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COMPARISON OF BITE REGISTRATION MATERIAL ACCURACY ON IN-OFFICE LASER SCANNED DIGITAL MODEL OCCLUSION

BY

ROHTAZ KAUR SANDHU

A THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in the
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2014

Submitted by Rohtaz Kaur Sandhu in partial fulfillment of the requirements for the degree of Master of Science specializing in Oral Biology.

Accepted on behalf of the Faculty of the Graduate School by the thesis committee:

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LIST OF ABBREVIATIONS

3D…………...Three dimensional

ABO…………American Board of Orthodontics

AAO…………American Association of Orthodontics

ANOVA……..Analysis Of Variance

CBCT……….Cone Beam Computerized Tomography

CO…………..Centric Occlusion

g……………..Gram

In…………….Inch

ICC………….Intraclass Correlation Coefficient

LLC………….Limited Liability Corporation

ml……………Milliliters

mm…………..Millimeter

OBJ…………Object module format

PLY…………Polygon format file

PVS…………Polyvinylsiloxane

SD…………...Standard Deviation

STL file……...StereoLithography format file

ACKNOWLEDGMENTS

First and foremost, I would like to thank Dr. Russell Weaver for being the foundation to this research project. His background knowledge was very critical in building this project, especially, in designing the study. Dr. Dickinson was very supportive in providing help with statistical analysis. Last but not least, a big thanks to my husband, parents and sisters for taking care of my daughter, Kunooz. Without their help, I would have not been able to go through the Masters' process. They have been very encouraging and supportive of me in continuing my education during the past two years.

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ABSTRACT

Objective: To compare the accuracy of the digital occlusions created by three bite registration materials scanned using an in-office laser surface scanner, Ortho Insight 3D

Materials and Methods: Fifteen stone dental models from an orthodontic practice were impressed and bite registrations were obtained using the three separate impression materials; Copper Wafer Wax, Blu-Moose and Byte Right. The impressions and bite registrations were then scanned into the Ortho Insight 3D system creating digital models. The digital dental models were then digitally occluded using the three separate scanned bite registrations. Eight inter-arch measurements were made on the stone models (control) and the three digitally occluded models.

Results: Statistical Analysis utilizing 2 way ANOVA revealed small but statistically significant variance due to the materials and interaction of the materials with the site. Stone models and Blu-Moose tend to give lower values than the Copper Wax and Byte Right. Blu-Moose and Byte Right have significantly lower variances, more precise measurements (narrower distributions) than Copper Wax.

Conclusion: Virtual digital models constructed from impressions and bite registration are clinically acceptable when compared to traditional stone models for inter-arch measurement based on selection of bite registration materials:

Blu-Moose≥ Byte Right>Copper Wax

INTRODUCTION

According to American Association of Orthodontics (AAO), pretreatment and post treatment records should include extraoral and intraoral photographs, dental models, intraoral and/or panoramic radiographs, cephalometric radiographs, as well as any additional indicated tests or procedures. Accurate records are essential for effective orthodontic diagnostic and treatment planning. Thus, study models are an essential part of an orthodontic record (White, Fallis, & Vandewalle, 2010). Information obtained from study models helps the orthodontist to classify malocclusions, identify aberrations and formulate treatment objectives. Additionally, for the purposes of education, evaluation, and research, models are used to present treatment results to colleagues and patients (Peluso, Josell, Levine, & Lorei, 2004).

Furthermore, a number of measurements and analyses such as tooth size-arch length discrepancy and prediction of permanent tooth size can be obtained from plaster study models. Measurements of tooth size-arch length discrepancies are recorded more accurately on the study models, hence eliminating the need to estimate the amount of crowding intraorally (Peluso, Josell, Levine, & Lorei, 2004). However, these gypsum-based study models are heavy and bulky, pose storage and retrieval problems, are liable to damage and can be difficult and time consuming to measure. Legislation relating to the retention of patient records after the completion of treatment has also led to huge demands on space for storage. This has prompted the development of alternative methods of recording occlusal relationships and electronic storage of records (Keating, Knox, Bibb, & Zhurov, 2008).

Transitioning to digital study models

In the 1990s, digital radiographs, photographs, and electronic charts were introduced in orthodontic practice (Whetten, Williamson, Heo, C, & Major, 2006). The introduction of "virtual study models" may allow the use of a fully electronic patient record for the orthodontic patient (Joffe, 2004). 3D images are a reliable way to archive study models without any fear of loss or damage to the original casts (Hajeer, Millet, Ayoub, & Siebert, 2004). Digital study models were introduced commercially in 1999 by OrthoCad (Cadent, Carlstadt, NJ, USA) and in 2001 by Emodels (GeoDigm, Chanhassen, MN, USA). OrthoCad uses "destructive scanning" with multiple scans of a model in thin slices whereas Emodels scans the surface of a complete plaster model. Emodels has software to slice through the image whereas OrthoCad actually slices through the model and images it (Fleming, V, & Johal, 2011).

Digital models have been shown to be an acceptable substitute for stone casts. Some studies have shown no statistical difference between the measurements made on digital models and stone casts, whereas other studies have found some statistically significant differences, but none that are clinically significant. However, even with statistically significant differences, diagnosis and treatment decisions are not statistically different when using digital models rather than stone casts (Horton, Miller, Gaillard, & Larson, 2010). Thus, the virtual counterparts are beneficial to orthodontist in the following areas: (1) patient records instantly accessible on the computer screen; (2) saving money on the monthly cost of storage space needed for plaster models; (3) accurate and efficient measurements of tooth and arch sizes and dental crowding; (4) perform accurate and simple diagnostic set ups of various extraction patterns; (5) ability to send virtual images anywhere in the world for instant referral or consultation and (6) objective model grading analysis for American Board of Orthodontics (ABO) certification (Stevens, C, Nebbe, Raboud, & Major, 2006)

3D laser scanners in orthodontics

With new advances in 3D dental and orthodontic software, the orthodontist can examine intra- and inter-arch relationships with much more precision (Hajeer, Millet, Ayoub, & Siebert, 2004). A device for recreating three-dimensional (3D) objects on a computer is the surface laser scanner. By triangulating distances between the reflecting laser beam and the scanned surface, the surface laser scanner can detect not only an object's length and width but also its depth (Kusnoto & Evans, 2002). The major advantages of laser scanners are high speed, accuracy, and reproducibility. Transverse relationships between upper and lower arches are also assessed when 3D models are viewed in occlusion from different angles on the screen (Hajeer, Millet, Ayoub, & Siebert, 2004). One way to obtain digital models is for the orthodontist to send alginate impressions and wax bites through overnight service to an outside company such as OrthoCad for processing. Within a week, models are ready to be downloaded via the Internet so the orthodontist can store, retrieve, diagnose and communicate their cases electronically. However, the production of digital models by these companies is associated with problems such as time required to ship impressions, processing times and also the dimensional stability of the impression material (Marcel, 2001).

Ortho Insight 3D by Motion View Software, LLC is an in-house high resolution 3D robotic laser scanner that scans full arch impressions, plaster models, and bite registrations to make virtual 3D models in the computer. The scanner uses three calibrated laser lines that allow the camera to sense depth via triangulation and determine the 3D surface of an object. Three motors are used to move the object and provide a complete view of the object to the camera and lasers without manually rotating or moving the object, which allows for the scanning of the undercuts. This results in a point cloud of hundreds of thousands of individual 3D coordinates that represent the surface of the object. These points are then processed and used to reconstruct the surface of the object and generate a mesh that can be saved in standard STL, PLY or OBJ file format. Trimmed models are ready to use immediately, however, untrimmed models and impressions can be placed in occlusion using bite registration materials and trimmed using custom virtual model trimmer software for articulation. Moreover, Motion View software integrates two dimensional radiographs with 3D models to determine the position of the incisors in relation to skeletal and soft tissues (Motion View Software, LLC, 2013). An additional advantage claimed by the manufacturer is the ability to scan impressions directly without having to pour stone models. This requires good quality impressions however and there are circumstances that make impression scanning difficult such as severe crowding and severe proclination of incisors.

Impression Materials

Impression materials are used to make an accurate replica or mold of the hard and soft oral tissues. Contact with tissues in the mouth and the needs of clinical procedures dictate critical requirements for the physical properties of dental impression materials. Some of the desirable properties of impression materials include 1) adequate shelf life for storage and distribution, 2) acceptable consistency and texture, 3) elastic properties with freedom from permanent deformation after strain, 4) adequate strength so it will not tear when removed from the mouth, 5) dimensional stability and 6) accuracy in clinical use (Powers & Sakaguchi, 2006)

Selection of a suitable impression material for the orthodontic records is very important. Polyvinylsiloxane (PVS) and alginate (irreversible hydrocolloid) are the two most commonly used materials for intraoral impressions. Due to its dimensional stability and detail reproduction, PVS is an excellent intraoral impression material. Dimensional stability was defined by Nicholls as “the ability (of material) to maintain accuracy over time” (Alcan, Ceylanoglu, & Baysal, 2009). PVS is least affected by pouring delays or second pours, maintaining its accuracy up to one week after the impression has been taken. However, due to cost limitations, most practioners prefer to use a material that has less dimensional stability over time. Therefore, the cost and potential locking into undercuts of fixed appliances has prevented polyvinylsiloxane from being a common impression material in orthodontics (White, Fallis, & Vandewalle, 2010).

Alginate impressions are commonly used due to their low cost, ease of manipulation, hydrophilic properties and ability to displace blood and body fluids. Nevertheless, the primary disadvantage of alginate lies in its dimensional instability over time (White, Fallis, & Vandewalle, 2010). Alginate impressions lose water by evaporation and shrink standing in air. Impressions left for as short as 30 minutes may become inaccurate enough to require remaking the impression (Powers & Sakaguchi, 2006). Even, when stored in 100% humidity conditions, alginate impressions will still contract, indicating that polymerization and syneresis are also involved along with dehydration (Alcan, Ceylanoglu, & Baysal, 2009). For maximum accuracy, alginate impressions should be poured (or laser scanned) as soon as possible since there is greater chance for distortion the longer the impression is stored (Powers & Sakaguchi, 2006). However, one study done by Alcan et.al showed that storing three brands of alginate impressions (Cavex, Orthoprint, Tropicalgin) in sealed plastic bags up to 4 days showed significant deformations and differences among one another but were not clinically significant for orthodontic analysis. To complete the record of the patients' dentition, a bite registration must be obtained no matter what material was used to take the impression (Alcan, Ceylanoglu, & Baysal, 2009).

Occlusal Registration Materials

Orthodontic study models can provide a three-dimensional view of a patient's occlusion. This may help in evaluating malocclusion in more detail compared to clinical examination (Quimby, Viq, Rashid, & Firestone, 2004). The patient's jaw relation can be determined either in maximum intercuspation given by occlusal morphology or mandibular position related to the centric position of the condyles (Utz, Muller, Luckerath, Fuss, & Koeck, 2002). According to Dawson, an accurate bite record must meet the following criteria:

1. No movement of teeth or displacement of soft tissues
2. Verify the accuracy of the interocclusal record in the mouth
3. Fit the dental casts as it fits in the mouth,
4. Verify the accuracy of the bite record on the dental cast and
5. Must not distort during storage or transportation to the dental laboratory (Dawson, 2007).

Waxes and polyvinylsiloxanes are the most commonly used recording materials (Ockert-Eriksson, Eriksson, Lockowandt, & Eriksson, 2000). Polyvinylsiloxanes demonstrates high stiffness, low percent strain in compression, low flow and low dimensional change even after 7 days (Powers & Sakaguchi, 2006). Conversely, the properties of waxes limit their accuracy since wax records can be distorted upon removal, may change dimensions by release of internal stresses, have high flow properties and can undergo large dimensional changes on cooling from mouth to room temperature (Powers & Sakaguchi, 2006). Various studies have shown significant variability between occlusal registrations of the same material but clinically these differences would not be apparent (Gross, Nemcovsky, Y, & Gazit, 1998). Companies such as OrthoCad strongly recommend using fast setting polyvinylsiloxane as the bite registration material even though a wax bite is considered to be acceptable.

Ortho Insight 3D manufactures a product called “Byte Right” as their bite registration material of choice to record patient’s occlusion with their laser scanner. The bite registration can then be scanned and computer oriented to the digitized maxillary and mandibular casts. Byte Right is made out of polystyrene, one of the most widely used plastic. Polystyrene is a synthetic aromatic polymer made from the monomer styrene, and a liquid petrochemical. Its ability to be cast into molds with fine detail is due to its temperature behavior. As a thermoplastic polymer, polystyrene is in a solid (glassy) state at room temperature but flows if heated above about 100 degrees Celsius, which is its glass transition temperature (Common Plastic Resins Used in Packaging, 2013). Ortho Insight 3D selected Byte Right as the material of choice because it exhibits rigidity after setting, less distortion, opaqueness and consistent light color. Ortho Insight 3D claims the light color reflects the laser light better therefore creating a better scanned bite registration (Motion View Software, LLC, 2013).

Present Study Focus

A Clinician has multiple choices of bite registration materials available to them. Each has associated pros and cons and the decision will be made based upon the clinicians' own preferences for cost and handling. However, the bite registration material must be able to re-create an accurate digital occlusion in the software no matter what material they choose. Each material scans differently in the laser scanner producing virtual occlusions of differing quality. Therefore, the purpose of the present in-vitro study is to evaluate the accuracy of three bite registration materials scanned using an in-office laser surface scanner, Ortho Insight 3D, to create a virtual occlusion. Specifically the aim of this study is to measure and compare interarch linear dimensions on a source model and the created digital model.

Specific aims of the present study include:

1. Compare the accuracy of bite registration materials in generating an inter-arch digital occlusion when compared to the stone model occlusion control.
2. Determine the intra-observer accuracy of repeated inter-arch measurements.

MATERIALS AND METHODS

The following study was approved by the Womack Army Medical Center Institutional Review Board for Research, Fort Bragg, NC and by the Uniformed Services University of the Health Sciences, Bethesda, MD. Funding for this study was provided by the United States Army Dental Activity, Fort Bragg, NC, USA. No commercial/financial relationship, interest, or association that might pose a conflict of interest has been present.

DESIGN:

Fifteen casts from previously treated orthodontic patients were selected for this study. The casts were being used for another study and patient information (name, identification number) were already removed for that study to maximize patient privacy. Selection criteria for the casts included a full dentition and minimal crowding (0-2mm) or moderate crowding (3-4mm). Each stone model was scored with number 2 round bur on the buccal or labial alveolar region apical to each maxillary and mandibular tooth crown (Figure 1).

Once the stone model set (maxillary/mandibular) was scored, an alginate impression (Henry Schein, Melville, NY) of each model set was taken. For the alginate impressions, liquid tray adhesive (Henry Schein, Melville, NY) was sprayed on stock impression trays (OrthoTechnology, Tampa, FL). The alginate material was utilized per manufacturer guidelines with a 7g alginate to 19ml water ratio. The material was spatulated in an Alginator (DUX Dental, Oxnard, CA) for 45 seconds and loaded into the impression tray. Each impression was inspected for distortion and voids and remade if unacceptable. The transfer of impressions for each model set to scanner and scanning occurred within 15 minutes to reduce the potential for dimensional changes. To scan, the impression was secured to the table inside the scanner using a double sided tape to hold the adjustable impression tray holder. A preliminary image was viewed to see if the impression scan was outside the camera view and adjusted if necessary to avoid any potential undercuts. The impression tray holder can also be rotated in the vertical axis to minimize the undercut area.

For each set of study models, three different bite registrations were made with the casts in maximum intercuspation using the plasterless, fixed plane Galetti Articulator (Kerr, Orange County, CA) (Figure 2). The three bite registration materials used were Copper wafer wax (OrthoTechnology, Tampa, FL), Blu-Moose (Henry Schein, Melville, NY), and Byte Right (Motion View Software LLC, Hixson, TN). Whip Mix Water bath (Whip Mix, Louisville, KY) was utilized to maintain temperatures in the range of 140F for softening the Copper Wafer Wax for 15 seconds and 170F to soften the Byte Right for 20-25 seconds, thus resulting in accurate bite registration imprint (Figure 3). A hook shaped metal stand known as the bite registration clip was used to secure the bite registration vertically on the impression tray holder. The bite registration must be as vertical as possible without leaning to one side and should not move during the scanning process. If the scan appeared distorted or displayed a blurred image, the bite registration was rescanned. Both the alginate impression material and the bite registration material were scanned per the software recommended preview exposure and the scan exposure settings according to the type of the material used (Table 1). Since, the exposure settings can affect details of the image; strict adherence to the manufacturer guidelines was maintained to minimize distortion. For example, the exposure setting especially the Scan exposure, meaning the intensity of light determines how long the shutter stays open on the camera. Thus, a longer time will give more light to the camera. Therefore, a lower exposure produces less detail and higher exposure produces more detail (Motion View Software, LLC, 2013). Hence, it is very critical to follow the manufacturer guidelines.

Recommended Settings			
Material	**Type**	**Preview Exposure**	**Scan Exposure**
White Alginate	Impressions	70	2-3
Blu-Moose	Bite Registration	70	3-4
Byte Right	Bite Registration	70	2.5
Wax	Bite Registration	70	20

Table 1: Ortho Insight 3D recommended exposure settings according to the type of the material.

Once the bite registration and the alginate impression for each model set were scanned, instructions were followed under the Digital “Model Trimmer” to create finished models with trim angles utilizing impression and bite registration (Figure 4- Figure 8).

The following eight linear interarch measurements (Site 1-Site8) were made on the three digitally occluded models (Figure 9):

- Maxillary right 1st molar to mandibular right 1st molar
- Maxillary right canine to mandibular right canine
- Maxillary left 1st molar to mandibular left 1st molar
- Maxillary left canine to mandibular left canine
- Maxillary right 1st molar to mandibular right canine
- Mandibular right 1st molar to maxillary right canine
- Maxillary left 1st molar to mandibular left canine
- Mandibular left 1st molar to maxillary left canine

The above eight interarch measurements were also completed manually on the stone casts (control) using a 4in Digital Caliper (Pittsburgh Model, 47256, Harbor Freight Tools, Camarillo, CA) (Figure 10). Measurements for both the stone casts and digital models were recorded to the nearest 0.01mm. 25% of the samples (4 models) were resurveyed to illicit any intra-investigator variability. Refer to Figure 11 for the flow chart related to the study.

SAMPLE SIZE AND POWER DETERMINATION

Based on the desired power (1-beta) of 80%, the significance level of 5% (alpha), the expected within group standard deviation (SD) of 0.185mm from previous articles, and the expected size difference of 0.2mm between the 2 groups to be compared, a sample size of 15 sets of study casts per group was used.

Probability of Type I Error (alpha):	0.05
Power (1-beta):	0.8
Difference to be detected:	0.2
Within group SD:	0.185
Sample size required (per group):	15

STATISTICAL ANALYSIS

All data was managed using a Microsoft Excel spreadsheet (Version 14.3, Microsoft, Redmond, WA) and analyzed using Graphpad Prism 6.0 software (Version 6.0, Graphpad, La Jolla, CA). Intra-observer reliability of 4 samples for Stone (control) and bite registration materials was assessed using an intraclass correlation coefficient (Shrout & Fleiss, 1979). The PAST: Paleontological Statistics software package was used for education and data analyses for the Intraclass Correlation Coefficient determination of reliability (Hammer, Harper, & Ryan, 2001).

Comparison was made between the stone models and three different bite registration materials. The mean of inter-arch measurements for all the 15 sets was calculated for each data collection method (three bite registration materials and stone models (control)). Two way ANOVA was used to test the relationship between measured occlusion distance and material at each model position. Two way ANOVA was cross checked with one way ANOVA and Tukey's post test. Non-parametric Friedman test was used for general comparison of measurements between the three groups and the control. If one or more materials significantly differed from others, spread of the values about the mean was evaluated.

Image of a Stone Cast

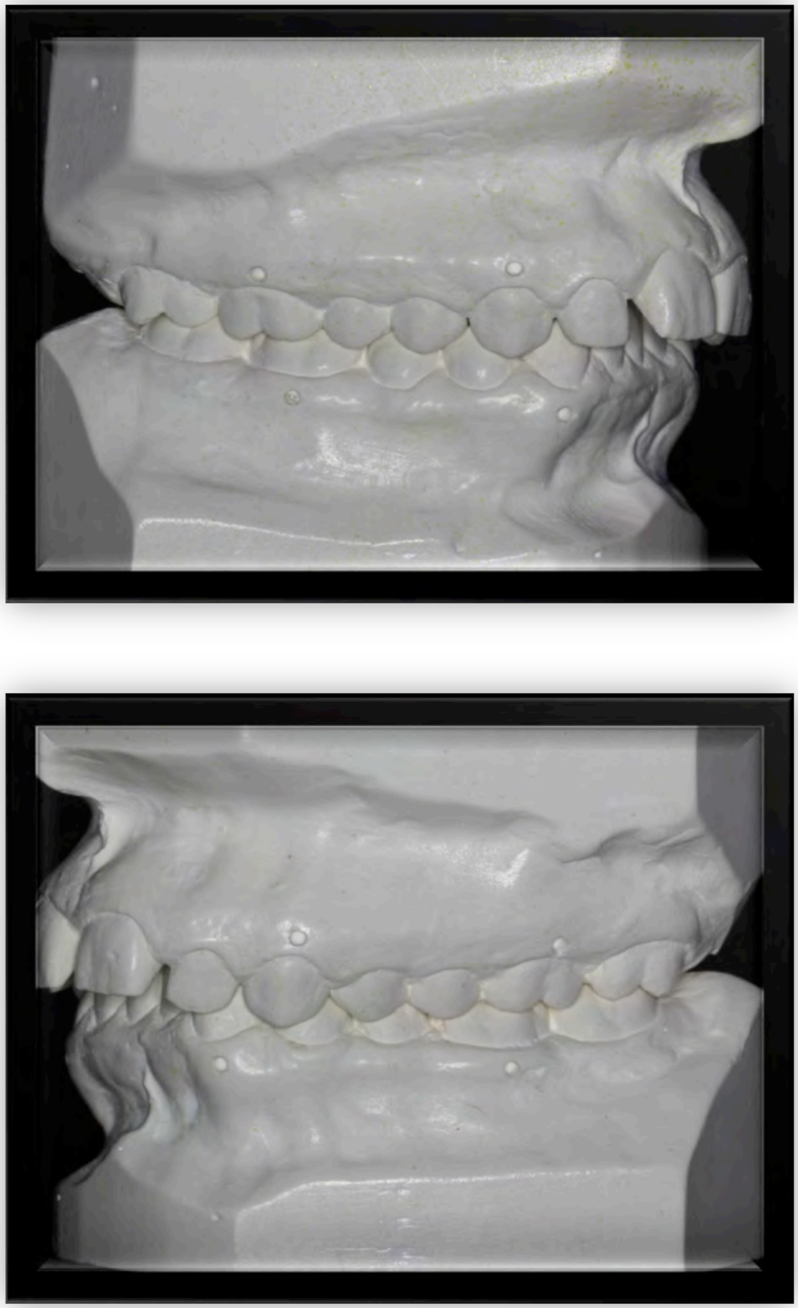


Figure 1. Images of Stone casts scored with Number 2 round bur on the buccal and labial alveolar region apical to the selected maxillary and mandibular teeth.

Image of Casts Mounted on Galetti Articulator

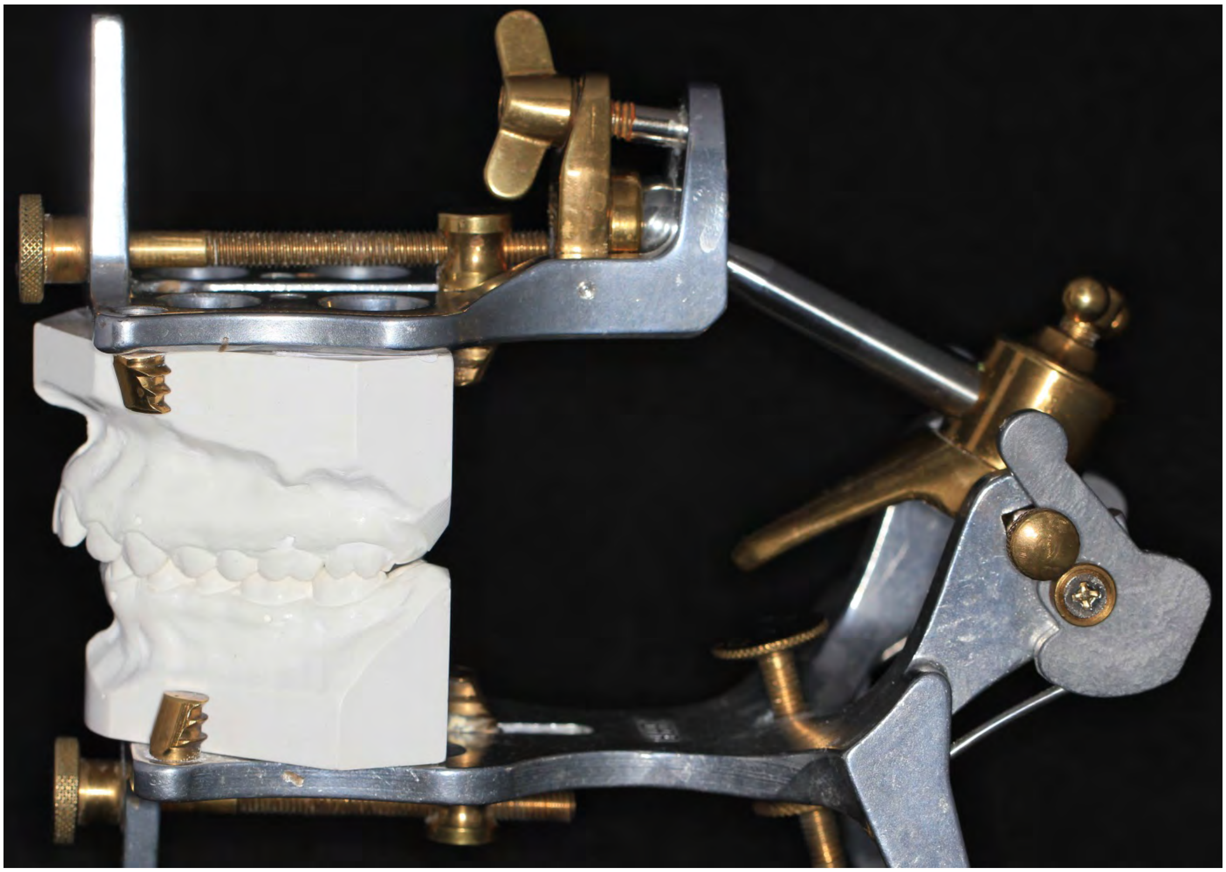


Figure 2. Image of casts in maximum intercuspation using the plasterless, fixed plane Galetti Articulator

Three Different Bite Registration Materials

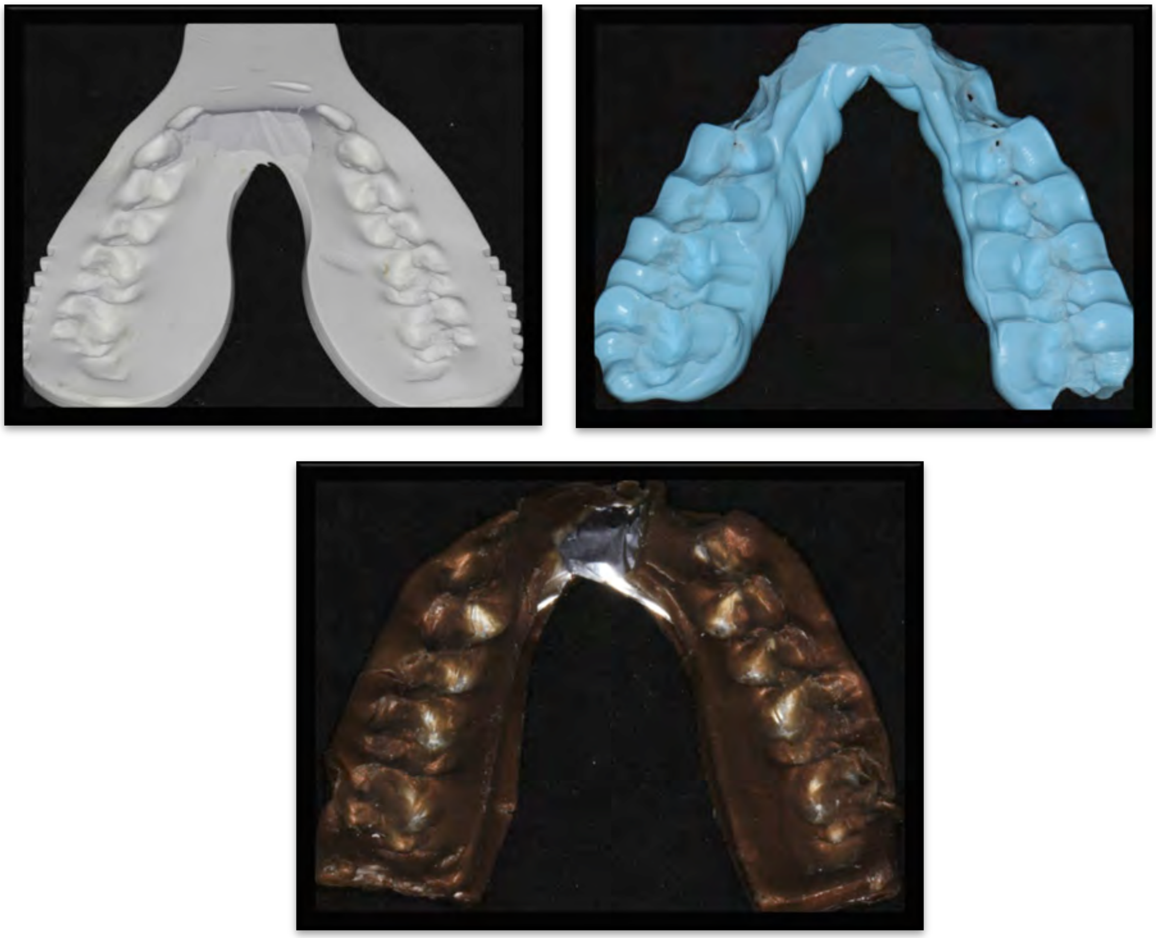


Figure 3.Three bite registration materials; Top Left: Byte Right, Top Right: Blu-Moose, Bottom Center: Copper Wafer Wax

Screen Image of Ortho Insight 3D Removal of Tray/base

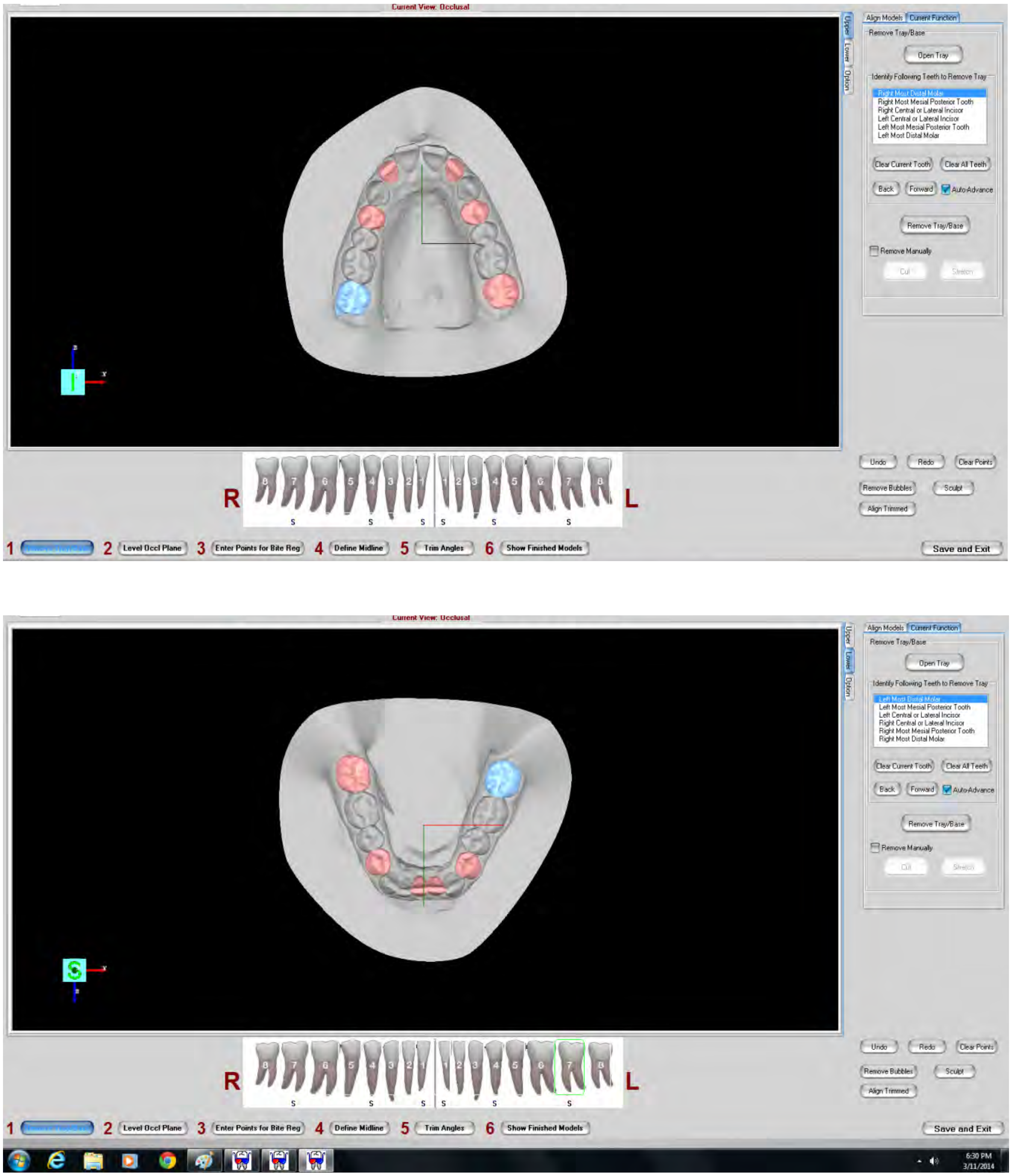


Figure 4. A screen image of the upper and lower impression with identified teeth to remove the tray/base

Screen image of Ortho Insight 3D Level the Occlusal Plane

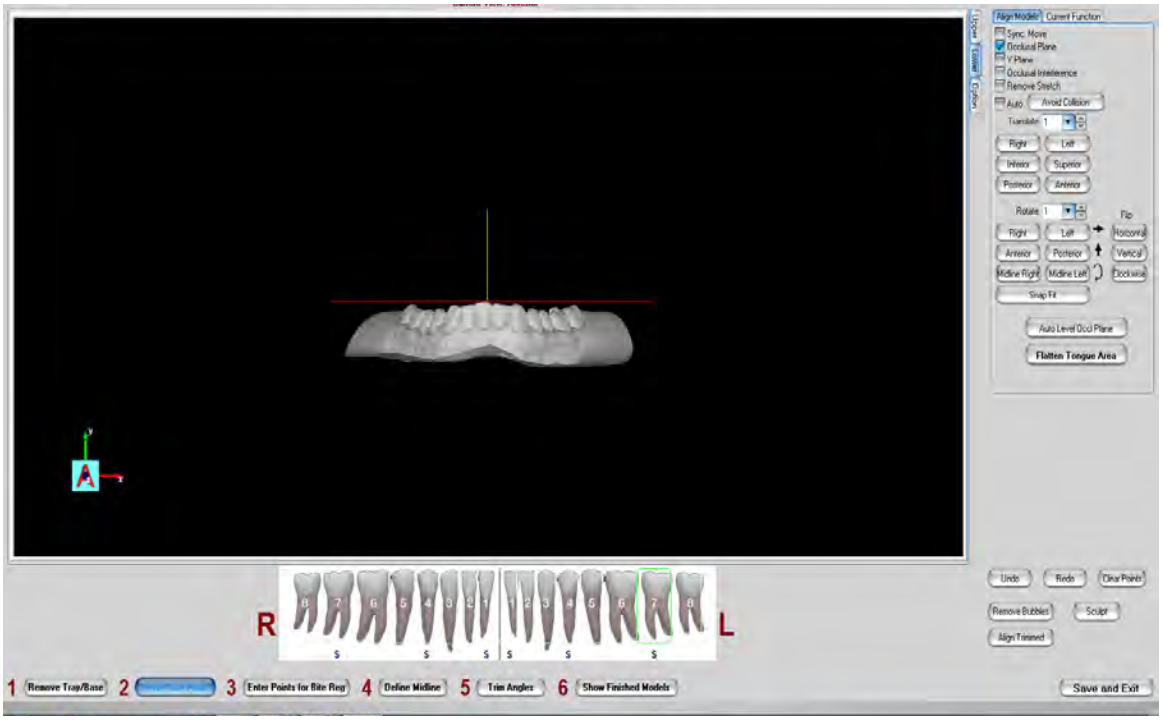
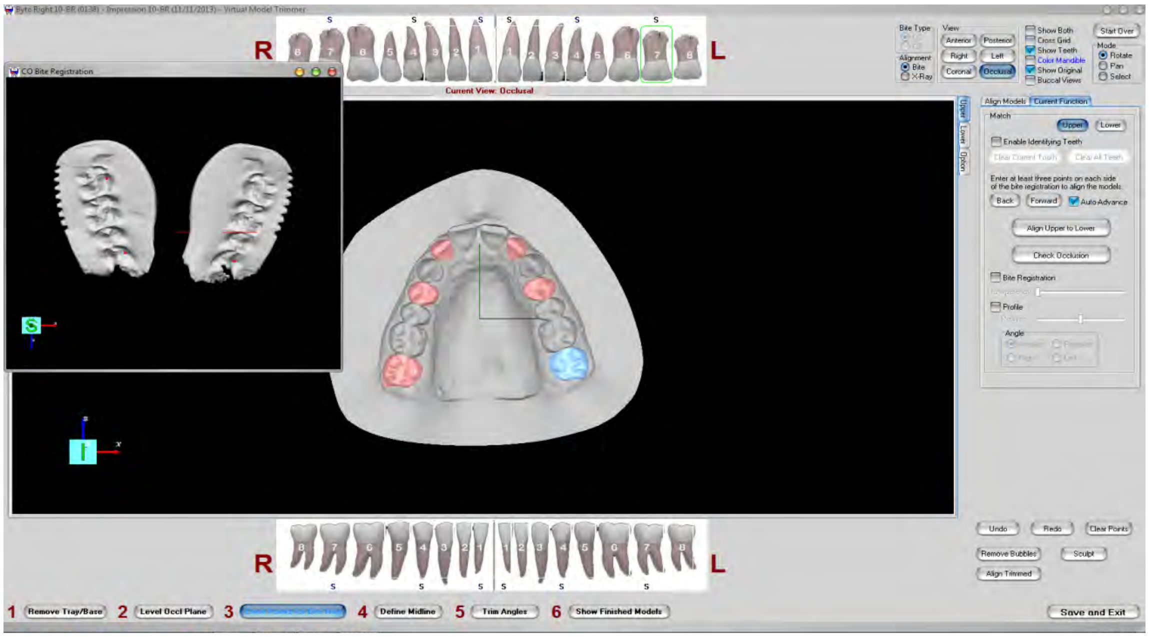


Figure 5. Screen image displaying the leveling of the occlusal plane under the model Trimmer section.

Screen Image of Ortho Insight 3D Bite Registration Markings



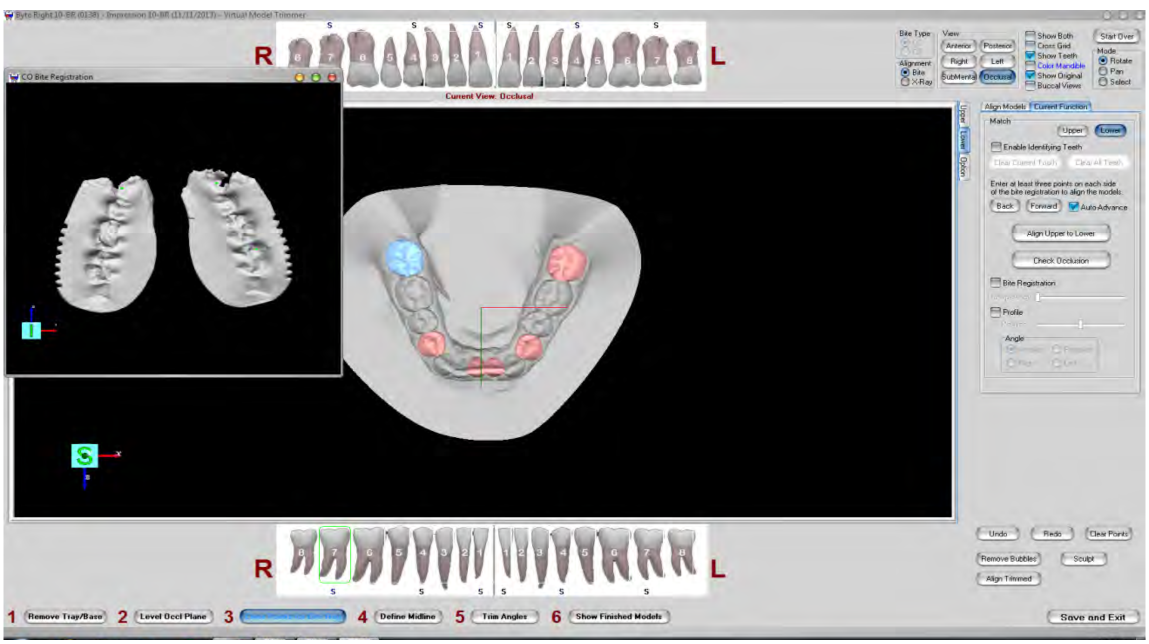


Figure 6. Screen image displaying the CO bite registration that needs to be identified to align the upper cast with the lower cast to check occlusion.

Screen Image of Ortho Insight 3D Draw Midline

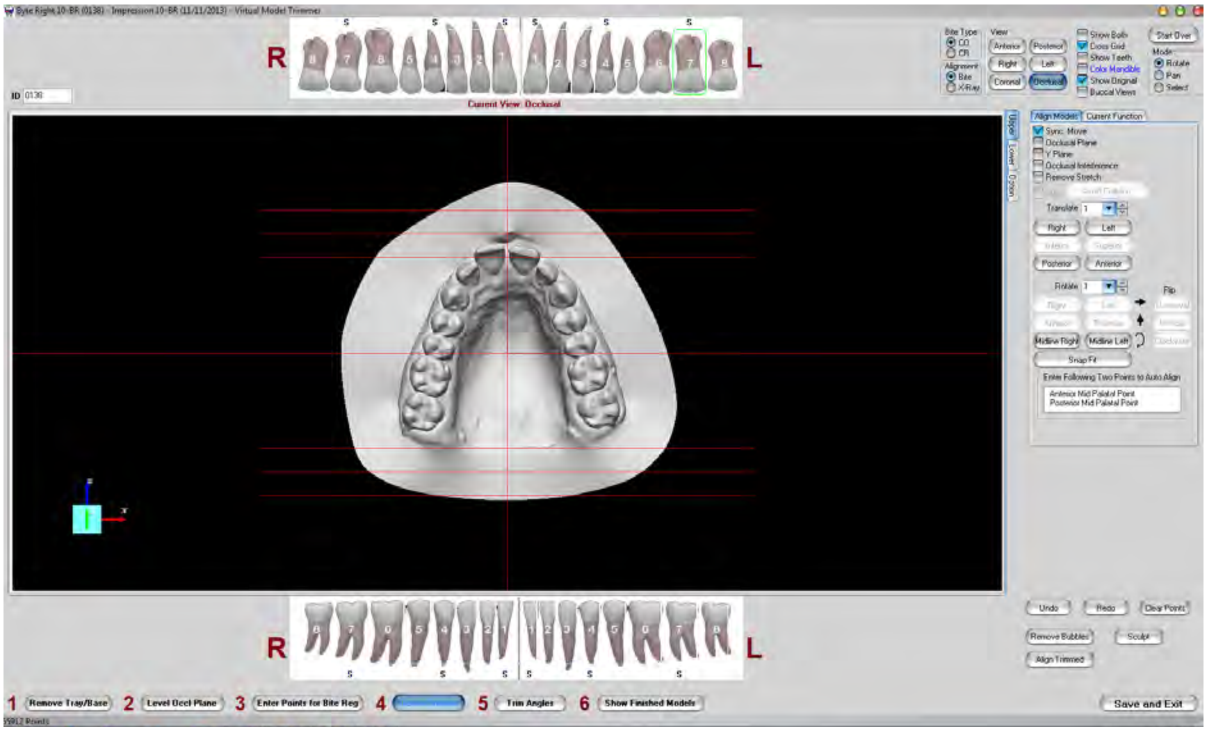


Figure 7. Screen image displaying the midline.

Screen Image of Ortho Insight 3D Finished Model

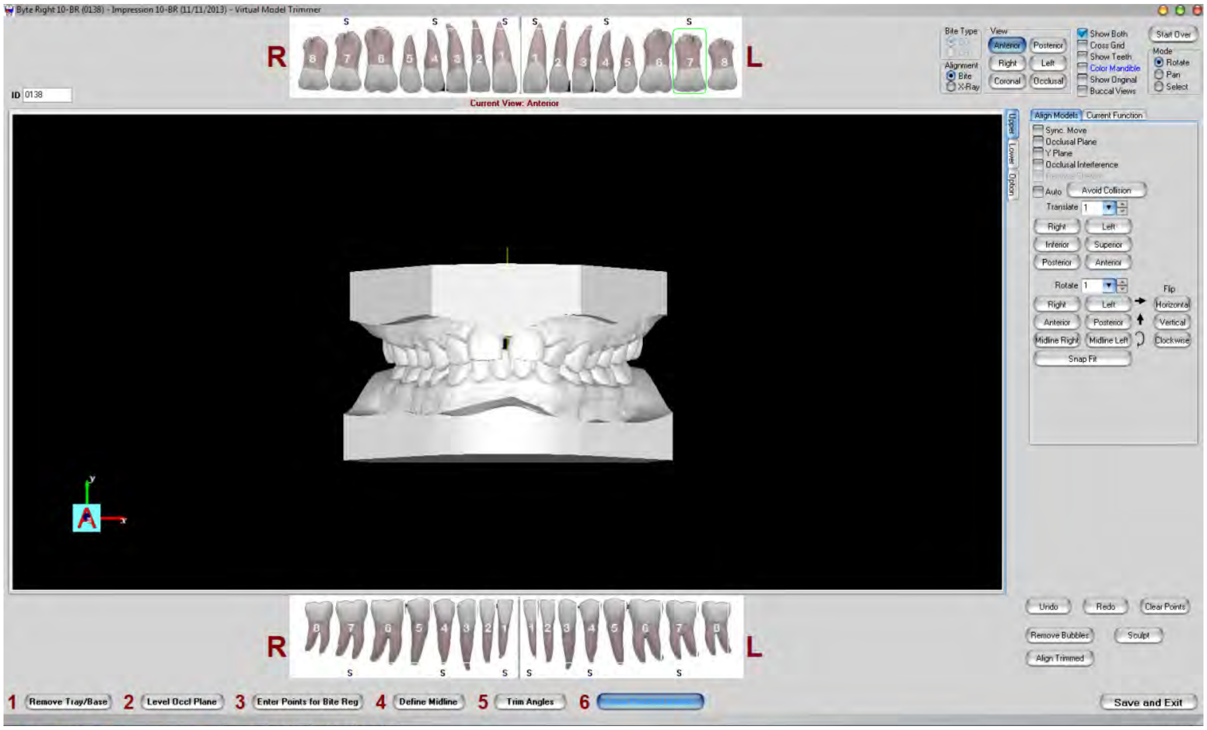


Figure 8. Screen image of the finished occluded virtual model with trim angles.

Screen Image of Ortho Insight 3D Linear Measurements

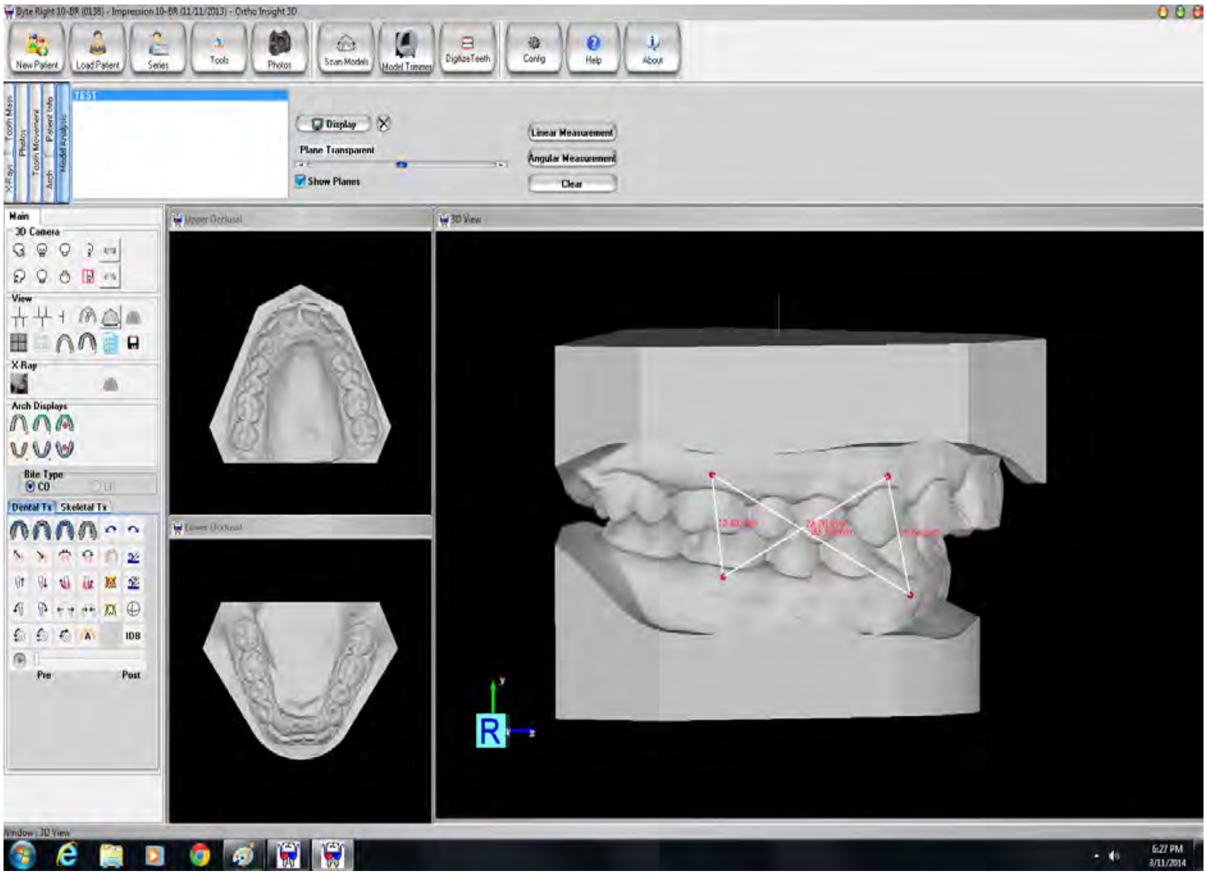


Figure 9. Screen image displaying different interarch linear measurements made on the virtual digitized models utilizing the scored round bur marks on the teeth.

Image of Linear Measurements on Stone Models (control)

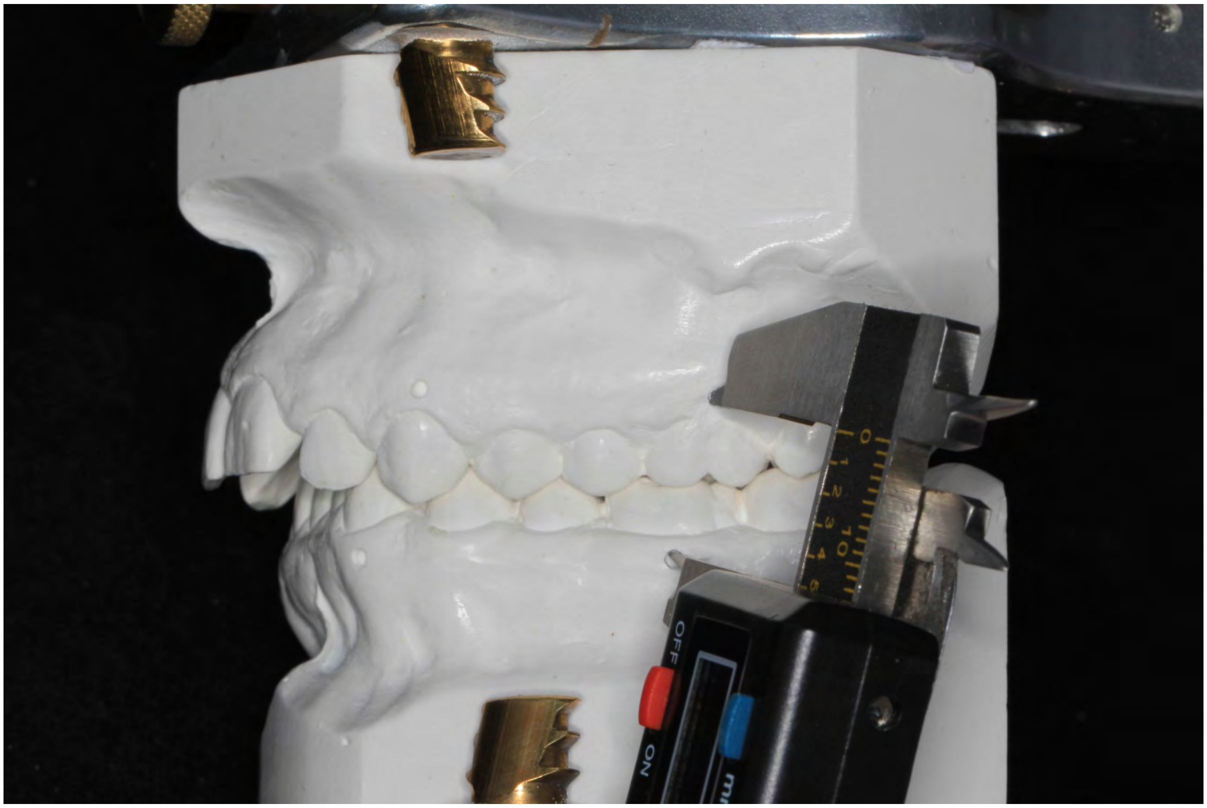


Figure 10. Image of Linear Measurements on the stone casts (control) using a 4 in Digital Caliper.

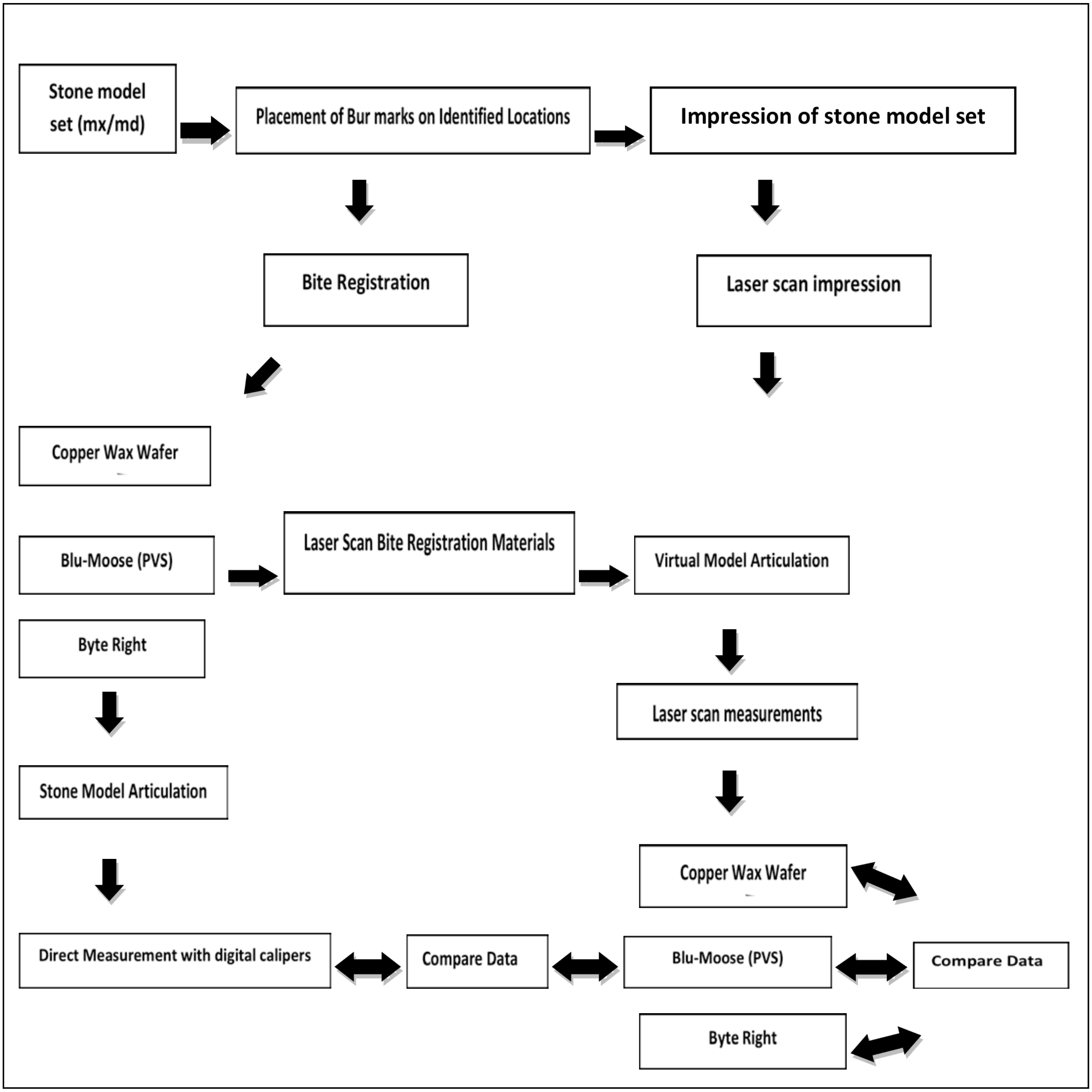


Figure 11. Flow diagram of study. Laser scanning performed with Ortho Insight 3D Scanner. Virtual model measurement performed with accompanying software.

RESULTS

Research Question 1: Compare the accuracy of bite registration materials in generating an inter-arch digital occlusion when compared to the stone model occlusion control.

We started by evaluating the distribution of values in the dataset, therefore, looking at the properties of raw data. Measurements at each site for each material were compiled into a single group, and a histogram was plotted. Each material gave a similar distribution of measurements (Figure 12), but the data is bimodal (different oral sites), thus, not normally distributed.

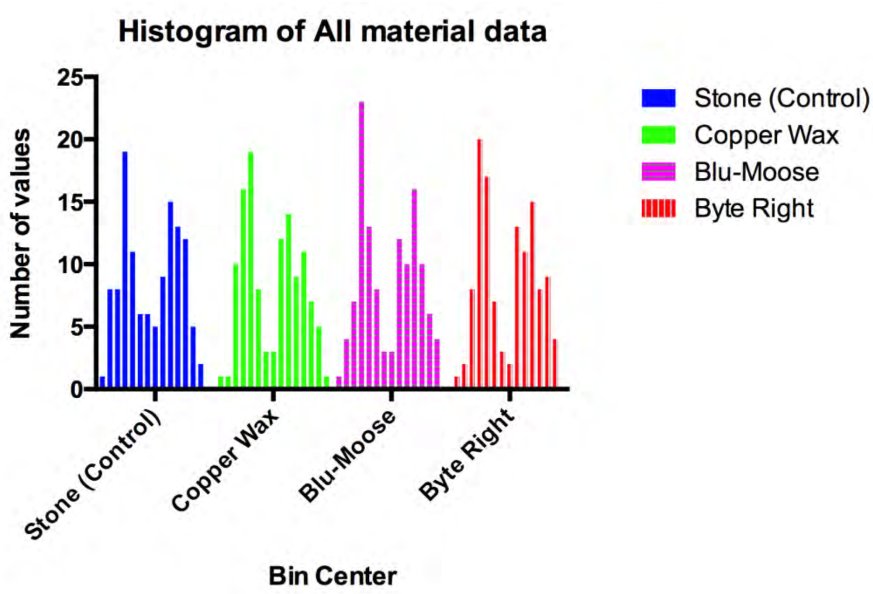


Figure 12. Histogram of occlusion measurement data. Data from all sites for the occlusion length (mm) (15 bins of equal size) in each model were plotted as a histogram for each material.

Subsequently, interaction plots were used to evaluate patterns of relationship between the mean of the dependent variable distance for the 15 models and the site (as the independent variable) or material independent variable (Figure 11A, B). All three materials and the control gave very similar mean values for the 15 models at each site.

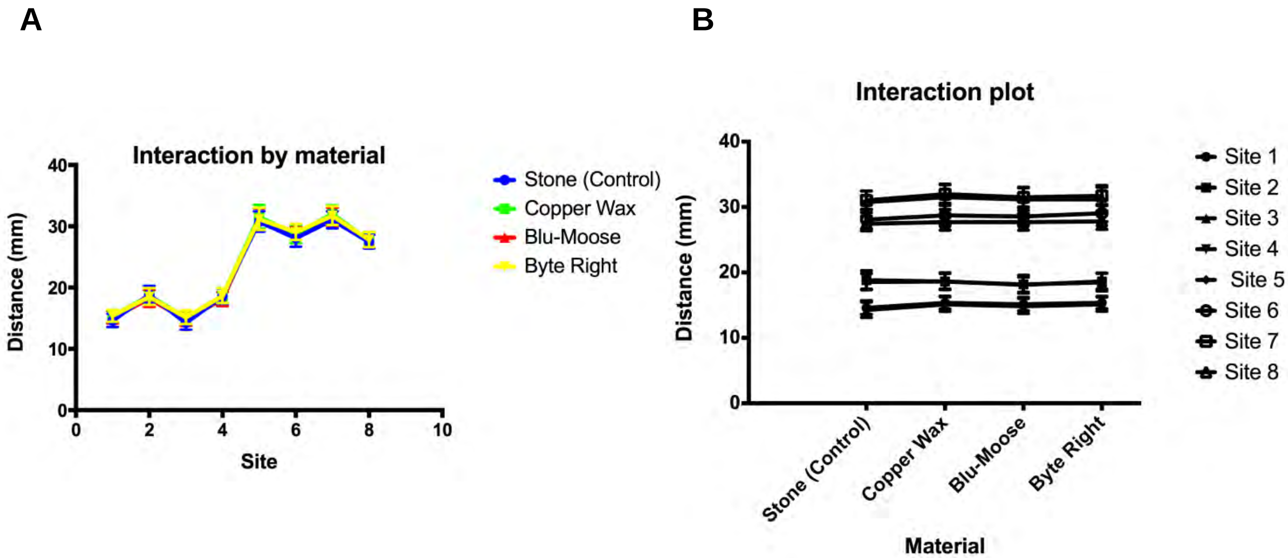


Figure 13A, B: Interaction plots of Distance (mm) versus Material by Site measured (A) or versus Site measured by Material (B). Means from the 15 models and 95% confidence intervals shown.

Hence, these observations indicate that within a site, there are no marked trends for an effect of a material, and no trends for marked differences in variances.

Then, statistical analysis utilizing rm two way ANOVA was used to test the relationship between measured occlusion distance and material at each model position. The rm 2 way ANOVA revealed small but statistically significant variance ($p < 0.0001$) due to the materials and interaction of the materials with the site ($p<0.0001$). In this test, site variance was the bulk of the variance ($p<0.0001$) since sites are different in size around the mouth. To crosscheck the 2 way ANOVA, a parametric one way ANOVA was performed to compare the effect of materials at each site since the 15 values determined at each of the eight sites broadly fit a normal distribution (Table 2). All but positions 2, 6, 8 showed a significant difference in mean occlusion distances between one or more materials. For eight ANOVA tests, a Bonferroni correction for the usual p=0.05 was made and the calculated value of p=0.00625 was used to reject the null hypothesis of no difference between any materials.

rm ANOVA	SITE1	SITE2	SITE3	SITE4	SITE5	SITE6	SITE7	SITE8
Mean (SD)	15.22 (0.35)	18.68 (0.28)	14.96 (0.40)	15.26 (0.39)	31.30 (0.33)	28.71 (0.40)	31.65 (0.41)	27.75 (0.16)
ANOVA p	0.0003	0.0287	0.0004	0.0023	0.0022	0.0078	0.0004	0.0391
Epsilon	0.754	0.776	0.567	0.819	0.794	0.565	0.715	0.838

Table 2. Summary rm one-way ANOVA results.

Next, Tukey's multiple comparison test (alpha=0.05) was used to examine differences between materials at each site. However, Tukey's post test only found a difference between Stone and Blu-Moose, therefore, raising suspicion about the result.

The basic conclusion from the post tests with rm two-way ANOVA and cross-check with rm one way ANOVA using each Sites dataset is that Stone tends to give lower values than the three bite registration materials, which are indistinguishable.

As we saw earlier in histogram plots (Figure 10), the aggregate data from all sites in each material group was non-normally distributed but each distribution had a similar shape. Hence, to make a general comparison of measurements between the groups, a non-parametric Friedman test was used. This gave a p-value of <0.0001, indicating highly significant differences between the groups. These results clearly indicate that Stone and Blu-Moose give lower measurements than Copper Wax and Byte Right.

Lastly, we compared the spread of the values about the mean to evaluate if one or more materials differ significantly from the others. The spread of the residual distributions (the standard distribution, SD) is a relative measure of the precision of the measurements for each material. Therefore, the lower values for the SD, the more precise the measurement. Basically, Blu-Moose and Byte Right have significantly lower variances (SD=0.3719 and SD=0.3811), thus more precise measurements (narrower distributions) than Copper Wax (SD=0.5035).

Combining it all together, the order of the selection of the materials based on the results and the above statistical analysis would be:

Blu Moose ≥ Byte Right>Copper Wax

Research Question 2: Determine the intra-observer accuracy of repeated inter-arch measurements?

To test for this, an intraclass correlation coefficient (ICC) for one observer, consistency was determined for data from each material. This coefficient quantifies the degree of relatedness between two or more groups. An ideal test would show a consistency of 1. All tests gave ICC values very close to 1, indicating highly reproducible repeat measurements by the observer (Table 3).

Material	**ICC**	**Confidence interval**
Stone	0.9994	0.9987 to 0.9997
Copper Wax	0.9986	0.9972, 0.9993
Blu-Moose	0.9985	0.997 to 0.9993
Byte Right	0.998	0.9959 to 0.999
All tests	0.9942	0.9924 to 0.9958

Table 3. Intraclass correlation coefficients for each material and for all tests.

DISCUSSION

The main study was designed to evaluate the accuracy of bite registration materials scanned using an in-office laser surface scanner, Ortho Insight 3D, to create a virtual occlusion. There are various materials available on the market used for bite registration of the patient's dentition. However, each material scans differently in the laser scanner producing virtual occlusions of differing quality. In this study, linear inter-arch measurements were made on virtual models created by three bite registration materials: Blu-Moose, Byte Right and Copper Wafer Wax. Linear inter-arch measurements were also made directly on the stone models utilizing digital calipers and served as a gold standard control. Statistical Analysis utilizing 2 way ANOVA and 1 way ANOVA concludes that Stone (control) gives lower values compared to the three bite registration materials, since less error is involved in performing linear measurements using digital calipers on the defined bur marks on the stone models.

On the other hand, significant differences were found among the three different bite registration materials. Non-parametric Friedman test concluded that Blu-Moose gave lower values compared to Copper Wafer Wax. As a result, Blu-Moose is significantly different than Copper Wafer Wax. Additionally, Blu-Moose and Byte Right have significantly lower variances, thus more precise measurements (narrower distributions) than Copper Wax. It is believed that these interarch mean differences are statistically but not clinically significant and suggest that bite registration method used for the digital modeling system plays a huge role in creating accurate virtual models. In a study done by White et. al, dimensional stability of the bite registration material, digital manipulation of the scanned wax bite registration material or a combination of both was suggested to be the source of error in accurately reproducing the interarch relationships. White et. al attributed the errors in dimensional stability of the wax bite to environmental conditions during shipment, deformation on removal from the mouth, or a distortion on placement in the flat storage dish for shipment. However, the present study was performed under controlled environment in which bite registration was scanned after it is taken on the articulated stone models, thus minimizing the distortion related to shipment conditions.

Furthermore, there are user errors associated with the digital manipulation of the scanned bite registration material. All three bite registration materials have different exposure settings for scanning. The user has to be well aware of the laser scanner software and should follow the manufacturer's guidelines for laser scanning the bite registration materials. Moreover, the user has to be aware of the different physical and handling properties of the bite registration materials. In the present study, it was shown that Copper Wax digital occlusion was significantly different from the other two bite registration materials and the stone (control). This could be ascribed to the handling properties of Wax since it can be distorted and have large dimensional changes associated with it. If the clinician chooses to use the wax bite registration due to its low cost, he or she needs to make sure that the staff is well trained in registering and laser scanning the bite in in-office laser scanner to minimize the inaccuracy related to digital representation of the interarch relationships.

Nevertheless, Blu-Moose and Byte Right are both dimensionally stable, rigid and a bit more expensive compared to Copper Wafer Wax. Therefore, it depends on the clinician in determining which bite registration material to use.

Also, in the study performed by White et. al, DigiModel software used by OrthoProofUSA includes a Collision Mapping Tool, which was utilized in the correction of bite inaccuracies in 6 degrees of freedom. Comparing to the present study, no manipulation or correction of the occlusion was performed after the digital models were occluded. An accurate method of recording the patient's occlusion is an integral part of any digital system designed to provide accuracy comparable with traditional plaster models (White, Fallis, & Vandewalle, 2010).

In comparison, in the present study, bur marks were placed on the labial/alveolar mucosa of the maxillary and mandibular teeth on the stone models. Impressions of the stone models were then laser scanned along with bite registration materials. It is suggested that some of the inaccuracies related to interarch mean measurements can be attributed to the investigator not fully capturing the bur marks in the laser scanned digital model. For future studies, it is recommended to either change the width, shape or place some material in marks for it to be definitively captured.

CONCLUSIONS

The present study clearly demonstrated a significant difference between linear interarch measurements collected from stone models and virtual models. However, the clinical significance was determined to be minimal depending on the choice of the bite registration material. Based on the results and the statistical analysis, the order of the selection of the materials would be: Blu-Moose≥ Byte Right > Copper Wax. We concluded that dimensional stability and digital manipulation of the bite registration material by the user/operator plays a huge role in accurate digital representation of the virtual models. If the operator is fully trained and knowledgeable about the in-office laser scanner, the user can confidently analyze and accurately treatment plan a patient based on impression/bite registration scanned virtual models. In conclusion, Ortho Insight 3D is capable of efficiently collecting and analyzing patient record data in regards to inter-arch linear measurements.