

**THE EFFECT OF EQUILIBRATING MASTER CASTS ON THE  
OCCLUSAL HARMONY OF CAST RESTORATIONS**

A Thesis

by

JOE MENG

Submitted to The Office of Research and Graduate Studies of  
The Texas A&M Health Science Center  
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Oral Biology

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**ABSTRACT**

The Effect of Equilibrating Master Casts On The Occlusal Harmony Of Cast Restorations  
(October 2008)

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**PURPOSE:** To determine the occlusal accuracy of mounted stone casts and the viability of a cast adjustment technique.

**MATERIALS AND METHODS:** A dentofrom mounted on an articulator served as the simulated patient. Derived dental stone casts were mounted and occlusal contacts/near contacts were compared. Cast mountings were also allocated for adjustment (experimental) and no adjustment (control). A mandibular complete crown was fabricated and adjusted on each set of casts, returned to the dentofrom, and polyvinylsiloxane occlusal records were made. The records were scanned for optical density and contacts were quantified as contact and near contact. Non-parametric tests were used.

**RESULTS:** Derived cast contact areas were different from each other and the simulated patient. Crown contacts fabricated from adjusted casts were different from the control. Actual contact areas were not different from the simulated patient.

**CONCLUSIONS:** A master cast adjustment procedure can aid in fabrication of restorations with accurate occlusal contacts.

## ACKNOWLEDGEMENTS

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## INTRODUCTION

Fabrication of indirect full coverage restorations that are in occlusal harmony upon delivery remains a problem in restorative dentistry. The materials and the techniques that are used to facilitate fabrication of these restorations undoubtedly have inherent inaccuracies that still manifest in the final product. Even upon perfect execution of all required techniques, inevitable errors are present in final impressions, master casts and mountings, as well as the investment and casting processes. If problems are not intercepted in the laboratory phase, the loss of valuable chair time will result.

With regard to the accuracy of final impressions, some researchers advocate the use of custom trays over stock trays<sup>1-4</sup>, regardless of the material that comprises them<sup>5</sup>. Others<sup>6,7</sup>, feel that stock trays are capable of producing clinically accurate results, although metal stock trays may be indicated over plastic stock trays.<sup>8</sup> Polyvinylsiloxane seems to be the preferred impression material for reproducibility and long term stability, especially with multiple pours.<sup>7</sup> The effects of common disinfection practices on final impression materials have also been studied<sup>9-11</sup>, but have not been proven to cause any significant distortion, dimensional changes, or negative effects on surface quality<sup>10</sup> of the resulting gypsum master cast when appropriately employed.

The gypsum products comprising most master casts, have long been suspected of inaccuracies relating to their expansion.<sup>12,13</sup> Currently the American Dental Association specification No. 25 for dental gypsum products, specifies the requirement for testing and classification of these products.<sup>14</sup> Although specification 25 indicates that final setting expansion measurements are made 2 hours after mixing, it is known from Heshmati et. al that type IV and V dental stones show delayed linear expansion or early contraction

continuing for 72 -120 hours.<sup>15</sup> It is also known that different brands of die stones with equivalent ADA classifications may be dramatically different with respect to expansion properties.<sup>16</sup> Additionally, degradation of surface quality on master casts has been reported with certain impression material/gypsum combinations, even when the impression material was able to perform individually within ADA standards.<sup>17</sup> Müller et. al supported this phenomenon in a series of studies relating to accuracy of interocclusal recording media. It was found that different media were less accurate when measured in conjunction with duplicated Die-Keen casts, as compared to their parent casts for which they were fabricated. This strongly infers that the specific accuracy of the recording material is critically influenced by the properties and characteristics of the derived casts.<sup>18-</sup>

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Another critical factor paramount in the in the fabrication process of indirect restorations is the proper articulation of master casts; mounting error and occlusal features of the restoration such as cusp height, fossa depth, and ridge/groove direction are all dependent on articulation. Interocclusal records are one method by which this process can be facilitated, and may be the only method if the number and location of occlusal contacts are limiting. Historically wax has been a common material used for interocclusal records as it is inexpensive, easy to reinforce, and allows verification and remanipulation when making a centric relation record; the use of tripod contacts is advocated when possible.<sup>21</sup> Recent studies have shown that specific materials, namely rigid polyvinylsiloxane, seem to perform with higher accuracy and more overall stability than thermoplastic or acrylic resin materials<sup>22</sup>; accuracy is also maximized when the thickness of the rigid PVS materials is minimized<sup>23</sup>, and the record has been properly trimmed to represent only cusp tips<sup>24</sup>. If a

patient has a stable occlusion and maximum intercuspation is the desired cast relationship, some investigators<sup>24-26</sup> have advocated direct “hand articulation” of the casts as the most accurate method of articulation. The use of unique stabilization techniques and materials have also been suggested to improve the stability of casts during the mounting procedures, regardless of the articulation method<sup>27</sup>. Some authors have advocated the use of quadrant style, dual-arch impression techniques, to overcome some mounting inaccuracies present with other techniques<sup>28, 29</sup>. Nonetheless, these techniques also have shortcomings which limits their use in many patients. Regardless of how precisely cast articulation and mounting procedures are performed though, the present cumulative literature on the topic would suggest that duplication of a patient’s occlusal articulation is still not 100% predictable, however no investigations have objectively substantiated this. Additionally, anecdotal clinical reports have indicated that casts from patients with premature occlusal contacts in centric relation ( $CR \neq MI$ ), can be mounted with more accuracy than those from a patient with harmonious occlusal contacts in centric relation ( $CR = MI$ ).

The application of occlusal refinement techniques to master casts has been briefly discussed in the literature in attempts to manage some of the inherent material/procedural inaccuracies. Davis described “supraocclusion” of the final restoration as the most commonly encountered problem, primarily because the gypsum teeth on the casts do not intercuspate as closely as do the patient's teeth. He proposed a solution of adjustment to the posterior teeth on the cast, until the most anterior teeth known to contact in the mouth also contact on the casts<sup>30</sup>. Davies et. al also discuss the phenomenon and described the adjustment procedures as “Model Grooming”<sup>31</sup>. Boyarsky and colleagues found that master cast occlusal adjustment procedures performed by lab technicians after mounting,

decreased the adjustment time of single posterior full coverage restorations at delivery by student clinicians, when compared to restorations fabricated on unadjusted master casts<sup>32</sup>. Although the “supraocclusion” phenomenon is known to many, and empirical cast adjustment methods seem to have been successfully employed, no studies have been designed to specifically objectify application of the technique.

In order to maximize the validity of a study of occlusal variation, the ability to accurately and objectively quantify occlusal contacts is of importance. Traditional clinical methods utilizing materials such as articulating paper, shim stock or wax will not suffice for final measurements because they are subjective and cannot be quantified; areas of occlusal contacts on the other hand, can be.

The topic of contact areas between opposing teeth has been a well studied phenomenon. Past observations that reduced numbers of functional teeth, and thus reduced quantities of occlusal contacts result in reduced masticatory performance, has been well established in the literature.<sup>33-40</sup> The idea of contact area has also been described and appears to be equally if not more important in chewing efficacy than number of contacts. Manly and Yurkstas were the first to present the idea of the relationship between masticatory performance and contact area in 1949.<sup>41</sup> Yurkstas later evaluated the relationship between masticatory performance and occlusal contact area in a particular patient set. It was concluded that there was a positive relationship between the area of contact and the total occlusal contact areas. Although the specific number of tooth contacts was not related to chewing performance, smaller areas of contact demonstrated diminished masticatory ability.<sup>42</sup> Lambrecht added to this with the finding of a positive correlation between the reduction in the size of the “potential contact area” and loss of

chewing effectiveness.<sup>34</sup> Similarly, and much later in 1996, Julien and colleagues further provided evidence to the theory in the observation that subjects with greater posterior contact areas performed significantly better in a chewing test, than did their counterparts of the same sex and weight with smaller contact areas.<sup>43</sup>

The concept of “near” contact area has also been alluded to by several, and may even play a greater role in masticatory function than actual contact area. Bates and colleagues found that teeth were only in static contact for 1/5 of the masticatory cycle, and consumed only 1/10 of the total occlusal table area<sup>38,39</sup>. In 2002, Owens performed a study which evaluated actual contacts and near contact area using a digitized silicon interocclusal record, as well as masticatory efficacy via chewing study. This investigation concluded that the greatest areas of both actual contact and near contact correlate to greatest chewing efficacy.<sup>44</sup>

Numbers of occlusal contacts have also been associated with occlusal stability. In an investigation by Parkinson, proximity of occlusal contacts were evaluated in orthodontic patients pre and post treatment using digitized interocclusal records. It was found that the areas of actual and near contact below 300µm increased significantly in analyses of the post treatment records. It was also concluded that actual contact and near contact areas may be important factors in the long term stability of horizontal and vertical overlap.<sup>45</sup>

Since importance of contact area on masticatory function<sup>34, 38, 39, 41-44</sup> and occlusal stability has been well established and can be readily quantified, it seems reasonable that its application could be extended to the study of occlusal harmony on gypsum casts.

Various methodologies have been used over the years to quantify occlusal contact areas. The first was first was by Manly and Yurkstas in 1949. They developed an instrument which passed light through an occlusal registration consisting of wax between two layers of fused cellophane. The light passing through translucent areas of contact was then absorbed by a galvanometer calibrated for output readings in square millimeters of effective occlusal contact area.<sup>41</sup> Unfortunately, this method lacked the ability to measure contact intensity numerically in the form of actual contacts and near contacts.

In 1984, Millstein perfected this technology. He made silicone bite registrations that depicted contact, near contact, and non-contact areas. The bite registrations were illuminated on a light box and photographed in black and white over a transparent grid of silicon spheres. The photograph was then made into a transparency to be analyzed by a computerized microdensitometer. The microdensitometer recorded quantities of transmitted light according to their optical densities based on 256 intensity levels of gray. Since the silicon spheres had a known thickness, they were able to be used to assign a given level of gray to a specific thickness of material.<sup>46</sup> While this technique was far more advanced than that proposed previously by Manly and Yurkstas, it appears to have been quite cumbersome, technique sensitive, and time consuming.

Much like Millstein, Wright also developed a technique to measure areas of contact and near contact from a silicon record, based on the principle that increased thickness of material has a related increase in opacity to transmitted light. This technique utilized a video camera and special digitizing software to determine various thresholds of passed light as related to material thicknesses. This technique appears to be useful and slightly

simpler than Millstein's method, although it still requires some sophisticated equipment, and the author did not comment on the level of accuracy.<sup>47</sup>

Recent researchers have developed and refined an objective occlusal measurement technique. This technique adheres to the following protocol: 1.) Recording interocclusal relationship with a polyvinylsiloxane (PVS) material. 2.) Scanning the record with a flatbed optical scanner (capable of transparency scanning) to record light transmission through areas of contact and near contact. 3.) Recording the optical densities of transmitted light via an easy to use and free imaging software package. 4.) Importing histogram data of optical densities into a statistical software package to analyze and quantify contact areas and intensities within the threshold of detection (determined by a step wedge relating transmitted light to known PVS thickness). The authors report a detectable range of 50-300µm range, with the ability to specifically analyze and compare thicknesses anywhere within the range between different records<sup>43-45, 48, 49</sup>. Of all methods noted from the previous literature, this method seems to be the least cumbersome, simplest, most cost effective method, and with the most versatility.

The aim of this investigation achieved the following goals: 1.) Qualitative comparison between occlusal contacts in a simulated patient with bilateral posterior occlusal interferences, and respective mounted derived stone casts from a type IV and type V dental gypsum. 2.) Quantitative and statistical comparison between occlusal contacts in a simulated patient with a harmonious occlusion (CR=MI), and respective derived mounted stone casts from a type IV and type V dental gypsum. 3.) Quantitative and statistical comparison between occlusal contacts in a simulated patient after insertion of a single molar crown fabricated on adjusted and unadjusted derived master casts.

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## **THE EFFECT OF EQUILIBRATING MASTER CASTS ON THE OCCLUSAL HARMONY OF CAST RESTORATIONS**

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## ABSTRACT (Journal of Prosthetic Dentistry)

**Statement of the Problem:** The effects of expansion of dental stone necessary for the fabrication of indirect dental restorations has been suspected as a major problem relating to their frequent hyperocclusion upon delivery.

**Purpose:** This study was undertaken to determine the possibility of accurately replicating an equilibrated patient's occlusion with gypsum casts on an articulator. The viability of a cast adjustment procedure to improve the occlusal fit of an indirectly fabricated restoration was also assessed.

**Materials and Methods:** A dentoform mounted on an articulator served as the simulated patient. Derived dental stone casts were mounted and occlusal contacts/near contacts were compared. Cast mountings were also allocated for adjustment (experimental) and no adjustment (control). A mandibular complete crown was fabricated and adjusted on each set of casts, returned to the dentoform, and polyvinylsiloxane occlusal records were made. The records were scanned for optical density and contacts were quantified as contact and near contact. Non-parametric tests were used.

**Results:** Actual and near contact areas for cast mountings of the equilibrated patient were statistically different from the patient for both stone types (Kruskal-Wallis ANOVA:  $P=0.0001$ ;  $P=0.001$ ). Actual and near contact areas for inserted crowns fabricated from adjusted casts were different from the control (Kruskal-Wallis ANOVA:  $P=0.0001$ ;  $P=0.007$ ), but actual contact areas were not different from the patient with no crown inserted. (Kruskal-Wallis ANOVA:  $P=0.650$ ).

**Conclusions and Clinical Implications:** A patient's occlusal harmony cannot be accurately replicated with mounted die stone casts; a cast adjustment procedure however, can aid in fabrication of restorations with accurate occlusion.

**Keywords:** Dental stone expansion, cast adjustment, contact area, occlusion.

## INTRODUCTION

Fabrication of indirect full coverage restorations that are in occlusal harmony upon delivery is problem that remains to be solved. The materials and techniques that are used to facilitate fabrication of these restorations undoubtedly contain inherent inaccuracies that manifest in the final product. Even with perfect execution of all required techniques and pattern generations, inevitable errors are present in final impressions, master casts and mountings, as well as the investment and casting processes. If problems are not intercepted in the laboratory phase, the loss of valuable chair time will result.

With regard to the accuracy of final impressions, some researchers advocate the use of custom trays over stock trays,<sup>1-4</sup> regardless of the material that comprises them.<sup>5</sup> Others feel that stock trays are capable of producing clinically accurate results,<sup>6,7</sup> although metal stock trays may be indicated over plastic stock trays.<sup>8</sup> Polyvinylsiloxane seems to be the preferred impression material for reproducibility and long term stability, especially with multiple pours.<sup>7</sup> The effects of common disinfection practices on final impression materials have also been studied,<sup>9-11</sup> but they have not been proven to cause any significant distortion, dimensional changes, or negative effects on surface quality of the resulting gypsum master cast when appropriately employed.<sup>10</sup>

The gypsum products comprising most master casts, have long been suspected of inaccuracies relating to their expansion.<sup>12,13</sup> Currently, the American Dental Association's specification No. 25 for dental gypsum products, requires testing and classification of these products.<sup>14</sup> Although specification 25 indicates that final setting expansion measurements should be made two hours after mixing, it is known from Heshmati et. al that type IV and V dental stones show delayed linear expansion or early

contraction continuing for 72 -120 hours.<sup>15</sup> Different brands of die stones with equivalent ADA classifications may be dramatically different with respect to expansion properties.<sup>16</sup> Additionally, degradation of surface quality on master casts has been reported with certain impression material/gypsum combinations, even when the impression material was able to perform individually within ADA standards.<sup>17</sup> Evaluating the accuracy of interocclusal recording media, Müller et. al found that different media were less accurate when measured in conjunction with duplicated Die-Keen casts, as compared to the parent casts from which they were fabricated.<sup>18-20</sup> This strongly suggests that the specific accuracy of the recording material is influenced by the properties and characteristics of the derived casts.

Another critical factor in the fabrication process of indirect restorations is the proper articulation of master casts, which primarily affects the occlusal surface. Interocclusal records are one method by which this process can be facilitated, and may be the only method if the number and locations of occlusal contacts are limiting. Historically wax has been a common material used for interocclusal records because it is inexpensive, easy to reinforce, and allows verification and remanipulation when making a centric relation record; the use of tripod contacts is advocated when possible.<sup>21</sup> Recent studies have shown that specific materials, namely rigid polyvinylsiloxane, perform with higher accuracy and more overall stability than thermoplastic or acrylic resin materials;<sup>22</sup> accuracy is also maximized when the thickness of the rigid PVS materials is minimized,<sup>23</sup> and the record has been properly trimmed to represent only cusp tips.<sup>24</sup> If a patient has a stable occlusion and maximum intercuspation is the desired cast relationship, some investigators<sup>24-26</sup> have advocated direct “hand articulation” of the casts as the most

accurate method. The use of unique stabilization techniques and materials have also been suggested to improve the stability of casts during the mounting procedure, regardless of the articulation method.<sup>27</sup> Some authors have advocated the use of quadrant style, dual-arch impression techniques, to overcome some mounting inaccuracies present with other techniques.<sup>28,29</sup> Nonetheless, these techniques also have shortcomings, which limits their use in many patients. Regardless of how precisely cast articulation and mounting procedures are performed, the literature suggests that duplication of a patient's occlusal articulation is still not 100% predictable. However, no investigation has objectively and directly substantiated this. Additionally, anecdotal clinical reports have indicated that casts from patients with premature occlusal contacts in centric relation (CR≠MI) can be mounted with more accuracy than those from patients with harmonious occlusal contacts in centric relation (CR=MI).

Occlusal refinement techniques to master casts have been applied to manage some of the inherent material/procedural inaccuracies. Davis described "supraocclusion" of the final restoration as the most commonly encountered problem, primarily because the gypsum teeth on the casts do not intercusate as closely as the patient's teeth. Thus it was proposed to adjust the posterior teeth on the cast, until the most anterior teeth known to contact in the mouth also contact on the casts.<sup>30</sup> Davies et. al also discussed the phenomenon and described the adjustment procedures as "Model Grooming".<sup>31</sup> Boyarsky and colleagues found that master cast occlusal adjustment procedures, performed by lab technicians after mounting, decreased the adjustment time of single posterior full coverage restorations at delivery by student clinicians, when compared to restorations fabricated on unadjusted master casts.<sup>32</sup> Although the "supraocclusion" phenomenon is known to

many, and empirical cast adjustment methods seem to have been successfully employed, no studies have been designed to objectify the application of the technique.

The importance of contact area on masticatory function<sup>34, 38, 39, 41-44</sup> and occlusal stability<sup>45</sup> has been well established in previous studies and can be readily quantified. An occlusal measurement technique which objectifies occlusal contact area relationships is of importance when attempting to make comparisons. One advocated technique utilizes a polyvinylsiloxane material to record the occlusal contact relationship, an optical scanner to record light transmission and optical density through various known thicknesses of material, and imaging software to analyze and quantify areas of “actual contact” and “near contact” up to 300 $\mu\text{m}$ <sup>43-45, 48, 49</sup>.

The purpose of this investigation was threefold: 1) Qualitatively compare the occlusal contacts in a simulated patient with bilateral posterior occlusal interferences (CR $\neq$ MI; unequilibrated), with respective “derived” mounted stone casts from two dental commonly used gypsum products (Part 1). 2) Quantitatively compare the occlusal contacts in a simulated patient with a harmonious occlusion (CR=MI; equilibrated), with respective derived mounted stone casts from two dental gypsum products (Part 2). 3) Quantitatively compare the occlusal contacts in a simulated patient after insertion of a single molar crown fabricated from adjusted and unadjusted derived master casts (Part 3).

## MATERIALS AND METHODS

This investigation was performed in three parts as described above. (Figure 1) For all parts a complete anatomic dentoform (Model #R-1560, Columbia Dentoform Corp, New York, NY) with all 16 permanent teeth was arbitrarily mounted in maximum

intercuspatation on a SAM 3 semi adjustable dental articulator (SAM, Munich, Germany) with Mounting Stone (WhipMix Corporation, Louisville, KY) to simulate an average patient position; this dentoform articulation served as the simulated patient to be used for the remainder of the investigation. Repeated procedural steps utilized in this investigation are described individually in detail at the end of this section and referenced accordingly as: *impression protocol, mounting protocol, and scanning protocol*. All dental stones used in this study were utilized according to the manufacturer's recommended powder/de-ionized water ratios. All statistical measurements were performed utilizing (SPSS Statistics v15.0, SPSS Inc., Chicago, IL). Non-parametric statistical tests were performed due to sample size, despite relative normal distributions. All statistical comparisons were considered to have statistical significance at the  $p \leq 0.05$  level.

#### Part 1- Non- equilibrated simulated patient

From the simulated patient (SP) mounting, the lower member was adjusted into a forward position using the articulator's protrusive and condylar adjustments so that bilateral occlusal interferences were created on a pair of molars in each arch; this resulted in an open anterior vertical dimension at the incisal pin ( $CR \neq MI$ ). A Blu-Mousse (Parkell, Inc. Edgewood, NY) interocclusal record was made to capture the occlusal relationship of the entire arch. Articulator settings were returned to normal, and the lower member of dentoform was then remounted using the interocclusal record. Two maxillary and mandibular full arch impressions were made of the dentoform, and subsequent master casts were fabricated according to the *impression protocol*. One impression set was poured in Die Keen (DK) [high expansion] (Modern Materials, Heraeus Kulzer, South Bend, IN) and

the other was poured in Silky Rock (SR) [low expansion] (Whip Mix Corporation, Louisville, KY) (Table 1). Both sets of casts were mounted/articulated according to the *mounting protocol*. Red silk marking ribbon (Madame Butterfly 3 5/8" Silk, Almore International, Portland, OR) was used to mark points of contact for the SP the DK and the SR casts and all were photographed. Bilateral Blu-Mousse occlusal registrations were made and scanned and quantified according the *scanning protocol*. Resulting numerical figures for "actual contact" (AC) and "near contact" (NC) were qualitatively compared.

#### Part 2 –Equilibrated simulated patient

The SP occlusion was adjusted (equilibrated) so that all teeth were occluding in a cusp-fossa/cusp-marginal ridge relationship, and with equal intensity, as judged subjectively with 0.0005 inch Shimstock ribbon (Artus Corp. Englewood, NJ). The left mandibular 1<sup>st</sup> molar was prepared for a full coverage cast gold restoration. Twenty maxillary and 20 mandibular full arch impressions were made and subsequent master casts were fabricated according to the *impression protocol*. Ten impression sets were poured in DK and the other 10 in SR. After 72 hours of setting time, all mandibular casts were pinned (Axio Pins, SAM, Munich, Germany) and bases were poured with Flow Stone (Whip Mix Corporation, Louisville, KY). All sets of casts were mounted/articulated according to the *mounting protocol* and allowed to set for at least 72 hours. Split-cast mounting plates were used for mounting verification. Bilateral Blu-Mousse occlusal registrations were made for each mounted set of casts. All Blu-Mousse registrations were scanned and quantified according to the *scanning protocol*. Resulting numerical figures for AC and NC were statistically compared utilizing the Mann-Whitney U statistical test.

### Part 3- Equilibrated Simulated Patient with an inserted crown

The 10 sets of Silky Rock casts used in part 2 were used in this part of the study, and 10 additional sets of mounted Silky Rock casts were fabricated utilizing the identical protocol followed in part 2.

Of the 20 sets of mounted silky rock casts, half were randomly assigned to a control group and half to a experimental group. All mandibular casts were sectioned so that the preparation die and the adjacent segments in the left quadrant were removable; the right quadrant remained rigidly fixed to the cast base. Two layers of Tru-Fit die spacer (George Taub Products, Jersey City, NJ) were placed all preparation dies.

For all mounted casts, the centric locks on the articulator were released, the lower articulator member was positioned so the casts were occluded into maximum intercuspation (MI), and the articulator pin was reset to this position. The centric locks were reset, and the pin opening was recorded utilizing Triad light cured gel (Dentsply International, Inc., York, PA). The thickness was measured using a digital caliper (Digital Caliper Model #DA-1, Kori, Japan) and recorded as pin opening for each cast.

Casts assigned to the experimental group were systematically equilibrated until the incisal pin attained contact with its table (Figure 3). Casts in the control group received no occlusal adjustment.

A full contour waxup (Geo Wax, Renfert Dental Corp., Hilzingen, Germany) was fabricated on each die for all experimental and control casts. The wax patterns were removed from the dies, sprued, invested (Cristobalite, WhipMix Corporation, Louisville, KY), and cast in type IV high noble dental alloy (Ney- Oro 60, Dentsply Ceramco,

Burlington, NJ) utilizing the lost wax technique. Upon de-vestment, each of the restorations were adjusted to its master cast, with the occlusion being adjusted to hold shim stock with the same firmness as the adjacent teeth. (Figure 4) The restorations were delivered to the SP individually. The intaglio of each was adjusted if necessary to allow complete seating of the restorations. Optical magnification (4.3x) and an explorer were used to verify closed margins and thus complete seating. Bilateral Blu-Mousse occlusal registrations were made of the SP with each delivered restoration in place. The records were subsequently scanned and quantified following the *scanning protocol*. AC and NC were statistically compared utilizing the Mann-Whitney U statistical test.

Additionally, the level of pin opening was compared to levels of AC and NC for the crowns fabricated from the control casts. Degree of correlation was measured using Spearman's rho correlation coefficient.

#### Reliability of scanning measurement protocols

To determine the reliability of the interocclusal record fabrication and scanning protocols collectively, 10 Blu-Mousse records were made of the equilibrated SP, and scanned according to the *scanning protocol*. Interclass Correlation Coefficient and Cronbach's Alpha statistical figures were determined for AC and NC areas.

**Impression protocol:** Standardized custom trays were fabricated with Triad VLC tray material (Dentsply International, Inc., York, PA), with stops and positioning guides in the land area of both dentofrom members, and with 1-2 mm of space for impression material. Each tray was painted with a PVS tray adhesive (Kerr Corp, Orange, CA), and allowed to set for at least 1-6 hours. A dual-phase polyvinylsiloxane impression technique with type I and a type III Extrude PVS (Kerr Corp, Orange, CA) was utilized to make each

impression; separation time was 12 minutes after seating the impression tray. Utilizing custom standardized base formers for maxillary and mandibular impressions, the impressions were poured in either SR or DK. The casts were separated from impressions after 1-2 hours of set time. The SR and DK casts were allowed to set for 72 hours. All impressions were poured only once.

**Mounting Protocol:** A facebow transfer record was made of the simulated patient on the articulator, utilizing the SAM Transfer Stand and Transfer Fork Assembly AX. Aluwax (Aluwax Dental Products Co., Allendale, MI) was used as the recording medium in a tripod fashion with the record being trimmed to expose only cusp tip imprints. Maxillary casts were mounted using this “facebow recording” and Mounting Stone. The position of the cast was stabilized by hand on the bite fork until the Mounting Stone had reached a “snap set”. To facilitate mounting of the mandibular cast, an Aluwax centric relation record was made according to Wirth.<sup>21</sup> This record was used for all mounting procedures. Mounting Stone was used to facilitate mounting of the lower cast. The cast was held by hand and stabilized until a snap set was achieved. The minimum amount of stone needed to attach the base plate to the cast was initially used to minimize distortion. Magnetic split cast mounting plates (SAM Axiosplit System) were used to facilitate mounting; the split cast allowed for mounting accuracy verification. (Figure 2)

**Scanning protocol:** A double sided flatbed scanner was used to facilitate grey scale scans of each Blu-Mousse record, based on the amount of light transmitted through perforated/near perforated occlusal contact areas. The bilateral record was carefully trimmed on both sides to allow it to sit flat on the scanner. All scans were performed with the records placed in the scanner in the same location, and at the same sitting. Scans were

performed at 600 dpi. ImageTool Version 3.0 Software (University of Texas Health Sciences Center at San Antonio, San Antonio) was used to perform optical density analysis of the transmitted light through perforations/near perforations from the 1<sup>st</sup> premolars though the 3<sup>rd</sup> molars bilaterally. A calibration step wedge of various thicknesses was fabricated and scanned so that a regression equation relating transmitted light to Blu-Mousse thickness could be formulated, based on the pixel gray scales (GS).

$$\text{Thickness} = 0.0436 + 0.0002(\text{GS}) + 0.000003(\text{GS})^2$$

GS allowed areas of near contact to be measured between 50 and 300  $\mu\text{m}$ . Thicknesses of material  $\leq 50$   $\mu\text{m}$  were classified as AC, those between 50-300  $\mu\text{m}$  were classified as NC. SPSS statistical software package was used to quantify recorded pixel densities for each record as areas of AC and NC respectively in  $\text{mm}^2$ .

## RESULTS

### Part 1 - Non- equilibrated simulated patient (Figure 5-7)

The respective AC and NC areas were 2.17 and 12.44 $\text{mm}^2$  for the non-equilibrated SP, 2.31 and 11.74 $\text{mm}^2$  for the SR cast mounting, and 3.06 and 14.75 $\text{mm}^2$  for the DK cast mounting. No statistical comparisons were made due to sample size.

### Part 2 – Equilibrated simulated patient (Table 3, Figure 8)

Mean areas of AC for SP were greater than SR, which were greater than DK. Mean areas of NC for SP were greater than DK, which were greater than SR. Group comparisons (Kruskal-Wallis) revealed a significant difference between three groups for AC ( $p=0.0001$ )

and NC ( $p=0.001$ ). Paired group comparisons (Mann-Whitney U) analysis for AC revealed a significant difference between SP/SR ( $p=0.0001$ ) and SP/DK ( $p=0.0001$ ) pairs, but not for the SR/DK ( $p=0.257$ ) pair. Similarly, paired group comparisons (Mann-Whitney U) for NC revealed a significant difference between SP/SR ( $p=0.001$ ) and SP/DK ( $p=0.001$ ), but not for the SR/DK ( $p=0.821$ ) pair.

### Part 3- Equilibrated Simulated Patient with an inserted crown (Table 4, Figure 9)

Mean areas of AC for SP with no inserted crown (SP No Crown) were nearly equal to those of the SP with the experimental crown (SP Exp. Crown) inserted, which were both significantly greater than those of the SP with the control crown (SP Control Crown) inserted. Mean areas of NC for the SP Exp Crown, were greater than SP No Crown, which were greater than SP Control Crown. Group comparisons (Kruskal-Wallis) revealed significant group differences for AC ( $p=0.0001$ ) and NC ( $p=0.003$ ).

Paired group comparisons (Mann-Whitney U) for AC revealed a significant difference between SP No Crown/SP Control Crown ( $p=0.0001$ ) and SP Control Crown/SP Exp. Crown ( $p=0.0001$ ) pairs, but not the SP No Crown/SP Exp. Crown ( $p=0.650$ ) pair. Paired group comparisons (Mann-Whitney U) for NC revealed a significant difference between SP No Crown/SP Control Crown ( $p=0.049$ ), SP No Crown/SP Exp. Crown ( $p=0.007$ ), and SP Control Crown/SP Exp. Crown ( $p=0.007$ ) pairs.

Mean pin opening for 19 of the 20 total mountings (one measurement lost) was  $0.17 \pm 0.06$  mm, with a minimum opening of 0.06 mm and a maximum opening of 0.29 mm. Statistical comparison between mean pin opening and mean areas of AC and NC for the SP Control Crown subjects did not prove to be statistically correlated (Spearman's rho: AC  $p=0.827$ , NC  $p=0.380$ ).

### Reliability of scanning measurement protocols

Methods used for obtaining and scanning interocclusal records showed a high level of reliability for AC and NC. (Interclass correlation coefficients: AC=0.976, NC=0.986; Cronbach's Alpha: AC=0.998, NC=0.999)

### DISCUSSION

This investigation aimed to determine whether or not it is possible to exactly duplicate a patient's centric occlusion on an articulator utilizing two ADA certified dental gypsum products. In addition to dental casts used for diagnostic purposes, close laboratory replication of a patient's specific occlusal contacts becomes very important when used for indirect fabrication of dental restorations with planned occlusal contacts. Even slight discrepancies in occlusion between the patient and their representative dental casts can result in increased chair time and loss of occlusal morphology upon insertion due to necessary adjusting procedures.

The findings of Heshmati et. al <sup>15</sup>, suggest that the effect of stone expansion is a major problem when duplicating a patient's occlusion on a dental articulator. It also has been suggested that the occlusal contacts of a patient with bilateral premature posterior occlusal contacts in centric relation ( $CR \neq MI$ ) can be more accurately represented and verified on an articulator if the representative casts are mounted in that position, than a patient who has centric relation coincident with maximum intercuspation.

Photographically only the 3<sup>rd</sup> molars were examined because this was the only location where actual contacts could be identified with shim stock, wax, or ribbon. The location, size, and shape of the contacts were visibly very similar, but with some small

differences (Figure 5 and 6). There was a distinct mark that appeared on the SR cast that did not appear on the DK cast or the SP. The character of the ink markings was also slightly different on each subject. There was a distinct difference in the markings of the SP in comparison to the cast subjects, and very subtle differences between the cast subjects. It was difficult however to determine the significance of any perceived differences in markings due to variability of the technique and effect of the ribbon ink on different materials.

Visual comparison of the scanned interocclusal records revealed obvious differences in all three records. Areas of AC as confirmed by shim stock and wax had no discernable differences, but there were obvious differences in NC areas between all three records. SR and DK casts appeared to have areas of NC that extended more anterior than did those for SP. Numeric comparison revealed the following trend for areas of AC and NC respectively:  $SP < SR < DK$  and  $SR < SP < DK$ . Although differences were apparent, they are small and difficult to interpret, especially with only one subject per group. It is reasonable to assume that any differences would be magnified as the number of contacts in the SP is increased. This is important to note as very few actual contacts were physically present in the SP, and therefore inference of any possible cause (ie. impression error, stone expansion, mounting error, other) of the perceived differences cannot be made, at least not without more subjects in each group. One additional note with respect to AC areas is that that the upper threshold for the scanned records is  $50\mu\text{m}$  whereas that of shim stock is only  $12\mu\text{m}$ . Therefore the AC areas for the scanned records is exaggerated in comparison to what would be identified with shim stock. Furthermore, it is difficult to draw any further conclusions as to the meaning of the data in this portion of the investigation.

The finding that the Equilibrated SP had significantly greater areas of AC and NC when individually compared to SR and DK clearly indicates a difference in one's ability to replicate a patient's occlusion on mounted casts. Further, the lack of statistical difference between the SR and DK mountings suggests that any differences in expansion between the two gypsum products did not yield the ability to replicate a patient's occlusion any more accurately.

Although not statistically different, the observation of slightly greater AC area for SR (10.37 mm<sup>2</sup>) in comparison to DK (6.41 mm<sup>2</sup>), while the NC areas were roughly equivalent, is interesting. Differences in stone expansion may explain the difference in AC area, if greater expansion leads to more occlusal disharmony. The mechanisms by which this may occur include: 1) Vertical expansion of stone on a flat or inclined surface (cusp tip to fossa). 2) Horizontal expansion of stone on an inclined surface (inclined plane to inclined plane). In both cases, this expansion may cause slight vertical opening which could result in loss of some AC area with slight gain in NC area; this hypothesis is consistent with the present results for SR and DK and previous findings related to stone expansion for the two gypsum products.<sup>15</sup>

One additional observation relates to the coefficient of variability for AC and NC areas as quantified by the scanned records from each group. From the 10 interocclusal records made directly from the simulated patient, there was 12.5% and 9.6% variation from the mean for AC and NC area respectively. Since mounting error and stone expansion are irrelevant for this group, it can be assumed that all observed variation between records occurred as a result of the record making and scanning processes. The difference in variation between SP AC and NC areas and SR and DK groups was 65.6/31.7% and

55.7/31.5% respectively. Since all mounting procedures for the SR and DK casts were performed using the exact same protocol and with the same “centric relation” record, it can be inferred that the difference in variation from the mean for the SR and DK mountings when compared to the SP were due to the effects of stone expansion alone.

The finding that the AC areas for the SP Exp. Crown were significantly greater than those of the SP Control Crown is important when evaluating the efficacy of the cast adjustment intervention, as is the finding of no statistical difference between SP No Crown and SP Exp. Crown. The mean areas of AC for SP Exp. Crown and SP No Crown were almost equivalent, indicating that the adjustment intervention to the master casts substantially increased the area of AC to near that of the patient (exact AC achieved on the cast is unknown because records were not made of the adjusted casts with the crown in place).

With respect to the areas of NC, all three groups showed a significant difference in a pairwise comparison. It is interesting that SP Exp. Crown had significantly greater areas of NC when compared to the SP No Crown, while there was no difference in AC between the two. This observation would indicate that adjustment of the cast yields a greater gain of NC than AC when the crown is inserted in the patient. However, the SP with crowns fabricated from unadjusted casts (SP Control Crown) had significantly less areas of NC than the SP with no crown inserted (SP No Crown), even though SP Control Crown had a greater potential for more areas of NC. This would suggest that insertion of a crown that was fabricated from unadjusted casts will lead to a level of hyperocclusion that yields a significant loss in area of NC in the patient.

Although previous studies which examine AC and NC suggest that NC may actually be more important for mastication and occlusal stability<sup>38, 39, 44, 45</sup> than AC area, this investigation suggests that AC is more important when attempting to accurately articulate two casts. Decreased areas of AC corresponded with slight increase in the vertical dimension in the patient of upon insertion of a crown fabricated from those casts. The inference that low values of AC area indicate less occlusal harmony whereas higher values indicate greater occlusal harmony has been made in lieu of these observations. The cause of low values of AC area were believed to be the result of the effects of greater stone expansion, which manifest in opening of the occlusal pin, and a greater CR to MI slide artifact. The intervention directly altered actual contact areas which were artifacts of stone expansion, and thereby prevented a fabricated crown from being in hyperocclusion upon insertion.

These findings indicate that the cast adjustment protocol (intervention) followed in this investigation was successful in eliminating the majority of the occlusal disharmony in the casts believed to be caused by the effects of stone expansion. Conversely, areas of AC for the SP when crowns fabricated from unadjusted casts were inserted, were statistically different from both SP No Crown and SP Exp. Crown. This indicates that even when all human error related variables are controlled in an in vitro setting, crowns fabricated on unadjusted casts will be in significant hyperocclusion when inserted into the patient, and will cause significant occlusal disharmony if not adjusted for. Unfortunately, this necessary adjustment comes at the expense of valuable chair time and loss of occlusal morphology. This finding is consistent with the observations from Davis<sup>30</sup>, Davies<sup>31</sup>, and

Boyarsky<sup>32</sup> in previous reports. It is reasonable to assume that the magnitude of the problem would be magnified if multiple restorations were fabricated.

With respect to the pin opening that was observed with the SR cast set (DK cast set not measured), statistical measures were not able to relate the amount pin opening to level of occlusal harmony (AC or NC areas) in the SP Control Crown. This data should be interpreted with caution however, since the gap was not measured directly; rather it was measured indirectly via the thickness of a light cured material which may undergo a small amount of distortion during polymerization.

Analysis of the methods of measurement in this investigation proved to be highly reliable. Interclass correlation coefficients for the ten repeated patient records for AC and NC was very high. This indicates that procedures involving making the interocclusal record, scanning the record, and numerically quantifying areas of AC and NC, were highly reliable. Likewise, the trendline relating optical density to material thickness from the calibration step wedge had a high correlation value when the material thickness was 50-300 $\mu\text{m}$ . It should be noted though that the limited range of material thickness that could be accurately analyzed was a product of the specific scanner used. Use of a scanner capable a greater light output would be expected to increase the upper threshold for material thickness, allowing a higher range of near contacts for analysis. The lower threshold was limited to the properties of the Blu Mousse material. Differences in optical density were too variable below 50  $\mu\text{m}$  to be of any reliable value.

Another limitation to this study was that it was done in vitro on a dentoform, to decrease axis location variables. The teeth in the dentoform were rigidly fixated simulating ankylosed teeth or dental implants, without functional periodontal ligaments.

Previous literature has stated that healthy, non-periodontally involved teeth may have an average mobility of about 28-40 $\mu$ m in an axial direction,<sup>50,51</sup> and 97 $\mu$ m faciolingually<sup>50,52</sup> as a result of normal periodontal ligament (PDL) resiliency; periodontally involved teeth would be expected to have greater mobility. Although this investigation cannot be directly applied to periodontally healthy teeth per se, it assumes a more stringent level of evaluation due the absence of the PDL buffer; it could be applied to a full mouth fixed implant reconstruction however. An additional factor relating to this in vitro study was that the stomatognathic system was not factored in. The standardized patient was only allowed one condylar position which was referred to as centric relation (CR), for which all patient casts were articulated. A recent study (unpublished) at our institution revealed 180 $\mu$ m of variation in recording this position in patients with healthy TMJs; with other studies revealing even higher variations<sup>53,54</sup>. Further, the facebow transfer process used in this study may have a transfer error that has been described with its earbow counterpart<sup>55</sup>, with an effect on the arc of closure for the patient. This study attempted to focus only on the effects of stone expansion.

The technique for cast alteration in this investigation required that the patient's casts be mounted in centric relation. Although clinically the acquired, forward postured, maximum intercuspal position may be the treatment position of choice for single tooth restorations in many patients, the effects of stone expansion observed in this study will likely preclude the ability to articulate the casts in this position. It therefore seems logical that some form of cast adjustment will be necessary in order to attain the patient's "true" VDO in the MI position. As CR is the only anatomically directed reference position, the ability to adjust any patient into their desired MI position requires CR mounting of the

master casts. Future studies should replicate the control and intervention with casts mounted in an MI position to determine if equally satisfactory results can be obtained with respect to occlusal contact areas.

## CONCLUSIONS

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

1. Casts from a simulated patient with coincident centric relation (CR) and maximum intercuspal (MI) positions cannot be accurately mounted to replicate the patient's occlusal contact areas.
2. When casts from a simulated patient with coincident CR and MI positions are mounted, an artifact CR-MI discrepancy will appear.
3. When a single posterior tooth casting is fabricated on master casts from a patient with coincident CR and MI positions, the resulting casting will be in significant hyperocclusion upon insertion into the patient
4. When the master casts have been "adjusted" prior to crown fabrication, the casting will be in near occlusal harmony with the remaining dentition upon insertion.

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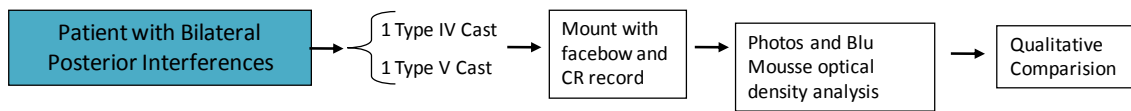
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## ACKNOWLEDGEMENTS

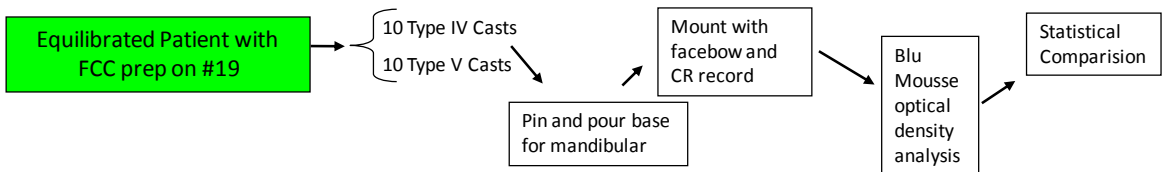
This study was supported by Baylor College of Dentistry, Texas A&M Health Sciences Center, Dallas, TX

## FIGURES

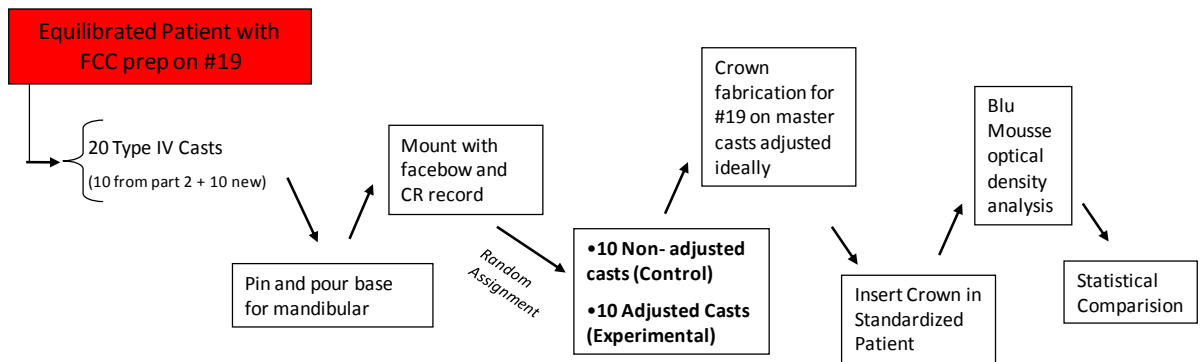
### Part 1- Non- Equilibrated Simulated Patient



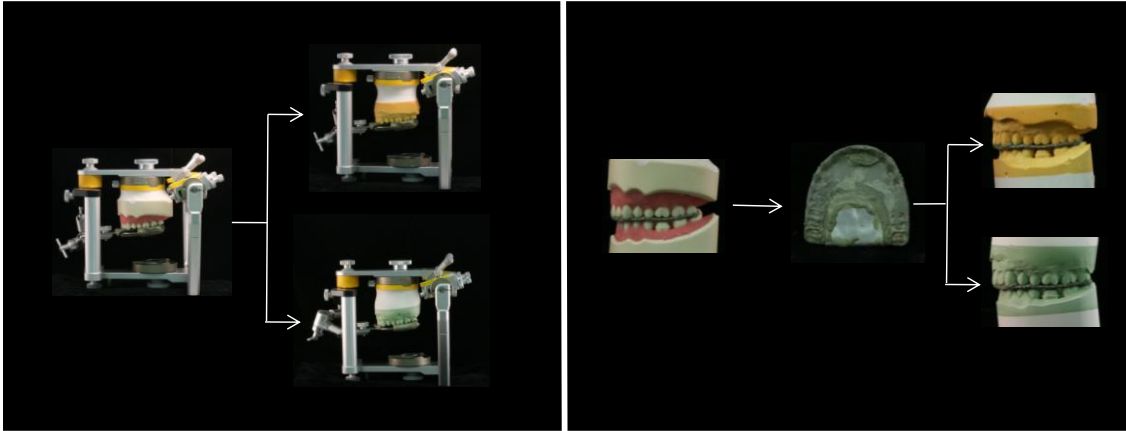
### Part 2 –Equilibrated Simulated Patient



### Part 3- Equilibrated Simulated Patient with an Inserted Crown



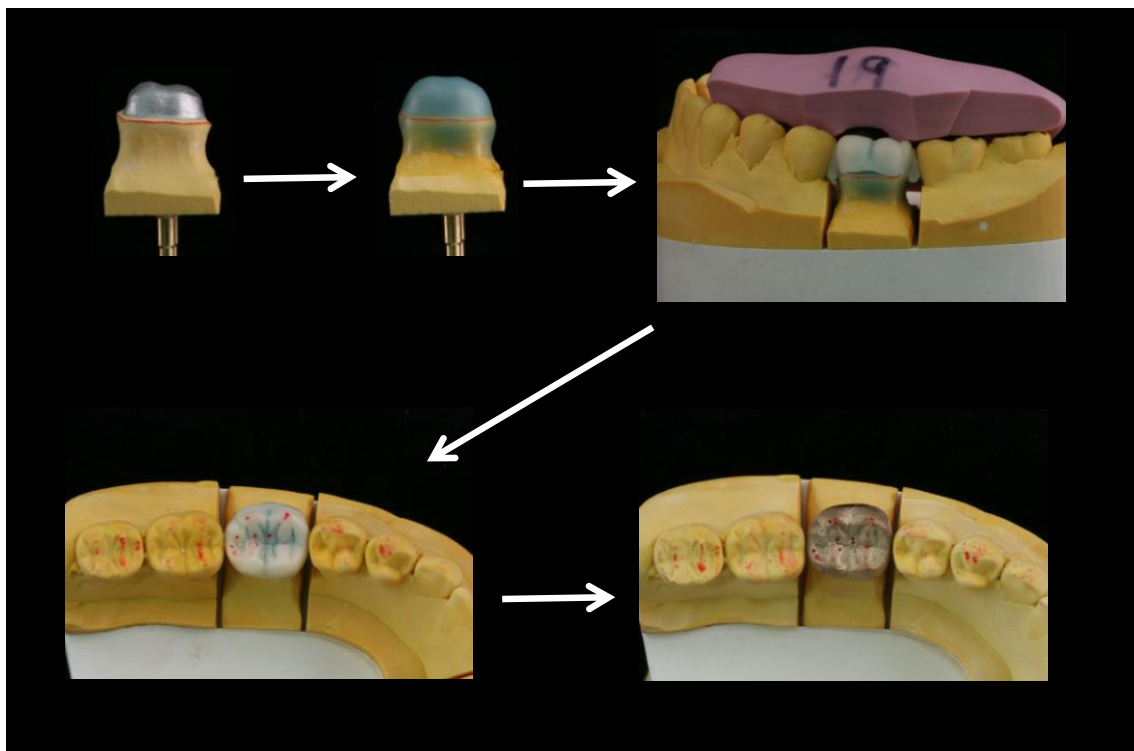
**FIGURE 1** Outline of materials and methods



**FIGURE 2** Facebow transfer, Aluwax interocclusal record, and mounting

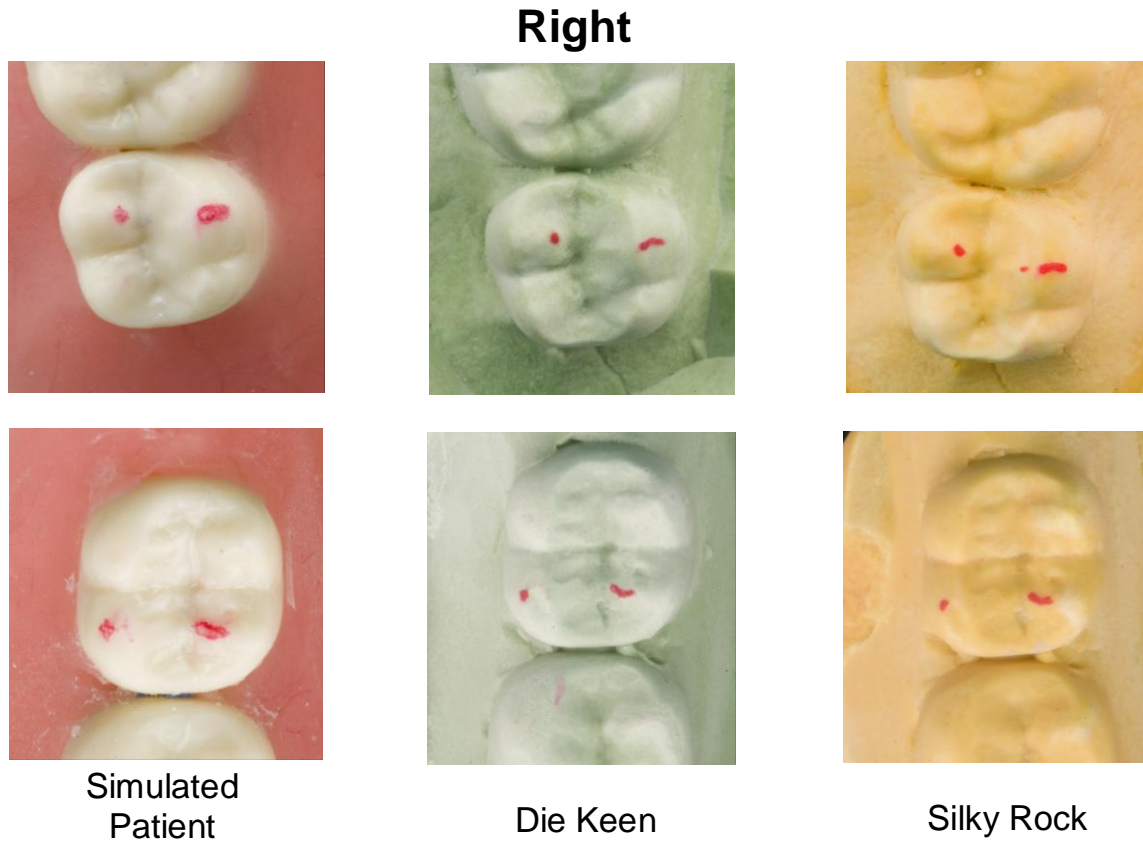


**FIGURE 3** Master casts in the experimental group carefully adjusted prior to crown fabrication. Casts were adjusted to remove the artifact CR-MI slide. Adjustment was complete when the articulator pin contacted is table.

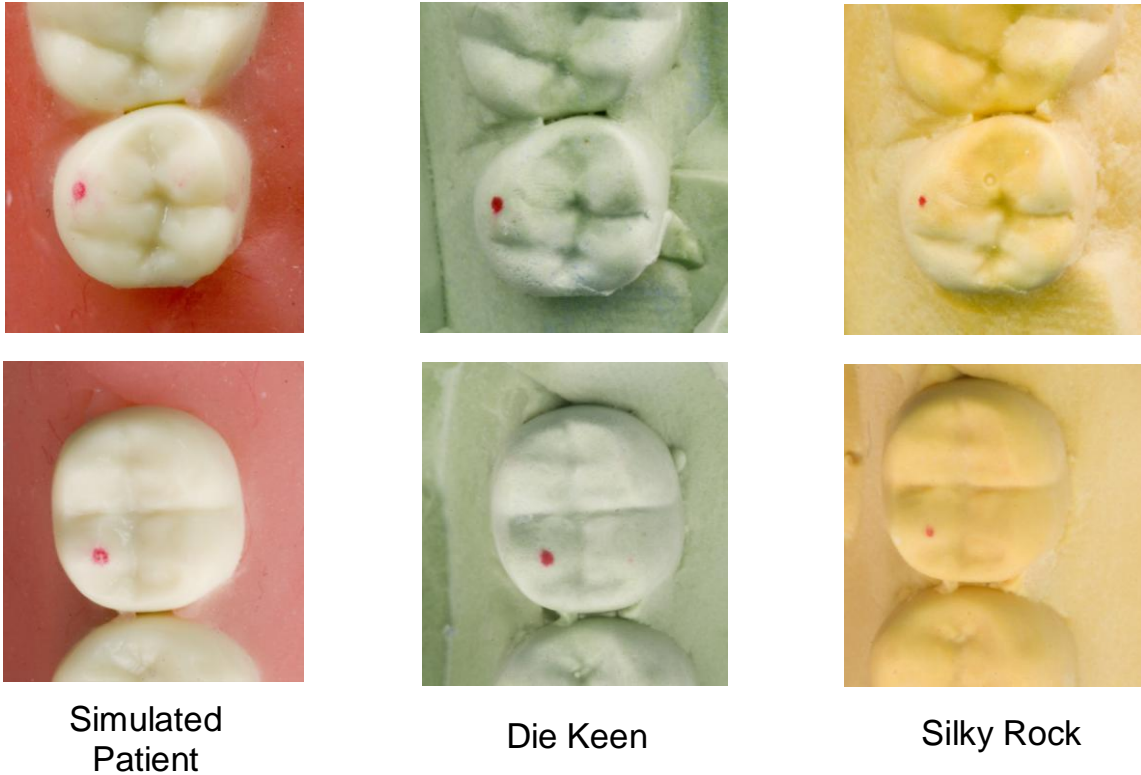
**FIGURE 4**

Crown fabrication steps as follows:

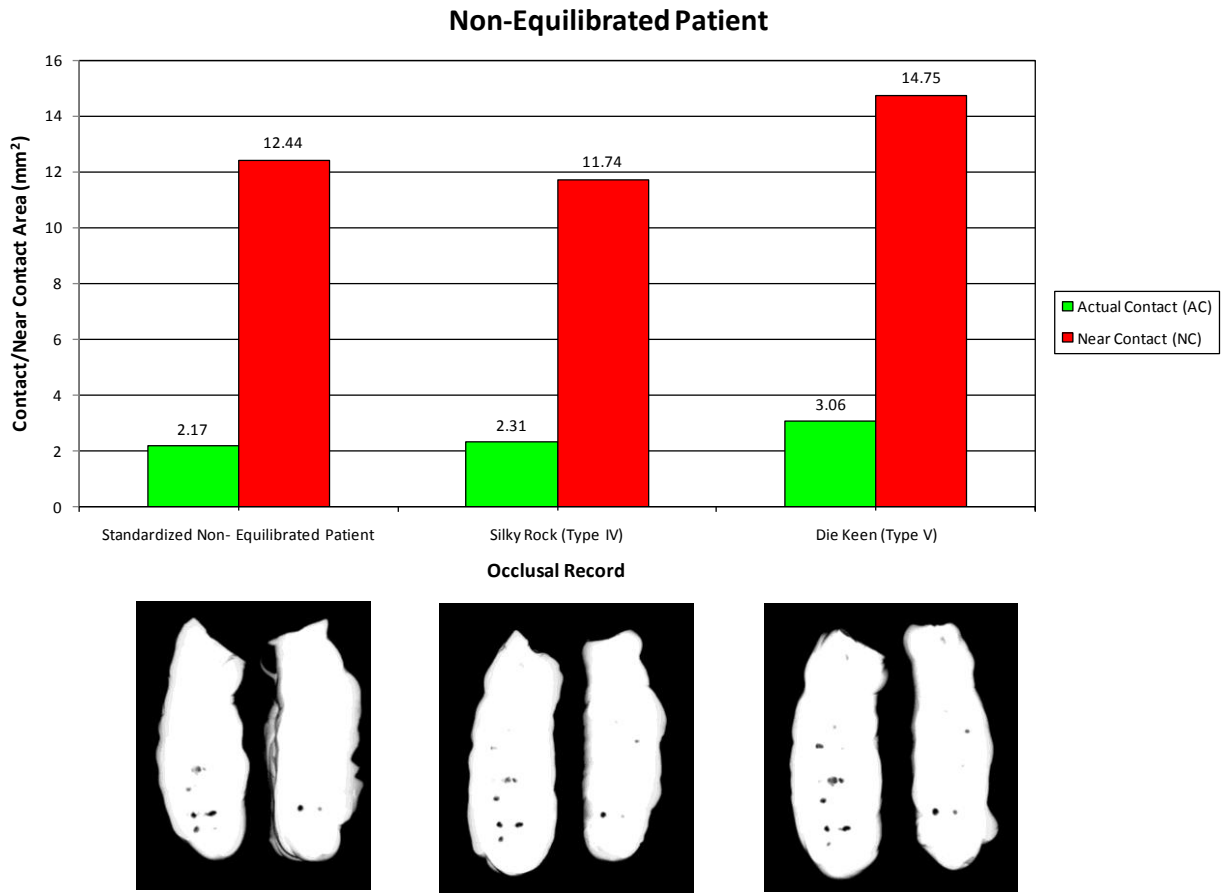
- 1.) Dies were dipped in coping wax. 2.) A wax mold was used to make a “rough” pattern. 3.) Cameo contours and occlusal tables of the wax patterns were refined. Castings were made from a ADA type IV dental alloy using the lost wax technique with gypsum bonded investment material. 4.) Occlusal contacts of castings were refined.



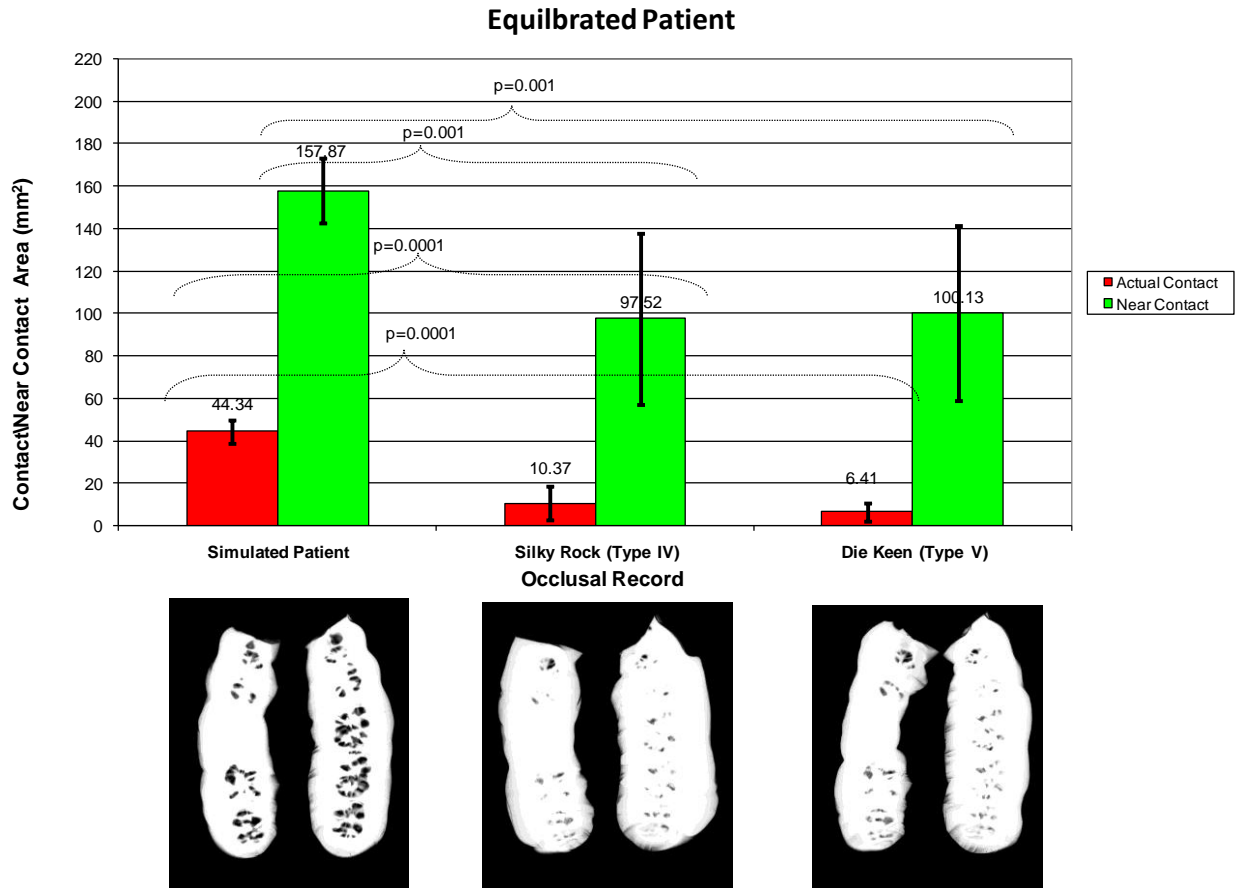
**FIGURE 5** Right side qualitative contact area comparison of the un-equilibrated Simulated Patient (SP) and cast representation with two different dental gypsum stones – Ribbon markings

**Left**

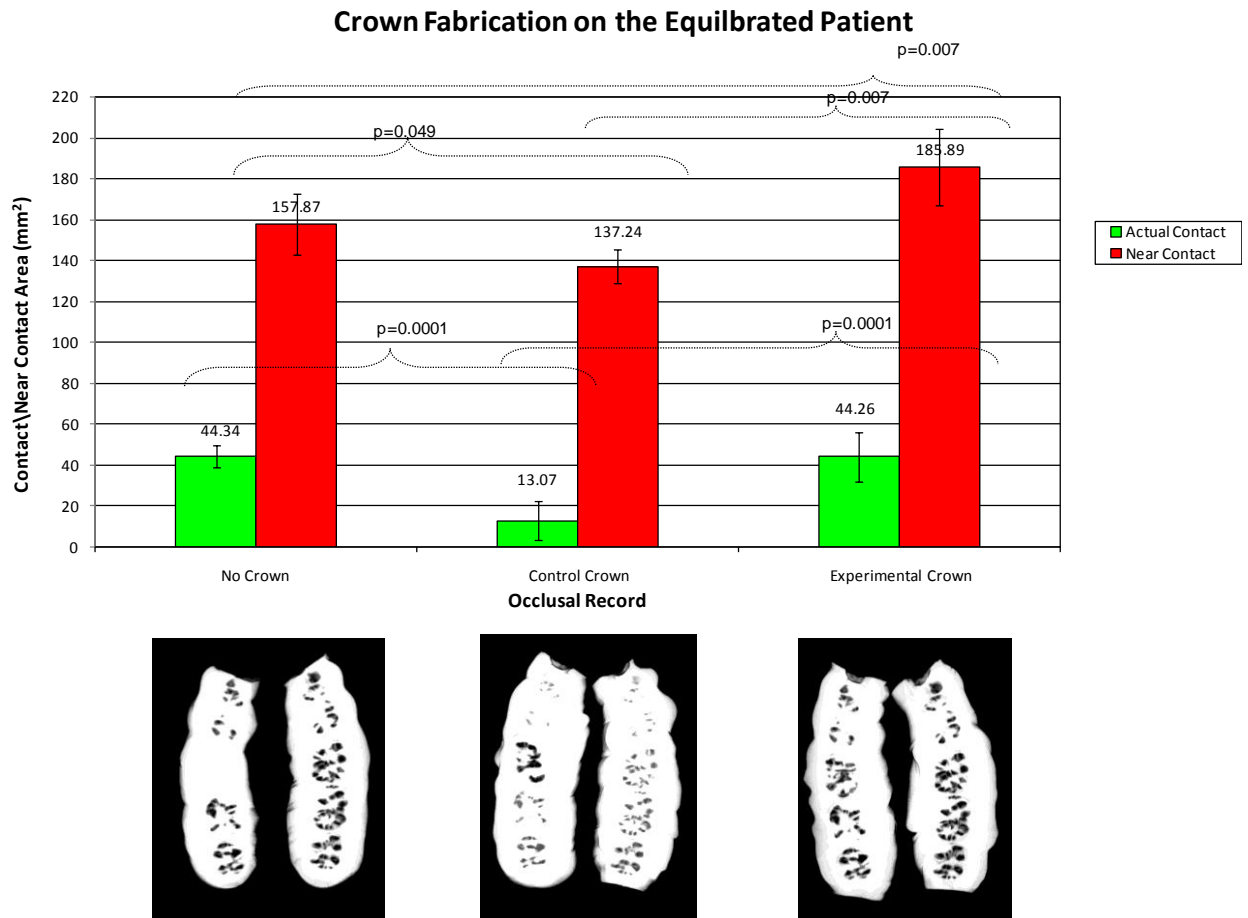
**FIGURE 6** Left side qualitative contact area comparison of the un-equilibrated Simulated Patient (SP) and cast representation with two different dental gypsum stones - Ribbon markings.



**FIGURE 7** Contact area comparison of the un-equilibrated Simulated Patient (SP) and cast representation with two different dental gypsum stones – Interocclusal records.



**FIGURE 8** Group comparison showed statistical differences for actual contact ( $p=0.0001$ ) and near contact ( $p=0.001$ ). Statistically significant differences also existed for some of the paired group comparisons.



**FIGURE 9** Group comparison showed statistical differences for actual contact ( $p=0.0001$ ) and near contact ( $p=0.003$ ). Statistically significant differences also existed for some of the paired group comparisons.

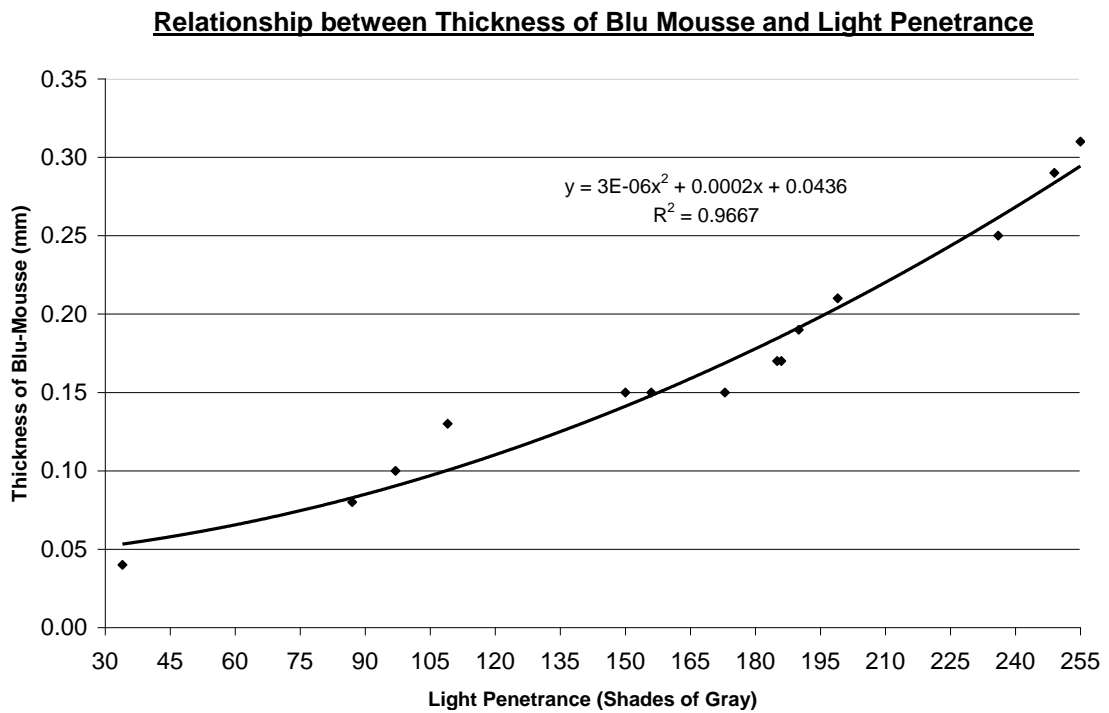
## TABLES

Die Stones	Manufacturer	ADA type	2 Hour Expansion (%)*	72 Hour Expansion (%)**
Silky Rock	Whip Mix	IV	0.09	0.14
Die Keen	Modern Materials	V	0.19	0.35

\*Manufacturer determined

\*\*Determined by Heshmati et. Al <sup>15</sup>

**TABLE 1**



**TABLE 2** Calibration step wedge data - A line of best fit for the relationship between thickness of blue mousse and light transmission was described by a quadratic equation with a high level of correlation.

	Descriptive Statistics						Group Comparisons	Paired Group Comparisons		
	Standardized Patient		Silky Rock (SR)		Die Keen (DK)		SP vs. SR vs. DK	SP vs. SR	SP vs. DK	SR vs. DK
	Mean (mm <sup>2</sup> )	SD	Mean (mm <sup>2</sup> )	SD	Mean (mm <sup>2</sup> )	SD	p value	p value	p value	p value
Actual Contact (AC)	44.34	5.54	10.37	8.10	6.41	4.37	0.0001	0.0001	0.0001	0.257
Near Contact (NC)	157.87	15.18	97.52	40.34	100.13	41.17	0.001	0.001	0.001	0.821

**TABLE 3** Quantitative comparison of contact areas for the equilibrated Standardized Patient (SP) and representative mounted casts from two different dental gypsum stones.

	Descriptive Statistics						Group Comparisons	Paired Group Comparisons			
	SP no Crown		SP Control Crown		SP Experimental Crown		No Crown vs. control vs. Exp.	SP No Crown vs. Control Crown	SP No Crown vs. Exp. Crown	SP Control Crown vs. Exp. Crown	
	Mean (mm <sup>2</sup> )	SD	Mean (mm <sup>2</sup> )	SD	Mean (mm <sup>2</sup> )	SD	p value	p value	p value	p value	
Actual Contact (AC)	44.34	5.54	13.07	9.63	44.26	11.82	0.0001	0.0001	0.650	0.0001	
Near Contact (NC)	157.87	15.18	137.24	8.24	185.89	18.52	0.003	0.049	0.007	0.007	

**TABLE 4** Quantitative comparison of contact areas for the equilibrated Standardized Patient (SP) and representative mounted casts from two different dental gypsum stones.

## APPENDIX – METHODS

Maxillary and mandibular members of the Columbia Dentofom (Columbia Dentofom Corp, New York, NY; model R-1560) were prepared for mounting



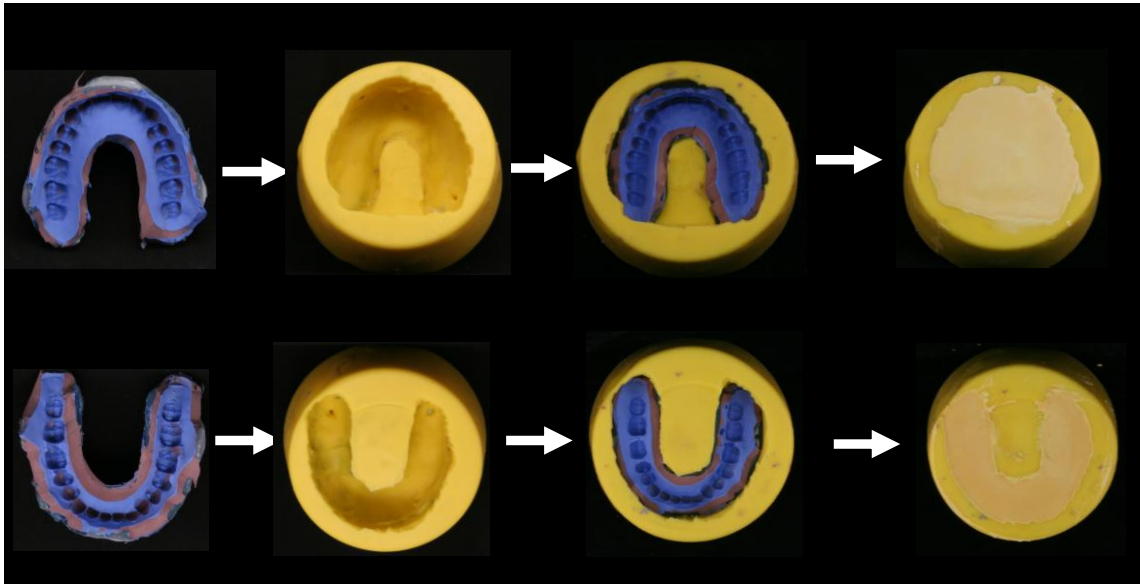
Custom tray fabrication jigs were made to ensure standardized trays (Triad VLC tray material; Dentsply International, Inc., York, PA) with consistent spacing for impression material, and stops on the land areas. PVS tray adhesive (Kerr Corp, Orange, CA) was applied prior to impression (1-2 hours)



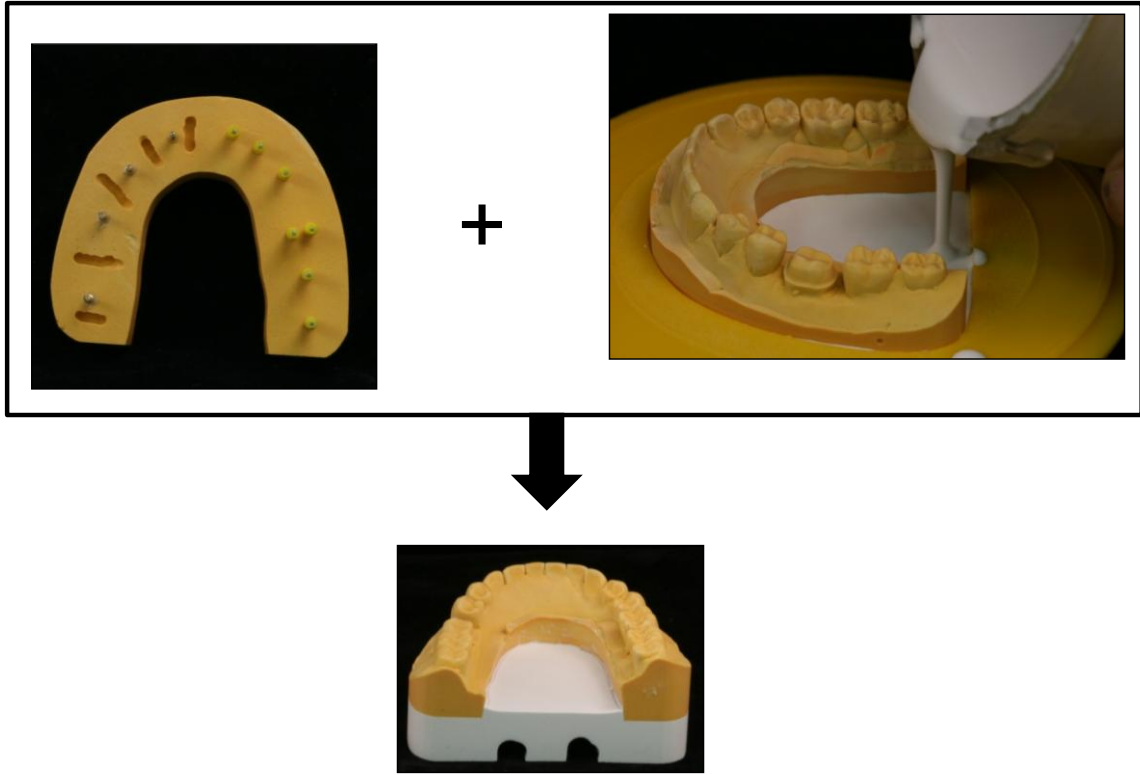
A standardized impression protocol was followed. A dual phase impression technique was used with types 1 and 3 polyvinylsiloxane material (Extrude; Kerr Corp, Orange, CA). All impressions were allowed 12min of set time before separation.



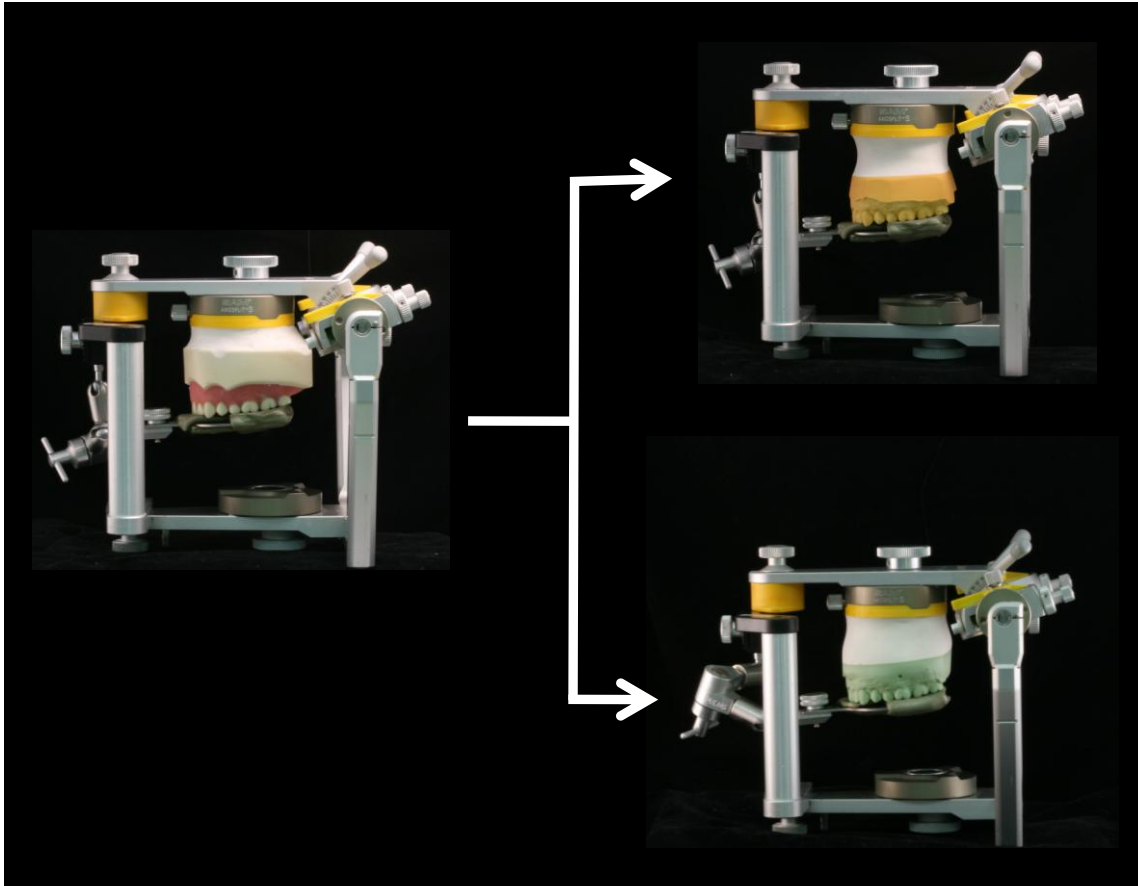
All impressions were poured using a standardized “boxing” mold to ensure that all maxillary and mandibular casts were comprised with roughly the same volume of die stone.



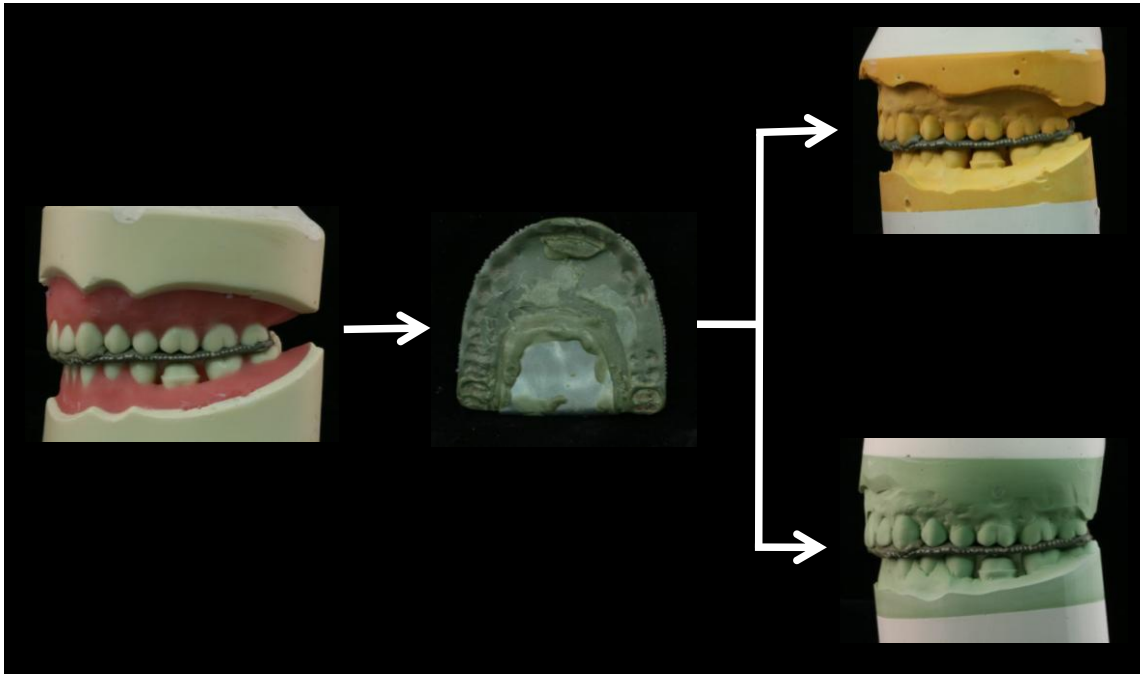
Lower casts were all pinned and poured bases prior to mounting. Only the left quadrant was allowed to be removable.



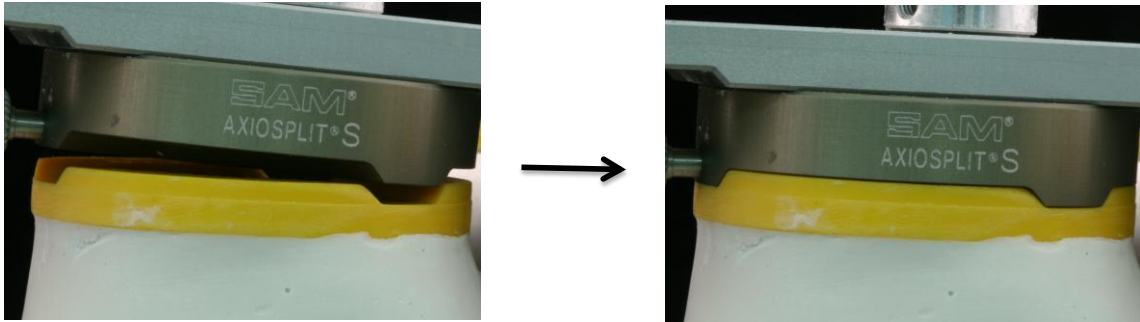
Position of the simulated patient's maxillary arch was recorded using the SAM facebow transfer jig and aluwax, which was in turn used to facilitate mounting of the maxillary Silky Rock and Die Keen casts.



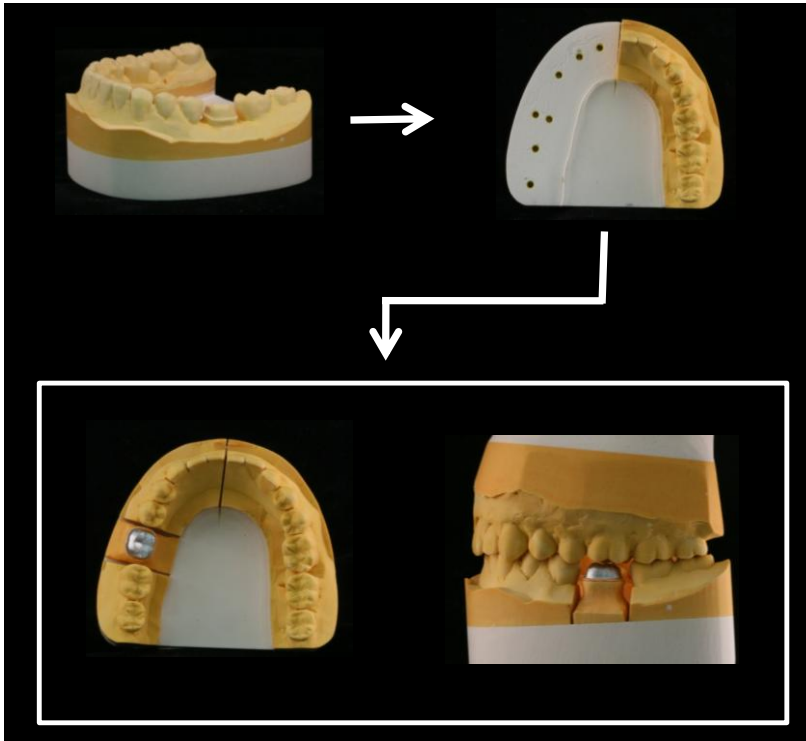
A reinforced Aluwax centric relation record was made on the simulated patient. This record was used to facilitate mounting of the mandibular members of the respective Silky Rock and Die Keen Casts.



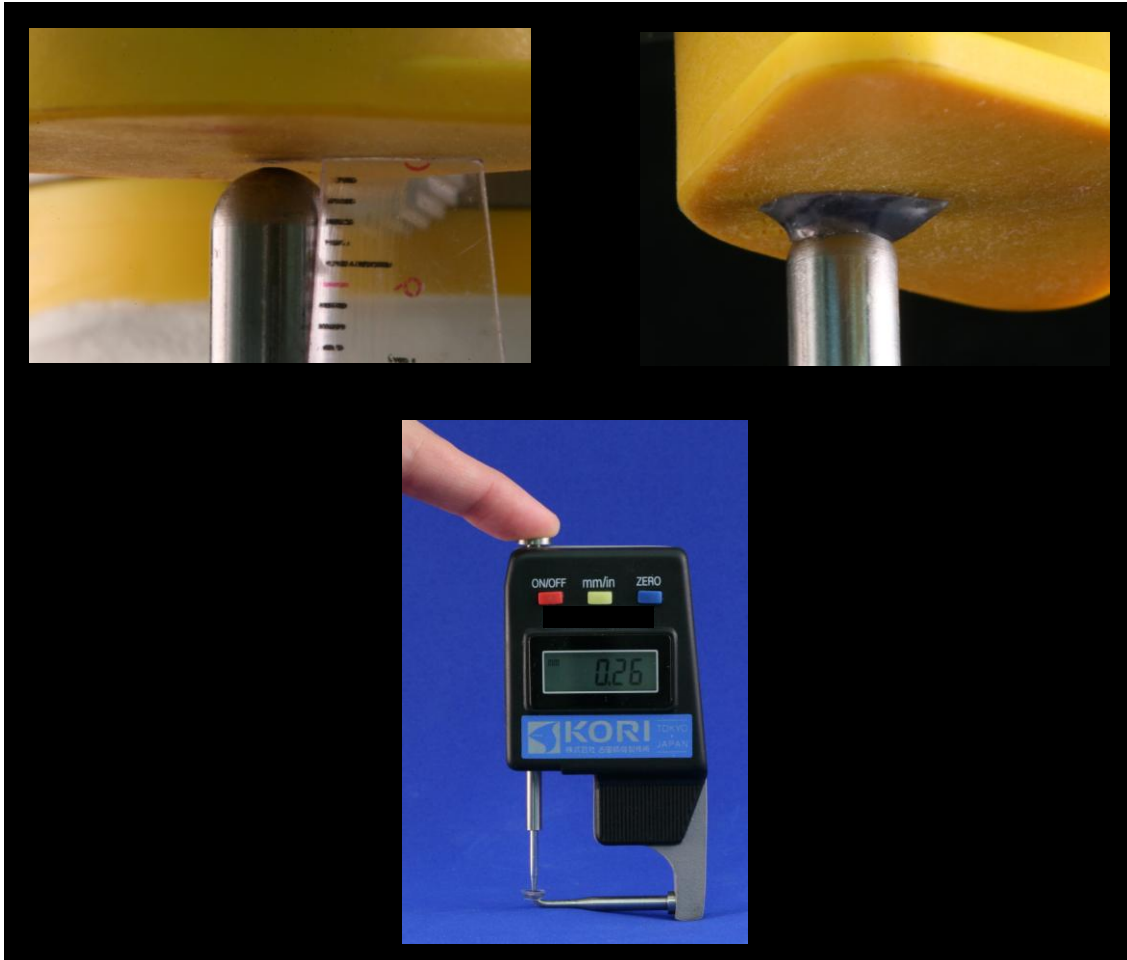
All cast mounting were done with split cast mounting plates to allow verification after mounting with the CR record



Pinned sections on mandibular left were sectioned, the die was trimmed, hardened, and 2 layers of spacer were placed



The quantity of the artifact CR-MI slide was recorded with Triad VLC gel (Dentsply International, Inc., York, PA), and indirectly measured using a digital caliper (Digital Caliper Model #DA-1, Kori, Japan)

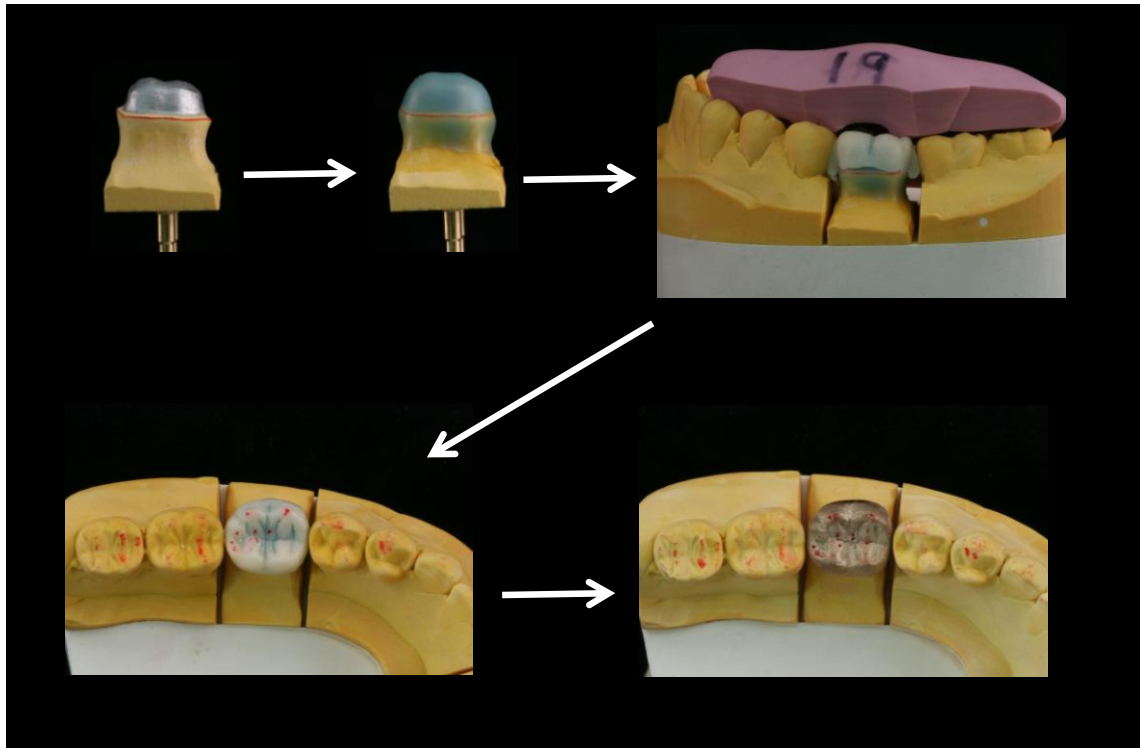


The casts assigned to the experimental group were adjusted to remove the artifact CR-MI slide. The adjustment was complete once the articulator pin became in contact with its table



Crown fabrication steps as follows:

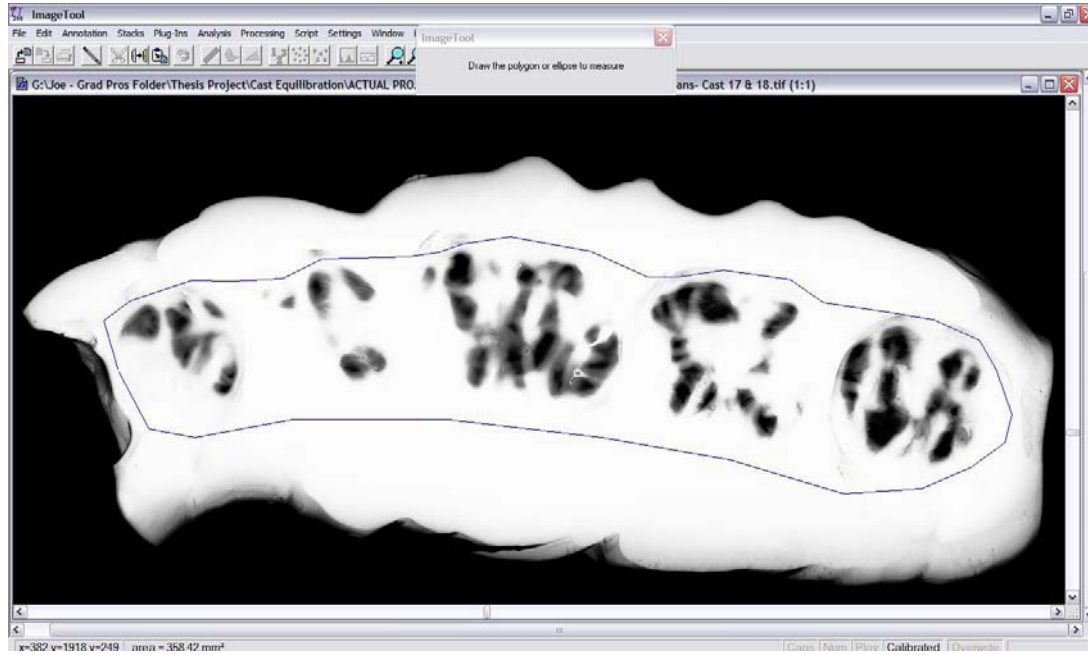
- 1.) Dies were dipped in coping wax.
- 2.) A wax mold was used to make a “rough” pattern.
- 3.) Cameo contours and occlusal tables of the wax patterns were refined.
- Castings were made from a ADA type IV dental alloy using the lost wax technique with gypsum bonded investment material.
- 4.) Occlusal contacts of castings were refined.



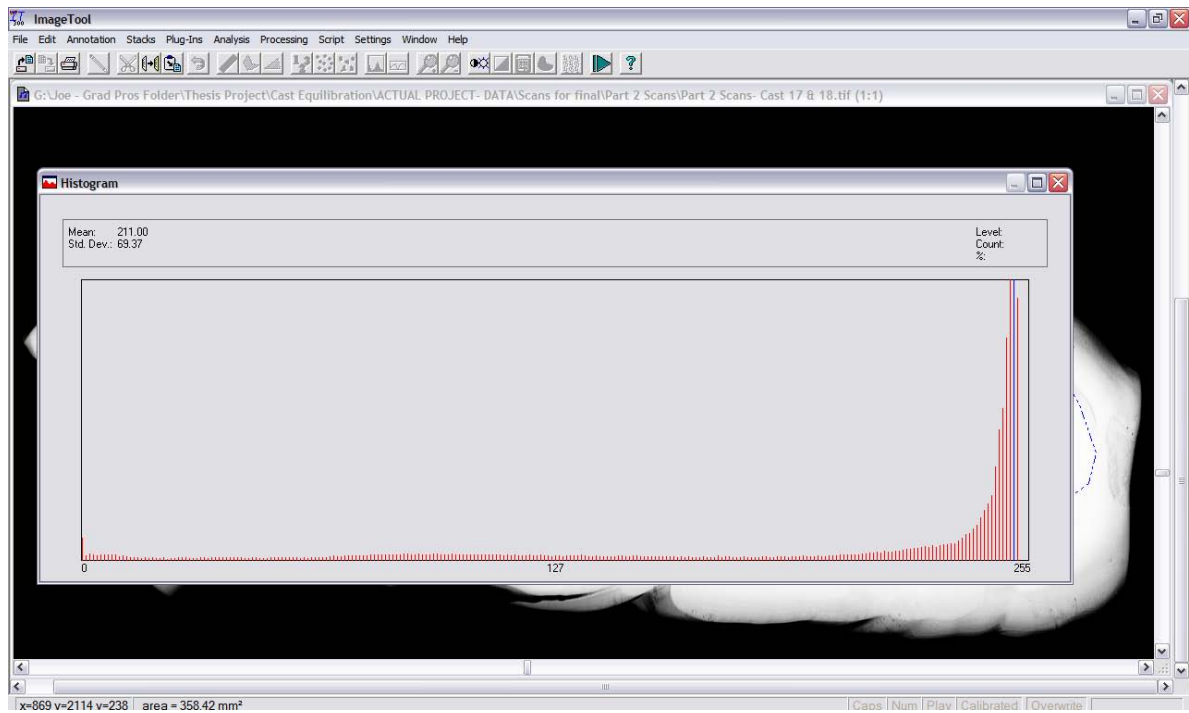
The castings were delivered to the simulated patient. Complete seating was verified using 4.3x magnification and an explorer. Full arch Blu Mousse interocclusal records were made and trimmed into bilateral segments extending from 1<sup>st</sup> premolar distal to 3<sup>rd</sup> molar. The records were then scanned in negative transparency mode at 600 dpi. A block of known length was placed in the scan field for measurement calibration purposes.



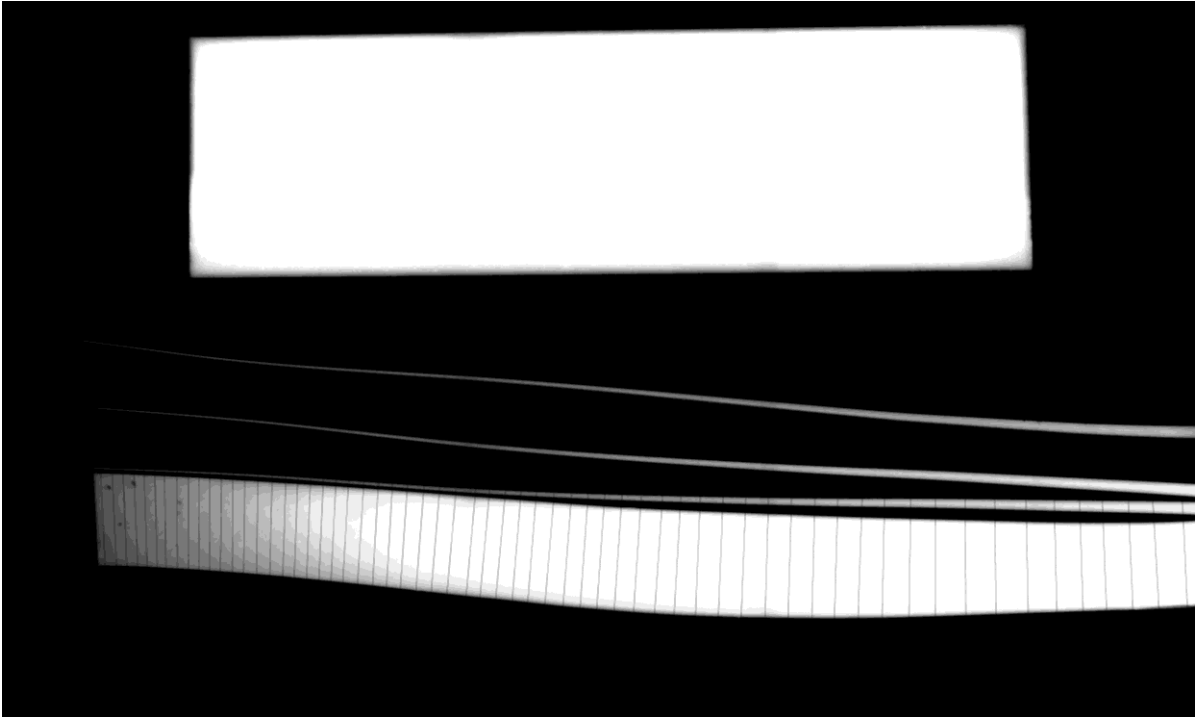
## Imagetool interface –outlining for optical density measurement



Imagetool interface – histogram for optical density measurement. Areas for each of 256 levels of optical density were saved in an Microsoft Excel spreadsheet for each unilateral record.



Calibration step wedge used to determine Blu Mousse thickness vs. optical density trend.  
Scan has been reformatted to facilitate calibration measurements.



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**PUBLICATIONS**

*Abstracts:* **Meng J.**, Everts J., Gratton D., Qian F. Implant-abutment interface micromotion of three different implant neck designs. *J Dent Res*, 2005; Vol 84, #0435

Everts J., **Meng J.**, Gratton D. Flexural strength of zirconia frameworks fatigued under simulated oral conditions. *J Dent Res*, 2005; Vol 84, #0425.

**Meng J.**, Everts J., Gratton DG. Flexural strength of treated zirconia frameworks under simulated oral conditions. *J Dent Res*, 2006; Vol 85, #1876.

*Articles:* Steinberg EK., Lindner KR., Gallea J., Maxwell A., **Meng J.**, Allendorf FW. Rates and patterns of microsatellite mutations in pink salmon. *Molecular Biology & Evolution*. Vol. 19(7):1198-202, 2002 Jul.

**Meng J.**, Everts J., Qian F., Gratton DG. Influence of Connection Geometry on the Dynamic Micromotion at the Dental Implant-Abutment Interface. *Int J Prosthodont* 2007;20:623–625.