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Predicted vs. Attained Surgical Correction in an Orthognathic Surgery

Patient Population Using CBCT

Brandon Cummins

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Predicted vs. Attained Surgical Correction in an Orthognathic Surgery Patient Population Using CBCT

A THESIS

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By

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San Antonio, TX

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Predicted vs. Attained Surgical Correction in an Orthognathic Surgery Patient Population Using CBCT

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DEDICATION

This thesis is dedicated to my family. My wife Margaret has been a true blessing to my life. Her support during the residency has been wonderful, and I am so grateful to have her by my side as my best friend. I could not have done this without her. My parents and sister have been so supportive throughout my entire life, and I couldn't have asked for a better family.

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ABSTRACT

Purpose: To validate the effectiveness of Mimics software, using Cone Beam Computed Tomography (CBCT), in predicting the soft tissue changes from orthognathic surgery. **Methods**: CBCT's for 10 patients were superimposed, pre- and post- Bilateral Sagittal Split Osteotomy (BSSO) advancement, to measure the exact surgical skeletal moves, which were modified within Mimics® to create 3-D pre-surgical soft tissue predictions. Corresponding soft tissue landmarks were identified on the pre-surgical and the final soft tissue matrices, and discrepancies between corresponding points were measured using Geomagic®. A panel of orthodontists subjectively assessed the overall accuracy of the predictions, in addition to the landmarks using a visual analog scale. **Results**: 68% of predicted soft tissue landmarks fell within 2 mm of discrepancy between the predicted soft tissue position and the actual soft tissue result. In decreasing order of accuracy were the upper lip, lower lip, corners of the mouth, soft tissue B-point, and soft tissue Pogonion. In addition, the panel deemed the actual final results more esthetic than the pre-surgical predictions. **Conclusion**: Pre-surgical predictions by Mimics software are reliable. Except for the chin, all other soft tissue landmarks under review exhibited a mean discrepancy within 2mm between the predicted and actual position. The panel's assessments did not correlate closely with the measured findings, indicating the minor discrepancies were not clinically significant. Soft tissue morphology may play a greater role than soft tissue bodily position in perceived accuracy.

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I. BACKGROUND

A. Introduction

The first theories related to orthognathic surgery arose during the late 1800's to early 1900's. Bolstered by advanced techniques developed in treating facial trauma suffered in World Wars I and II, the early pioneers of modern orthognathic surgery spawned an era of rapid development in their field beginning in the early 1950's. The first orthognathic surgeries were restricted to the mandible. In 1954, the Americans Caldwell and Letterman first developed the vertical ramus osteotomy, which initiated an era of development in Europe. The Bilateral Sagittal Split Ramus Osteotomy (BSSO) was introduced at the "Vienna School" of maxillofacial surgery by Trauner and Obwegeser in 1957. The ability to correct mandibular deformities in three planes of space without a bone graft was revolutionary (Sarver, 1998).

Surgical procedures to address the maxilla soon followed, as Obwegeser started performing a large series of what would later be described as LeFort I osteotomies in the 1960's. Surgeons now had the ability to manipulate both jaws in all three planes of space, and Obwegeser galvanized his role as the father of modern orthognathic surgery by performing the first total two-jaw surgery in 1970. Over 40 years of refinements and innovations have ensued, all with the goal of being able to deliver a predictable result that is safe, functional, and esthetic for the patient. The focus of this paper will be to provide a brief synopsis of those very methods of predicting success, which is best summarized by Jacobson – "Our ability to predict the outcome of an orthognathic procedure relies on the surgeon's ability to accurately reproduce the desired skeletal movements and on our understanding of the soft tissue changes associated with those movements" (Jacobson, 2002).

It is almost impossible to convey to a patient the facial appearance changes that can be expected to occur as a result of orthognathic surgery without the use of visual aids. The first attempts to provide patients an accurate prediction of the soft tissue changes anticipated from orthognathic surgery were made by oral surgeons and orthodontists in the 1970's. Traditionally, this involved tracing the pertinent skeletal relationships on acetate paper, incorporating the planned orthodontic movements within the respective jaws, and then rearranging the jaws in accordance with the planned orthognathic moves to achieve an anticipated final skeletal result. From there, an arbitrary drawing of anticipated soft tissue changes could be incorporated on the same acetate paper based on the hard tissue movements, which could be presented to the patient.

Early researchers attempted to quantify the soft tissue changes that could be expected as a result of specific hard tissue movements during various orthognathic surgeries to provide a more accurate surgical prediction. In 1991, Ewing et al. published an article stating soft tissue changes during a mandibular advancement regarding B-point and Pogonion followed a 1:1 soft to hard tissue ratio in vertical and anteroposterior directions. However, the authors concluded these guidelines were quite inaccurate, as the range of movement at B-point and Pogonion was +/- 2.6mm. The soft tissue changes regarding the lower lip were even more problematic, showing a range of +/- 4mm. Another compilation of soft tissue to hard tissue ratios was provided by Jensen et al. to describe what occurs during a simultaneous maxillary impaction and mandibular advancement. The authors observed a slight elevation of the tip of the nose, along with a 1:1 of soft to hard tissue movement of the chin. Other findings included a lower lip change of 70% of lower incisor movement, a 1-2mm shortening of the upper lip, and an upper lip change of 80% of upper incisor movement. Again, the ranges in observed soft tissue changes varied considerably (Hu et al. 1992).

Much of the information modern practitioners utilize concerning the soft tissue changes from various increments of hard tissue movements during orthognathic surgery is provided by Dr. William Proffit. For example, he purports that during maxillary superior repositioning, the upper lip shortens 1 to 2 mm, whereas the lower lip rotates 1:1 with mandible. Similarly, during maxillary advancement, slight elevation of the tip of the nose can be expected, while the base of the upper lip advances 20% of the advancement of A-point, and the upper lip advances 60% of incisor protraction and shortens 1 to 2 mm. Similar expected changes are described in cases of mandibular advancement, mandibular setback alone, mandibular setback plus maxillary advancement, and mandibular inferior border repositioning. Critical to understanding these figures is Dr. Proffit's own admission that "soft tissue adjustments can be misleading if the clinician forgets that these are based on a series of highly arbitrary judgments" (Proffit 2003).

Failing to take into account other variables in predicting a patient's soft tissue response to orthognathic surgery may contribute to inaccuracies in pre-surgical predictions. Researchers have investigated the contribution of such factors as race, gender, and initial soft tissue thickness in calculating the soft to hard tissue ratios that one may expect as a result of orthognathic surgery. Hu et al. found that females demonstrated a statistically significant difference in soft to hard tissue response as a result of orthognathic surgery than their male counterparts among a Chinese sample. The females showed an 11% higher ratio for the lower lip and a 12% greater ratio for the soft tissue chin in a sample of patients who underwent a mandibular setback surgery (1999). Similarly, soft tissue changes after skeletal repositioning were significantly higher in females than in males. In fact, the observed change was 20% greater in females for the upper lip in the same sample (Mobarak 2001).

Ethnic differences in soft tissue to hard tissue movement ratios have been found in the literature, which could also account for inaccuracy in predicting the soft tissue response following orthognathic surgery. Clemente-Panichella et al. calculated soft to hard tissue ratios among a Hispanic population who underwent orthognathic surgery. His findings showed that these ratios varied considerably from Caucasian populations. For example, larger soft tissue ratios at Subnasale were evident in the Hispanic population in vertical and horizontal movements of the maxilla, though significantly smaller movement ratios for the lower lip were found among Hispanics during horizontal movement of the mandible (Clemente-Panichella et al. 2000).

Finally, initial soft tissue thickness has been found to be another variable that contributes to soft tissue response to hard tissue movements from orthognathic surgery. Mobarak et al. noted that increased initial soft tissue thickness of the lips corresponded with soft tissue changes of greater magnitude following mandibular setback. Similarly, increased preoperative depth of the mentolabial fold corresponded with a greater net change in depth following orthognathic surgery (2001). Additionally, Lew reported that lip morphology and posture could alter the lip response following surgery by labiomental interferences (1992).

B. Digital Advancements

With the rise of computer technology, providers soon abandoned paper and pencil in favor of computers, with the ability to digitize the cephalometric tracings and enter the data for a calculation of angles and measurements, greatly increasing the ease of measurement. Not only were these analyses available more quickly and easily, they soon proved to be as accurate as or more so than hand tracing and tedious measurement with rulers and protractors (Arridge et al. 1985). In addition, different types of analyses and minor adjustments could be made in a fraction of the time, which facilitated the ability to use more diagnostic tools in the form of multiple cephalometric analyses with the same digitized points in a fraction of the time. In addition, vast amounts of orthodontic data could be stored in the computer and incorporated instantaneously such as norms for age, ethnicity, and gender.

C. Early Two-Dimensional Predictions

Soon, a lateral image of the patient could be incorporated into the digital cephalometric tracing with software available to incorporate the hard and soft tissues to more easily create a Virtual Treatment Objective (VTO). With the hard and soft tissue relationships established, virtual treatment could be performed rapidly with available software programs to give the patient and provider a more realistic prediction of the anticipated outcome. Modifications could also be made quickly and easily. Critical for the success of these programs is the quality of the soft tissue algorithms available for profile prediction. In generating early surgical predictions, the creators of various software programs used soft tissue algorithms that moved the soft tissue a certain distance in direct proportion to the manipulated underlying skeletal changes at specific landmarks. Worth noting is that these soft tissue algorithms were likely written utilizing the same observed soft to hard tissue ratios discussed previously that were highly arbitrary and variable. Proffit states that these 2-D software programs had many “limitations,” since the quality of the surgical predictions were dependent on the same soft tissue algorithms (2003). The imaging for these predictions has always been handicapped, as the images were acquired in 2D, and rarely do patients perceive their appearance on profile. Also, orthodontists and surgeons have shifted their focus from the hard to the soft tissue, which has heightened the importance placed on the soft tissue prediction softwares.

The first programs available generally were received with mixed results, as difficulties were repeatedly encountered predicting the soft tissue profile of the lips, with the lower lip being especially problematic (Proffit 2003). In 1989, Hing conducted a study on 16 patients utilizing a program called Quick Ceph Image® and concluded that the soft tissue predictions did not accurately match the post-treatment results, as the program tended to overestimate horizontal landmark position and underestimate vertical changes (Hing 1989). Progress occurred in 1994, however, when a software program named COG 3.4® was developed that predicted soft tissue changes in 25 patients who had maxillary advancement osteotomies with some surprisingly good accuracy. However, predicting the final positions of the nose and upper lip were more problematic (Eales et al. 1994). The authors further called for more attention to studying initial size, morphology, and thickness of tissues in future software predictions.

A multitude of software programs followed that attempted to predict soft tissue changes based on hard tissue movements. Dentofacial Planner® was studied by Konstiantos et al., who looked at 21 white adult patients having a LeFort I osteotomy and concluded that the computer-generated soft tissue image differed from the postsurgical profile significantly in the horizontal and vertical dimensions for many soft tissue landmarks (Konstiantos 1994). Quick Ceph was studied again in 1997, as 40 Caucasian patients having a two-jaw surgery were included in a study; it was also found to have mixed results, with inaccuracy of the loaded algorithmic soft to hard tissue ratios of the program (Upton et al. 1997). In contrast, Quick Ceph was again evaluated two years later in a study involving 16 patients with more favorable results. The authors concluded that on average there were no significant differences from the predicted images and the post-treatment results regarding the soft tissue, as only N-ANS proved difficult to accurately predict (Mankad 1999).   A computer video imaging prediction using Dolphin Imaging® (Version 6) in 2003 also showed mixed results in a patient population of 30 adults undergoing bimaxillary orthognathic surgery. Dolphin did not accurately predict nasal tip, soft tissue A point, nor the upper and lower lip in the sagittal plane. The lower lip was the least accurate landmark. The program did fare much better at predicting landmarks in the vertical plane. In light of these results, the authors called for the need to “improve the accuracy and reliability of the prediction program and to include the consideration of changes in soft tissue tension and muscle strain” (Lu et al. 2003).

The next year, Koh investigated the ability of Computer-Assisted Simulation System for Orthognathic Surgery® (CASSOS) to predict changes to 35 Class III Chinese patients undergoing a LeFort I advancement and BSSO set-back. The upper and lower lip regions proved to be problematic, as the software tended to underestimate the vertical position of both the upper and lower lip and overestimate the horizontal position of the lower lip (Koh 2004).

Refinements were continually made to the computer software programs, though, and in 2011, Donatsky et al. investigated The Computerized, Cephalometric, Orthognatic Surgical Planning System, called TIOPS, with more favorable results, as the mean accuracy of the planned and predicted hard and soft tissue outcome was high, varying from only 0.0 mm to 0.5 mm. While problems persisted predicting the lower lip, the authors concluded TIOPS was accurate, even though individual variation was a significant factor in overall outcome (Donatsky et al. 2009).

In 2011, Ravindranath investigated the capabilities of two popular software programs, Dolphin Imaging® and Vistadent®, at prediction of soft tissue landmarks in mandibular advancement surgeries, as both programs appeared to be reliable and accurate. Once again, they both were weak at predicting lower lip position (Ravindranath et al. 2011).

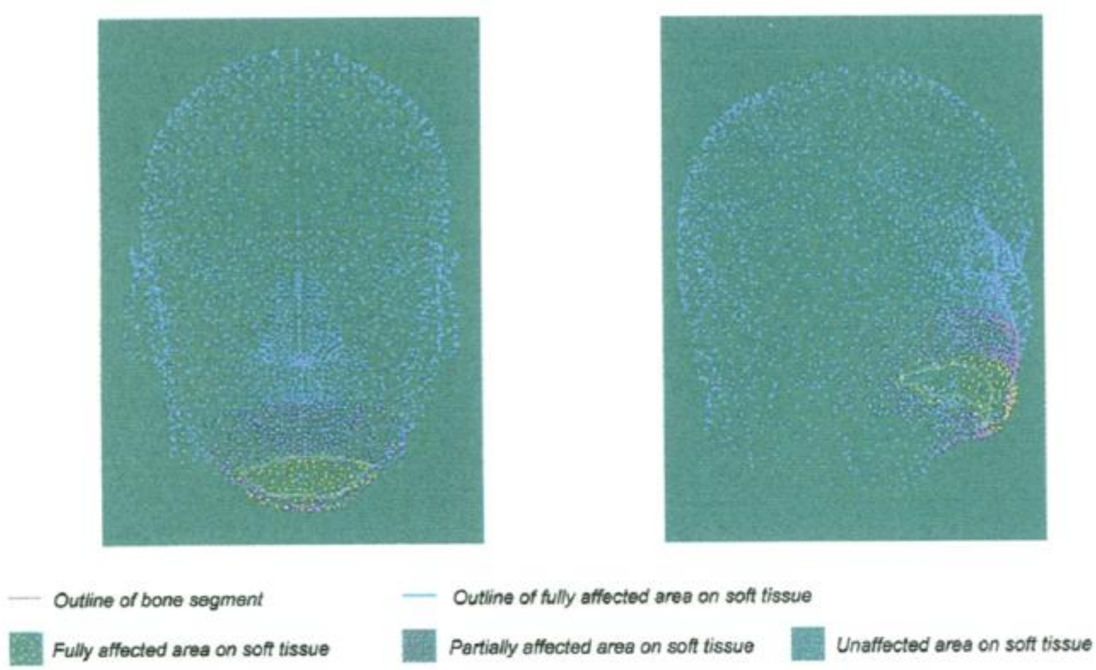
D. Three-Dimensional Predictions using (CBCT)

The newest advances in soft tissue predictions involved in orthognathic surgery planning and implementation involve three-dimensional radiographs and imaging software. CBCT has been revolutionary in providing the ability to construct three-dimensional images of the skull and soft tissues. No longer must clinicians interpret two-dimensional cephalometric tracings to plan complex surgical movements that involve all three planes of space.

In 2000, Xia et al. introduced a new technique for predicting three dimensional facial soft-tissue changes to aid orthognathic surgical planning. The prediction was based on a reconstructed CT visualization, which utilized two newly devised soft tissue algorithms – Surface Normal-based Model Deformation Algorithm and Ray Projection-based Model Deformation Algorithm. They were able to produce a three-dimensional color facial texture-mapping technique to generate a color photo-realistic facial model.

This new technology would soon reach the vernacular of surgeons and orthodontists and be simply referred to as "color mapping."

Figure 1: Three-dimensional soft tissue deformation after virtual genioplasty developed by Xia et al., using a surface normal-based model deformation.



This capability to view soft tissue changes in three dimensions rather than simply a profile photograph marked an important development (Xia et al. 2000).

In 2004, Soncul evaluated the soft tissue changes in a patient population of Class III patients who had undergone orthognathic surgery. He used an optical surface scanner as a three-dimensional imaging tool with thin-plate splines to create a soft-tissue construction with CogSof® digitizing software pre-operatively and at six months post-operatively. His findings suggest the soft tissues did not move solely on a horizontal plane but also exhibited vertical vectors, concluding that the final soft tissue positions were "difficult to predict" (Soncul 2004). Providing an improvement over previous soft tissue prediction software, Ulusoy introduced a technique he called the dynamic volume spline method. Rather than relying on soft tissue algorithms that provided mean soft to hard tissue ratios in the various skeletal movements, the dynamic volume spline incorporates tissue characteristics into the algorithm in three planes of space. Elastic behavior of the actual tissue is incorporated, creating a model that is "a hybrid of spring-mass and finite element," combining their advantageous qualities (2010). Post-surgical estimations were compared with a conventional prediction of the final result using photographs and cephalometric radiographs, and Ulusoy concluded post–surgical predictions were better with the three-dimensional volume spline method than by the conventional method (Ulusoy et al. 2010).

Further refinements to soft tissue prediction after orthognathic surgery have come in the way of CBCT. In 2009, Morenhout used Maxilim 3D® software to measure soft tissue changes on a mannequin using CBCT and compared its effectiveness with an optical surface scan of the head using Focus Inspection® software. The researchers verified that the 3D surface accuracy of CBCT scans segmented with Maxilim and Mimics software is high. In 2011, Simanca used 3dMD Vultus® software (3dMD, Inc, Atlanta, GA) to evaluate soft tissue changes with CBCT after soft tissue molding in cleft lip and palate patients and determined the three dimensional software to be highly valuable.

Using CBCT in 2010, Bianchi investigated the accuracy of SurgiCase CMF® software in predicting the final soft tissue profile of an orthognathic surgery population. Ten patients undergoing orthognathic surgery had pre-operative and post-operative CBCT's taken to determine the final skeletal and soft tissue changes as a result of treatment. The post-operative CBCT was taken 6 +/- 2 months after the surgery to allow swelling to subside. Using SurgiCase CMF® software, the planned surgical movements were incorporated into the pre-operative CBCT to produce a final hard and soft tissue surgical prediction. This was then compared to the post-surgical soft tissue profile and was determined to be extremely accurate (Bianchi et al. 2010).

E. Pioneering Features of this Study

While the Bianchi study provided critical information concerning the accuracy of soft tissue predictions, an assumption was made that the surgeons' planned surgical movements were completely accurate. Instead of relying on the planned movements to make a surgical prediction, this study intends to precisely measure the actual skeletal hard tissue movements that occurred by measuring the difference between the pre-surgical and post-surgical CBCT. The intent was to remove any ambiguities in the surgical hard tissue movements as an unknown variable into producing a soft tissue prediction. The known hard tissue skeletal moves were incorporated into the development of the soft tissue prediction, according to the soft tissue algorithm used by Mimics®. The differences between the soft tissue surgical prediction and the soft tissue final result for each patient were accurately measured. This was performed by selecting specific soft tissue landmarks in the pre-surgical prediction and the final result, and these differences were precisely measured. The present study sought to evaluate Mimics® to investigate its accuracy in predicting soft tissue profiles by comparing the three-dimensional surgical predictions with the post-surgical result by quantifying the differences between the two.

The implications of the technique may provide software makers an additional method to develop their soft tissue predictive algorithms.

Finally, a panel of orthodontists was polled to judge the accuracy of the same soft tissue predictions by viewing side-by-side comparisons of the predictions with the final results. The panel provided an overall subjective assessment, in addition to an assessment of specific regions to determine if the experts are able to adeptly appreciate the differences. The findings may help discern the threshold for which measured discrepancies become clinically significant.

II. OBJECTIVES

The purpose of this pilot study was to investigate the three-dimensional accuracy using CBCT of Mimics software in predicting the soft tissue outcome of a BSSO mandibular advancement population. In addition, this study sought to determine the ability of a panel of experts to correctly identify areas of discrepancy between the soft tissue predictions and the final results.

III. HYPOTHESIS

Hypotheses: There will be a significant difference between the soft tissue surgical predictions using Mimics software and the actual measured soft tissue outcomes; similarly, orthodontists will be able to perceive differences between the surgical predictions and the actual final results.

Null Hypotheses: There will be no difference between the soft tissue surgical predictions using Mimics software and the actual measured soft tissue outcomes; similarly, orthodontists will not be able to perceive differences between the surgical predictions and the final results.

IV. MATERIALS AND METHODS

A. Patient Selection

This retrospective study included 10 patients who had undergone orthognathic surgery limited to the mandible in conjunction with pre- and post-surgical orthodontics, at Joint Base San Antonio – Lackland, TX from January 1, 2007 to December 31, 2012. All subjects had a pre-surgical CBCT acquired using iCAT Platinum (Imaging Sciences International, Hatfield, PA). The CBCT images were taken within 2 months before and 6 +/- 5 months after surgery, at maximum intercuspation with lips in repose. The maxillofacial regions were scanned with a 17 x 23 cm field of view, 0.3 voxel size, tube voltage of 120 kVp, and the tube current of 37.1 mA, for a duration of 17.8 seconds (See Table I).

Table I. iCat CBCT unit: technical parameters and settings

Technical parameter	Value
Manufacturer	Imaging Sciences
X-ray source voltage	12 kVp
X-ray source current	5 mA
Focal spot size	0.5 mm
X-ray beam size	0.5 x 0.5 to 8 x 10”
Scanning time	17.8 seconds
Image acquisition	Single 360 degree rotation
Image detector	Amorphous silicon flat panel
Gray scale	12 bit
Field of view	17.0 cm (diameter) x 13.2 cm
Voxel size (mm)	0.3 mm
Primary reconstruction time	About 60 seconds
Secondary reconstruction time	Real time
Radiation exposure (mSV)	135-193 microSV
Patient positioning	Seated with flat occlusal plane

B. Segmentation

Using Mimics (a software to convert CT/MRI scans to medical models), the pre and post-surgical scans were segmented. Because the cranial base, orbital structures and hard palate did not change over the course of treatment, these structures were segmented and superimposed to determine mandibular movement during the BSSO procedure. Segmentation of the pre-surgical and post-surgical mandibles was performed, and virtual “cuts” in the osteotomy sites of the pre-surgical mandibles were performed. A virtual simulation of the surgery was performed on the pre-surgical model and each segment of bone which required repositioning was isolated as an individual object. The maxillary bone was preserved for the alignment procedure required to superimpose the post-surgical scan.

Figure 2: Segmentation of Pre-Surgical Scan

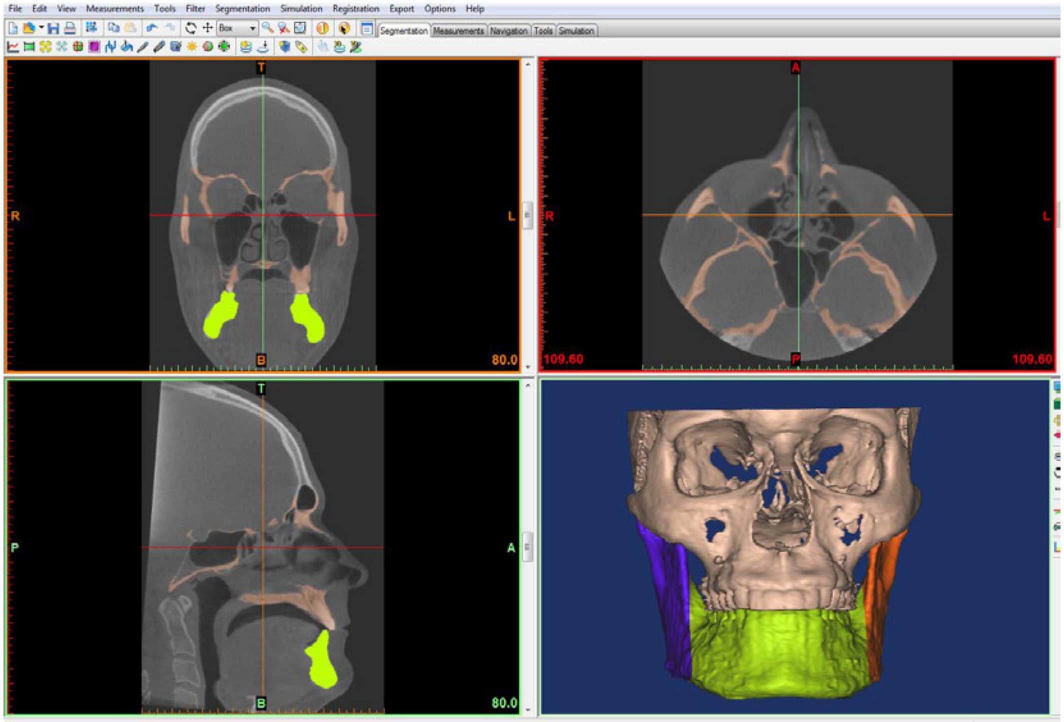
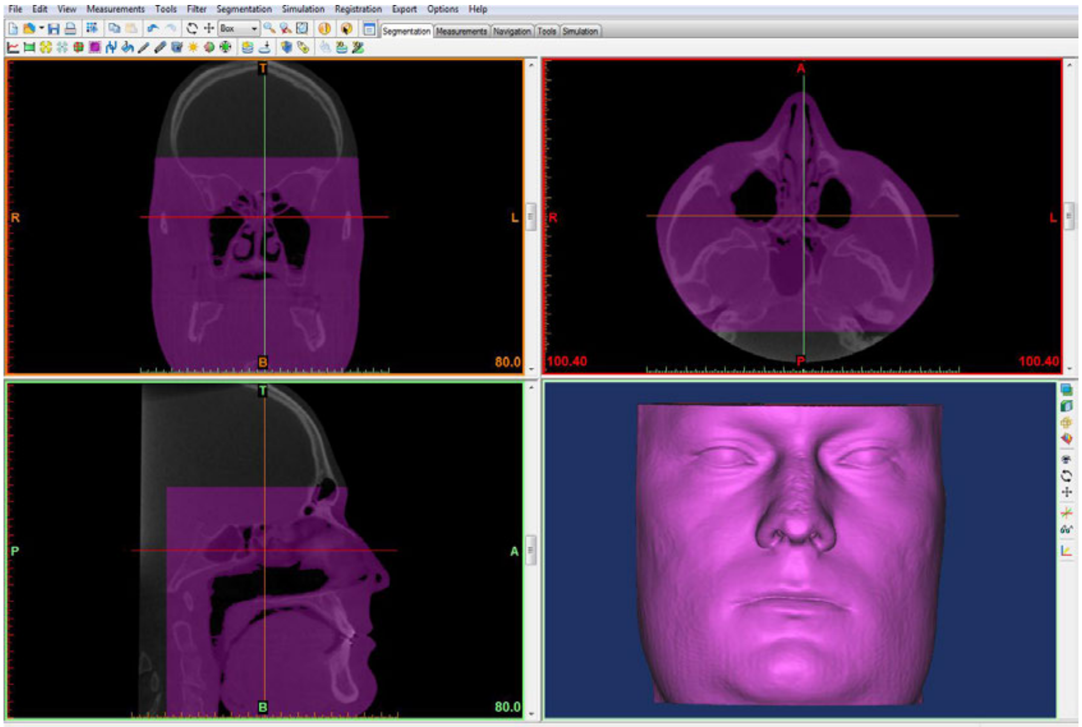


Figure 3: Segmentation of Soft Tissue in Post-Surgical Scan



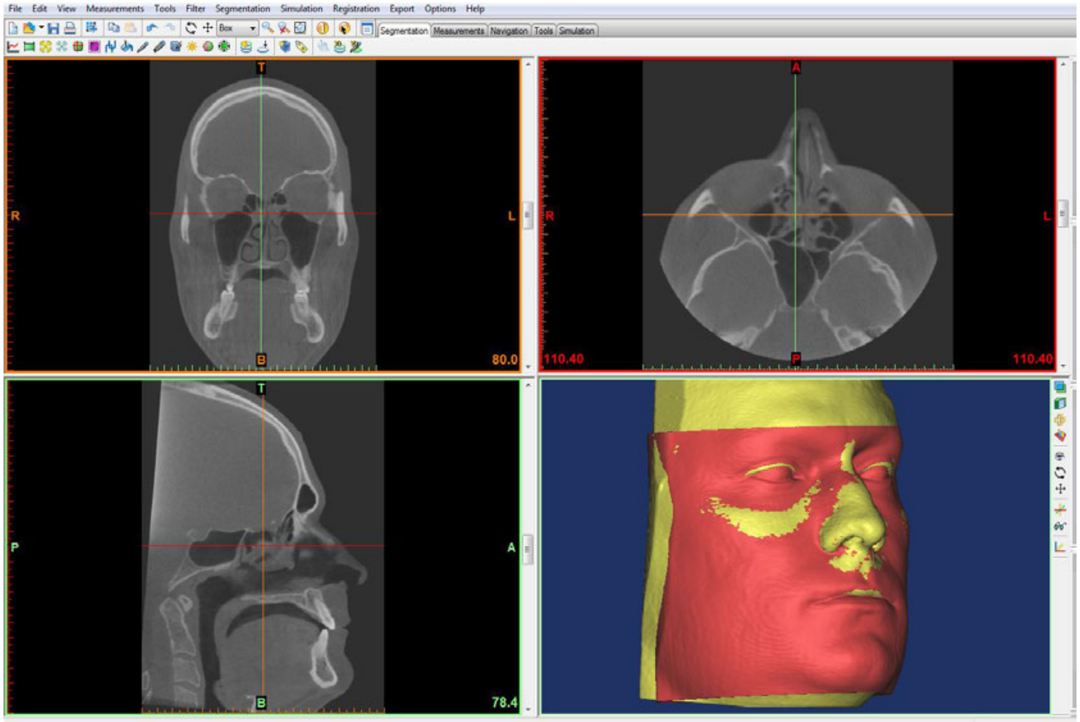
C. Superimposition and Surgical Simulation

After the virtual objects were created, the post-surgical objects were aligned to the location of the pre-surgical patient position. This was performed via a global registration algorithm available within the software. The researcher declared the pre-surgical model as a fixed object and repositioned the post-surgical (floating objects) model with the global registration function.

Once both of the scans shared the same coordinate space, the mandibular bone segments were repositioned to the outcome using the same function previously described. The magnitude and direction of the simulated movements were then guided by the registered postsurgical model. Movements for each surgical piece were performed allowing 6 degrees of freedom (anterior–posterior, lateral, superior–inferior, yaw, pitch, and roll).

Those movements were accurately discerned as values in the Mimics software virtual simulation tool to produce a final surgical soft tissue simulation.

Figure 4: Repositioning Pre-Surgical Mandible



The anterior segment of the pre-surgical mandible was repositioned to superimpose with the final position of the mandible. The pre-surgical soft tissue prediction accompanied the new mandibular position

D. Quantitative Evaluation

The validation of the predictive capacity of Mimics was evaluated quantitatively by comparing the soft tissue surfaces of the surgical prediction and the final result for each patient and measuring the difference in position of six points:

1.)Stomion Superius

2.)Stomion Inferius

3.)Left Chelion

4.)Right Chelion

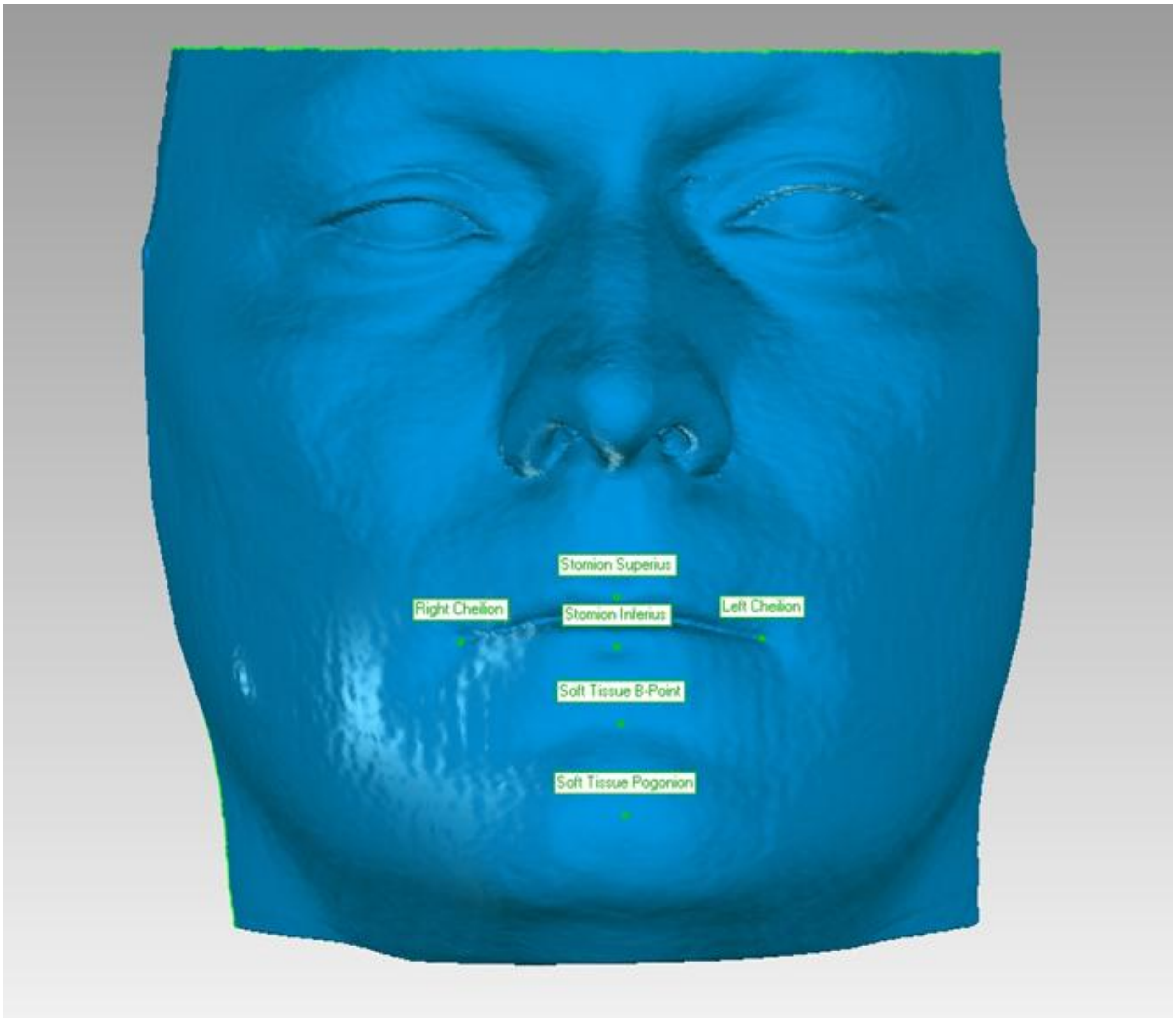
5.)Soft Tissue B-point

6.)Soft Tissue Pogonion.

Table 2. Description of landmarks

Landmark	Description
Stomion Superius	Most anterior point on the midline along the vermillion border of the upper lip
Stomion Inferius	Most anterior point on the midline along the vermillion border of the lower lip
Right Chelion	Point of the right commissure, or where the vermillion border of the superior labium (upper lip) meets that of the inferior labium (lower lip) on the right side of the mouth
Left Chelion	Point of the left commissure, or where the vermillion border of the superior labium (upper lip) meets that of the inferior labium (lower lip) on the left side of the mouth
Soft Tissue B-point	Most concave point between the lower lip and the soft tissue chin
Soft Tissue Pogonion	Most anterior point on the anterior curve of the soft tissue chin

Figure 5: Identification of Landmarks



The Primary Investigator (PI) selected these points for each patient, and Geomagic was used to calculate the anteroposterior (A-P) distance of those points. A coordinate system was defined for each patient where:

- Origin = Soft Tissue Pogonion
- X-axis: Right Cheilion -> Left Cheilion
- Y-axis: Soft Tisue Pogonion -> Stomion Superius
- Z-axis: Normal direction outward (away from face)

Figure 6: Coordinate Axes

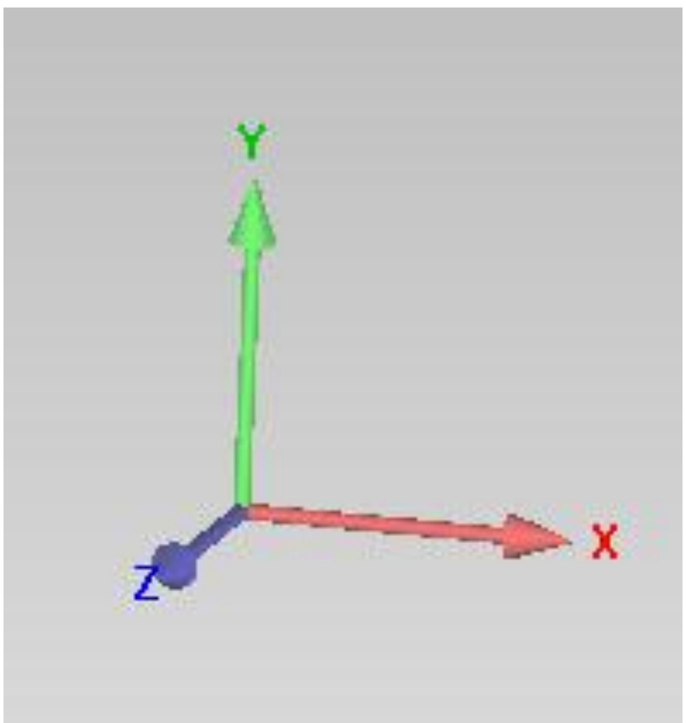
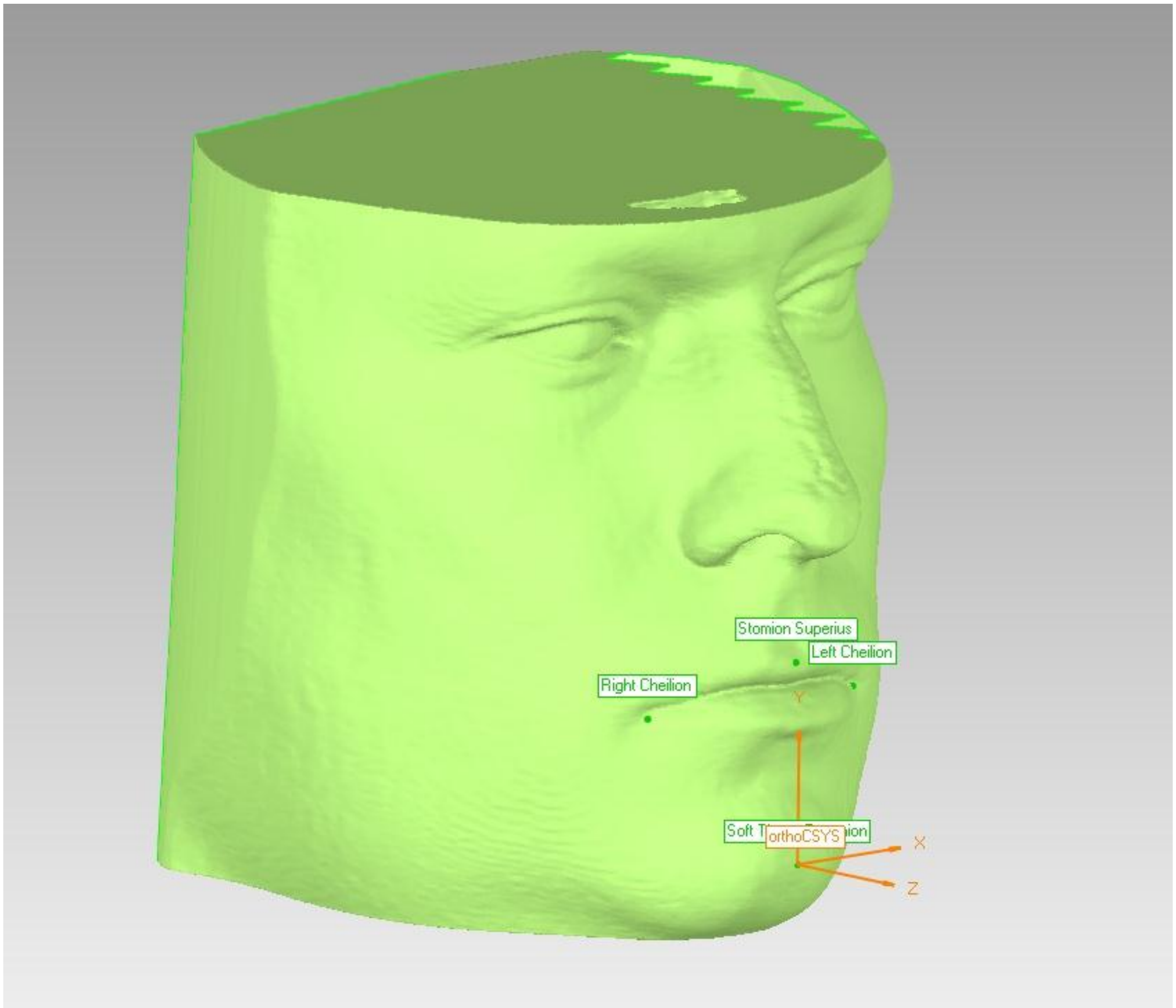
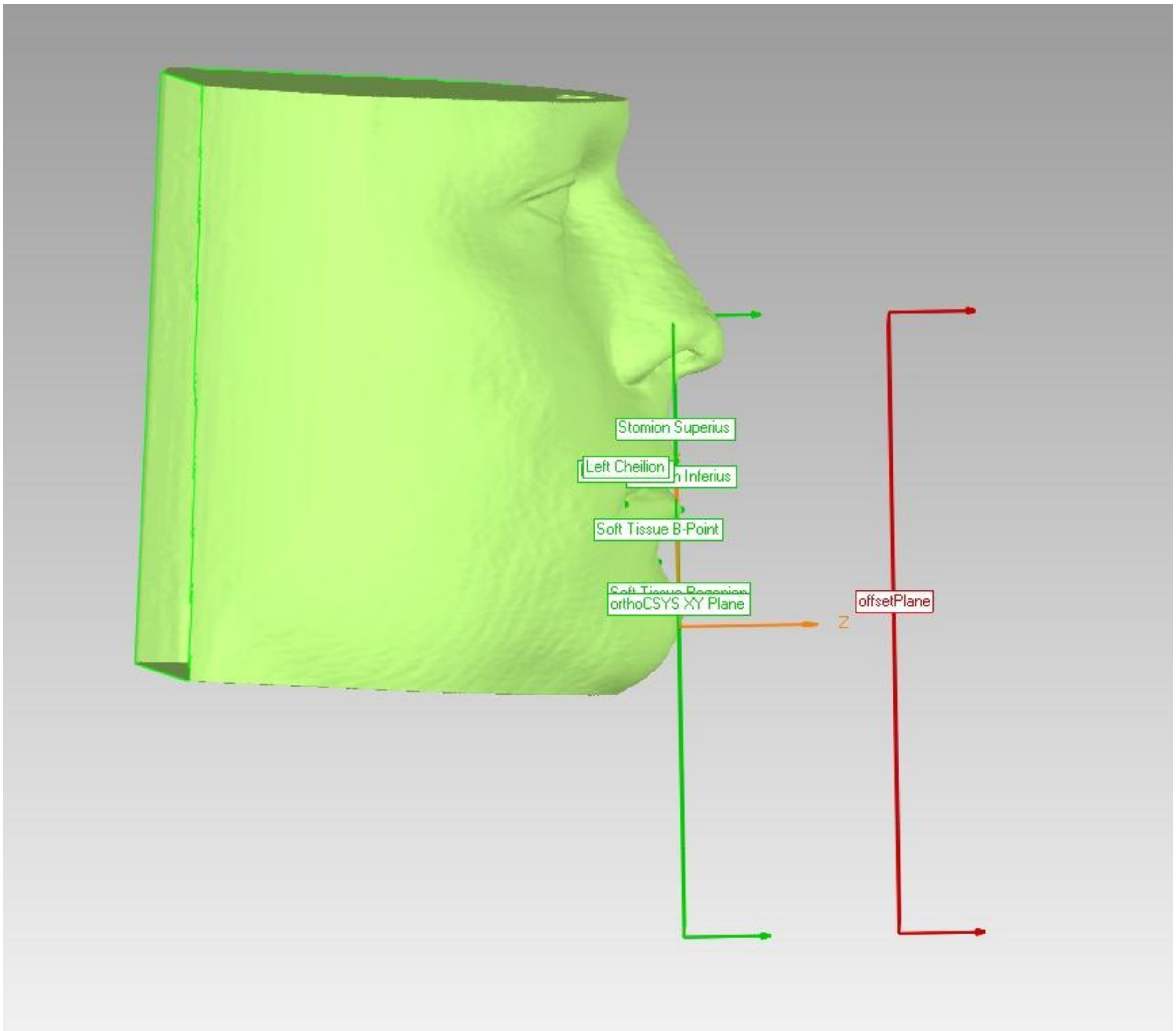


Figure 7: Landmarks along Coordinate Axes



The XY plane was then duplicated and projected outward away from the face along the Z-axis

Figure 8: Reference Plane



This procedure was necessary to prevent the possibility of negative values skewing the results for the given landmarks.

The defined points were projected to the offset plane for both of the models.

Figure 9: Landmarks in Relation to Reference Plane

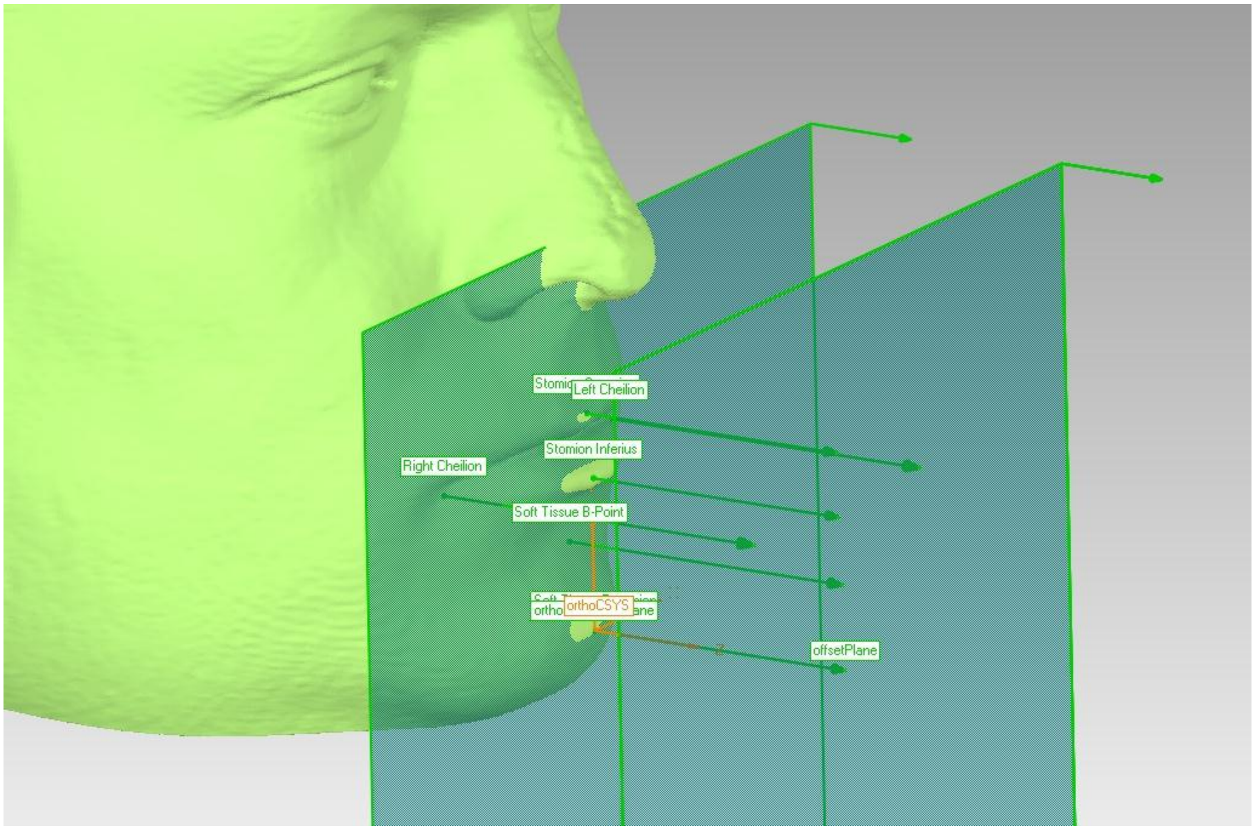
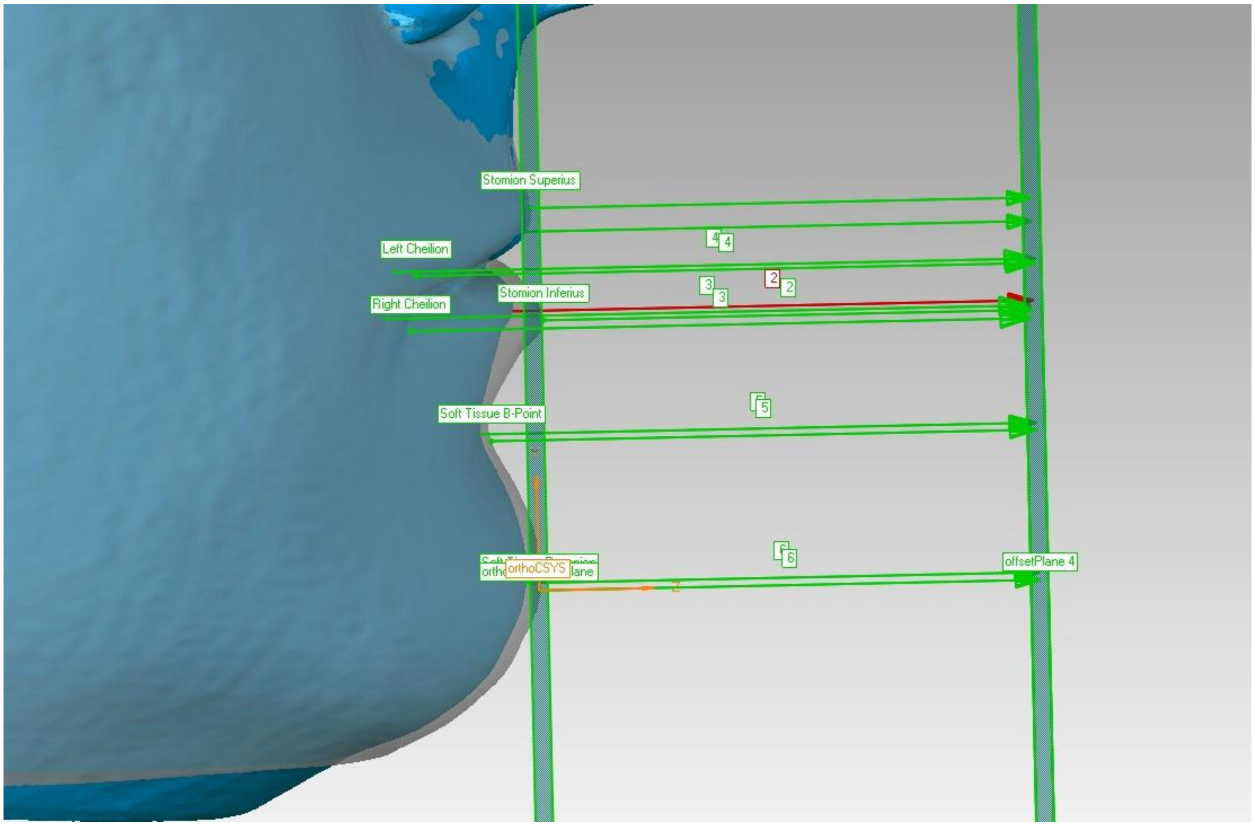


Figure 10: Calculating Discrepancies between Landmarks



The point distance was calculated using the following distance formula:

Figure 11: Calculation Formula

$$\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

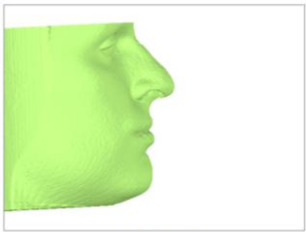
To attain the quantitative result value the absolute value of the difference of the compared landmarks was recorded.

E. Qualitative Evaluation

A panel of orthodontists was asked to qualitatively assess the accuracy of the pre-surgical three dimensional predictions generated by Mimics. This was performed by providing a PowerPoint® presentation that contained side-by-side comparisons of 3-D soft tissue surface representations of the post-surgical final result and the pre-surgical prediction. Each representation was generated by utilizing the coordinate system assigned to each patient. The screen captures were taken at 22.5 degree intervals rotating about the y-axis.

For the purposes of comparison, a series of nine screen shots was constructed for each patient, in the final result and the pre-surgical prediction. Starting with the patient in right profile view, screen shots rotating the patient every 22.5 degrees were progressively shown until the left profile view was evident. A sample viewing for a particular patient is demonstrated in Figure 12:

Figure 12: Sample Viewing of Comparison Between Final Result and Prediction

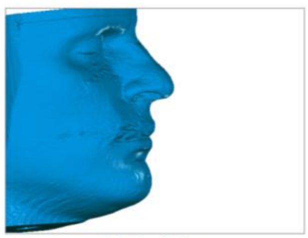


#7 – Actual result

#7 - Prediction

0 degrees

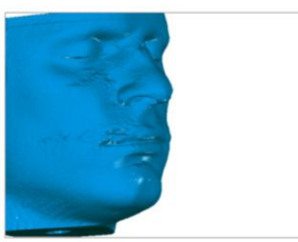
#7 – Actual result



#7 - Prediction

22.5 degrees

#7 – Actual result



#7 - Prediction

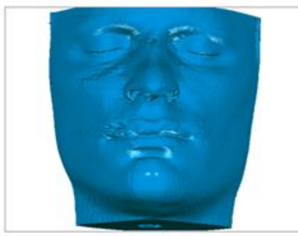
45 degrees

#7 – Actual result

#7 - Prediction

67.5 degrees

#7 – Actual result



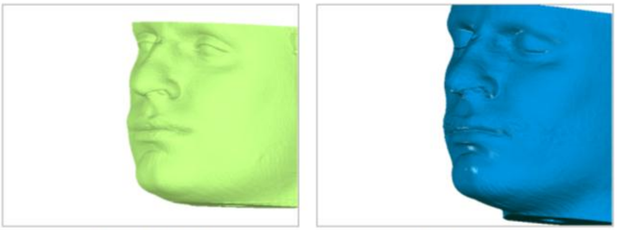
#7 - Prediction

90 degrees

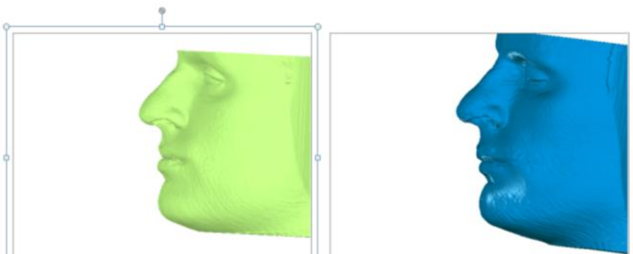
#7 – Actual result

#7 - Prediction

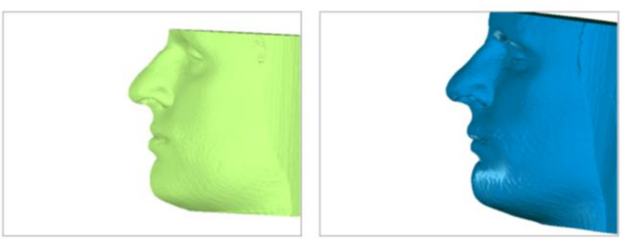
112.5 degrees



#7 – Actual result #7 - Prediction 135 degrees



#7 – Actual result #7 - Prediction 157.5 degrees



#7 – Actual result #7 - Prediction 180 degrees

Each panelist viewed the presentation individually, projected on a SMARTboard™ (SMART Technologies, Calgary, Canada) 800ixe-SMP with a UX60 projector in a dimly lit room. The lighting was turned off before the presentation began, as the only lighting in the room was provided by the projector screen and an illuminated radiograph view box, allowing the panelist to record his assessments. The PI read the statements from a prepared statement (Appendix A) immediately prior to showing the presentation and asking each panelist to record his assessments.

Once the presentation began, each screen shot was available for 10 seconds of viewing before automatically transitioning to the next screen shot. However, each panelist was allowed to request additional time in a view(s) of preference. Additional time was restricted to one minute, and no panelist was allowed to view a previous patient once the presentation progressed to the next patient. Each panelist was prompted to make an overall assessment of the resemblance of the prediction to the final result, using a - Visual Analog Scale (VAS) from 0-10 (0-No resemblance, 5-Moderate resemblance, 10-Excellent Resemblance). After that, each panelist was asked to specifically assess the following regions using the same VAS – 1.)Upper Lip, 2.)Lower Lip, 3.)Corners of the mouth, 4.)Soft tissue B-point, and 5.)Soft tissue Pogonion. Answers were recorded for the overall assessment and each individual region by marking an “X” for each specific region of the face.

Each “X” was assigned a numerical value by superimposing a numerical template drawn to scale, assigning a value and calculating each score to the tenth of a point. Finally, each panelist was prompted to indicate which depiction for each patient was more esthetic – the final result or the surgical prediction.

VI. RESULTS

A. Quantitative Results

For each of the 10 patients included in the study, the distances between landmarks identified in the pre-surgical prediction and the corresponding landmarks identified in the final result were measured (Appendix B). The results concerning the discrepancies measured in millimeters between the pre-surgical predictions and the final results are summarized in the table below:

Table 3 Raw Data – Quantitative Measurements for Soft Tissue Landmark Discrepancies Between Predicted and Actual Outcome

Patient #	Stomion Superius	Stomion Inferius	Chelion R	Chelion L	Soft tissue B-Point	Soft tissue Pogonion
#1	1.53	2.45	4.94	1.65	1.86	1.86
#2	0.51	3.35	3.60	1.16	2.45	2.77
#3	2.62	1.24	1.39	0.14	1.92	5.34
#4	0.96	2.01	2.56	2.67	3.51	5.22
#5	1.77	0.36	0.06	3.12	2.32	1.40
#6	0.47	1.56	2.38	1.74	0.63	0.80
#7	1.53	1.43	1.91	0.68	1.70	1.11
#8	0.84	0.79	0.14	1.72	2.68	3.33
#9	0.60	3.01	2.74	2.39	1.04	1.45
#10	2.49	1.02	2.19	1.91	2.00	1.05

The mean measurements for the landmarks along with standard deviations are listed in the table below:

Table 4 – Mean Discrepancies Among Subjects Between Surgical Predictions and Final Results for Specific Landmarks

	Overall	Stomion Superius	Stomion Inferius	Chelion	Soft tissue B-point	Soft tissue Pogonion
MEAN	1.90	1.33	1.72	1.95	2.01	2.43
STD DEV	1.16	0.75	0.92	1.18	0.77	1.61

Based on the mean measurements for the individual soft tissue landmarks, the upper lip exhibited the lowest discrepancy at 1.33mm +/- 0.75mm, followed by the lower lip (1.72mm +/- 0.92mm), corners of the mouth (1.95mm +/- 1.18mm), soft tissue B-point (2.01mm +/- 0.77mm), and soft tissue Pogonion (2.43mm +/- 1.61mm).

Figure 13: Color map of discrepancy for patient #1

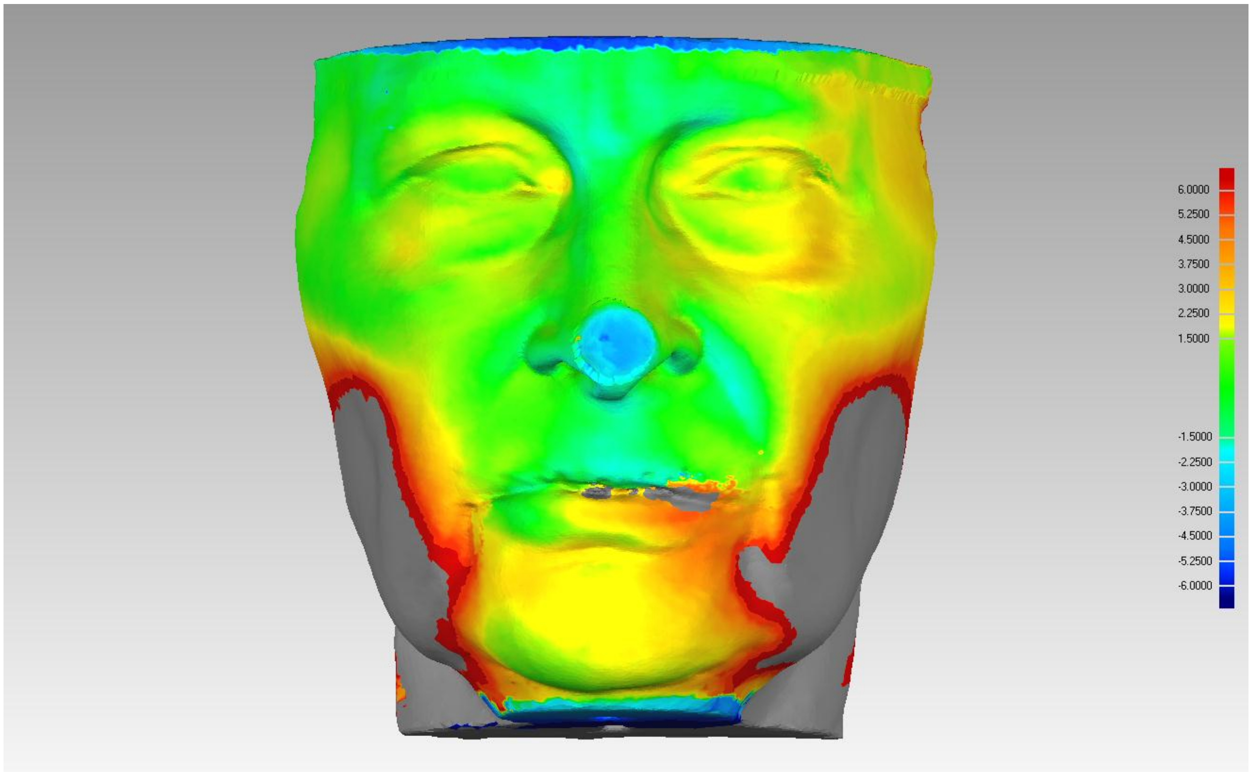


Figure 14: Color map of discrepancy for patient #2

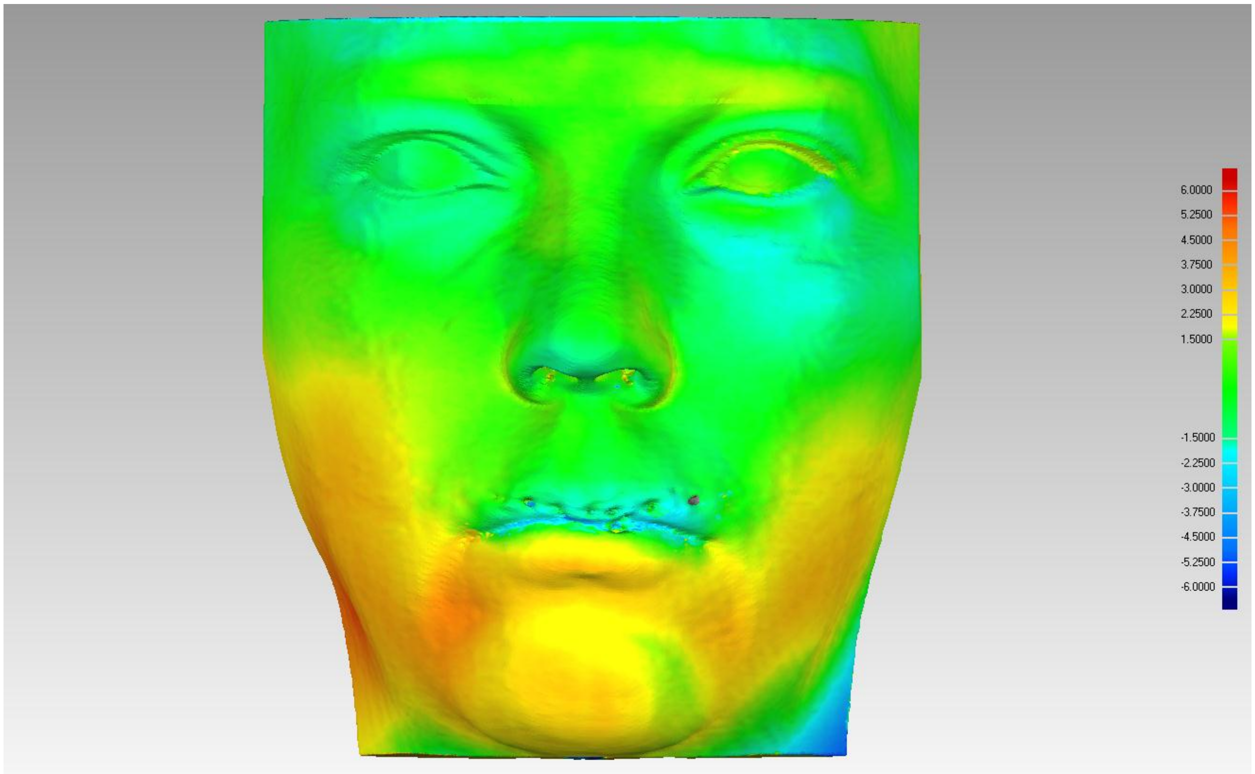


Figure 15: Color map of discrepancy for patient #3

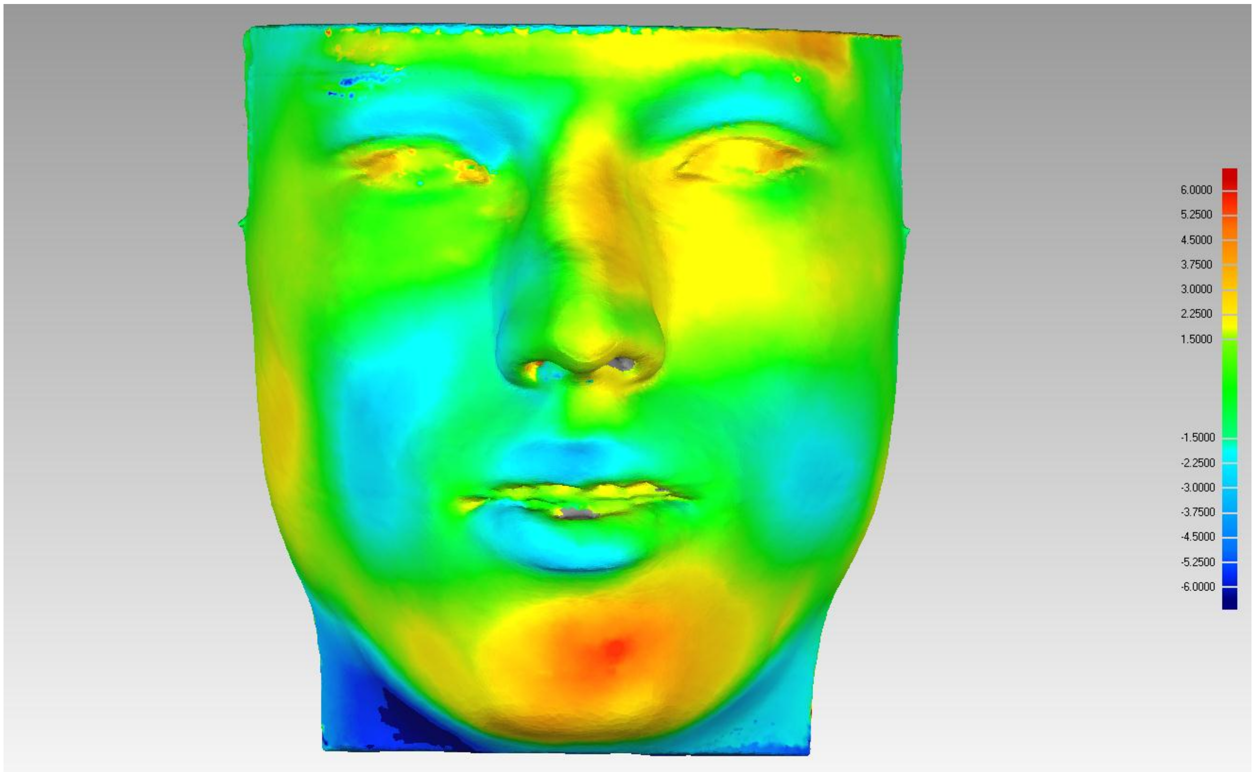


Figure 16: Color map of discrepancy for patient #4

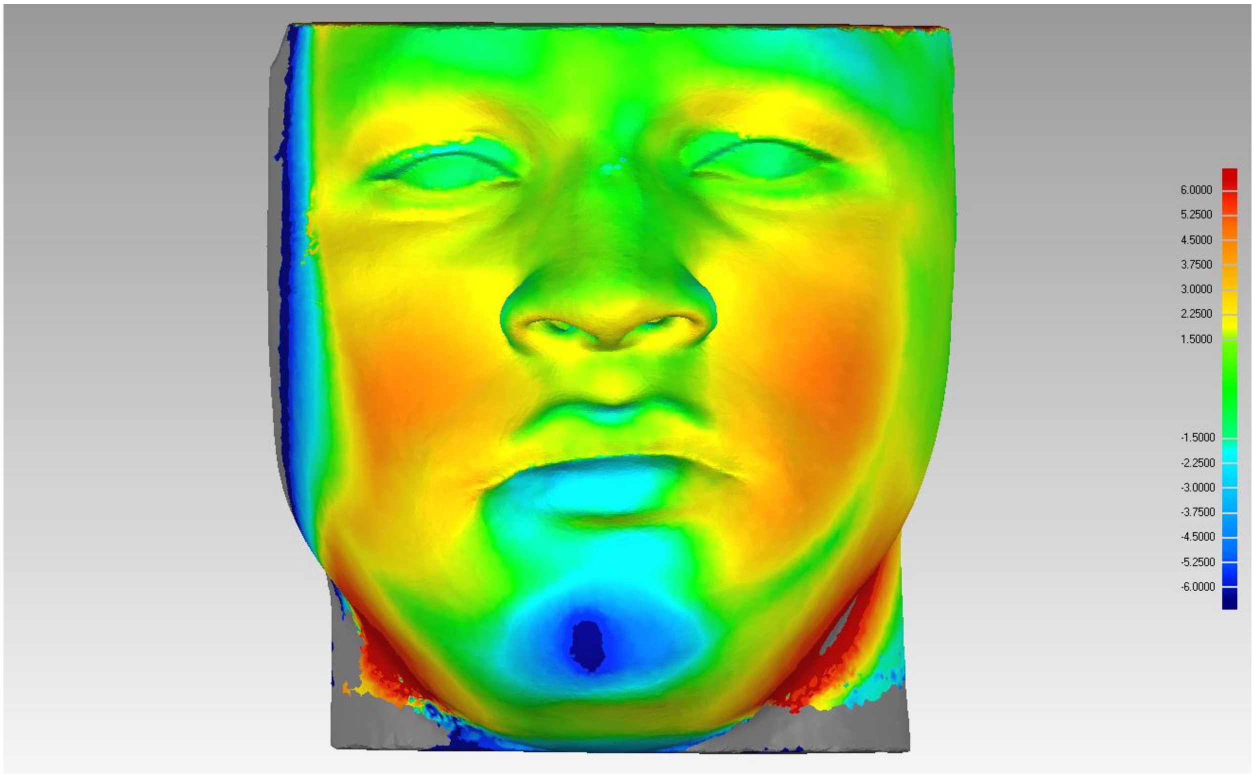


Figure 17: Color map of discrepancy for patient #5

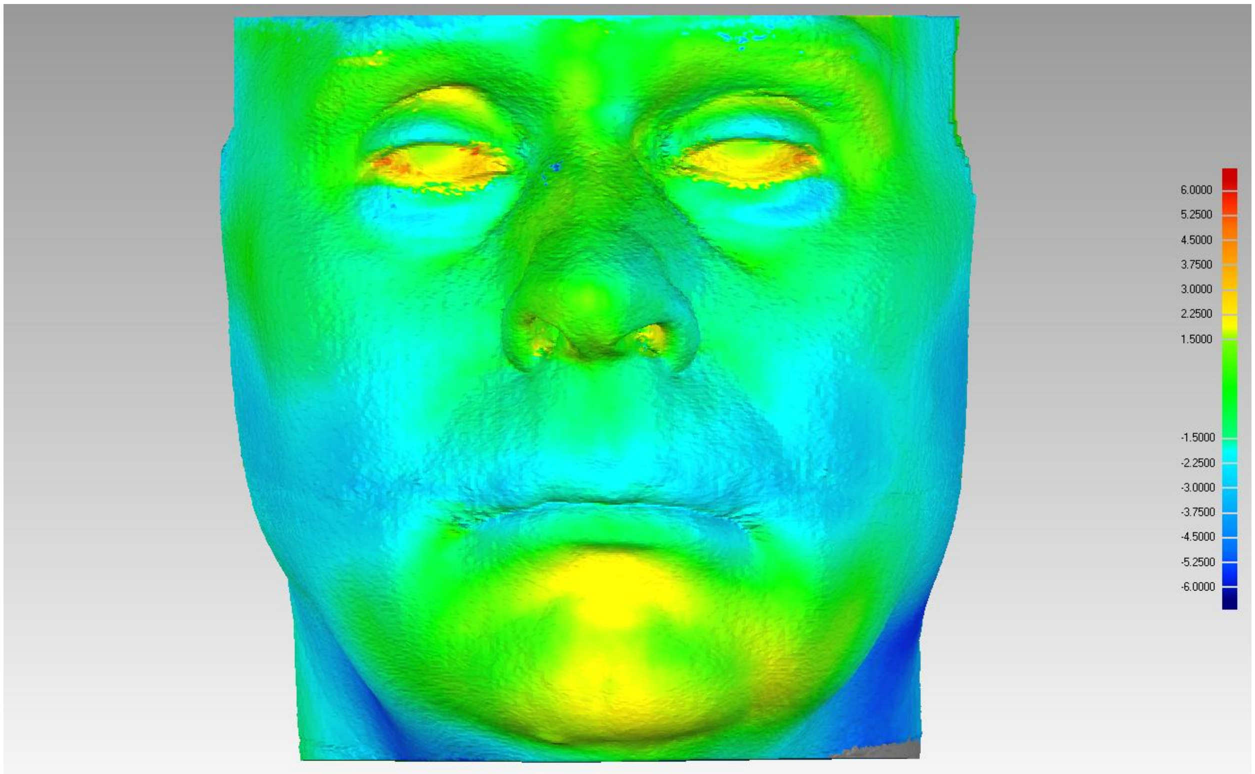


Figure 18: Color map of discrepancy for patient #6

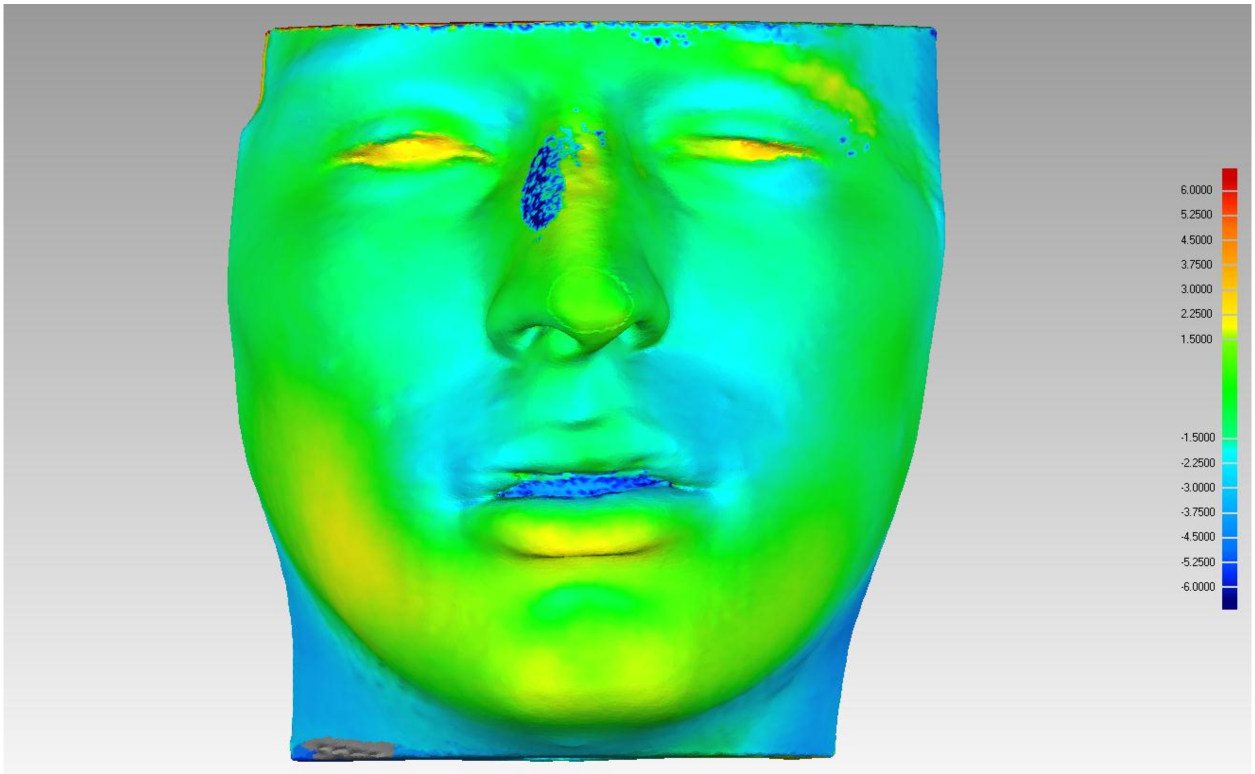


Figure 19: Color map of discrepancy for patient #7

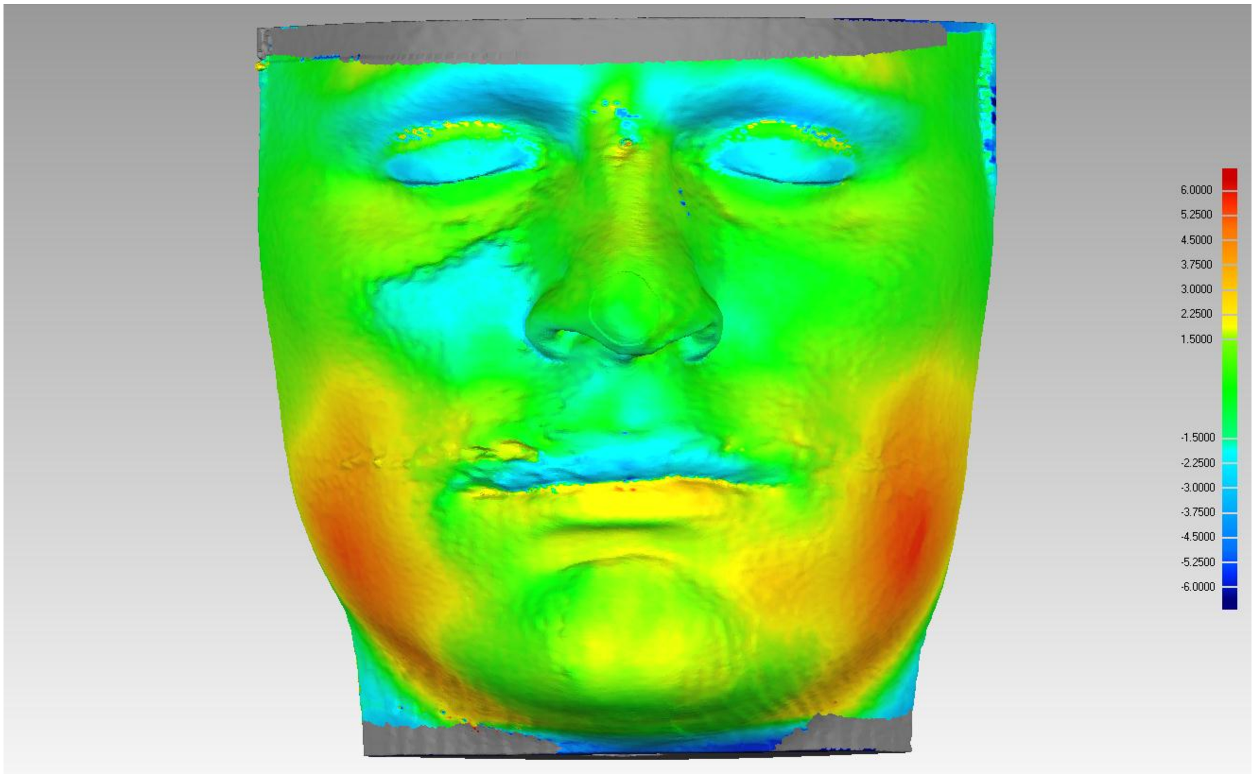


Figure 20: Color map of discrepancy for patient #8

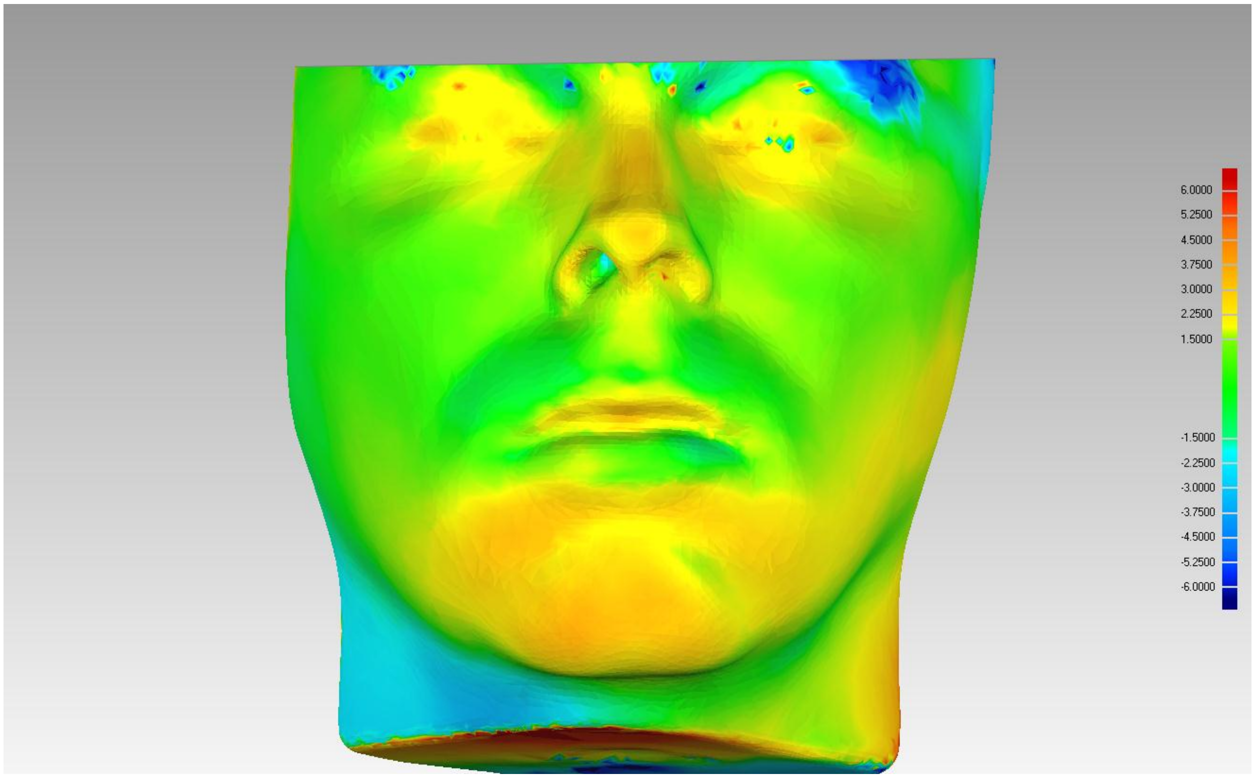


Figure 21: Color map of discrepancy for patient #9

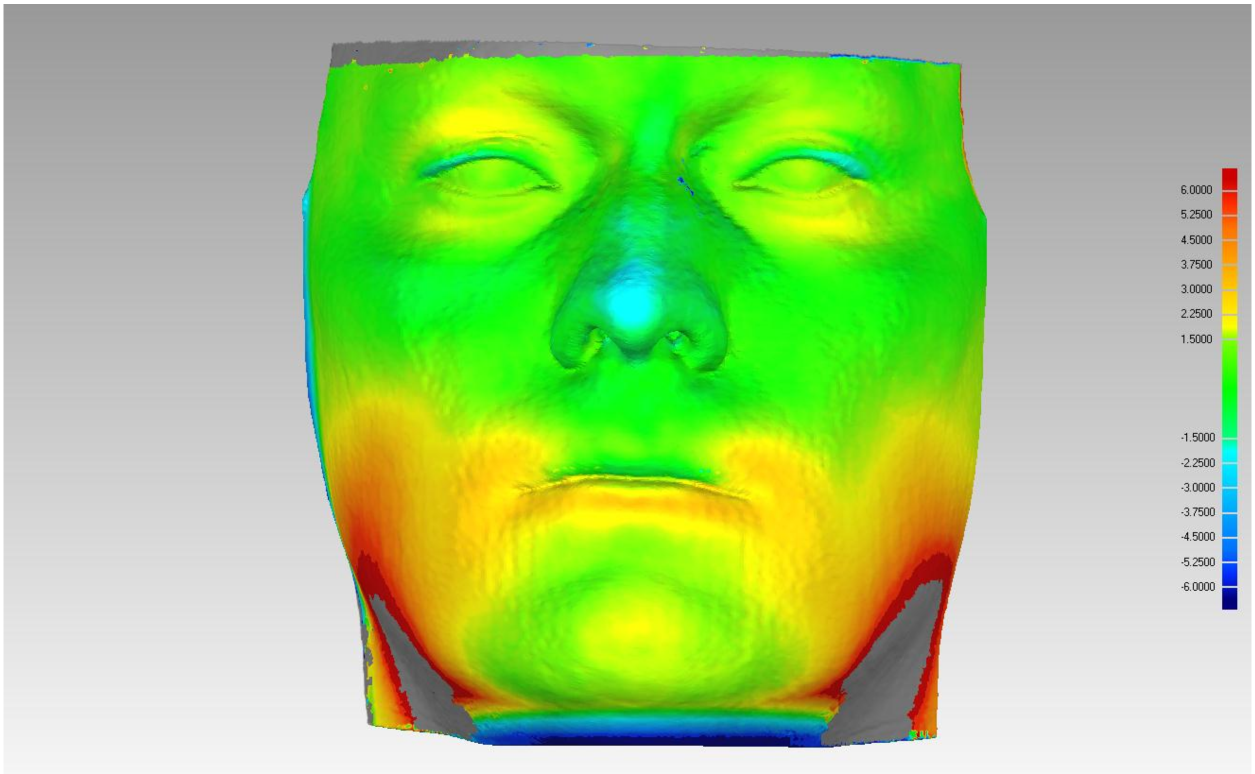
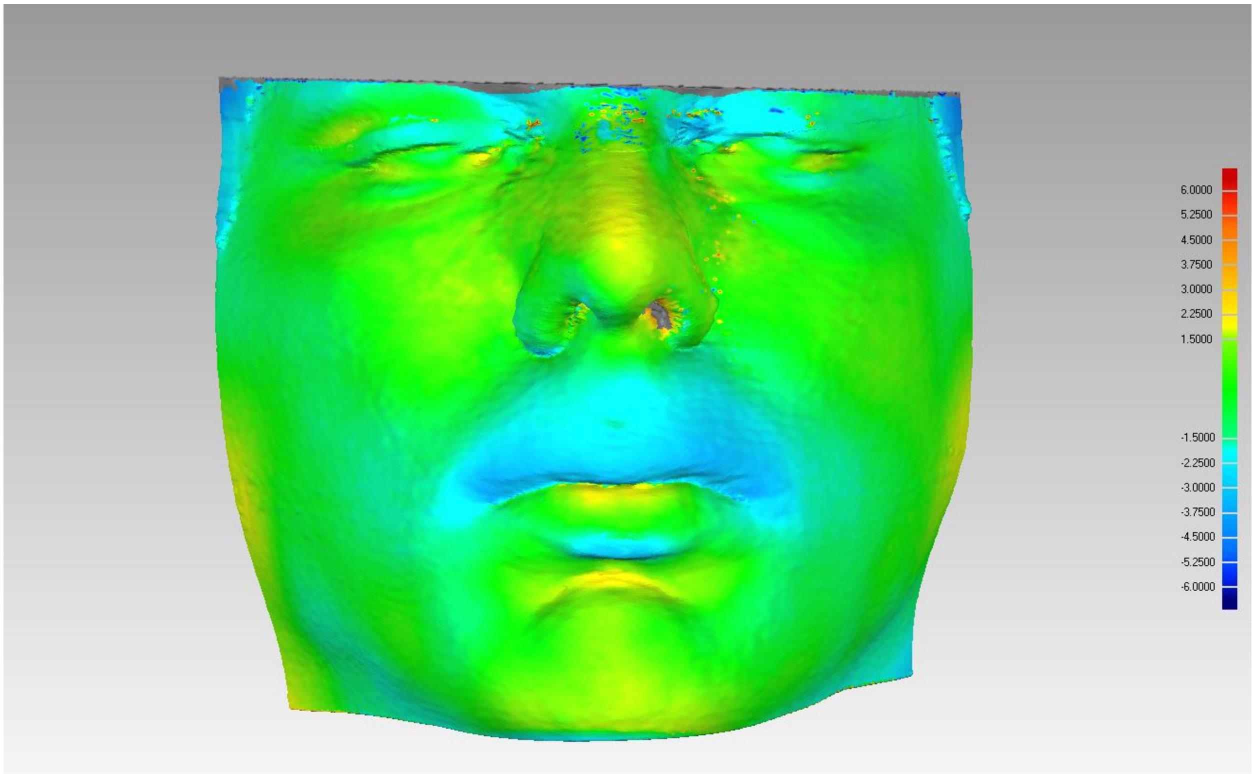


Figure 22: Color map of discrepancy for patient #10



B. Qualitative Results

The panel of orthodontists assessed the resemblance of the pre-surgical prediction with the final result. Six orthodontists comprised the panel, and their overall and specific landmarks assessments were recorded (Appendix C). The mean Visual Analog Scale (VAS) scores along with standard deviations are summarized in the table below:

Table 5 – Mean and Standard Deviation for Subjective Assessments

	Overall	Stomion Superius	Stomion Inferius	Chelion	Soft tissue B-point	Soft tissue Pogonion
Mean VAS	6.71	6.79	5.85	7.05	6.27	6.42
STD DEV	1.84	2.32	2.07	1.73	1.76	2.20

The panel assigned a mean overall VAS score of 6.71, indicating a reasonably accurate result. The panel found the most concordance between the prediction and the final result in the region of the corners of the mouth, assigning a VAS score of 7.05, followed by the upper lip (6.79). The panel was most critical of the position of the lower lip (5.85), followed by soft tissue B-point (6.27).

Interestingly, the panel preferred the actual result to the pre-surgical prediction in 73.3% of cases.

VII. DISCUSSION

Predictions with Mimics software proved to be reasonably accurate, with 68% of points falling within 2mm of discrepancy between the prediction and final result. The software exhibited weakness in accurately predicting soft tissue B-point (2.01mm average discrepancy) and soft tissue Pogonion (2.43mm average discrepancy). Interestingly, the panel of experts exhibited difficulty in discerning these differences. For example, despite the lower lip being the second most concordant landmark (1.72mm measured discrepancy), it was assessed by the panel to have to lowest concordance between pre-surgical and final result. It is possible that differences in lip morphology as a result of the surgery played a greater role in the panel's assessment than the bodily position of the lips. These findings are consistent with Lew's conclusion that lip morphology and posture could alter the lip response following orthognathic surgery through labiomental interferences (1992). Perhaps a software's ability to correctly predict soft tissue morphology (i.e. lip morphology) may be more important than predicting a tissue's bodily position in space.

Additionally, while soft tissue pogonion proved to be the most difficult landmark to accurately predict (2.43mm discrepancy), it was assessed by the judges to have average concordance with respect to the other landmarks. The panel was able to accurately detect the deficiency of the software in predicting soft tissue B-point; this landmark was measured to be the second least accurate (2.0mm) and was properly assessed by the panel to have the second least concordance between pre-surgical and final result, with a VAS of 6.3.

A variety of factors contributed to some of the soft tissue findings in the study. First of all, not all the patients in both the pre-surgical and final CBCT scan may have been in natural repose. Various degrees of mentalis strain or lip pursing may have accounted for some of the variation in soft tissue position. Some may have assumed a changed natural rest posture of soft tissues between CBCT scans as a result of the drastic change of orthognathic surgery. It is possible that some patients in the pre-surgical CBCT scan before a scheduled BSSO may have been lip incompetent, possibly making them more likely to exhibit mentalis strain. Equally likely is that some alteration of lip competence may have been observed in the post-surgical CBCT scans as a result of the BSSO advancement.

Given the retrospective nature of this study, there was no known uniformity among the radiology technicians taking the CBCT scan of proper coaching the patients to assume a natural lip posture in full repose throughout the CBCT scans. Another possible factor that may have accounted for variation in soft tissue position was soft tissue swelling as a result of the BSSO procedures that each of the 10 subjects underwent. There was variation among the subjects in the amount of time post-surgery before the final CBCT scan (2 weeks to 13 months). For certain, individual responses to surgical trauma and post-operative healing vary considerably.

Ideally, a larger sample size would have afforded the possibility of eliminating subjects who exhibited any sign of soft tissue flexure during the CBCT scans. A larger sample size could have potentiated an exclusion criterion of anyone with a post-operative CBCT scan less than four months post-surgery.

The findings of this study should alleviate concerns that patients undergoing orthognathic surgery may be disappointed with the final result after seeing a pre-surgical prediction. The panel of experts preferred the actual result to the prediction 73% of the time when reviewing the subjects. These findings are consistent with previous studies, as Sarver et al. found that 72% of orthognathic surgery patients who viewed a pre-surgical prediction in the planning stages of treatment felt that the surgical results were as good as or better than the generated two-dimensional pre-surgical prediction in profile view (1998). Additionally, in a randomized clinical trial, Phillips et al. found that patients who viewed a two-dimensional pre-surgical prediction prior to surgery had greater overall satisfaction with the outcome of treatment. In addition, these patients expressed a feeling of better communication with their doctors (1995).

Future research should target a comparison of several software programs in predictive accuracy, following the procedure outlined in this study. Software developers would seem to benefit by utilizing this approach of accurately discerning the exact hard tissue movements to refine their soft tissue algorithms in generating 3-D soft tissue surgical predictions. In addition, the ability to superimpose and incorporate a 3-D photo in the final prediction could provide an interesting means of comparing the surgical predictions. As researchers (Hockley 2012) have similarly compared esthetic assessments of a profile photo with a corresponding profile silhouette, comparing surgical predictions between a 3-D surface image and a 3-D photo may yield interesting results.

VI. CONCLUSIONS

1.) Predictions with Mimics software are reasonably accurate – 68% of landmarks identified among subjects exhibited a discrepancy of 2mm or less between the predictions and the final outcomes.
2.) Experts exhibited difficulty in accurately detecting areas of discrepancy, suggesting the discrepancies in the software were not clinically significant.
3.) The software was less reliable in predicting soft tissue B-point and soft tissue Pogonion.
4.) Experts preferred the overall esthetics of the post-surgical actual result 73% of the time when compared to the pre-surgical prediction.
5.) Experts perceived the lower lip position to be the least accurate region in the pre-surgical prediction.

VII. APPENDICES

Appendix A. Script Read to Panelists Prior to Qualitative Assessment

"Please observe the PowerPoint presentation prepared for you. Momentarily, you will be asked to provide your subjective impression of the following 3-D pre-surgical prediction. You will view side-by-side comparisons of the post-surgical 3-D surface representation of the final result on the left with the 3-D surgical prediction on the right generated by a third party software program. The prediction was created using a soft tissue algorithm that incorporated the exact, measured hard tissue movements observed on CBCT's taken before and after orthognathic surgery.

You will view side-by-side comparisons of 10 patients, using screen shots from nine different angles. Your task will first be to provide your overall subjective impression of how similar the surgical prediction is with the final result. Some images may contain surface artifacts; please disregard these in making your assessment. Not all of the renderings were able to be constructed in natural head position due to program limitations. In addition to your overall impression, you will be asked to subjectively assess the accuracy of the following five soft tissue regions:

1.)Upper Lip

2.)Lower Lip

3.)Corners of the mouth

4.)Soft tissue B-Point

5.)Soft tissue Pogonion

To assess each of the 10 subjects in terms of resemblance of the pre-surgical prediction to the final result, please mark an "X" on the pages provided using the following scale (0-10):

0	5	10
No resemblance	Moderate resemblance	Excellent resemblance

You will be given approximately one minute to assess each subject, though if you feel as if you need more time to render an accurate assessment, please feel free to request extra time in your view(s) of preference. Supplemental time viewing each patient will be restricted to one additional minute.

Finally, for each patient, you will be asked which representation is more esthetic – the final result or the pre-surgical prediction.

A scoring sheet has been provided in the following page to record your assessments.

Please let the presenter know if you have any additional questions prior to the beginning of the presentation. ”

Appendix B. Raw Data – Patient Discrepancy Measurements

Pt #1						
Landmark	Stomion S	Stomion I	Rt Cheilion	Lt Cheilion	B-Point'	Pg'
Post_Tissue	0.05	0.047665868	0.062003101	0.062003101	0.053546914	0.05
Simulation	0.0484689	0.050114542	0.066938861	0.060352639	0.055409499	0.051861314
Difference	1.5310842	2.448674353	4.935759874	1.650462024	1.862584517	1.861314381
Pt #2						
Post_Tissue	0.05	0.045862344	0.061098899	0.061098899	0.05215756	0.05
Simulation	0.0494917	0.049215132	0.064699085	0.062261113	0.054607447	0.052771669
Difference	0.508347	3.352788	3.600186	1.162214	2.449887	2.771669
Pt #3						
Post_Tissue	0.05	0.047366662	0.058438851	0.058438851	0.052034602	0.05
Simulation	0.0473825	0.04612235	0.059828035	0.058575803	0.053952163	0.056340946
Difference	2.617452	1.244312572	1.389184456	0.136952685	1.917560362	6.340946397
Pt #4						
Post_Tissue	0.05	0.045218288	0.059381034	0.059381034	0.051006179	0.05
Simulation	0.0509558	0.043211675	0.061936748	0.062051424	0.04749935	0.044781372
Difference	0.9557525	2.006613206	2.555713978	2.670389641	3.506828338	5.218628494
Pt #5						
Post_Tissue	0.05	0.049658679	0.067139561	0.067139561	0.051965822	0.05
Simulation	0.0482276	0.04929682	0.067202793	0.064019017	0.05428106	0.051401632
Difference	1.7724254	0.361859568	0.063232637	3.120543351	2.315237863	1.401632429
Pt #6						
Post_Tissue	0.05	0.046304432	0.066979462	0.066979462	0.054883943	0.05
Simulation	0.0495317	0.047863804	0.064602252	0.065244398	0.05551865	0.050803575
Difference	0.4683095	1.559371624	2.377209995	1.735063997	0.63470744	0.803575495
Pt #7						
Post_Tissue	0.05	0.049273406	0.063568161	0.063568161	0.054882562	0.05
Simulation	0.048466	0.050699554	0.065482609	0.064243895	0.056577917	0.051109668

Difference	1.5339763	1.426147991	1.914447858	0.675733986	1.695355122	1.109668145
Pt #8						
Post_Tissue	0.05	0.050997411	0.063154887	0.063154887	0.053940928	0.05
Simulation	0.0508356	0.050204501	0.063010454	0.06487516	0.056623546	0.053333298
Difference	0.8355917	0.792909942	0.144433614	1.720273013	2.682618328	3.33329798
Pt #9						
Post_Tissue	0.05	0.048996547	0.061887133	0.061887133	0.05445232	0.05
Simulation	0.0506047	0.052004044	0.064626493	0.064280188	0.055493526	0.051452258
Difference	0.6047192	3.007496796	2.739360378	2.393054954	1.041205738	1.452258287
Pt #10						
Post_Tissue	0.0475148	0.049740678	0.061358727	0.061637904	0.057940954	0.051046187
Simulation	0.05	0.048721036	0.063552096	0.063552096	0.055943297	0.05
Difference	2.485183	1.019642	2.193369	1.914192	1.997657	1.046187

Appendix C. Raw Data – Qualitative Assessments

Judge_1	Overall	Stomion Superius	Stomion Inferious	Chelion	B'	Pg'	Left better?
1	3.9	8	1.3	3.2	7.3	3	Actual
2	4.6	8.4	1.4	1.3	5.8	5.8	Actual
3	1.8	4.3	0.9	5.7	4.3	2	Actual
4	6.1	8.9	4.4	7.7	4.3	4.1	Actual
5	8	8	6.3	4.1	5.8	7.3	Actual
6	5.8	8.3	7.3	6.3	5.5	4	Actual
7	5.8	8.5	5.7	5.8	4.1	4	Actual
8	2.7	8.4	2.8	5.7	5.1	3.4	Actual
9	5.3	6.7	3	6	4.3	5.8	Actual
10	3.8	5.9	3.7	5.7	1.9	4.7	Actual
Judge_2							
1	5.6	2.7	4.5	5.8	5.6	8	Prediction
2	8.4	9.1	4.7	6.7	5.3	5.2	Prediction
3	3.8	3.8	3.8	6.4	3.7	3.6	Actual
4	7.9	8.3	7.2	6.4	6.2	3.3	Prediction
5	8	8.9	7.5	6.3	6.9	7.8	Actual
6	8.3	8.6	7.6	8.3	8.3	8.1	Prediction
7	8.7	8.8	8.5	8.4	6.9	8.3	Actual
8	6.6	8.7	6.4	8.8	8.7	8.7	Actual
9	7.9	8.2	7.2	8.2	7.3	8.2	Actual
10	9.3	9	8.4	8.7	8	8.7	Actual
Judge_3							
1	5	3.3	6.5	6	7.5	7.3	Prediction
2	5.4	7.7	5.2	6	5.8	5.6	Prediction
3	4	3.4	2.7	3.2	2.9	3.2	Actual
4	5.2	5.1	3.7	6.1	5.2	3.9	Actual
5	7	6.1	4.1	6.3	3.8	6.8	Prediction
6	7.6	7	4.5	7.3	6.7	7	Actual
7	7.2	4.3	7.7	7.6	7.7	6.7	Actual
8	7	7.1	5.8	6.8	7.6	7.5	Actual
9	6.9	5.5	4.1	6.4	5.9	6.3	Prediction
10	5.8	7	5.9	6.2	3.7	3.4	Actual
Judge_4							
1	4.1	0.7	4.9	6.2	7.4	7.1	Prediction
2	5	7.3	3.7	6.2	5.4	2.2	Actual

3	5	3.2	4.4	4.2	5.8	2.9	Actual
4	8	7.3	6.6	7.3	4.3	4.5	Prediction
5	7.8	7.3	5	8.1	5	5.4	Actual
6	6.8	7.3	5.2	7	5.6	6.2	Prediction
7	6.5	5	6.2	7.3	6.1	6.5	Actual
8	7.3	7.4	7.1	7	6.3	6.8	Actual
9	6.4	6.5	6	8.1	5.8	6	Actual
10	8.3	7.6	7.6	6.6	7.6	7.7	Actual
Judge_5							
1	6.3	5.3	9.3	9.2	5	9.3	Prediction
2	6.2	8.7	8.3	5	8.3	8.4	Actual
3	6.8	3.8	3.7	5.1	2.9	3	Actual
4	8.1	7.3	7.4	8.7	8	6.6	Actual
5	8.9	8.8	6.8	8.3	8.1	9.6	Actual
6	8.9	8.8	8.1	8.9	8.1	9.4	Prediction
7	6.9	7.4	8.1	7.4	8.1	8.9	Actual
8	7.9	8.7	6.7	8.2	8.3	8.7	Actual
9	8.4	9.1	6.4	7.7	7.8	8.5	Actual
10	7.4	8.5	7.9	8.3	6.7	8.9	Actual
Judge_6							
1	2.7	0.4	9.2	9.3	9.3	8.7	Prediction
2	7.9	1	5	9	7.3	6.9	Actual
3	6.4	4.2	4.7	8.4	4.7	3.1	Prediction
4	9.4	9.7	9.6	9.5	8.2	6	Prediction
5	9	8	6.2	9	4.7	8.8	Actual
6	8.2	9.7	3.9	8.9	9	9.2	Actual
7	8.2	5.4	5.4	8.7	9.1	8.9	Actual
8	9.7	9.1	8.8	9.2	8.8	9	Actual
9	9.3	8.9	7.7	9.4	7.1	8.8	Actual
10	7.8	7.2	8.3	9.3	5.3	7.7	Actual

VII. LITERATURE CITED

Arridge S, Moss JP, Linney AD, James DR. Three dimensional digitization of the face and skull. J Maxillofac Surg. 1985 Jun;13(3):136-43. Baik HS, Kim SY. Facial soft-tissue changes in skeletal Class III orthognathic surgery patients analyzed with 3-dimensional laser scanning. Am J Orthod Dentofacial Orthop. 2010 Aug;138(2):167-78.

Bianchi A, Muyldermans L, Di Martino M, Lancellotti L, Amadori S, Sarti A, Marchetti C. Facial soft tissue esthetic predictions: validation in craniomaxillofacial surgery with cone beam computed tomography data. J Oral Maxillofac Surg. 2010 Jul;68(7):1471-9.

Clemente-Panichella D, Suzuki S, Cisneros GJ. Soft to hard tissue movement ratios: orthognathic surgery in a Hispanic population. Int J Adult Orthod Orthognath Surg. 2000;15:255–264.

Donatsky O, Bjørn-Jørgensen J, Hermund NU, Nielsen H, Holmqvist-Larsen M, Nerder PH. Immediate postoperative outcome of orthognathic surgical planning, and prediction of positional changes in hard and soft tissue, independently of the extent and direction of the surgical corrections required. Br J Oral Maxillofac Surg. 2011 Jul;49(5):386-91.

Donatsky O, Bjørn-Jørgensen J, Hermund NU, Nielsen H, Holmqvist-Larsen M, Nerder PH. Accuracy of combined maxillary and mandibular repositioning and of soft tissue prediction in relation to maxillary antero-superior repositioning combined with mandibular set back A computerized cephalometric evaluation of the immediate postsurgical outcome using the TIOPS planning system. J Craniomaxillofac Surg. 2009 Jul;37(5):279-84.

Eales EA, Newton C, Jones ML, Sugar A. The accuracy of computerized prediction of the soft tissue profile: a study of 25 patients treated by means of the Le Fort I osteotomy. Int J Adult Orthodon Orthognath Surg. 1994;9(2):141-52.

Ewing, M, Ross, RR. Soft tissue response to mandibular advancement and genioplasty. Am J Orthod Dentofacial Orthop. 1992 Jun;101(6):550-5.

Hing NR. The accuracy of computer generated prediction tracings. Int J Oral Maxillofac Surg. 1989 Jun;18(3):148-51. Jacobson R, Sarver DM. The predictability of maxillary repositioning in LeFort I orthognathic surgery. Am J Orthod Dentofacial Orthop. 2002 Aug;122(2):142-54.

Hockley A, Weinstein M, Borislow AJ, Braitman LE. Photos vs silhouettes for evaluation of African American profile esthetics. Am J Orthod Dentofacial Orthop. 2012 Feb;141(2):161-8.

Hu J, Wang D, Luo S, Chen Y. Differences in soft tissue profile changes following mandibular setback in chinese men and women. J Oral Maxillofac Surg. 1999;57:1182–1186.

Jensen AC, Sinclair PM, Wolford LM. Soft tissue changes associated with double jaw surgery. Am J Orthod Dentofacial Orthop. 1992 Mar;101(3):266-75.

Koh CH, Chew MT. Predictability of soft tissue profile changes following bimaxillary surgery in skeletal class III Chinese patients. J Oral Maxillofac Surg. 2004 Dec;62(12):1505-9.

Konstiantos KA, O'Reilly MT, Close J. The validity of the prediction of Soft Tissue profile changes after LeFort I osteotomy using the dentofacial planner (computer software). Am J Orthod Dentofacial Orthop. 1994 Mar;105(3):241-9.

Lew KK. The reliability of computerized cephalometric soft tissue prediction following bimaxillary anterior subapical osteotomy. Int J Adult Orthod Orthognath Surg. 1992;7:97–101.

Lu CH, Ko EW, Huang CS. The accuracy of video imaging prediction in soft tissue outcome after bimaxillary orthognathic surgery. J Oral Maxillofac Surg. 2003 Mar;61(3):333-42.

Mankad B, Cisneros GJ, Freeman K, Eisig SB. Prediction accuracy of soft tissue profile in orthognathic surgery. Int J Adult Orthodon Orthognath Surg. 1999;14(1):19-26.

Moerenhout BA, Gelaude F, Swennen GR, Casselman JW, Van Der Sloten J, Mommaerts MY. Accuracy and repeatability of cone-beam computed tomography (CBCT) measurements used in the determination of facial indices in the laboratory setup. J Craniomaxillofac Surg. 2009 Jan;37(1):18-23.

Mobarak KA, Krogstad O, Espeland L, Lyberg T. Factors influencing the predictability of soft tissue profile changes following mandibular setback surgery. Angle Orthod. 2001;71:216–227.

Phillips C, Hill BJ, Cannac C: The influence of video imaging on patients' perceptions and expectations, Angle Orthod 65:263-270, 1995.

Proffit, W Contemporary Orthodonitcs 4th Edition. St. Louis: Mosby; 2007.

Proffit, W Contemporary Treatment of Dentofacial Deformity. St. Louis: Mosby; 2003.

Ravindranath S, Krishnaswamy NR, Sundaram V. Comparison of two imaging programs in predicting the soft tissue changes with mandibular advancement surgery. Orthodontics (Chic.). 2011 Winter;12(4):354-65.

Sarver D. Esthetic Orthodontics and Orthognathic Surgery, 1st Edition. St. Louis: Mosby; 1998.

Sarver D, Johnston MW, Matukas VJ. Video imaging for planning and counseling in orthognathic surgery. J Oral Maxillofac Surg. 1988 Nov;46(11):939-45.

Simanca E, Morris D, Zhao L, Reisberg D, Viana G. Measuring progressive soft tissue change with nasoalveolar molding using a three-dimensional system. J Craniofac Surg. 2011 Sep;22(5):1622-5.

Soncul M, Bamber MA. Evaluation of facial soft tissue changes with optical surface scan after surgical correction of Class III deformities. J Oral Maxillofac Surg. 2004 Nov;62(11):1331-40.

Ulusoy I, Akagunduz E, Sabuncuoglu F, Gorgulu S, Ucok O. Use of the dynamic volume spline method to predict facial soft tissue changes associated with orthognathic surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010 Nov;110(5):e17-23.

Upton PM, Sadowsky PL, Sarver DM, Heaven TJ. Evaluation of video imaging prediction in combined maxillary and mandibular orthognathic surgery. Am J Orthod Dentofacial Orthop. 1997 Dec;112(6):656-65.

Xia J, Samman N, Yeung RW, Wang D, Shen SG, Ip HH, Tideman H. Computer-assisted three-dimensional surgical planing and simulation. 3D soft tissue planning and prediction. Int J Oral Maxillofac Surg. 2000 Aug;29(4):250-8.