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Comparison of American Board of Orthodontics' Cast-Radiograph Evaluation (ABO-CRE) Scores Using Plaster and Digital Models

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Comparison of American Board of Orthodontics' Cast-Radiograph Evaluation (ABO-CRE) Scores Using Plaster and Digital Models

A THESIS

Presented to the Faculty of

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In Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE

By

Phillip S. Timmons, D.D.S.

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DEDICATION

This thesis is dedicated to my family. Without their support, I could not have made it this far. Thank you to my beautiful wife, Tracy, for walking beside me every step of the way through the hard work of dental school and residency. Your encouragement and love has meant so much to me. Thank you to Jenna and Jourdan for always putting a smile on my face when I come home each day and placing my priorities in perspective. Thank you to my mother for her countless sacrifices and inspiring me to pursue higher education. Thank you to my father for teaching me the true meaning of hard work, integrity, and compassion. Together you made possible the opportunities I enjoy today.

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ABSTRACT

Purpose: This study compared manual scoring of plaster models to computerized digital scoring utilizing American Board of Orthodontics' Cast-Radiograph Evaluation (ABO-CRE) criteria and a novel software algorithm. **Methods**: Twenty-five examiners manually scored two sets of post-treatment plaster study models. The models were subsequently digitized via laser scanning. Each examiner digitally registered prescribed points on each digitized model using Geomagic Studio 2014® (3D Systems, Inc., Rock Hill, South Carolina). Coordinates for each point were exported and inter-relationships analyzed using a novel scoring algorithm based on ABO-CRE criteria. **Results**: Medians, interquartile ranges, and intraclass correlations were calculated for plaster and digital groups in overall and individual CRE categories. Statistical differences were determined at the $p \leq 0.05$ level of significance. **Conclusion**: Statistically significant differences were observed between manual scoring of plaster models and computerized scoring of digital models. The digital group was found to be more consistent and reliable than the manual group.

TABLE OF CONTENTS

I. INTRODUCTION

As technology and the digital era have progressed orthodontics has attempted to keep pace. In the 1990s many orthodontic practices began transitioning toward digital radiographs, digital photography and electronic charts. In an attempt to continue to push the boundaries of technology as it pertains to diagnosis and treatment planning things like cone-beam computed tomography (CBCT), 3D imaging and intraoral scanners have become more and more prevalent. Clinicians are in constant pursuit of efficient, effective and affordable diagnostic modalities. Accurate diagnostic tools are prerequisites to effective treatment plans, appropriate orthodontic care, and desirable treatment outcomes.

While the transition to many forms of digital media has become commonplace in orthodontics, there is still one fundamental component of orthodontic records that has remained largely unchanged, plaster study models. Plaster study models have been a standard and somewhat indispensible part of the initial evaluation, diagnosis and treatment planning, progress records and assessment of results.[1] Despite technological advances in other areas of orthodontics plaster study models have continued to be the “gold standard” in terms of reproducing the patient’s dentition. Plaster models are often used to make linear measurements, evaluate individual tooth positions, and to examine intra-arch and inter-arch occlusal relationships. Using plaster models has multiple benefits. They are easy to produce, relatively accurate, inexpensive and you can manipulate them for diagnostic evaluation. The disadvantages of using plaster models are they require a significant amount of physical storage space, are prone to breakage, and retrieval from storage or attempting to utilize them for consultations can be cumbersome and time-consuming.[2] Therefore, there has been an increasing move to find an alternative method of creating diagnostic study models.

In 1999, OrthoCad® (Cadent Inc., Carlstadt, New Jersey) introduced digital dental model software. This was followed by E-Models® (GeoDigm Corporation Inc., Chanhassen, Minnesota) in 2001. To utilize this technology orthodontists mailed diagnostic impressions to the companies where they were electronically scanned and 3D digital models were created. The digital models could then be accessed using the company's proprietary software. The orthodontists would then be able to make measurements and diagnostically evaluate the digital models.

The benefits to using digital study models include faster record retrieval, more efficient archiving of records, faster and easier transfer of records for consultation purposes, saved physical storage space, no risk of damage to the models and faster dental measurements. An additional benefit to using digital study models not yet discussed is the ability to have them objectively graded as part of the ABO Clinical Examination for board certification.

At the same time OrthoCad® introduced their digital model software the ABO was implementing an objective grading system for grading post-treatment orthodontic models now known as the Cast-Radiograph Evaluation (CRE). The CRE was designed to improve reliability and consistency in the grading process.

There are eight criteria that make up the CRE, and seven of the eight criteria are scored using submitted case models (the eighth criteria uses a panoramic radiograph to measure root angulation).[3,4] The seven criteria scored on the models are: Alignment/Rotations, Marginal Ridges, Buccolingual Inclination, Overjet, Occlusal Contacts, Occlusal Relationship and Interproximal Contacts. With digital models becoming more commonplace in orthodontics it would be advantageous if they could be reliably used for case reports submitted to the ABO for board certification.

There have been many studies that have attempted to look at the accuracy of individual measurements using digital models in comparison to plaster models. Santoro, et al[5] designed a study to measure the accuracy of measuring tooth size, overjet and overbite using digital and plaster models. They found there was no difference in the overjet measurement, but there was a statistically significant (albeit clinically insignificant) difference when measuring tooth size measurements and overbite on the two different types of models.

Zilberman, et al[6] compared the use of electronic calipers on plaster models and digital models using OrthoCad® to test the accuracy of measuring tooth size and arch width. Their study concluded that while measurements made on plaster models were more accurate and reproducible than digital models both plaster and digital models produced clinically acceptable results.

Tomasetti, et al[7] performed Bolton analyses on 21 plaster study models using a vernier caliper and compared it to measurements done digitally. They found no statistical difference in the two methods of measurement, but did find clinically significant differences of >1.5 mm.

Quimby, et al[8] introduced the use of dentoform plastic models as their gold standard when comparing manual measurements to measurements made on computer-based digital models. They found high reproducibility and reliability with intraclass correlation (ICC) coefficients of >0.90.

While most of these studies compared linear measurements there have been more recent studies designed to assess the accuracy of measurements made on traditional plaster models compared to digital models when applying the ABO's CRE. Costalos, et al[9] used impressions from 24 finished orthodontic patients to create plaster and digital models. The plaster models were graded using the ABO's measurement gauge and the digital models were graded using OrthoCad® software. This study found poor inter-examiner reliability for both scoring methods (r=0.46 for the plaster models and r=0.69 for the digital models), but found a high-level intraclass correlation coefficient for the digital models. While overall they did not find a statistical significance in the total scores they did note statistically significant scoring differences when specifically comparing buccolingual inclination and alignment.

Likewise, Okunami, et al[10] used 30 cases to compare manual scoring of plaster models with the scoring of digital models using OrthoCad® software using the ABO's CRE. In their study they found statistically significant differences for occlusal contacts, occlusal relationships and total score. They concluded, "the current OrthoCad® program was not adequate for scoring all parameters as required by the ABO-CRE."

Additionally, Hildebrand, et al[11] used 36 case models to compare manual measurements using the ABO measuring gauge and digital models using OrthoCad® software. They found statistically significant differences in measurements of alignment, occlusal contacts and overjet. They also concluded that scoring of digital models using the ABO-CRE was not an acceptable replacement for measuring plaster models manually.

Although there have been many studies that have examined the scoring of digital models using the ABO-CRE, none have proven completely reliable and most have used proprietary software.

II. OBJECTIVES

A. Purpose of Study

The purpose of this study was to compare manual scoring of plaster orthodontic models to computerized scoring of digital models utilizing the ABO's CRE criteria and a novel software algorithm developed for this project.

B. Specific Hypothesis

The hypothesis tested was that grading digital orthodontic models using computer software and the American Board of Orthodontics' Cast-Radiograph Evaluation would be more consistent and reliable than those done manually on plaster study models.

C. Null Hypothesis

The null hypothesis was there would be no difference in grading digital models using computer software and grading done manually on plaster study models.

III. MATERIALS AND METHODS

A. Experimental Design

In this study two sets of post-treatment plaster study models were initially obtained using maxillary and mandibular alginate impressions. The two sets of models were de-identified and labeled “Set A” and “Set B.” The two sets of models were then duplicated 25 times each using polyvinylsiloxane and a duplicating flask (Figures 3-1 and 3-2). Polyvinylsiloxane was chosen due to its documented accuracy and stability.[12] The duplicated study models were individually examined by the primary investigator to be free of defects, chips, and fractures. The 50 sets of study models (25 of Set A and 25 of Set B) were then carefully packaged and mailed to the American Board of Orthodontics’ headquarters in St Louis, MO.

Twenty-five ABO examiners were randomly assigned a number 1 through 25 and they were each matched to similarly numbered grade sheets and study models. Each of the 25 graders manually graded both sets of models (A and B) utilizing the ABO measuring gauge (Figure 3-3), and the ABO’s scoring methodology as outlined by the ABO-CRE (Figures 3-4 and 3-5). An eighth criterion that uses a panoramic radiograph to measure root angulation was not evaluated in this study. Prior to grading the models an inter-examiner calibration was performed. The data from the manual grading and the 50 sets of study models were then mailed back to the primary investigator for data collection and statistical analysis.

The plaster study models were subsequently digitized via laser-scanning using a 3Shape R700™ digital scanner (ESM Digital Solutions Ltd, Dublin, Ireland) that was found to be accurate and reliable to within 60 microns.[13,14] The 3Shape R700™ imports models in Standard Tessellation Language (.stl) that is a universal file format output currently required by the ABO for submission of pretreatment digital models. The digital scanner used in this study was calibrated and maintained in good working order by the hospital's Biomedical Engineering Department. The primary investigator laser-scanned all 50 sets of study models and labeled them 1-25 (A and B) to ensure they could be matched to their appropriate grader for the computerized portion of the grading. Via remote computer access each examiner digitally registered 130 points on each digitized model set using Geomagic Studio 2014® software (Figures 3-6, 3-7, and 3-8). Coordinates for each point were exported and inter-relationships analyzed using a custom script and novel scoring algorithm based on the ABO's CRE criteria.

B. Script Code Explained

The analyses of the digitized model sets were executed using a custom written script. A script is a runtime program that is useful for automating repetitive tasks. The script was written in the scripting language Python™ (Python Software Foundation, Beaverton, Oregon) embedded within the Geomagic Studio 2014® application program interface (API). The Geomagic Studio® (API) had an extensive library of classes and functions that were useful for manipulating and analyzing mesh and surface data.

Two opposing models, a maxillary and mandibular, were imported into the program. The imported models were occluded and oriented so the bases of the models were perpendicular to the global y-axis. A maxillary and mandibular text file consisting of 3D point coordinates that were created during the study were imported and parsed to map the points to the appropriate maxillary or mandibular model.

Global variables were declared for both the maxillary and mandibular models. The global variable was a data object that was visible to every function within the script. The variable was a data object that had a unique user defined name and was assigned either a single value or an array of values. Each global variable also had a unique name to distinguish it from other variables. These global variables consisted of arrays of point identifiers that specified which points were used for specific calculations. Unique variables were created to identify which points were to be used for alignment/rotation, marginal ridge, buccal inclination and occlusal relationship calculations. For instance, the AR_maxRight variable identified points 5, 6, 11, 12, 15, 16, 19 and 20 to be used in the alignment and rotation calculation of the maxillary right molars and bicuspids.

The script contained eight functions written to accomplish specific tasks. The functions were a group of commands that executed a desired procedure that may or may not have returned a value. Once a function was defined it could be called and executed anywhere within the script allowing for the reuse of code. An area in the script defined as Main() in the comments section called and executed the various functions. It should be noted that Python™ did not use a

Main() function as it was an interpreted programming language and not a compiled language. However, calling a section Main() in the comments was used to easily distinguish the execution portion from the function definitions portion of the script.

The first function, getModel() imported the models in Standard Tessellation Language (.stl) format.

The second function, getPoints() took a variable (e.g. “arch”) as a parameter. It opened and read the text file of 3D point coordinates, converted the coordinates into a Point Feature and based on the "arch" parameter assigned the points to either the mandibular or maxillary model. In Geomagic® a Point Feature is a data object that described a single point assigned to a model. Each point was assigned a name from 1 to 130 that corresponded with the 130 digital points registered by each examiner.

The third function, getLandmarks() took "activeModel" and "PointsArray" as parameters. It retrieved and returned the points to the calling function and performed the calculations.

The fourth function, createLine() took "model" and "points" as parameters. It used the first and last points passed as parameters as the start and end of a line. The line was assigned as a feature to the model parameter. It returned the line object to the calling function.

The fifth function, makePlane() took "model," "p1," "p2" and "axis" as parameters. It used the p1, p2 and axis parameters to define a plane. Based on the axis parameter, the plane was oriented parallel to either the z or y global 3D axis. The created plane was assigned as a feature to the model defined in the model parameter. It returned the plane object to the calling function.

The sixth function, distPoint2Plane() took "model," "plane" and "p3" as parameters. It calculated the distance from point p3 to the plane in millimeters. It returned the delta of the calculation.

The seventh function, calcOccRel() took "maxPointsArray," "manPointsArray," "text" and "axis" as parameters. It first opened a comma separated value file called "test.csv." The function created a plane, by calling makePlane(), based on the most posterior points defined on the mandibular model and oriented the plane parallel to the global 3D y-axis. Next, the distance to that plane was calculated for each mandibular and maxillary point passed as a parameter in maxPointsArray and manPointsArray. Each calculation was appended to the test.csv file with the appropriate labeling based on the text parameter. Once the calculations were complete the test.csv file was returned to the calling function for use by other script functions.

The last function, lineFunction() took "PointsArray," "text" and "axis" as parameters. It opened the test.csv file and appended data to it. It used the first and last points passed in from PointsArray and created a plane oriented parallel to the global 3D y-axis. It then calculated the distances between each point in the array and the plane. It recorded the delta of each calculation in the test.csv file with an appropriate label based on the text parameter and returned the file to the calling function.

The remainder of the script executed calculations by calling the lineFunction() or calcOccRel() functions as necessary. The arguments passed in each function call were predefined in the maxillary and mandibular global variables.

C. Explanation of Algorithms Used for Calculations

Maxillary Arch Alignment/Rotation

For the posterior teeth, a line was defined from point 42 to point 57 on the left side and point 5 to point 20 on the right side. The points represented the mesial marginal ridge of the first bicuspid and distal marginal ridge of the second molar. A plane was defined between the two points that was parallel to the global y-axis to create a plane that was perpendicular to the occlusal plane. The distance from the established plane to the points that were placed on the mesial and distal marginal ridges of the bicuspids and first molar and mesial marginal ridge of the second molar were measured. The delta between adjacent marginal ridge points was calculated and used to establish a score.

Mandibular Arch Alignment/Rotation

For the posterior teeth, a line was defined from point 59 to point 79 on the left side and point 111 to point 94 on the right side. The points represented the distal buccal cusps of the second molars and distal incisal aspect of the cuspids. A plane was defined between the two points that was parallel to the global y-axis to create a plane that was perpendicular to the occlusal plane. The distance from the established plane to the points that were placed on the buccal cusp tips of the bicuspids and first molar and mesial buccal cusp tip of the second molar were measured. The delta between adjacent cusp tips was calculated and used to establish a score (Figure 3-9).

For the anterior teeth a different measurement strategy was developed. The distance from a plane and points registered on the mesial and distal incisal edges of each anterior tooth was measured. A point placed on the distal incisal edge of the cuspids was measured from a plane established between a point on the cusp tip of the first bicuspid and cuspid that was oriented parallel to the global y-axis to establish a score. For the remaining incisors, a plane was established based on two points placed at the middle incisal edge of two adjacent teeth and was oriented parallel to the global y-axis. The distance between the two proximal points of the two adjacent teeth and the plane was measured. The delta between the two measurements was calculated to establish a score (Figures 3-10 and 3-11).

Marginal Ridges

For both arches, the marginal ridge heights were calculated by establishing a plane using the points placed on the cusp tips immediately adjacent to the marginal ridges being compared. For example, to measure the mesial marginal ridge of the maxillary second molar and distal marginal ridge of the maxillary first molar; a plane was established using the points on the mesial buccal cusp tip of the second molar and distal buccal cusp tip of the first molar. The plane was oriented parallel to the global z-axis. The distance between each of the two points and the plane was measured. The delta between the two measurements was used to establish a score (Figure 3-12).

Buccolingual Inclination

For both arches, a plane was established between the buccal cusp tips of the teeth on opposite sides of an arch and was oriented parallel to the z-axis. The distance between the lingual cusp tips of the same teeth and the plane were measured to establish a score (Figure 3-13).

Occlusal Relationships

A plane was established between point 117 and point 124 of the mandibular arch and was oriented parallel to the global y-axis. For the maxillary arch, the distance between the points on the mesial buccal cusp tips of the molars and points on the buccal cusp tips of the bicuspids and the plane were measured. For the mandibular arch, the distance between the points at the buccal groove of the molars and points at the interproximal embrasures of the molars, bicuspids and cuspids and the plane were measured. The delta between each maxillary point that opposed the appropriate buccal groove/interproximal embrasure was calculated for a score (Figure 3-14).

Overjet and Occlusal Contacts

Distances between opposing arches as it pertained to both overjet and occlusal contacts was assessed using 3Shape OrthoAnalyzer™ software. Color maps were created on opposing arches and distances were measured using a colorized distance scale (Figures 3-15 and 3-16). Grades were tabulated using the parameters set forth by the ABO's CRE and categorical scores were given for each model set.

Interproximal Contacts

An overlay grid was superimposed over the occlusal surfaces of each arch using 3Shape OrthoAnalyzer™ software. The grid was scaled to 1 mm x 1 mm increments and was used to measure distances between interproximal contacts (Figure 3-17). An appropriate grade was given for each model set.

D. Figures of Materials and Methods Procedures

The images of the research procedures are listed and documented in the order of their occurrence.

Figure 3-1. Polyvinylsiloxane and duplicating flask

Figure 3-2. Duplicated plaster study model

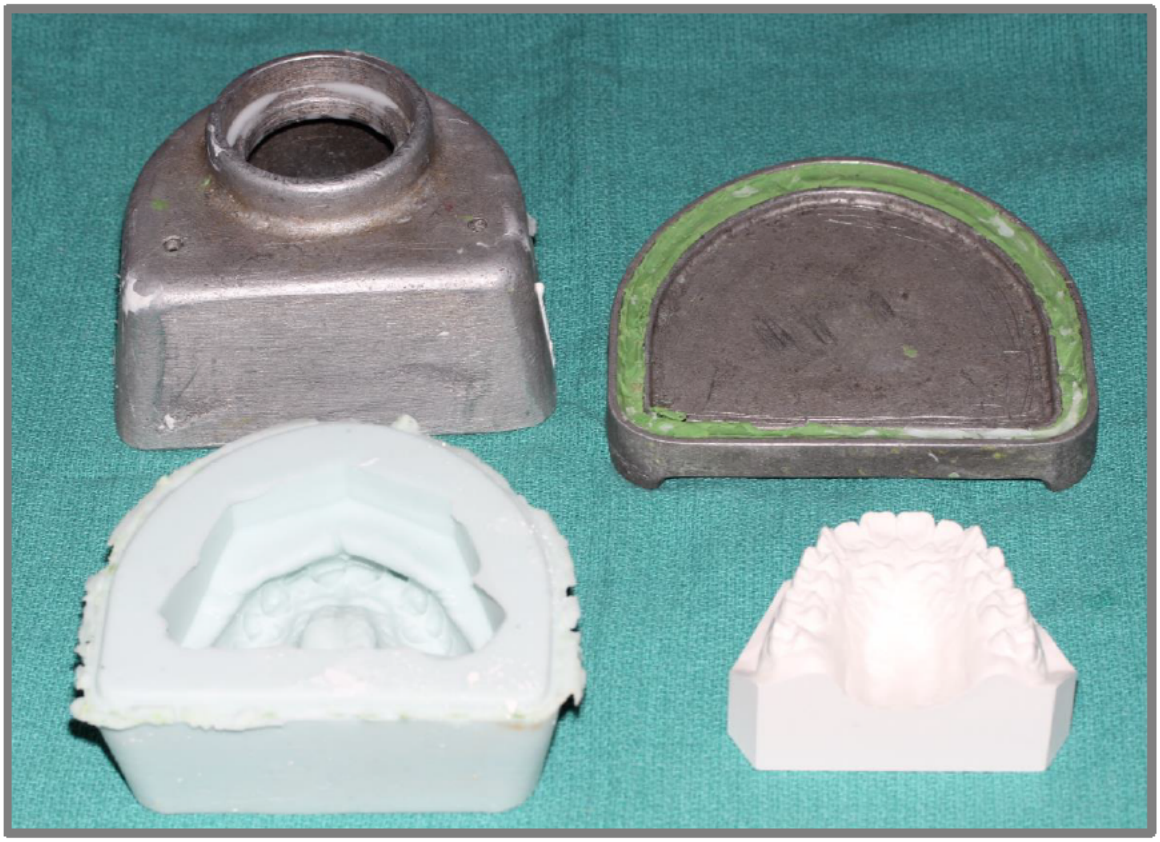
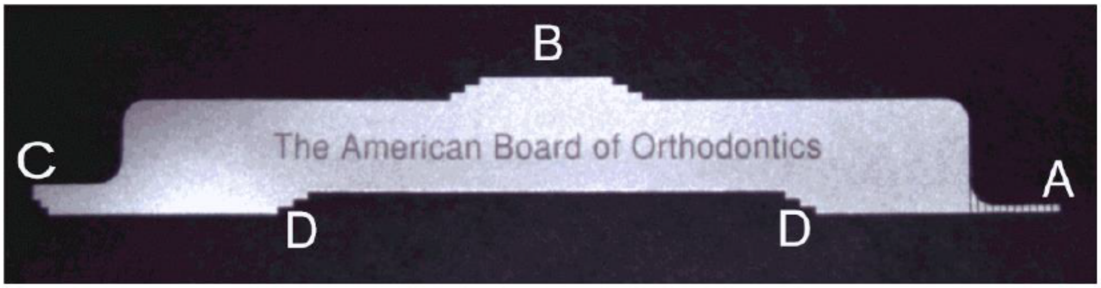


Figure 3-3. ABO measuring gauge[15]



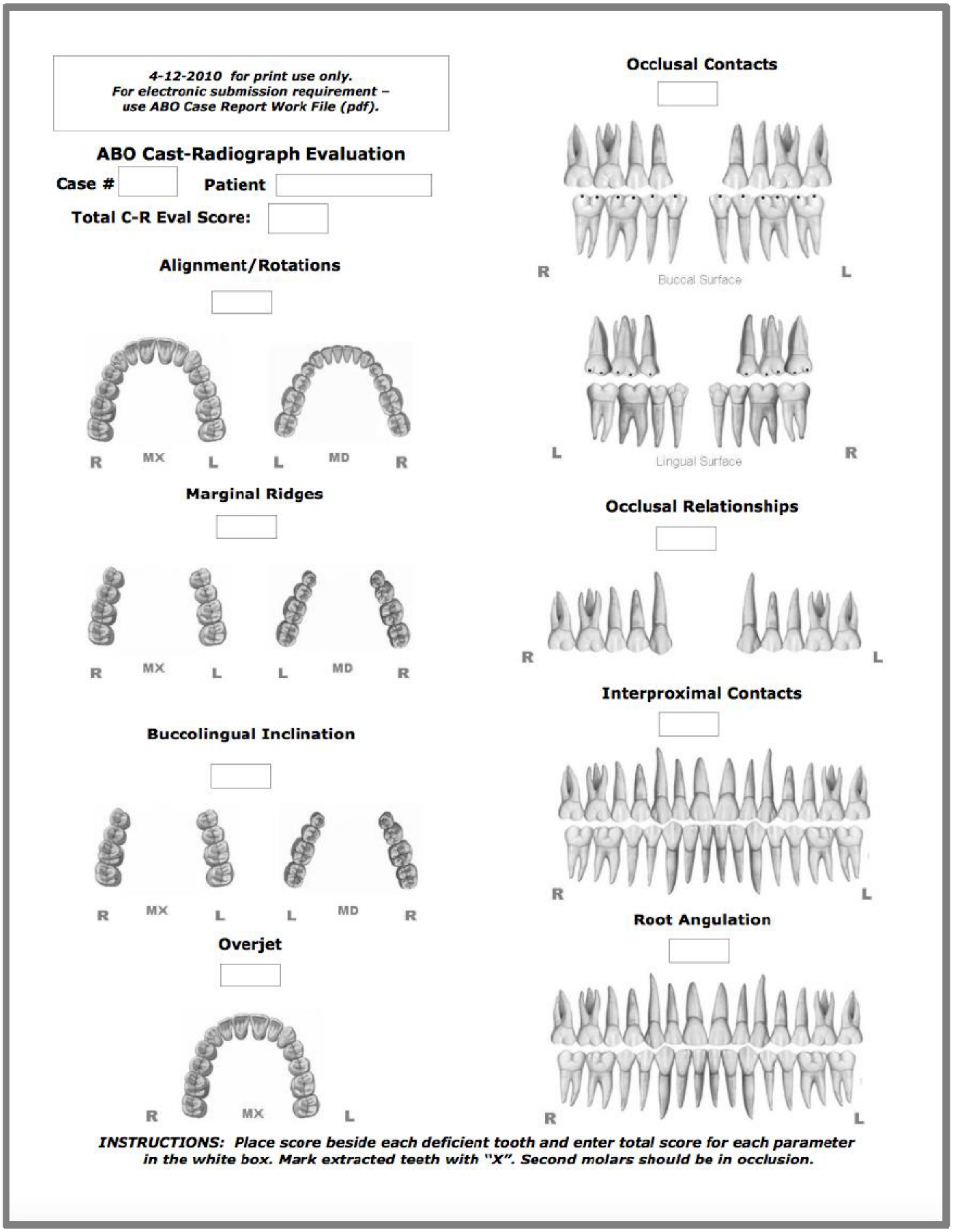
A This portion of the gauge is in 1 mm increments and is used to measure discrepancies in alignment, overjet, occlusal contact, interproximal contact, and occlusal relationships. The width of the gauge is 0.5 mm.

B This portion of the gauge has steps measuring 1 mm in height and is used to determine discrepancies in mandibular posterior buccolingual inclination.

C This portion of the gauge has steps measuring 1 mm in height and is used to determine discrepancies in marginal ridges.

D This portion of the gauge has steps measuring 1 mm in height and is used to determine discrepancies in maxillary posterior buccolingual inclination.

Figure 3-4. ABO Cast-Radiograph Evaluation[16]



4-12-2010 for print use only.
For electronic submission requirement –
use ABO Case Report Work File (pdf).

ABO Cast-Radiograph Evaluation

Case # ____ **Patient** ____

Total C-R Eval Score: ____

Alignment/Rotations

R MX L L MD R

Marginal Ridges

R MX L L MD R

Buccolingual Inclination

R MX L L MD R

Overjet

R MX L

Occlusal Contacts

R Buccal Surface L

L Lingual Surface R

Occlusal Relationships

R L

Interproximal Contacts

R L

Root Angulation

R L

INSTRUCTIONS: ***Place score beside each deficient tooth and enter total score for each parameter in the white box. Mark extracted teeth with "X". Second molars should be in occlusion.***

Figure 3-5. ABO Cast-Radiograph Evaluation scoring methodology[17]

Reference - ABO Cast/Radiograph Evaluation

See Grading System for Casts-Radiographs for entire discussion

ALIGNMENT/ROTATIONS

0.5 - 1 mm = 1 for each tooth
> 1 mm = 2 for each tooth

OCCLUSAL CONTACTS

0 mm = satisfactory
≤ 1 mm = 1 (for each posterior
> 1 mm = 2 tooth out of contact)

** Do **not** score diminutive distolingual cusps of the maxillary 1st and 2nd molars, nor lingual cusps of the mandibular first premolars. **Maximum of 2 points per tooth**.

MARGINAL RIDGES

0.5 - 1 mm = 1 (for each interproximal contact
> 1 mm = 2 between posterior teeth)

** Do **not** include the canine-premolar contact.
Do **not** include the distal of lower 1st premolar.

OCCLUSAL RELATIONSHIP

< 1 mm = satisfactory
1 - 2 mm = 1 (for each maxillary **tooth** from the
> 2 mm = 2 the canines to the 2nd molars)

BUCCOLINGUAL INCLINATION

0 - 1 mm = satisfactory
1.1 - 2 mm = 1 (for each posterior tooth)
> 2 mm = 2

** Do **not** score the mandibular 1st premolars nor the distal cusps of the second molars.

INTERPROXIMAL CONTACTS

0.6 - 1 mm = 1 (for each interproximal
> 1 mm = 2 **contact)**

OVERJET

Anterior teeth must be contacting.

0 mm = satisfactory
≤ 1 mm = 1 (for each maxillary
> 1 mm = 2 tooth)

Transverse posterior teeth:
Mandibular buccal cusps are measured to the central fossa of the maxillary teeth.

ROOT ANGULATION

Parallel = 0
Not parallel = 1
Root contacting adjacent root = 2 (for each **occurrence**)

Do **not** score the maxillary and mandibular canines.

NOTE: Gauge Width is 0.5 mm; Gauge Height is 1 mm
Third molars are not scored unless they substitute for the second molars.
No tooth is scored more than two points per individual parameter.

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Figure 3-6. Location and pattern of registered occlusal points on a digitized maxillary model using Geomagic® software

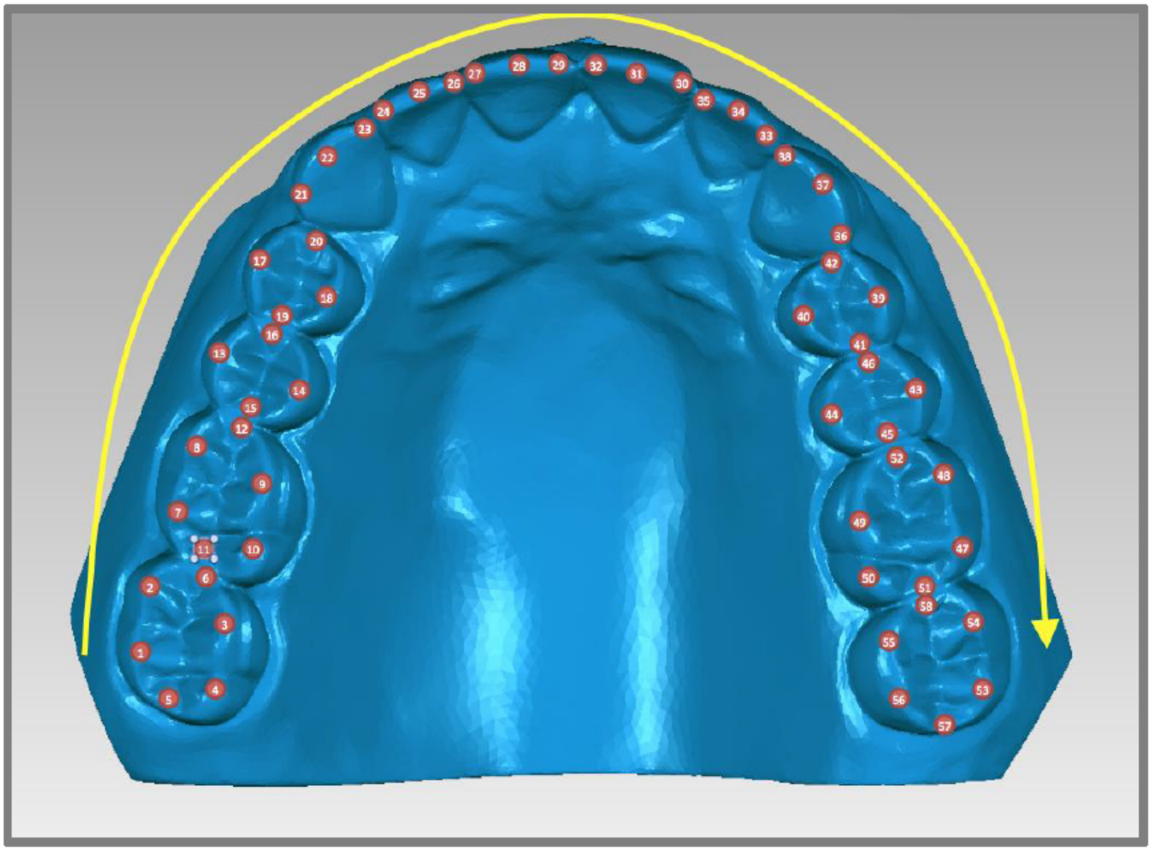


Figure 3-7. Location and pattern of registered occlusal points on a digitized mandibular model using Geomagic® software

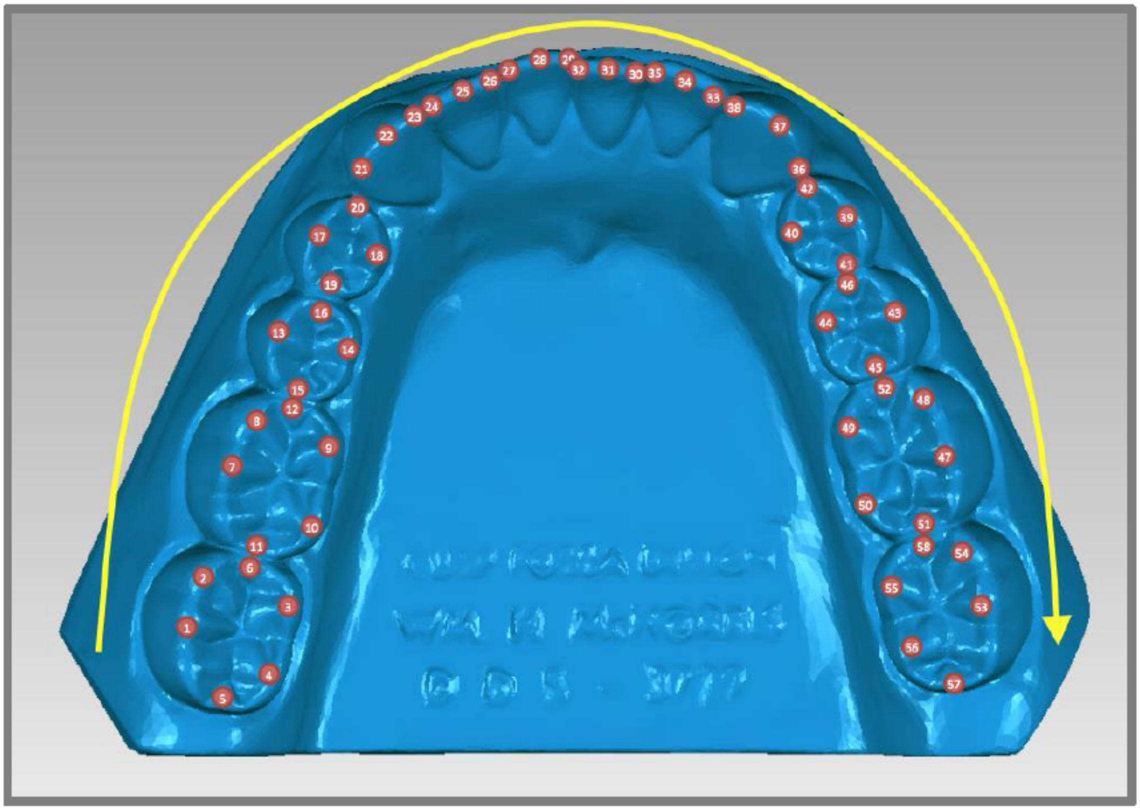


Figure 3-8. Location and pattern of registered buccal points on a digitized mandibular model using Geomagic® software

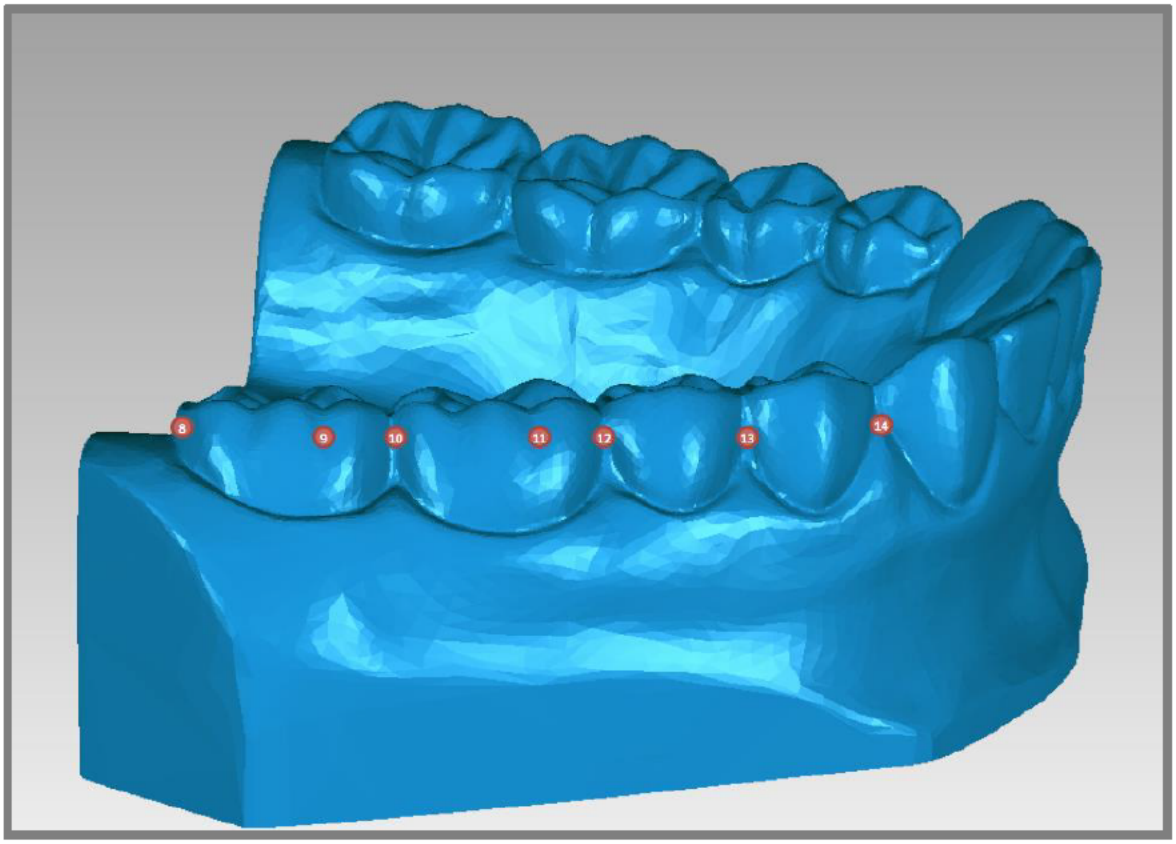


Figure 3-9. Algorithmic derived plane used to measure mandibular alignment of posterior teeth

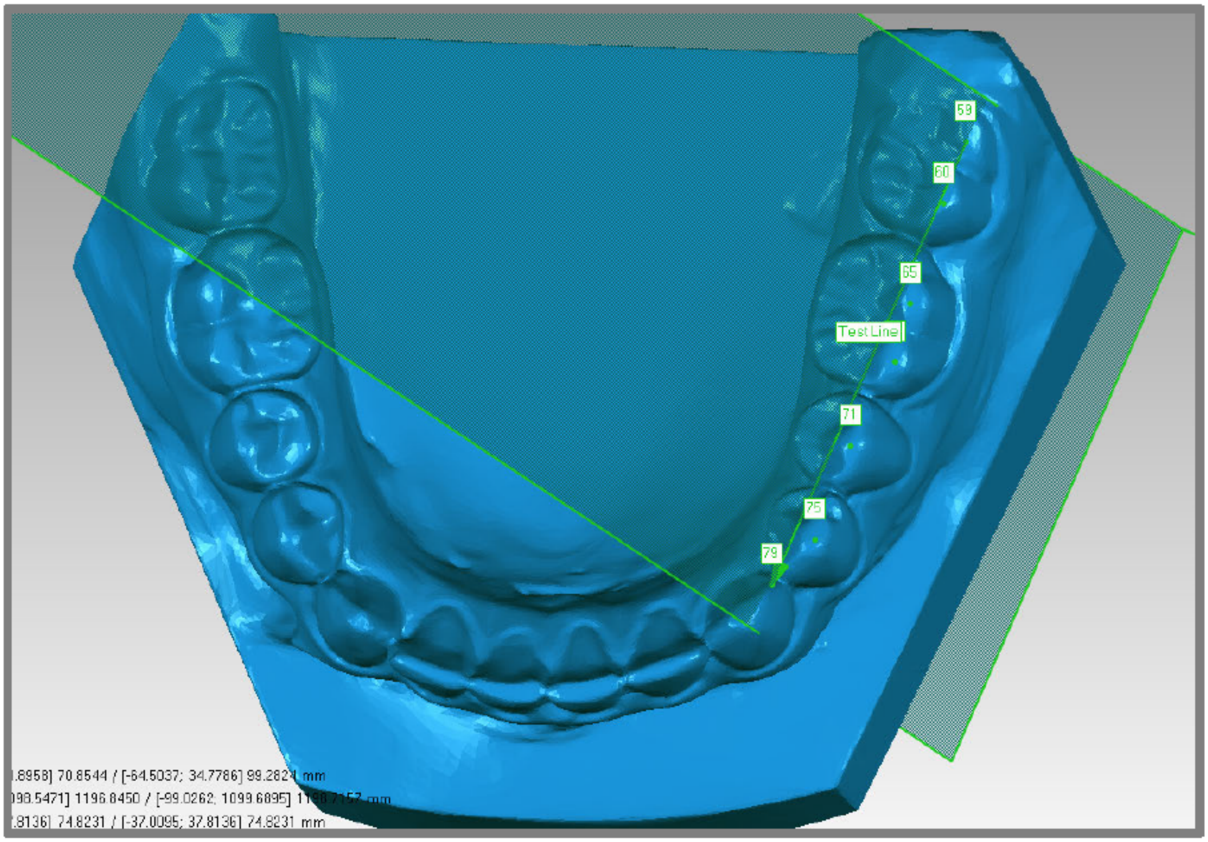


Figure 3-10. Algorithmic derived plane used to measure mandibular alignment of anterior teeth

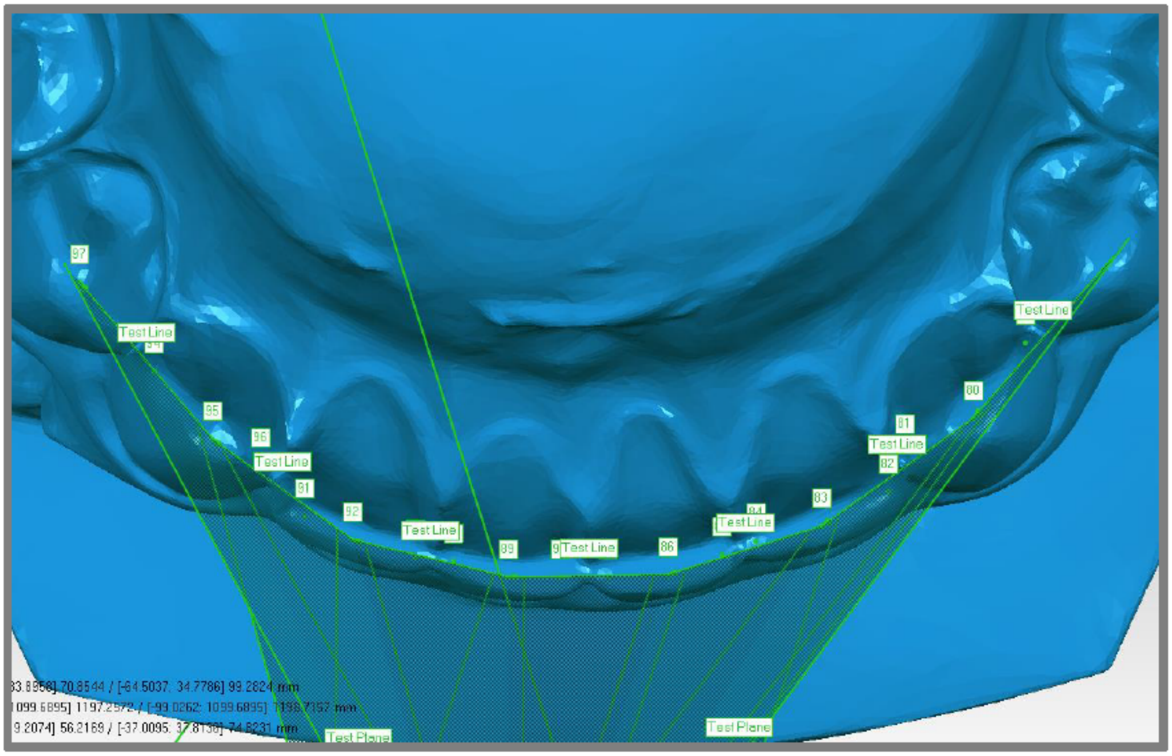


Figure 3-11. Algorithmic derived plane used to measure mandibular alignment of anterior teeth (close up)

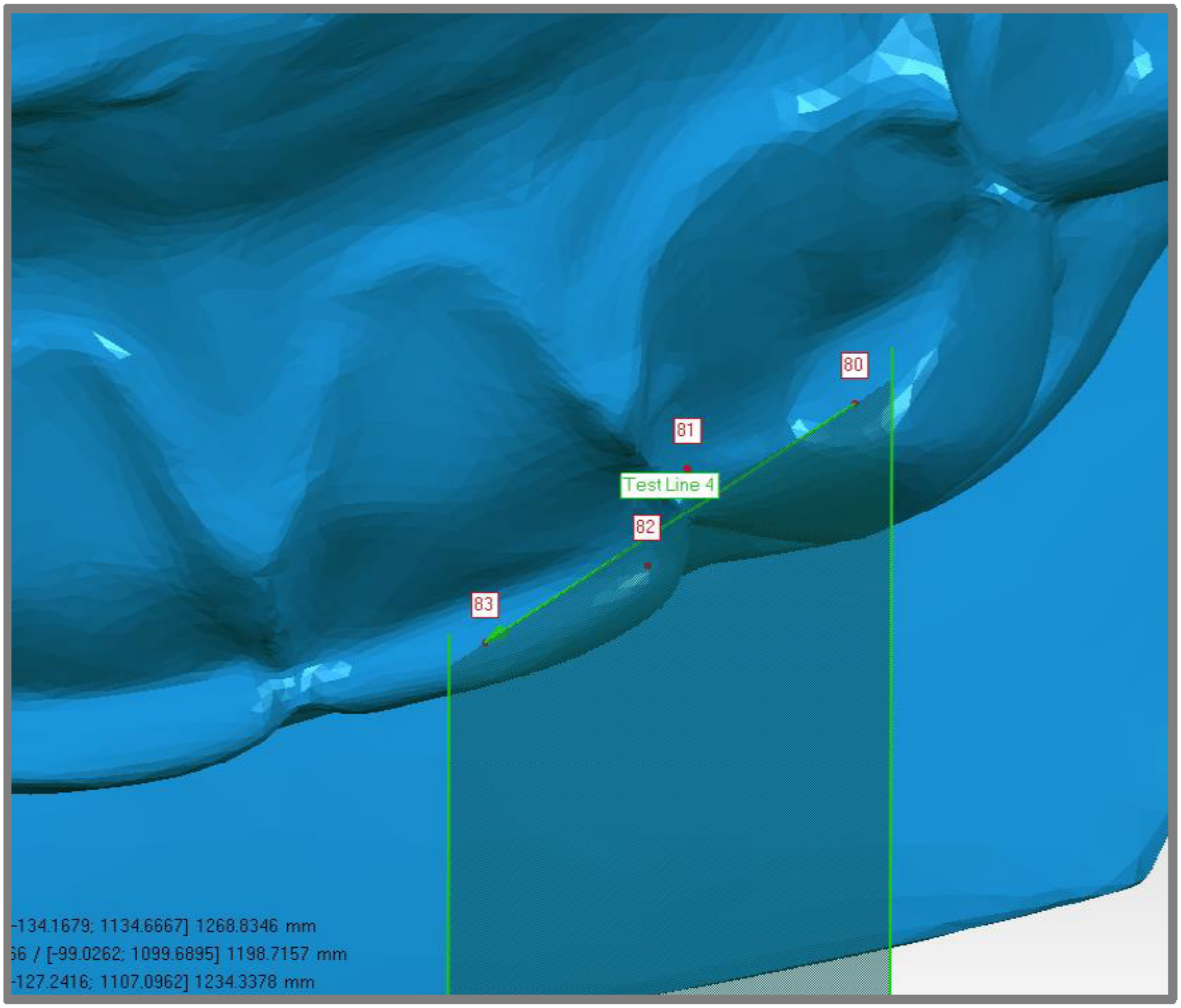


Figure 3-12. Algorithmic derived plane used to measure marginal ridge relationships of adjacent teeth

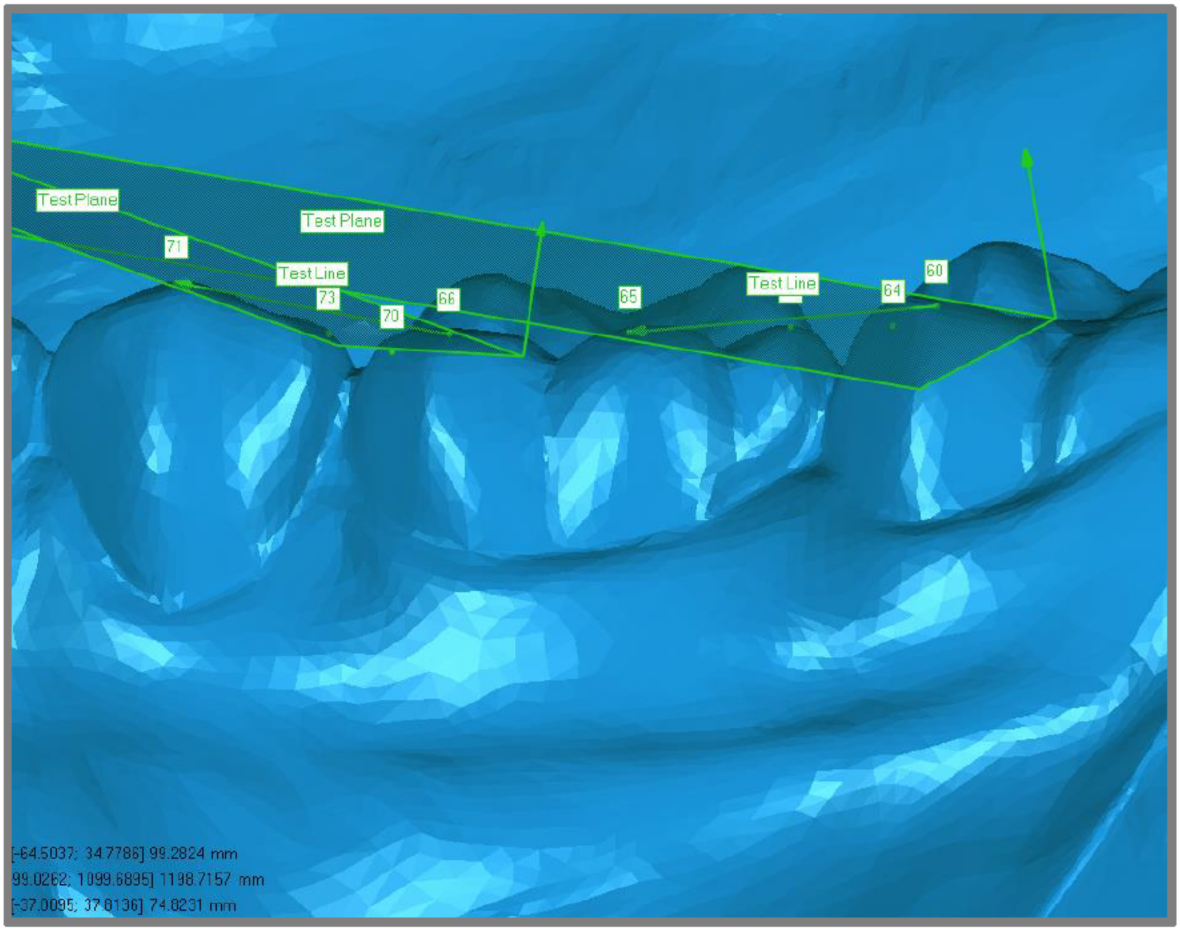


Figure 3-13. Algorithmic derived plane used to measure buccolingual inclinations

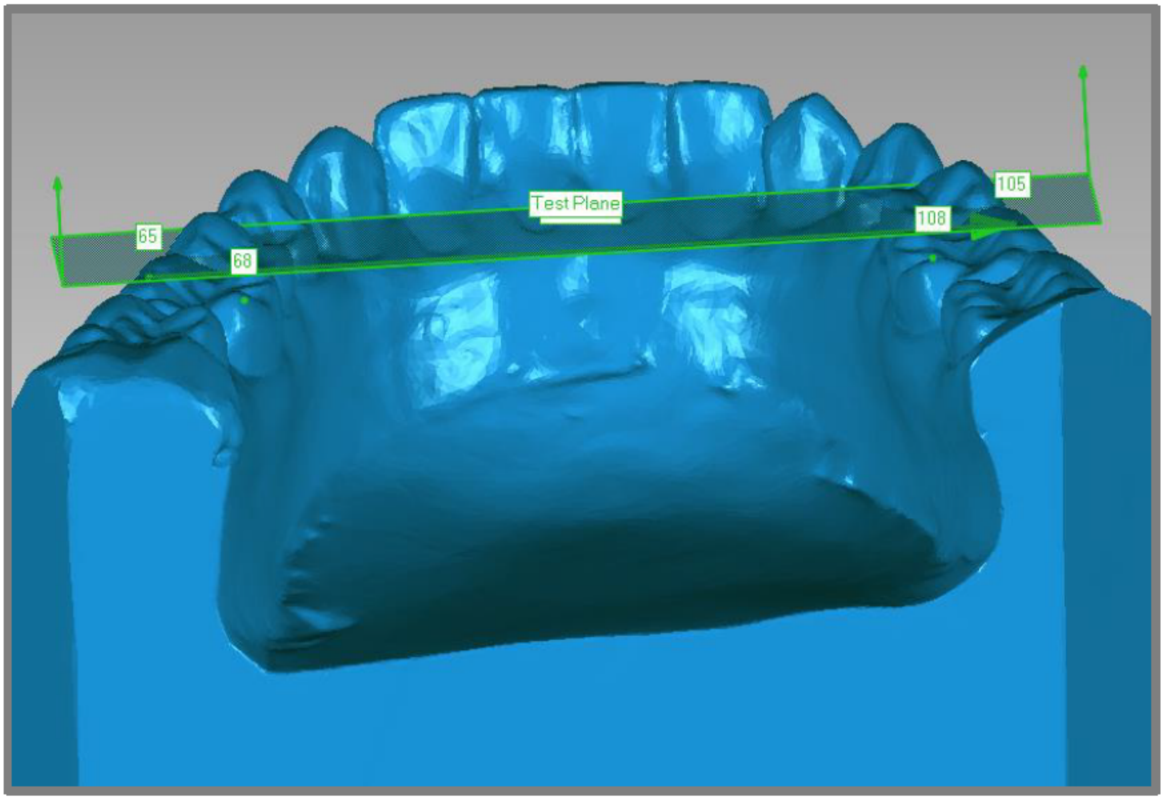


Figure 3-14. Algorithmic derived plane used to measure occlusal relationships

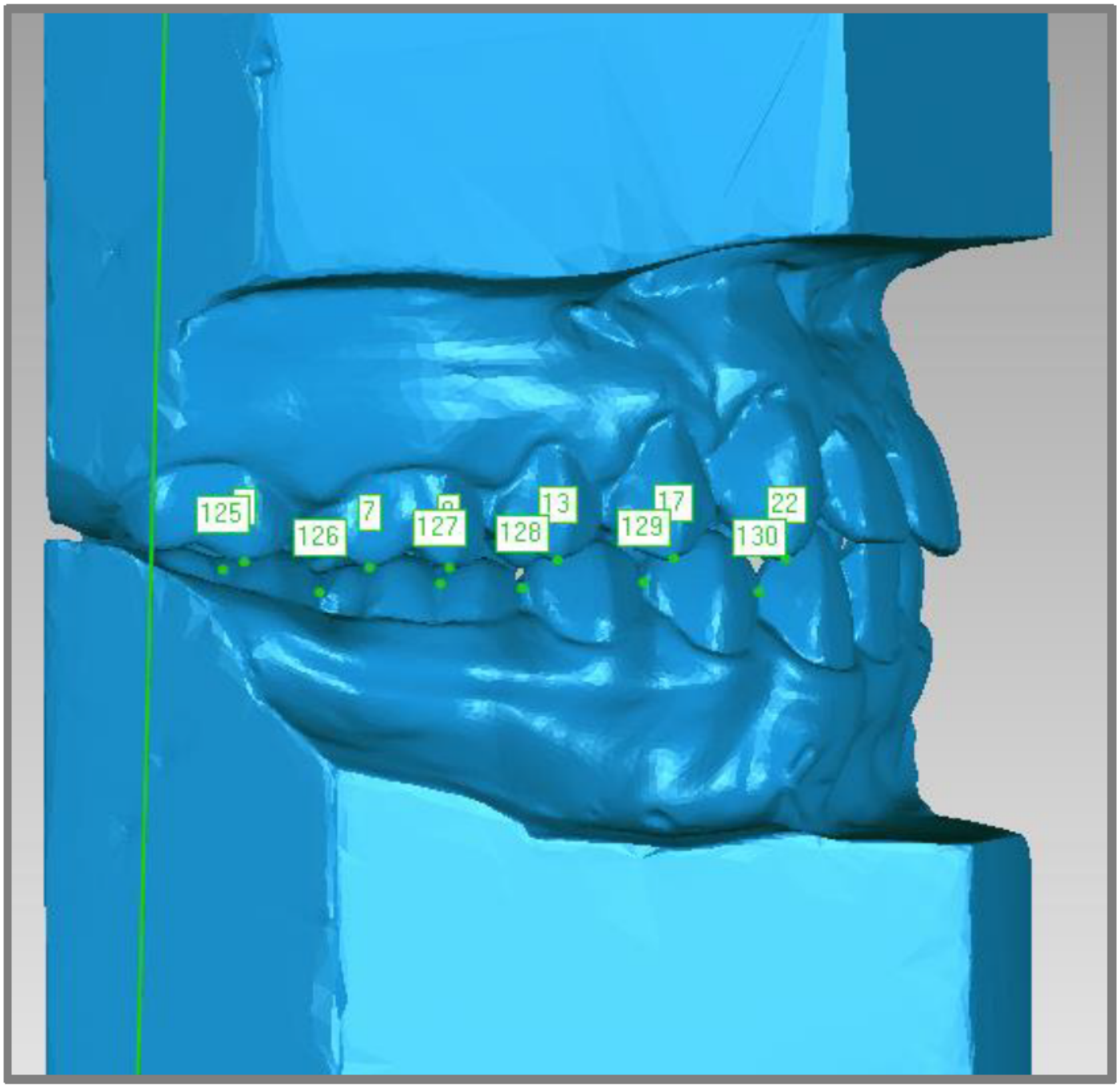


Figure 3-15. Overjet measured using color mapping produced by 3Shape OrthoAnalyzer™ software

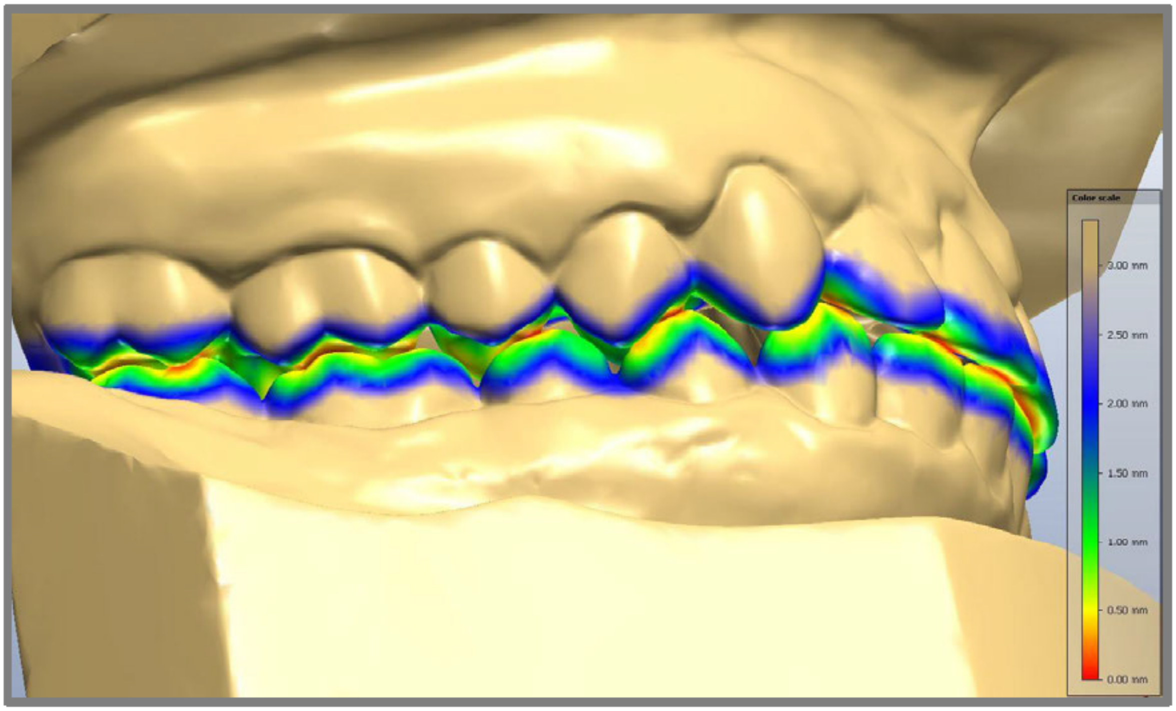


Figure 3-16. Occlusal contacts measured using color mapping produced by 3Shape OrthoAnalyzer™ software

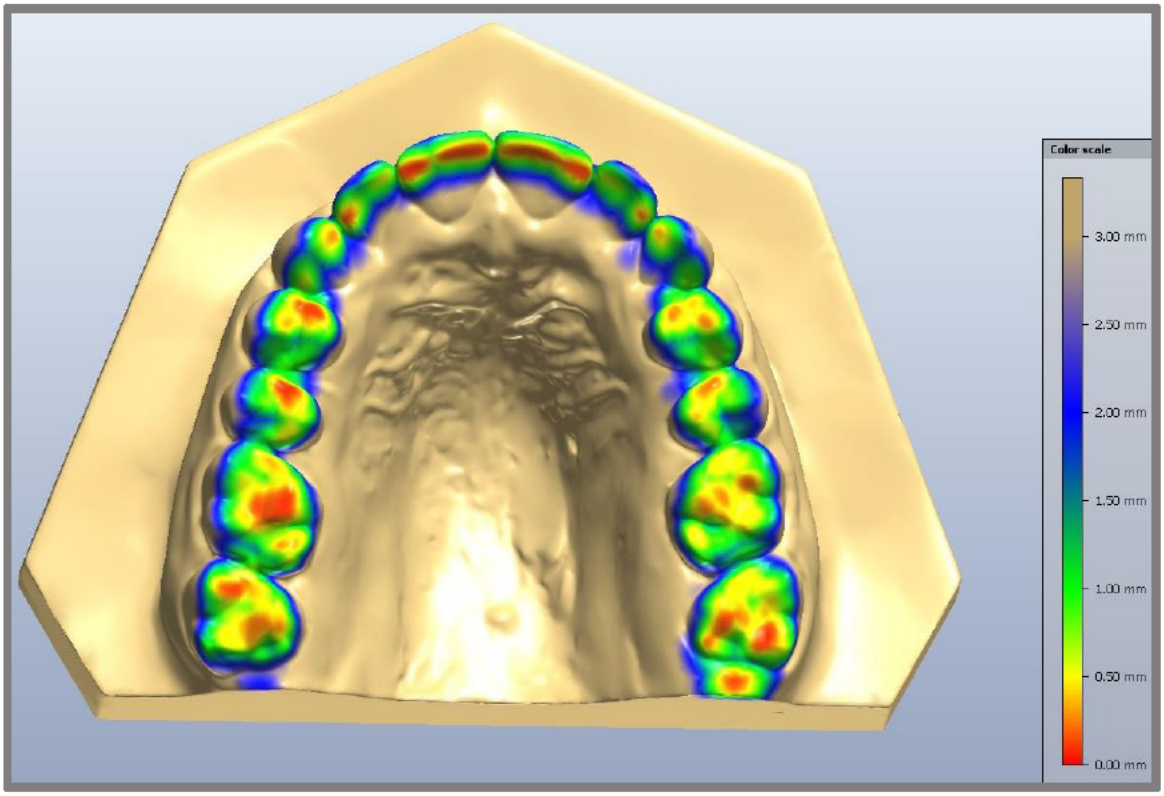
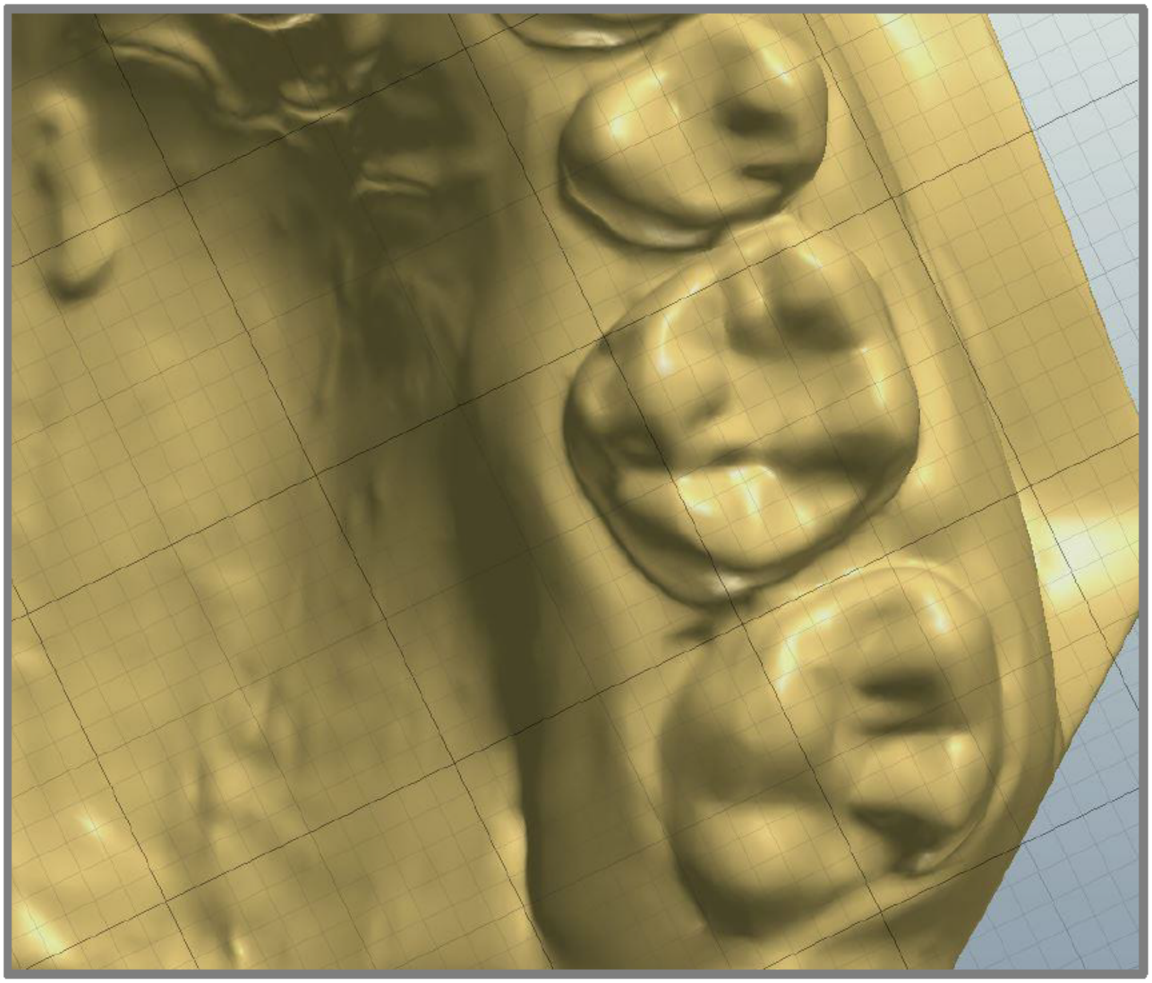


Figure 3-17. Interproximal contacts measured using an overlay grid in 1 mm x 1 mm increments produced by 3Shape OrthoAnalyzer™ software



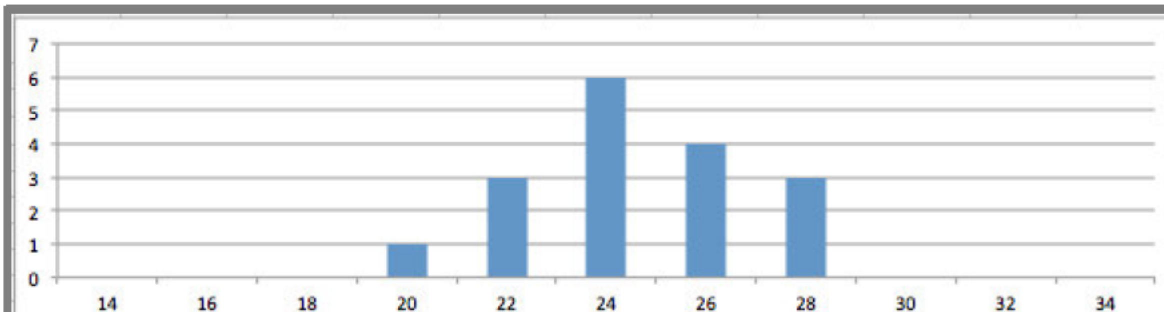
IV. RESULTS

At the onset of the project and prior to manually grading the plaster model sets used for the study (A and B) the 25 examiners completed a calibration exercise. This involved using an ABO assigned plaster model set with a pre-assigned score and an ABO measuring gauge. The scores for each category and the total scores were compiled and the results are summarized below (Tables 4-1 and 4-2):

Table 4-1. Inter-examiner calibration results

Category	Board Score	Mean	Median	Std Dev	Min	Max	Range
Alignment/Rotations	4	5.29	5.00	1.72	3	9	6
Marginal Ridges	2	2.06	2.00	0.83	1	3	2
Buccolingual Inclination	6	4.12	4.00	1.54	2	8	6
Overjet	2	2.35	2.00	0.70	2	4	2
Occlusal Contacts	6	4.71	5.00	1.69	1	7	6
Occlusal Relationships	3	5.59	6.00	2.24	3	12	9
Interproximal Contacts	0	0.00	0.00	0.00	0	0	0
Total	23	24.12	24.00	2.18	20	28	8

Table 4-2. Inter-examiner calibration results



0	0	0	1	3	6	4	3	0	0	0
14	16	18	20	22	24	26	28	30	32	34

Following the calibration test each examiner was assigned two plaster model sets (A and B) to be graded using the ABO-CRE. The scores for each plaster model set and the summarized results for each CRE category are illustrated in the tables below (Tables 4-3 and 4-4):

Table 4-3. Summarized results for manual scoring of plaster Model Set A

	MANUAL SCORING OF PLASTER MODEL A							
GRADER	ALIGNMENT	MARGINAL RIDGES	BUCCOLINGUAL INCLINATION	OVERJET	OCCLUSAL CONTACTS	OCCUSAL RELATIONSHIP	INTERPROXIMAL CONTACT	TOTAL SCORE
1A	4	3	1	0	4	5	1	18
2A	6	8	4	0	1	6	0	25
3A	8	3	4	1	5	8	2	31
4A	6	3	1	1	4	11	0	26
5A	10	6	3	1	5	6	1	32
6A	7	3	3	3	3	4	2	25
7A	9	4	4	2	4	8	0	31
8A	6	3	3	2	7	9	2	32
9A	8	5	2	2	4	9	2	32
10A	5	7	1	3	2	7	2	27
11A	9	2	1	1	5	9	2	29
12A	7	2	6	2	3	6	2	28
13A	6	4	3	2	4	4	2	25
14A	9	3	3	4	4	10	0	33
15A	7	4	3	3	2	8	0	27
16A	9	3	2	0	6	5	0	25
17A	6	6	2	2	1	9	2	28
18A	6	7	4	7	3	8	0	35
19A	8	5	4	1	2	9	2	31
20A	7	4	3	2	3	10	2	31
21A	7	5	3	2	6	6	0	29
22A	6	4	3	3	2	6	0	24
23A	8	5	4	2	3	6	0	28
24A	9	5	3	2	2	8	0	29
25A	5	3	1	1	3	13	0	26
IQR 1	6	3	2	1	2	6	0	26
IQR 3	8	5	4	2	4	9	2	31
IQR	2	2	2	1	2	3	2	5
MEAN	7.12	4.28	2.84	1.96	3.52	7.6	0.96	28.28
SD	1.50519102	1.562562	1.222456543	1.427725	1.526302722	2.172556098	0.958331884	3.583518
MEDIAN	7	4	3	2	3	8	1	28

Table 4-4. Summarized results for manual scoring of plaster Model Set B

	MANUAL SCORING OF PLASTER MODEL B							
GRADER	ALIGNMENT	MARGINAL RIDGES	BUCCOLINGUAL INCLINATION	OVERJET	OCCLUSAL CONTACTS	OCCUSAL RELATIONSHIP	INTERPROXIMAL CONTACT	TOTAL SCORE
1B	3	3	5	1	0	3	0	15
2B	6	7	7	0	2	1	0	23
3B	7	4	4	1	0	3	0	19
4B	4	1	4	4	0	4	0	17
5B	5	6	6	0	0	0	0	17
6B	4	6	3	1	0	2	0	16
7B	5	2	6	1	2	0	0	16
8B	7	5	7	2	3	1	0	25
9B	5	1	5	4	1	4	0	20
10B	1	4	5	1	0	2	0	13
11B	6	2	3	2	0	3	0	16
12B	3	3	6	3	0	1	0	16
13B	6	6	6	2	0	2	0	22
14B	6	5	6	4	2	4	0	27
15B	5	1	5	3	0	2	0	16
16B	8	3	3	2	0	2	0	18
17B	6	1	6	0	0	3	0	16
18B	5	5	7	1	5	4	0	27
19B	4	4	3	1	2	2	0	16
20B	4	0	5	2	2	4	0	17
21B	4	5	6	2	0	2	0	19
22B	3	0	5	2	2	0	0	12
23B	6	5	8	2	0	2	0	23
24B	5	3	8	1	0	2	0	19
25B	2	2	4	3	0	4	0	15
IQR 1	4	2	4	1	0	2	0	16
IQR 3	6	5	6	2	2	3	0	20
IQR	2	3	2	1	2	1	0	4
MEAN	4.8	3.36	5.32	1.8	0.84	2.28	0	18.4
SD	1.6	1.99759856	1.462053351	1.16619	1.286234815	1.28124939	0	3.949684
MEDIAN	5	3	5	2	0	2	0	17

Using the points registered by each grader on their assigned digitized model set and the software algorithms created computerized measurements were calculated and scored. Scoring of the measurements was performed in a manner consistent with the ABO-CRE. The scores for each digital model set and the summarized results for each CRE category are illustrated in the tables below (Tables 4-5 and 4-6):

Table 4-5. Summarized results for computer scoring of digital Model Set A

	COMPUTER SCORING OF DIGITAL MODEL A							
GRADER	ALIGNMENT	MARGINAL RIDGES	BUCCOLINGUAL INCLINATION	OVERJET	OCCLUSAL CONTACTS	OCCUSAL RELATIONSHIP	INTERPROXIMAL CONTACT	TOTAL SCORE
1A	7	4	4	4	6	11	2	38
2A	9	3	4	4	6	10	2	38
3A	8	4	5	4	6	13	2	42
4A	11	5	3	4	6	12	2	43
5A	14	5	5	4	6	11	2	45
6A	15	4	4	4	6	14	2	49
7A	11	2	2	4	6	15	2	44
8A	12	5	5	4	6	16	2	49
9A	9	4	4	4	6	14	2	43
10A	9	6	6	4	6	15	2	46
11A	9	6	6	4	6	16	2	48
12A	7	4	4	4	6	14	2	40
13A	9	4	4	4	6	14	2	43
14A	11	3	3	4	6	15	2	45
15A	11	3	3	4	6	14	2	45
16A	7	5	5	4	6	14	2	41
17A	11	5	5	4	6	15	2	46
18A	11	4	4	4	6	13	2	44
19A	9	3	3	4	6	13	2	40
20A	11	5	5	4	6	12	2	44
21A	7	3	3	4	6	13	2	38
22A	10	5	5	4	6	14	2	44
23A	9	5	5	4	6	14	2	43
24A	10	3	3	4	6	12	2	41
25A	8	5	5	4	6	14	2	44
IQR 1	9	3	3	4	6	13	2	41
IQR 3	11	5	5	4	6	14	2	45
IQR	2	2	2	0	0	1	0	4
MEAN	9.8	4.2	4.2	4	6	13.52	2	43.32
SD	2.019900988	1.019803903	1.019803903	0	0	1.499866661	0	3.04263
MEDIAN	9	4	4	4	6	14	2	44

Table 4-6. Summarized results for computer scoring of digital Model Set B

	COMPUTER SCORING OF DIGITAL MODEL B							
GRADER	ALIGNMENT	MARGINAL RIDGES	BUCCOLINGUAL INCLINATION	OVERJET	OCCLUSAL CONTACTS	OCCUSAL RELATIONSHIP	INTERPROXIMAL CONTACT	TOTAL SCORE
1B	10	6	7	3	2	12	0	40
2B	12	6	5	3	2	11	0	42
3B	8	8	6	3	2	9	0	39
4B	7	9	7	3	2	11	0	39
5B	10	3	7	3	2	12	0	37
6B	13	6	7	3	2	11	0	41
7B	13	8	7	3	2	10	0	43
8B	16	4	7	3	2	10	0	42
9B	10	8	7	3	2	12	0	42
10B	10	8	7	3	2	12	0	45
11B	8	9	7	3	2	12	0	42
12B	6	5	7	3	2	11	0	34
13B	11	6	7	3	2	12	0	41
14B	6	4	7	3	2	11	0	33
15B	12	7	7	3	2	10	0	41
16B	5	5	7	3	2	12	0	34
17B	11	6	7	3	2	13	0	42
18B	13	9	7	3	2	13	0	47
19B	16	8	7	3	2	11	0	47
20B	12	4	8	3	2	11	0	39
21B	7	5	8	3	2	10	0	34
22B	12	5	8	3	2	11	0	41
23B	7	8	8	3	2	11	0	36
24B	11	9	9	3	2	9	0	42
25B	9	6	10	3	2	12	0	39
IQR 1	8	5	7	3	2	11	0	39
IQR 3	12	8	7	3	2	12	0	42
IQR	4	3	0	0	0	1	0	3
MEAN	10.2	6.48	7.24	3	2	11.16	0	40.08
SD	2.898275349	1.791535654	0.906862724	0	0	1.046135746	0	3.719355
MEDIAN	10	6	7	3	2	11	0	41

Box plots were created to illustrate the differences in the interquartile ranges (IQR) for the different CRE categories and for each model set (Figures 4-1 through 4-8):

Figure 4-1. Alignment Model Set A and B

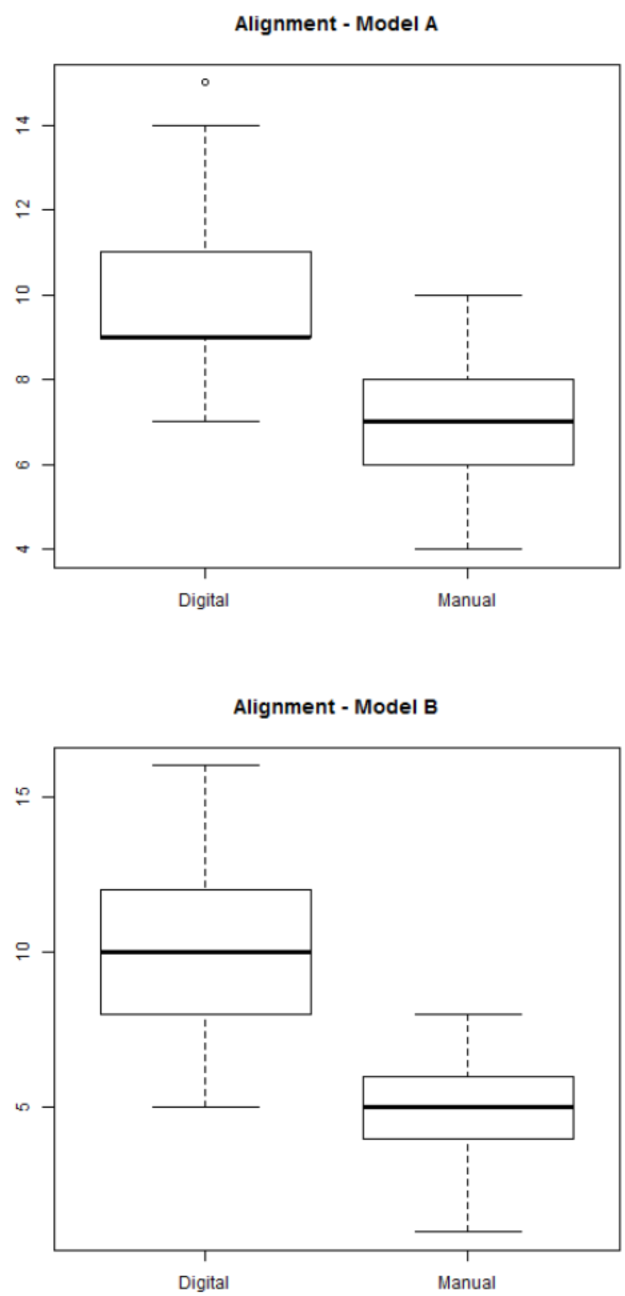
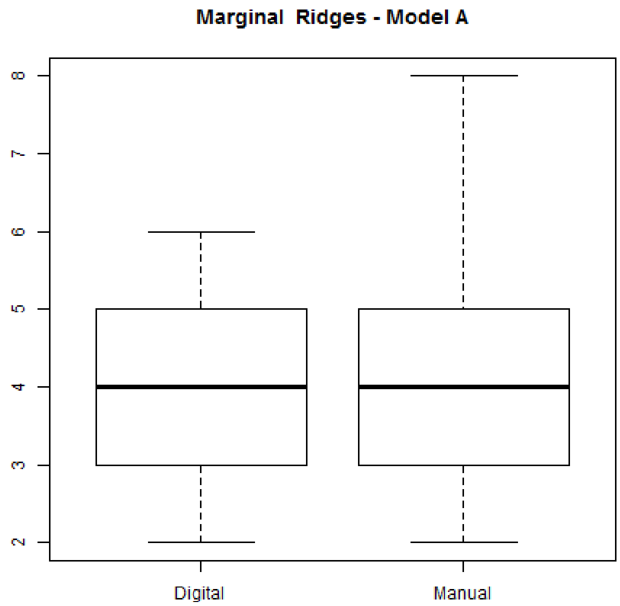


Figure 4-2. Marginal Ridges Model Set A and B



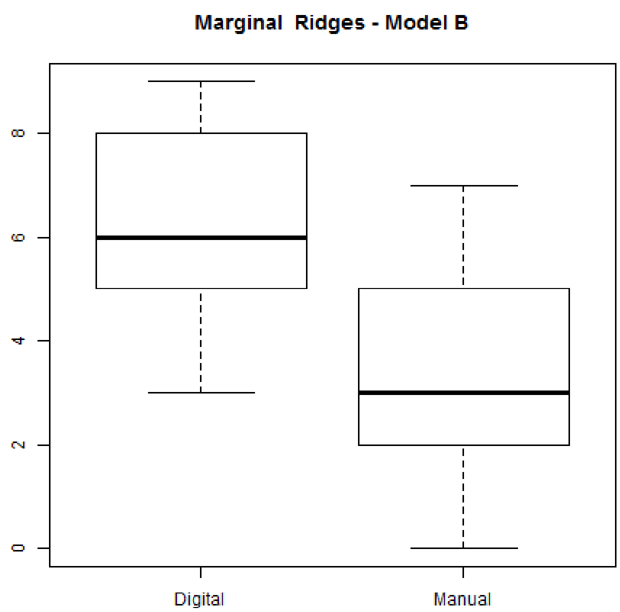
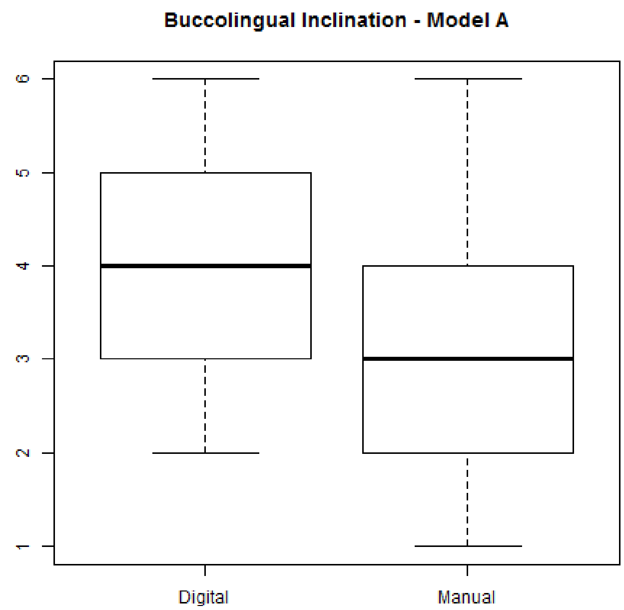


Figure 4-3. Buccolingual Inclination Model Set A and B



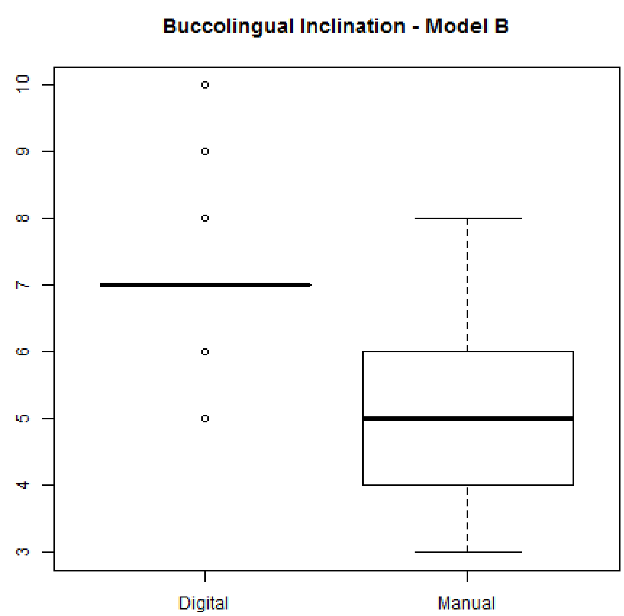
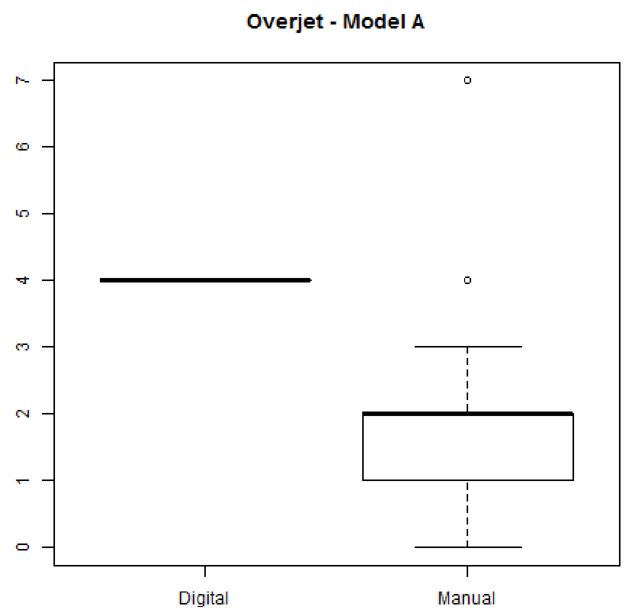


Figure 4-4. Overjet Model Set A and B



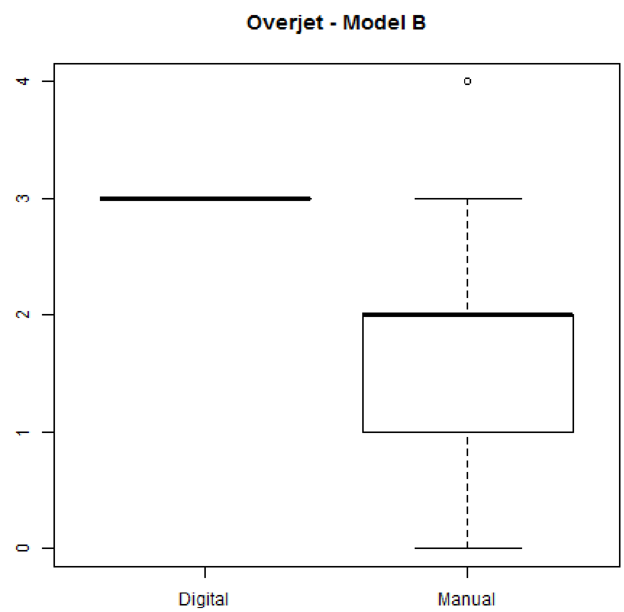
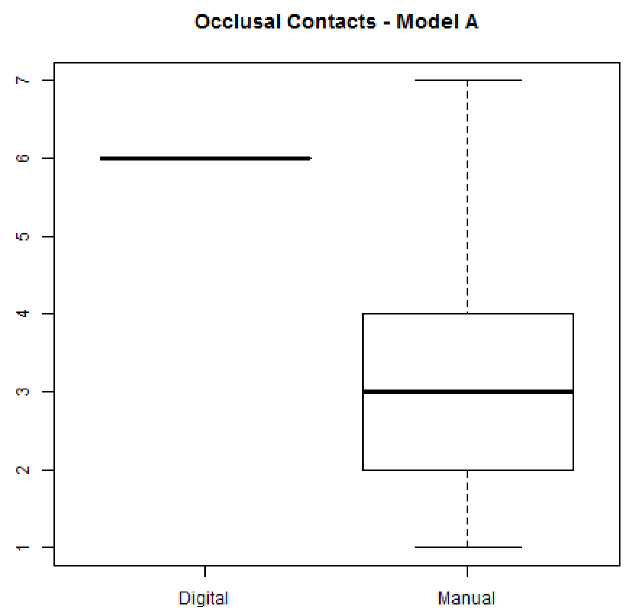


Figure 4-5. Occlusal Contacts Model Set A and B



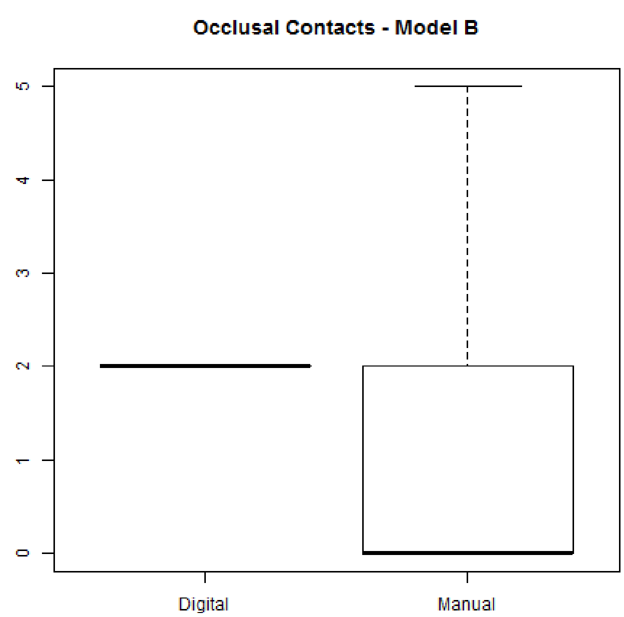
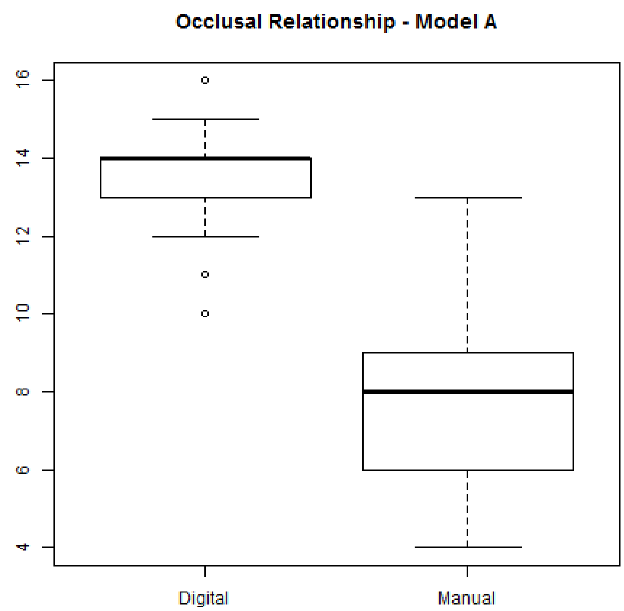


Figure 4-6. Occlusal Relationship Model Set A and B



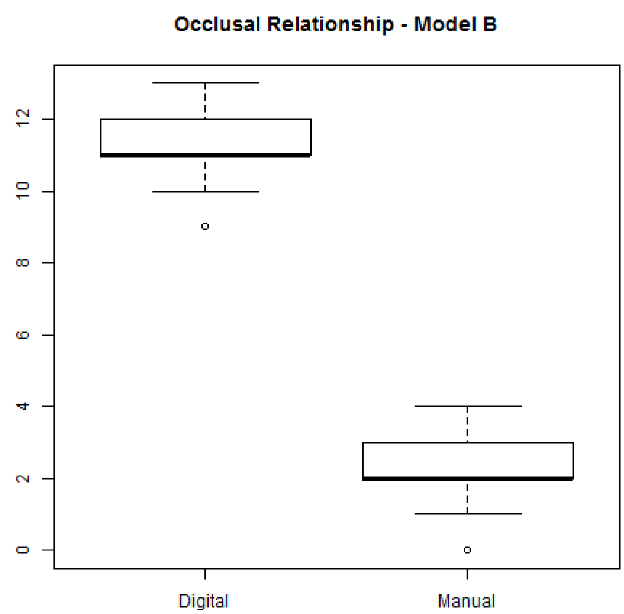
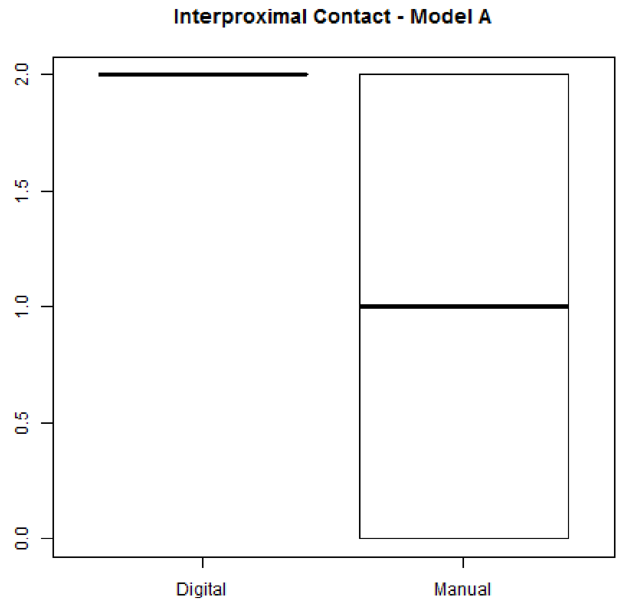


Figure 4-7. Interproximal Contact Model Set A and B



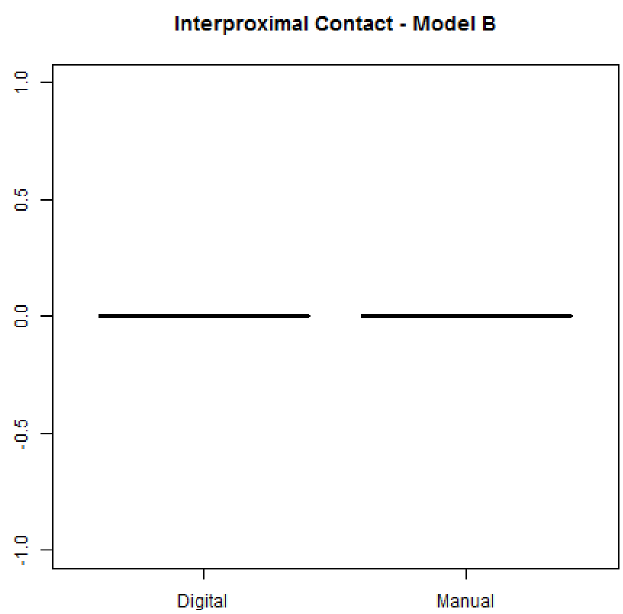
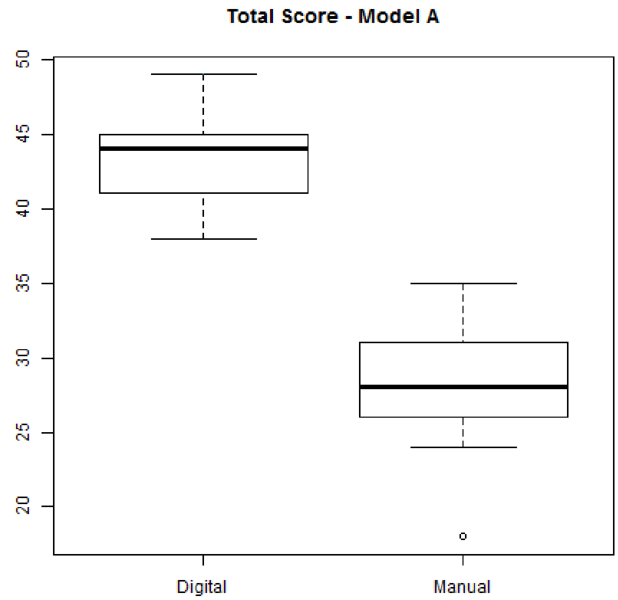
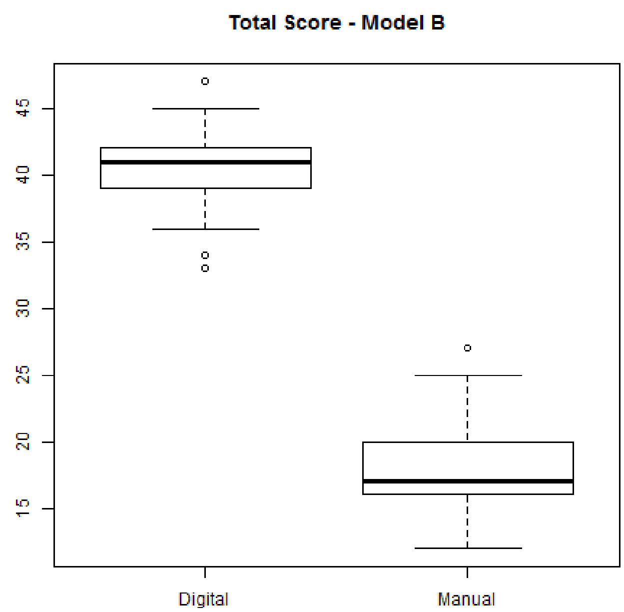


Figure 4-8. Total Score Model Set A and B





In instances where the digital and manual measurements had a different IQR a Snedecor's F-Test for variance equality was computed, and the P-value was measured. The results determined at the $p \leq 0.05$ level of significance are summarized below (Table 4-7):

Table 4-7. Snedecor's F-Test for Variance Equality

Snedecor's F-Test of Scale Equality				
Model	Measurement	Digital	Manual	P-Value
A	Occlusal Contacts	0	2	0
A	Interproximal Contact	0	2	0
A	Overjet	0	1	0
A	Occlusal Relationship	0	1	0.0378
A	Total Score	4	5	0.2143
B	Alignment	4	2	0.0025
B	Buccolingual Inclination	0	2	0.0115
B	Occlusal Contacts	0	2	0
B	Overjet	0	1	0
B	Total Score	3	4	0.3854

In instances where the digital and manual measurements had similar IQRs that differed only in location a Two Sample "Adjusted" Kolmogorov-Smirnov Test was computed to test for shape equality. The results determined at the $p \leq 0.05$ level of significance are summarized below (Table 4-8):

Table 4-8. Kolmogorov-Smirnov Test for Shape Equality

Two Sample "Adjusted" Kolmogorov-Smirnov Test for Shape Equality		
Model	Measurement	P-value
A	Buccolingual Inclination	0.4676
A	Marginal Ridges	0.0783
B	Interproximal Contact	1.0000
B	Marginal Ridges	0.6994
B	Occlusal Relationship	0.0783

For each scoring category a Wilcoxon signed-rank test was used to determine where differences between the manual scoring of the plaster model sets and computerized scoring of the digital model sets occurred. The results determined at the $p \leq 0.05$ level of significance are summarized below (Table 4-9):

Table 4-9. Wilcoxon Signed-Rank Test

	Align	Marginal Ridges	B/L Inclin.	Overjet	Occlusal Contact	Occlusal Relation	Inter-Proximal Contact	Total Score	Comments
Model A Manual vs. Digital (p-values)	0.000	0.921	0.003	0.000	0.000	0.000	0.000	0.000	Except for Marginal Ridges scores were significantly different in all categories
Model B Manual vs. Digital (p-values)	0.000	0.000	0.000	0.000	0.001	0.000	1.000	0.000	Except for Interproximal Contacts scores were significantly different in all categories

For each of the model sets (A and B) and for each of the two grading mechanisms (manual and computerized) consistency of scoring amongst graders and inter-rater reliability was assessed by calculating the ICC for all examiners in all grading categories. The results are summarized below (Table 4-10):

Table 4-10. Intraclass Correlation Coefficient

	Manual Model A	Digital Model A	Manual Model B	Digital Model B	Comments
Intraclass Correlation Coefficient	0.7127	0.9324	0.6646	0.8981	Computerized grading of the digital models (A and B) demonstrated a higher level of correlation than the manual grading of the plaster models (A and B).

V. DISCUSSION

This project was designed to compare the results obtained from manually graded plaster model sets to the results obtained from computer graded digital model sets utilizing the ABO-CRE. Twenty-five calibrated ABO examiners manually graded two sets of post-treatment orthodontic models using the ABO-CRE scoring methodology and an ABO measuring gauge. Subsequently the same 25 examiners registered prescribed data points on cusp tips, incisal edges, marginal ridges and buccal landmarks on the digitized versions of the plaster model sets.

Using digital data points plotted by the 25 examiners and a unique programming script with Geomagic Studio 2014® software, reference planes were created. The reference planes were used to measure discrepancies in alignment, marginal ridges, buccolingual inclinations, and occlusal relationships of the digitized model sets. Additionally, 3Shape OrthoAnalyzer™ software was used to create color mappings and overlay grids to measure overjet, occlusal contacts, and interproximal contacts.

Scores obtained from the manually graded plaster models were individually compared to those obtained from the computer graded digital models for each of the seven CRE categories and total scores. Scores for each model set (A and B) and each model type (plaster and digital) were statistically evaluated for significant differences (determined at the $p \leq 0.05$ level of significance), central tendency, dispersion from the central tendency, and inter-rater reliability.

The Wilcoxon signed-rank test with $\alpha = 0.05$ was used to compare significant differences in scores between the plaster and digital models. It was determined the scores obtained in manual scoring were significantly different from those obtained in computerized scoring in all seven categories and total score. The only exceptions were marginal ridge discrepancy in Model Set A and interproximal contact in Model Set B.

The higher scores observed in the digital model group can possibly be explained by the complete objectivity inherent in the computerized scoring process and the discrete nature of the computerized measurements. The software used in this study evaluated discrepancies in measurements to a 100-micron level of sensitivity. Therefore, very slight discrepancies could be detected and could have resulted in higher scores.

Further statistical analysis of the scoring differences between the plaster and digital model sets utilizing medians and IQRs indicated the computerized scoring of the digital models had consistently higher scores with similar or less variability than the manual scoring of the plaster models. To determine the variance equality of the IQRs the Snedecor's F-Test for scale equality was computed. It was found that a statistically significant difference ($p \leq 0.05$) existed in the IQRs for Occlusal Contacts, Interproximal Contact, Overjet, and Occlusal Relationship in Model Set A and Alignment, Buccolingual Inclination, Occlusal Contacts, and Overjet in Model Set B. The rest of the categories did not demonstrate a statistical significance in IQR as verified through a two-sample Kolmogorv-Smirnov Test for shape equality.

To assess consistency of the two scoring methods and within all of the scoring categories an ICC was performed on the data. The ICC computed the inter-rater reliability of all 25 examiners throughout all seven CRE categories. In both model sets (A and B) and within both scoring methods (manual and computerized) the inter-rater reliability as indicated by the ICC was high. The ICC for the manually graded plaster models was r = 0.71 for Set A and r = 0.66 for Set B. However, the inter-rater reliability within the digital model group was demonstrably higher with almost perfect agreement r = 0.93 for Set A and r = 0.90 for Set B.

There were some limitations to the study that could potentially be addressed in future studies. Having examiners remotely login to gain computer access to the software program was required based on our software, but it is a potential source of error. Depending on Internet speeds there was sometimes an observable lag time between the examiner's intended action and the execution of that action on the screen. With remote login examiners could use different types of computer hardware and the cursor control varied from examiner to examiner depending on what type of computer they had access to. Some examiners used a mouse and others used track pads. It appeared through observation that data point placement using a track pad was not as accurate as using a mouse. When examiners would remotely login for computer access they had the ability to view the digital models and independently register data points, but they lacked the ability to independently manipulate the digital models. If examiners wanted an image rotated or enlarged for better visualization they described the view they wanted and relied on the primary investigator to provide the requested actions. This process was cumbersome and could have led to reluctance in obtaining an altered and perhaps more optimal view of the digital models than if the examiner was able to manipulate the digital models directly. Additionally, examiners were directed to register points on cusp tips and marginal ridges, but were not explicitly directed to register points on the marginal ridges in line with the central groove. The alignment of the maxillary molars and bicuspids are referenced from the central grooves. Therefore, if examiners registered marginal ridge points without regard to the central groove there would be potential inaccuracies in the scoring of the alignment for these teeth. Finally, the plane created as the reference for measuring occlusal relationship was parallel to the base of the cast. Measurements done from this perspective seemed to result in significantly higher scores than those done manually on plaster casts where the view for scoring is likely done looking perpendicular to the alveolar ridges. The difference in views could result in scoring differences due to parallax error.

Recommendations for future studies would include having the examiners register points directly on a computer with the software to eliminate the need for remote login. This would eliminate lag times and enable examiners to have independent ability to manipulate the digital models to the view they prefer. It would also be important to explicitly direct the examiners to register data points along the central groove for more accurate measures of alignment. For scoring occlusal relationship the reference plane could be developed perpendicular to the plane created for alignment of the molars and bicuspids. This would best approximate measurements on a line parallel to the alveolar ridge and provide more accurate scoring. Finally, the digitized model was a 3D rendition, but it was on a flat screen that limited true depth perception when viewing the models. This created difficulty in registering a data point on the exact tip of the cusps or the height of the marginal ridges. Developing the software to autocorrect registered points within a prescribed area to be localized to the highest point, or to utilize centroids would eliminate depth perception errors and potentially improve consistency and reliability.

VI. CONCLUSIONS

1. Using the methodology described computerized scoring of laser-scanned digital models results in equal or higher scores in all seven scoring categories of the ABO-CRE as well as total scores.

2. Using the methodology described computerized scoring of laser-scanned digital models demonstrates a higher degree of inter-rater reliability than manually scored plaster models.

3. Using the methodology described computerized scoring of laser-scanned digital models demonstrates less variability than manually scored plaster models.

VII. APPENDICES

Appendix A. Software Script Used for Scoring Digital Models

```
##### To run this script successfully ensure that Mesh Doctor is disabled by default. Go to    #####

##### St 3DS -> Options -> FileI/O -> Polygons -> Prompt to Run Mesh Doctor After Loading    #####

##### The script was written considering the mandibular model and points file are chosen first #####

##### This script calculates Alignment/Rotations, Marginal Ridges, Buccolingual Inclination    #####

##### and Occlusal Relationships of point features on a maxillary and mandibular model set    #####

##### then saves the data to a .csv file.                                    #####

import geomagic.app.v2

for m in geomagic.app.v2.execStrings: exec m in locals(), globals()

import geoapiall

for m in geoapiall.modules: exec "from %s import *" % m in locals(), globals()

import os

##### MAXILLARY arrays of points #####

AR_maxRight = [5, 6, 11, 12, 15, 16, 19, 20]

AR_maxLeft = [42, 41, 46, 45, 52, 51, 58, 57]

AR_5_6 = [17, 21, 22]

AR_6_7 = [22, 23, 24, 25]

AR_7_8 = [25, 26, 27, 28]

AR_8_9 = [28, 29, 32, 31]

AR_9_10 = [31, 30, 35, 34]

AR_10_11 = [34, 33, 38, 37]
```

```
AR_11_12 = [37, 36, 39]

MR_2_3 = [2, 6, 11, 7]

MR_3_4 = [8, 12, 15, 13]

MR_4_5 = [13, 16, 19, 17]

MR_14_15 = [54, 58, 51, 47]

MR_13_14 = [48, 52, 45, 43]

MR_12_13 = [43, 46, 41, 39]

BI_5_12 = [17, 18, 40, 39]

BI_4_13 = [13, 14, 44, 43]

BI_mesial3_14 = [8, 9, 49, 48]

BI_distal3_14 = [7, 10, 50, 47]

BI_2_15 = [2, 3, 55, 54]

OR_Max = [54, 48, 43, 39, 37, 22, 17, 13, 8, 2]

##### MANDIBULAR arrays of points #####

AR_manLeft = [59, 60, 65, 66, 71, 75, 79]

AR_manRight = [111, 112, 105, 106, 101, 97, 94]

AR_21_22 = [75, 79, 80]

AR_22_23 = [80, 81, 82, 83]

AR_23_24 = [83, 84, 85, 86]

AR_24_25 = [86, 87, 90, 89]

AR_25_26 = [89, 88, 93, 92]

AR_26_27 = [92, 91, 96, 95]

AR_27_28 = [95, 94, 97]

MR_man18_19 = [60, 64, 69, 65]

MR_man19_20 = [66, 70, 73, 71]
```

```
MR_man31_30 = [112, 116, 109, 105]

MR_man30_29 = [106, 110, 103, 101]

BI_20_29 = [71, 72, 102, 101]

BI_mesial19_30 = [66, 67, 107, 106]

BI_distal19_30 = [65, 68, 108, 105]

BI_mesial18_31 = [60, 61, 113, 112]

BI_distal18_31 = [59, 62, 114, 111]

OR_Man = [124, 125, 127, 128, 129, 130, 123, 122, 121, 120, 118, 117]

##### Function to import .stl file #####

def getModel():

        ##### Convert object to millimeters #####

        geo.modify_units(1, 0, 1)

        ##### Select an STL file and import model #####

        try:

          openDialog = gui.OpenFileDialog()

          fileName =
openDialog.getFilePath(u"Z:\\Research\\2015_Timmons\\Digital Models", u"STL
(*.stl)")

          ##### Add arch model to the model mgr #####

          geoapp.importFile(fileName)

          activeModel = geoapp.getActiveModel()

        except IOError as e:

          print "Model import not successful :-("

        except:

          sys.exc_info()[0]

##### Function to import points text file and return a Points() object #####
```

```
def getPoints(arch):

        ##### Select a points file to read and parse the data #####

        try:

          openDialog = gui.OpenFileDialog()

          fileName =
openDialog.getFilePath(u"Z:\\Research\\2015_Timmons\\Digital Models", u"Text
File (*.txt)")

          f = open(fileName)

          arr = f.readlines()

          f.close()

        except IOError as e:

          print "Points import not successful :-("

        except:

          sys.exc_info()[0]

        ##### Create points as PointFeature() objects and save to the active
model #####

        activeModel = geoapp.getActiveModel()

        PtsNum = 59

        if arch == "Max":

          PtsNum = 1

        for p in arr:

          pt = PointFeature()

          ptLabel = str(PtsNum)

          p0 = p.split(' ')  ##### use blank space as separator #####

          label = str(p0[0])

          if label != "dnu":
```

```
            x = float(p0[1])
            y = float(p0[2])
            z = float(p0[3])
            pt.name = ptLabel
            pt.position = Vector3D(x/float(1000), y/float(1000), z/float(1000))
            geoapp.addFeature(activeModel, pt)
            PtsNum = PtsNum + 1
##### Get cusps for alignment calculations and save to Points() array #####
def getLandmarks(activeModel, PointsArray):
  geoapp.setActiveModel(activeModel)
  print "Active Model = " + activeModel.name
  pts = Points()
  for pt in PointsArray:
     feature = PointFeature()
     feature = geoapp.getFeatureByName(activeModel, str(pt))
     print ("feature = " + feature.name)
     pts.addPoint(feature.position)
  return pts
##### Function that creates line given 2 points #####
def createLine(model, points):
  activeModel = geoapp.getActiveModel()
  line = Line()
  line.start = points.getPosition(0)
  num = points.numPoints
  line.end = points.getPosition(num - 1)
```

```
  line.name = "Test Line"
  geoapp.addFeature(activeModel, line)
  return line
##### Function that creates a plane #####
def makePlane(model, p1, p2, axis):
  ##### Identify plane points #####
  fitPlaneFrom3Points = FitPlaneFrom3Points()
  fitPlaneFrom3Points.point1 = p1
  fitPlaneFrom3Points.point2 = p2
  p3 = PointFeature()
  p3.position = Vector3D(0.0, 1.0, 0)
  if axis == "z":
     p3.position = Vector3D(1.0, 0.0, 1.0)
  fitPlaneFrom3Points.point3 = p3
  fitPlaneFrom3Points.run()
  ##### Create and save plane form points #####
  plane = fitPlaneFrom3Points.resultFeature
  plane.name = u"Test Plane"
  geoapp.addFeature(model, plane)
  return plane
##### Function that calculates distance from point to plane #####
def distPoint2Plane(model, plane, p3):
  compPoint = Vector3D(p3.position)
  distance = compPoint.dist(plane.normal)
  return distance
```

```
##### Function that calculates Occlusal Relationship measurements and appends #####

##### data to the test.csv file #####

def calcOccRel(maxPointsArray, manPointsArray, text, axis):

  with open("Z:\\Research\\2015_Timmons\\Digital Models\\test.csv", "a") as pointStatFile:

       pointStatFile.write(text + ",Point,Delta from plane\n")

       models = geoapp.getModels()

       plane = Plane()

       p1 = PointFeature()

       p2 = PointFeature()

       p3 = PointFeature()

       for model in models:

          if model.name != "World":

             modelName = model.name

             print modelName

             geoapp.setActiveModel(model)

              if modelName.endswith("Maxillar"):

                   activeModel = geoapp.getActiveModel()

                   cuspTips = getLandmarks(activeModel, maxPointsArray)

                   p1.position = line.start

                   p2.position = line.end

                   plane = makePlane(activeModel, p1, p2, axis)

              for ct in cuspTips:

                   p3.position = cuspTips.getPosition(ct)

                   distance = plane.getDistance(p3.position)
```

```
                if distance < 0:
                    distance = (distance * -1)
                print str(cuspTips.getPosition(ct)) + " Dist from plane: " +
str(distance * 1000)
               pointStatFile.write("," + str(maxPointsArray[ct]) + "," + str(distance *
1000) + "\n")
        else:
                activeModel = geoapp.getActiveModel()
                cuspTips = getLandmarks(activeModel, manPointsArray)
                line = createLine(activeModel, cuspTips)
                ###### Iterate through the points, call functions and print results
#####
                p1.position = line.start
                p2.position = line.end
                plane = makePlane(activeModel, p1, p2, axis)
        for ct in cuspTips:
                p3.position = cuspTips.getPosition(ct)
                distance = plane.getDistance(p3.position)
                if distance < 0:
                    distance = (distance * -1)
                print str(cuspTips.getPosition(ct)) + " Dist from plane: " +
str(distance * 1000)
                pointStatFile.write("," + str(manPointsArray[ct]) + "," + str(distance
* 1000) + "\n")
  return file
##### Function that calculates Alignment/Rotations, Marginal Ridges, and
Buccolingual Inclination #####
```

```
##### and appends to the  test.csv file
#####

def lineFunction(PointsArray, text, axis):

   with open("Z:\\Research\\2015_Timmons\\Digital Models\\test.csv", "a") as
pointStatFile:

       pointStatFile.write(text + ",Point,Delta from plane\n")

       activeModel = geoapp.getActiveModel()

       cuspTips = getLandmarks(activeModel, PointsArray)

       line = createLine(activeModel, cuspTips)

       ###### Iterate through the points, call functions and print results #####

       p1 = PointFeature()

       p1.position = line.start

       p2 = PointFeature()

       p2.position = line.end

       p3 = PointFeature()

       plane = Plane()

       plane = makePlane(activeModel, p1, p2, axis)

       for ct in cuspTips:

           p3.position = cuspTips.getPosition(ct)

           distance = plane.getDistance(p3.position)

           if distance < 0:

               distance = (distance * -1)

           print str(cuspTips.getPosition(ct)) + " Dist from plane: " + str(distance *
1000)

           pointStatFile.write("," + str(PointsArray[ct]) + "," + str(distance * 1000) +
"\n")

   return file
```

```
##### Main() #####
getModel()
getPoints("Man")
getModel()
getPoints("Max")
models = geoapp.getModels()
for model in models:
   if model.name != "World":
        modelName = model.name
        print modelName
        geoapp.setActiveModel(model)
        if modelName.endswith("Maxillar"):
            ##### Maxillary function calls #####
            axis = "y"
            lineFunction(AR_maxRight, "AR_maxRight", axis)
            lineFunction(AR_maxLeft, "AR_maxLeft", axis)
            lineFunction(AR_5_6, "AR_5-6", axis)
            lineFunction(AR_6_7, "AR_6-7", axis)
            lineFunction(AR_7_8, "AR_7-8", axis)
            lineFunction(AR_8_9, "AR_8-9", axis)
            lineFunction(AR_9_10, "AR_9-10", axis)
            lineFunction(AR_10_11, "AR_10-11", axis)
            lineFunction(AR_11_12, "AR_11-12", axis)
            axis = "z"
            lineFunction(MR_2_3, "MR_2-3", axis)
```

```
    lineFunction(MR_3_4, "MR_3-4", axis)
    lineFunction(MR_4_5, "MR_4-5", axis)
    lineFunction(MR_14_15, "MR_14-15", axis)
    lineFunction(MR_13_14, "MR_13-14", axis)
    lineFunction(MR_12_13, "MR_12-13", axis)
    lineFunction(BI_5_12, "BI_5-12", axis)
    lineFunction(BI_4_13, "BI_4-13", axis)
    lineFunction(BI_mesial3_14, "BI_mesial3-14", axis)
    lineFunction(BI_distal3_14, "BI_distal3-14", axis)
    lineFunction(BI_2_15, "BI_2-15", axis)
else:
    ##### Mandibular fuction calls #####
    axis = "y"
    lineFunction(AR_manLeft, "AR_manLeft", axis)
    lineFunction(AR_manRight, "AR_manRight", axis)
    lineFunction(AR_21_22, "AR_21_22", axis)
    lineFunction(AR_22_23, "AR_22_23", axis)
    lineFunction(AR_23_24, "AR_23_24", axis)
    lineFunction(AR_24_25, "AR_24_25", axis)
    lineFunction(AR_25_26, "AR_25_26", axis)
    lineFunction(AR_26_27, "AR_26_27", axis)
    lineFunction(AR_27_28, "AR_27_28", axis)
    calcOccRel(OR_Max, OR_Man, "Occ Relationships", axis)
    axis = "z"
    lineFunction(MR_man18_19, "MR_man18_19", axis)
```

```
        lineFunction(MR_man19_20, "MR_man19_20", axis)
        lineFunction(MR_man31_30, "MR_man31_30", axis)
        lineFunction(MR_man30_29, "MR_man30_29", axis)
        lineFunction(BI_20_29, "BI_20_29", axis)
        lineFunction(BI_mesial19_30, "BI_mesial19_30", axis)
        lineFunction(BI_distal19_30, "BI_distal19_30", axis)
        lineFunction(BI_mesial18_31, "BI_mesial18_31", axis)
        lineFunction(BI_distal18_31, "BI_distal18_31", axis)
close("test.csv")##### END #####
```

VIII. LITERATURE CITED

1. Han U. Consistency of orthodontic treatment decisions relative to diagnostic records. Am J Orthod and Dentofacial Orthop 1991; 100:212-219.
2. Hans MG. Standards for digital storage, retrieval and analysis of orthodontic records: workshop report. 1993 Case Western Reserve University, Cleveland.
3. Casko JS, Vaden JL, Kokich VG, Damone J, James RD, Cangialosi TJ, Riolo ML, et al. American Board of Orthodontics objective grading system for dental casts and panoramic radiographs. Am J Orthod and Dentofacial Orthop 1998; 114:589-99.
4. Vaden JL, Kokich VG. American Board of Orthodontics: past, present, and future. Am J Orthod Dentofacial Orthop 2000; 117: 530-2.
5. Santoro M, Galkin S, Teredesai M, Nicolay O, Cangialosi T. Comparison of measurements made on digital and plaster models. Am J Orthod and Dentofacial Orthop 2003; 124:101-5.
6. Zilberman O, Huggare J, Parikakis K. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. Angle Orthod 2003; 73:301-6.
7. Tomassetti JJ, Taloumis LJ, Denny JM, Fischer JR. A comparison of 3 computerized Bolton tooth-size analyses with a commonly used method. Angle Orthod 2001; 71:351–357.
8. Quimby M, Vig K, Rashid R, Firestone A, Mayers M. The accuracy and reliability of measurements made on computer-based digital models. Angle Orthod 2004; 74:298–303.

9. Costalos PA, Sarraf K, Cangialosi TJ, Efstratiadis S. Evaluation of the accuracy of digital model analysis for the American Board of Orthodontics objective grading system for dental casts. Am J Orthod and Dentofacial Orthop 2005; 128:624–629.

10. Okunami TR, Kusnoto B, BeGole E, Evans CA, Sadowsky C, Fadavi S. Assessing the American Board of Orthodontics objective grading system: digital vs plaster dental casts. Am J Orthod and Dentofacial Orthop 2007; 131:51–56.

11. Hildebrand JC, Palomo JM, Palomo L, Sivik M, Hans M. Evaluation of a software program for applying the American Board of Orthodontics objective grading system to digital casts. Am J Orthod and Dentofacial Orthop 2008; 133:283–289.

12. Mandikos MN. Polyvinylsiloxane impression materials: An update on clinical use. Australian Dental J 1998;43:(6):428-34.

13. Hayashi K, et al. Assessment of the accuracy and reliabiligy of new 3-dimensional scanning devices. Am J Orthod Dentofacial Orthop 2013 Oct; 144(4):619-25.

14. Sousa MV, Vasconcelos EC, Janson G, Garib D, Pinzan A. Accuracy and reproducibility of 3-dimensional digital model measurements. Am J Orthod Dentofacial Orthop 2012 Aug; 142(2):269-73.

15. http://americanboardortho.com/portal/professionals/downloads/Grading%20System%20Casts-Radiographs.pdf

16. http://www.americanboardortho.com/media/1184/cast-radiograph-worksheet-for-print.pdf

17. http://www.americanboardortho.com/media/1213/cast-radiograph-reference.pdf