap distance. The use of autopolymerizing resins on multiple implants would most likely compound the error observed in this study. This study used two implant analogs to simulate a basic implant supported fixed dental prosthesis. When multiple implants are utilized for a full arch fixed prosthesis, the observed error will likely have a
compounding effect as several sections would need to be made between the implants resulting in an increase in distortion of the verification jig or luted impression copings. This resultant shrinkage would occur in many different axes: medial-laterally, anterior-posteriorly and superior-inferiorly.

Another aspect to note in the study is related to the properties of the acrylic resin, mainly the thermal coefficient of expansion and water sorption. As the acrylic is utilized in the oral cavity, moisture would be incorporated into the material causing an expansion process. According the Powers et al. (2006), this water sorption is 0.69 mg/cm$^2$. Furthermore, the temperature change when transferring the material from the intraoral environment to the laboratory environment would result in distortion of the material due to the TCE. The intraoral environment and human body temperature is 37 degrees Celsius, while room temperature is 20 degrees Celsius. This is a 17 degree change in temperature. Using the formula discussed earlier, a distance of 17mm would result in a 23um change or 0.14% change in length when moving from body temperature to room temperature. This would essentially double the observed change due to polymerization shrinkage. Thus, clinicians need to be cognizant of the fact that the materials we choose have different physical and mechanical properties that lead to increased error and variability. It is only when clinicians understand the materials used in the verification process that greater accuracy in the working casts can be achieved.
5.5 Future Research Direction

Future research should be aimed initially at duplicating the results of this study with a larger sample size. This will serve as verification of the observed results, decrease the study variance, and more accurately determined the amount of change due to the shrinkage of autopolymerizing resin. Another aspect that should be address in future studies is the effect of polymerization time on a 1mm vertical gap distance. This would determine whether or not polymerization time results in a statistically significant difference. Testing polymerization time on a 1mm vertical gap distance would better isolate the polymerization time variable.

The study could then evolve into comparisons of different distances aside from the 17mm distance between the impression copings. The investigators in this study chose 17mm as it is an average distance for a 3-unit, first molar to first premolar FPD. Future studies can also evaluate the verification of three or more implants as increasing the implant number potentially compounds the error.

There has been recently literature suggesting that verification can easily be accomplished using intra-oral welding (Degidi, 2012). The intra-oral welding technique involves very little heat and time. A comparison between the standard methods of autopolymerizing resin with intra-oral welding may result in a more accurate and efficient way of verifying implants for an implant supported fixed dental prosthesis.

Lastly, a comparison of autopolymerizing resin to a packable composite resin that is light cured may also demonstrate an increase in accuracy with
composites. Composite resins with more filler and less matrix would have properties that would contribute to better transfer of implant location to a working laboratory model. Composite resins have lower polymerization shrinkage and decreased thermal coefficient of expansion (TCE). This would result in decreased shrinkage from the material itself and from intraoral to the laboratory setting when there could be a change in temperature of 15-20 degrees Celsius. The TCE of composite resins are typically in the range of 20-40 x 10^{-6}/°C while the TCE of acrylics are 70-81 x 10^{-6}/°C (Powers 1979, 2006). This will result in greater dimensional stability with composite materials. Autopolymerizing acrylic resins display volumetric shrinkage in the range of 6-8% whereas a highly filled, low matrix composite would have polymerization shrinkage of 1-2%. This would result in a lower percent change in overall length of the assembly. Furthermore, composite resins have an elastic modulus of 5-8 GPa compared to acrylic’s 2 GPa (Powers, 2006) which indicates its ability to better resist deformation upon removal of the material from its intraoral location. Lastly, composite resins are easier to use than autoploymerizing acrylics. Gap distances can be controlled by incrementally curing the composite resin to the desired distance. Bridging the impression copings incrementally also allows the segments to polymerize in steps. This stepwise approach ensure that the final connection between the copings will be minimal and result in only a minute amount of polymerization shrinkage, just as the investigators attempted to do with autoploymerizing resins in this experiment by prefabricating resin cylinders.
6. CONCLUSIONS

Within the limitations of this study, when verifying implant location on working cast the following can be concluded:

1. A larger gap distance between the impression copings for fresh autopolymerization material to bridge will result in more shrinkage, distortion, and introduce more error into the system. This distortion is in the range of 10um for a 1mm vertical gap distance, 12-22um for a 3mm vertical gap, and 18 to 27um for the 5mm vertical gap distance. The gap width of the assembly should be minimized to reduce the amount of material shrinkage. The alternate hypothesis is accepted for this aspect of the investigation.

2. The luting orientation of the gap distance (1mm vertical, 1mm diagonal, 1mm horizontal) did not result in a statistically significant difference. Based on the results of this investigation, the null hypothesis is accepted.

3. Polymerization time of 3 minutes for a 3mm vertical gap, as per manufacturer recommendation, is suitable for accuracy. There was no statistically significant difference in waiting 3, 10, or 17 minutes with respect to shrinkage and distortion of the material in this study. Based on the results of this investigation, the null hypothesis is accepted.
Cited Literature


Error From Ideal Scenario

\[ y = \sqrt{c^2 - x^2} \]

\[ \cos(a) = \frac{y}{c} \]

\[ a = \cos^{-1}\left(\frac{y}{c}\right) \]
APPENDIX B

Measurement Apparatus

The measurement apparatus consisted of an aluminum block cut into the shape of an “L”. A bottom portion of the “L” had a hole fitted with a 3.5/4.0 Dentsply analog. This analog could be fixated using a brass screw preventing the analog and its attached specimen from rotating about its axis. This measurement jig could be fixated in two positions on the Nikon Profile Projector to allow side view horizontal measurements as well as top down measurements (figures below). A corner point on the measurement apparatus to the specimens’ bottom left side served as the (0,0) point prior to determining the specimens start point. This allowed for consistent placement of the specimen on the measurement jig and allowed the specimen to be in the identical location for both pre- and post-test measurements.
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