Uniformed Services University of the Health Sciences

Manuscript/Presentation Approval or Clearance

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5. Type of clearance: __Paper __Article __ Book ___Poster ___Presentation_X_Thesis

6. Title: Predicted Versus Attained Surgical Correction of Maxillary Advancement Surgery Using CBCT

7. Intended publication/meeting: Requirement for Masters in Oral Biology

8. "Required by" date: 01-July-2016

9. Date of submission for USU approval: 01-July-2016

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6. DoD clearance/date:

7. DoD Disapproval/date:

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External Affairs Approval Date

Predicted Versus Attained Surgical Correction of Maxillary Advancement Surgery Using Cone Beam Computed Tomography

Casey J. Burns

APPROVED:

Brent J. Callegari, D.D.S., M.S.D., Supervising Professor and Program Director

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1 - Jul - 2016

Date

APPROVED:

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Predicted Versus Attained Surgical Correction of Maxillary Advancement Surgery Using Cone Beam Computed Tomography

A THESIS

Presented to the Faculty of

Uniform Services University of the Health Sciences

In Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE

By

Casey J. Burns, D.D.S.

San Antonio, TX

May 2016

Predicted Versus Attained Surgical Correction of Maxillary Advancement Surgery Using Cone Beam Computed Tomography

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DEDICATION

God has blessed me with incredible family and friends, and to them I dedicate this thesis. Thank you especially to Alan, the best husband, partner, and friend a girl could ever have. You are always up for an adventure and are quick to say, "Yes, let's do that." I so appreciate the sacrifices you have made to care for our little one and support our Navy life and my desire to complete this residency. Thank you for all those dinners you brought us and for loving my co-residents like family! Thank you also to my parents for making education a high priority for me and for sacrificing so much to ensure that I had opportunities at my fingertips. You guys rock!

ACKNOWLEDGEMENTS

I would like to thank the faculty and staff at the Tri-Service Orthodontic Residency Program. In particular, I thank Dr. Brent Callegari, who contributed his time, insight, and encouragement to this project. Special thanks to Daniel Sierra for his selflessness and willingness to provide the software and the computer coding expertise required to make this project possible, as well as Ms. Cara Olsen for her statistical knowledge and assistance.

I would also like to thank Drs. Curtis Marsh, Gary Gardner, David Lee, Ryan Snyder, Brian Penton, Kelly Johnson, and Neil Kessel for their contributions to this project and for their outstanding mentorship during my entire orthodontic residency experience. I owe you each a great deal for helping to create in me an increased love for orthodontics.

ABSTRACT

Purpose: To evaluate the accuracy of predicting soft tissue changes from orthognathic surgery utilizing Cone Beam Computed Tomography (CBCT) and Mimics® software. **Methods**: Pre- and post- surgical CBCT's for eight LeFort I Maxillary Advancement patients were superimposed. Exact skeletal movements were measured and recreated within Mimics® to create 3-D pre-surgical soft tissue predictions. Corresponding landmarks were identified on pre-surgical and final soft tissue matrices, and discrepancies were measured using Geomagic Studio®. A panel of orthodontists then subjectively assessed the accuracy of the predictions using a visual analog scale. **Results**: Only 31% of predicted landmarks fell within 2 mm of the actual result. The most accurate points were the right and left ala. Corners of the mouth and upper lip were least accurate. The panel deemed the actual results more esthetic than the predictions. **Conclusion**: Orthognathic surgery soft tissue predictions via Mimics® software were found to be inaccurate in this study, which were not consistent with the outcomes of previous studies. While there were many influential variables contributing to the statistically significant differences, one of the most important was the evident edema in the post-surgical CBCTs that were taken within four months of surgery.

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I. INTRODUCTION

Orthodontists have the ability to not only improve tooth function through biomechanics and science, but also to enhance a patient's facial features and esthetics. Esthetic improvement is often the primary goal for surgical intervention. When the specialty of orthodontics was established 100 years ago, the Angle Paradigm was the conceptual foundation for clinical practice. Edward Angle, the Father of Modern Orthodontics, hinged his philosophy on the belief that good facial esthetics followed from ideal occlusion. As time passed, cephalometric radiographs began to discredit Angle's assumptions and clinicians recognized that hard tissue was not a reliable determinant of facial esthetics. It is ultimately good soft tissue proportions that are the goal of orthodontic treatment, and the field now accepts that the soft tissues, by-in-large, determine the limits of orthodontic and orthognathic treatment. It is imperative that diagnosis and treatment planning are shaped by the Soft Tissue Paradigm, basing what is done on what is evaluated esthetically. A problem-oriented approach with the goal of superior soft tissue esthetics is now the standard for diagnosis and treatment planning in orthodontics, which works in concert with the treatment of dentofacial deformity. Systematic evaluation of the facial soft tissues and facial proportions is critical to the success of both orthodontic and surgical-orthodontic patients (Proffit, 2003).

In order to treatment plan more effectively, orthodontists and oral and maxillofacial surgeons should be able to accurately conceptualize soft tissue objectives. The current systematic examination of facial proportions is more than mere evaluation of the patient's profile; the frontal and oblique views must also be considered in the antero-posterior, transverse, and vertical planes. Tooth-to-lip relationships in repose as well as animation are also critical in achieving superior facial esthetics (Proffit, 2003). Traditionally, orthodontic diagnosis has depended on a two-dimensional plane to accurately represent a three-dimensional image. Standard radiographs and static photos are useful, but they offer limited proficiency in predicting successful three-dimensional outcomes. Fortunately, advancements in software and technology have given orthodontists and their surgical counterparts the ability to use virtual treatment outcomes and three-dimensional computerized surgical predictions to assist treatment planning. These visual aids both increase patient understanding and involvement in their individual treatment as the result of improved communication (Kennebrew *et al*., 1983).

Significant technological advances have afforded opportunities to move away from hand-traced cephalograms and arbitrarily predicted surgical outcomes for patients, especially when it comes to soft tissue adjustments. Although these techniques have given a solid foundation for soft tissue predictions, technology now allows predictions that are more accurate and more easily produced. Forty years ago, researchers were anticipating that one day it would be possible to use computers to aid pre-surgical diagnosis and facial reconstructions (Arridge *et al*., 1985). It is true that orthodontists could continue to hand-trace a lateral cephalograph and estimate the soft tissue results. They could then communicate to a patient that, for example, the upper lip will likely shorten 1 to 2 mm after a maxillary advancement (Proffit, 2007). However, if more accurate measurements are attainable, which would allow patients the opportunity to reliably visualize the outcome of their surgery, why would guesswork even be considered? Technology continues to open new doors for clinicians, improving the field of orthodontics, but more importantly, increasing patients' satisfaction with their results (Kinnebrew *et al*., 1983). Computers have the ability to render varying analyses, save incredible amounts of data, and digitize at the click of a button; saving both time and money in a busy practice.

Digital advancements have not come without challenges. Early programs focused on the hard tissue and directly correlated the soft tissue surgical moves with the hard tissue moves in two dimensions. It is much easier to predict hard tissue moves than soft tissue moves, but the variability between the two can be quite high (Donatsky et al., 2011). In a maxillary advancement, the movement is not a simple 1:1 ratio. According to Proffit, there is slight elevation of the tip of the nose, the base of the upper lip soft tissue change is 20% of Point A, and the upper lip is 60% of incisor protraction. When orthodontics shifted its focus to the soft tissue, the software began to refocus on creating more accurate soft tissue representations, as well. Soft tissue algorithms are critical for profile prediction, and the quality suffered in early two-dimensional versions. The first programs available showed repeated difficulties while predicting the soft tissue profile of the lips (Proffit, 2003). Csaszar et al. evaluated Dentofacial Planner® (DFP®) prediction software and found that there were appreciable prediction errors in the lip region, especially with maxillary surgical predictions (Csaszar *et al*., 1999).

Konstiantos et al. also concluded that the computer-generated soft tissue image from DFP® differed from the post-surgical profile significantly in both the horizontal and vertical dimension (Konstiantos *et al*., 1994). In addition, computer video imaging prediction using Dolphin Imaging® (Version 6) in 2003 also showed mixed results. Dolphin® did not accurately predict nasal tip, soft tissue A point, nor the upper and lower lip in the sagittal plane. Although there was improvement in predicting the vertical plane, the authors indicated that improvement in accuracy and reliability was needed (Lu *et al*., 2003). In another study, the authors had similar results, relaying that although Dolphin Imaging Software® could be suitable for patient education and communication, efforts were needed to improve the accuracy of predictions in regards to soft tissue, especially subnasale and the upper lip (Akhoundi *et al*. 2012).

However, research has also shown that the current small inaccuracies that are measured and criticized in our software are markedly better than surgical predictions by hand (Eckhardt, 2004). When Jacobson and Sarver retrospectively studied DFP®, they found that 80% of the predicted points fell within 2 mm of the original prediction, and that 43% of them fell within 1 mm (Jacobson and Sarver, 2002). Another program, Quick Ceph®, was evaluated in a study involving 16 patients with more favorable results. It was found that on average, there were no significant differences from the predicted images and the post-treatment results regarding the soft tissue (Mankad *et al*., 1999). Repeated digitization accuracy has also found to be acceptable (Gerbo *et al*., 1997), and retrospective reviews of the average prediction errors have consistently been less than 2 mm (Kaipatur and Flores-Mir, 2009).

The two-dimensional software has been met with mixed results, but was an improvement from hand-tracing and measuring. To make matters even more difficult, surgical predictions are further complicated by the fact that race, gender, and soft tissue thickness may affect outcomes. For example, soft to hard tissue ratio in Hispanic patients were shown to vary considerably from the measurements of white patients (Clemente-Panichella *et al*., 2000). Flynn et al found that in black patients, there is greater maxillary skeletal prognathism, upper and lower lip lengths, soft tissue thickness of the lips and chin, less nasal depth, and a smaller nasolabial angle than in a white population (1989). Future software updates should incorporate ethnic differences in initial size, morphology, and thickness of tissues to increase accuracy. Although a giant step from hand-tracing, two-dimensional software continued to show that it, too, had its share of problems and needed improvements.

Soft tissue predictions have evolved into orthognathic surgery treatment planning via three-dimensional radiographs and imaging software. Cone Beam Computed Tomography (CBCT) allows for the construction of three-dimensional skull and soft tissue images. An important development in our capabilities to view soft tissue changes in three-dimensions came from the introduction of a technique called “color mapping”. Based on a reconstructed CT and new soft tissue algorithms, the researchers were able to produce a color three-dimensional facial texture-mapping technique to generate a realistic model of the face (Xia *et al*., 2000). Another advancement in three-dimensional predictions came from Ulusoy *et al*., who introduced the dynamic volume spline method (2010). The dynamic volume spline method incorporates elastic soft tissue characteristics into the algorithm in three planes of space rather than relying on traditional soft tissue algorithms. Post-surgical predictions were compared with conventional predictions of the final result using photographs and cephalometric radiographs. Ulusoy *et al*. concluded that the post–surgical predictions were better with the three-dimensional volume spline method than by the conventional method (2010).

CBCT has offered a wealth of improvements in the search for accurate soft tissue surgical predictions. Morenhout *et al*. observed that the three-dimensional surface accuracy of mannequin head CBCT scans segmented with Maxilim® and Mimics® software is high (2009). Bianchi *et al*. examined the accuracy of SurgiCase CMF® software in predicting the final soft tissue profile of an orthognathic surgery population (2010). A post-operative CBCT was taken approximately six months after the surgery to allow edema to subside. Using SurgiCase CMF® software, the planned surgical movements were incorporated into the pre-operative CBCT, compared to the post-surgical soft tissue profile and were revealed to be extremely accurate (Bianchi *et al*., 2010). Shafi *et al*. found that utilizing Maxilim® to predict soft tissue movements of thirteen LeFort I surgeries resulted in “acceptable” three dimensional representations, with significant errors only at the upper lip (2013). Other software, such as SurgiCase®, affirms the previous results with report that “an accurate forecast” of the patient's soft tissue results from three-dimensional prediction (Marchetti *et al*., 2011).

This study intended to continue to evaluate the accuracy of Mimics® three-dimensional prediction software which was initiated by Dr. Brandon Cummins. His study focused on BSSO (bilateral sagittal split osteotomy) soft tissue predictions and concluded that Mimics® is reliable. All reviewed soft tissue landmarks except the chin had a mean discrepancy within 2 mm between the predicted and actual (2014). This study focused on LeFort I maxillary advancements utilizing the accuracy of precisely measuring the actual maxillary hard tissue advancements that occurred and comparing the difference between the pre-surgical and post-surgical CBCT with Mimics® software. The differences between soft tissue surgical predictions and final results were accurately measured, based on specifically identified soft tissue landmarks.

To provide a subjective human assessment and avoid "treating to the numbers", a panel of orthodontists was polled to judge the accuracy of the same soft tissue predictions. This also helped determine a threshold of acceptability.

II. OBJECTIVES

A. Purpose

To investigate the three-dimensional accuracy of Mimics® software using CBCT in predicting the soft tissue outcome of a LeFort I maxillary advancement population, including a subjective assessment of the predictions from a panel of orthodontists

B. Specific Hypothesis

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 perceive differences between the surgical predictions and the actual final results.

C. Null Hypothesis

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 perceive differences between the surgical predictions and the final results.

III. MATERIALS AND METHODS

A. Patient Selection

This retrospective study included eight patients who had orthognathic surgery limited to LeFort I maxillary advancement, in conjunction with pre- and post-surgical orthodontics, at Joint Base San Antonio – Lackland Air Force Base in San Antonio, Texas between January 1, 2007 to December 31, 2014. All subjects had a pre-surgical CBCT using iCAT Platinum (Imaging Sciences International, Hatfield, PA). The CBCT images were taken at the completion of final orthodontic movements and six plus/minus five months after surgery, at maximum intercuspation with lips in repose. The technical parameters and settings of the iCAT Platinum are displayed in Table 3-1.

Table 3-1: iCAT CBCT: 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. Image Segmentation, Superimposition, and Surgical Simulation

Using Mimics®, the post-surgical soft tissue scans and post-surgical hard tissue scans were imported into the pre-surgical scan (Figure 3-1 and 3-2). Because the cranial base and orbital structures did not change over the course of treatment, these structures were segmented and superimposed to determine maxillary movement during the surgical procedure. Using landmarks of the post-surgical soft tissue scan (the upper bridge of the nose, the eyes, and the forehead, as well as internal structures of the sinus), the post-surgical soft tissue and hard tissue scans were moved simultaneously and aligned to the pre-surgical scan (Figure 3-3). The segmentation of the pre-surgical maxillae was performed utilizing virtual "osteotomies" of the pre-surgical maxillae (simulating the surgery), where the maxilla was identified using thresholding (Figure 3-4). In image processing, "thresholding" is a process by which one may isolate a structure from other structures (Gonzales and Woods, 2002), which enabled the virtual osteotomy on the maxilla only. For the purpose of this study, thresholding identified what was and was not the maxilla. Next, the facial soft tissue was highlighted and the simulation was executed (Figures 3-5, 3-6, 3-7, and 3-8). Then, the resulting stereolithography (STL) files were exported for comparison to the post-surgical soft tissue scans. Finally, the soft tissue simulation and pre-surgical soft tissue scans were imported into Geomagic Studio® (3D Systems, Inc., Rock Hill, South Carolina) for analysis (Figure 3-9).

Figure 3-1: Imported Post-Surgical Hard Tissue Scan

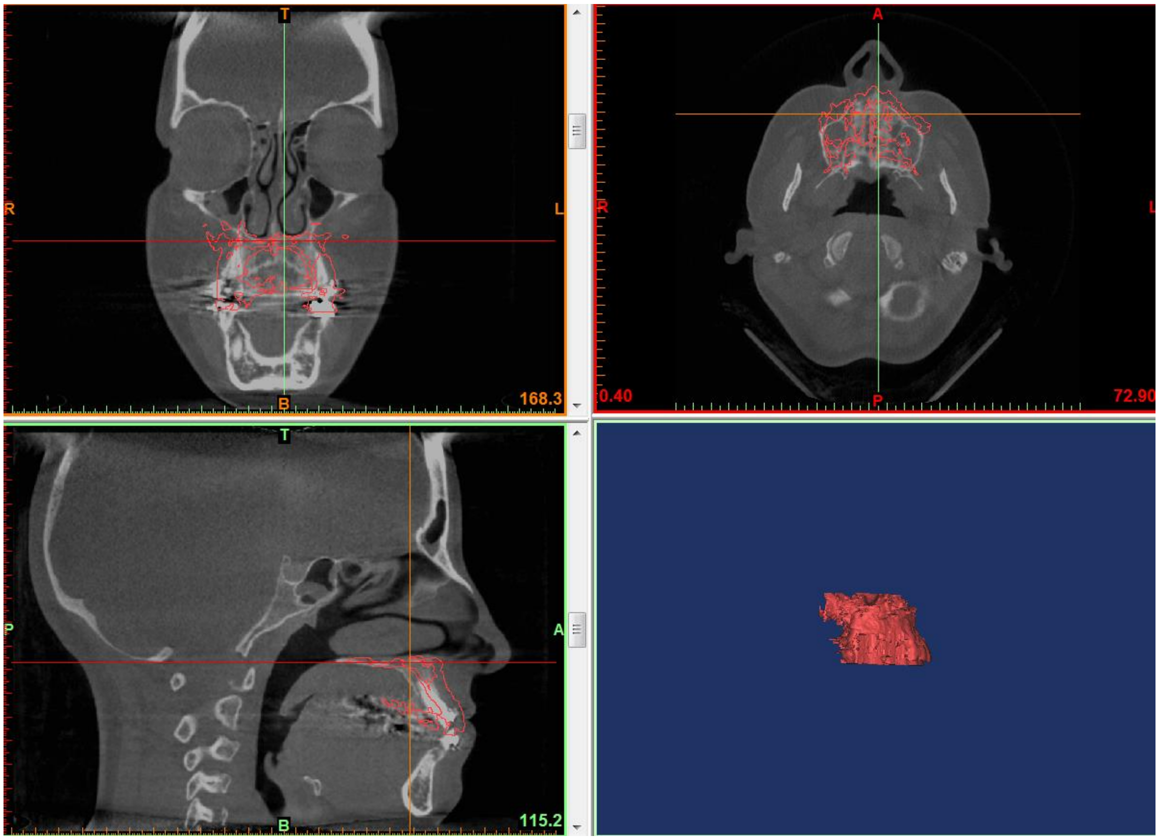


Figure 3-2: Imported Post-Surgical Soft Tissue Scan

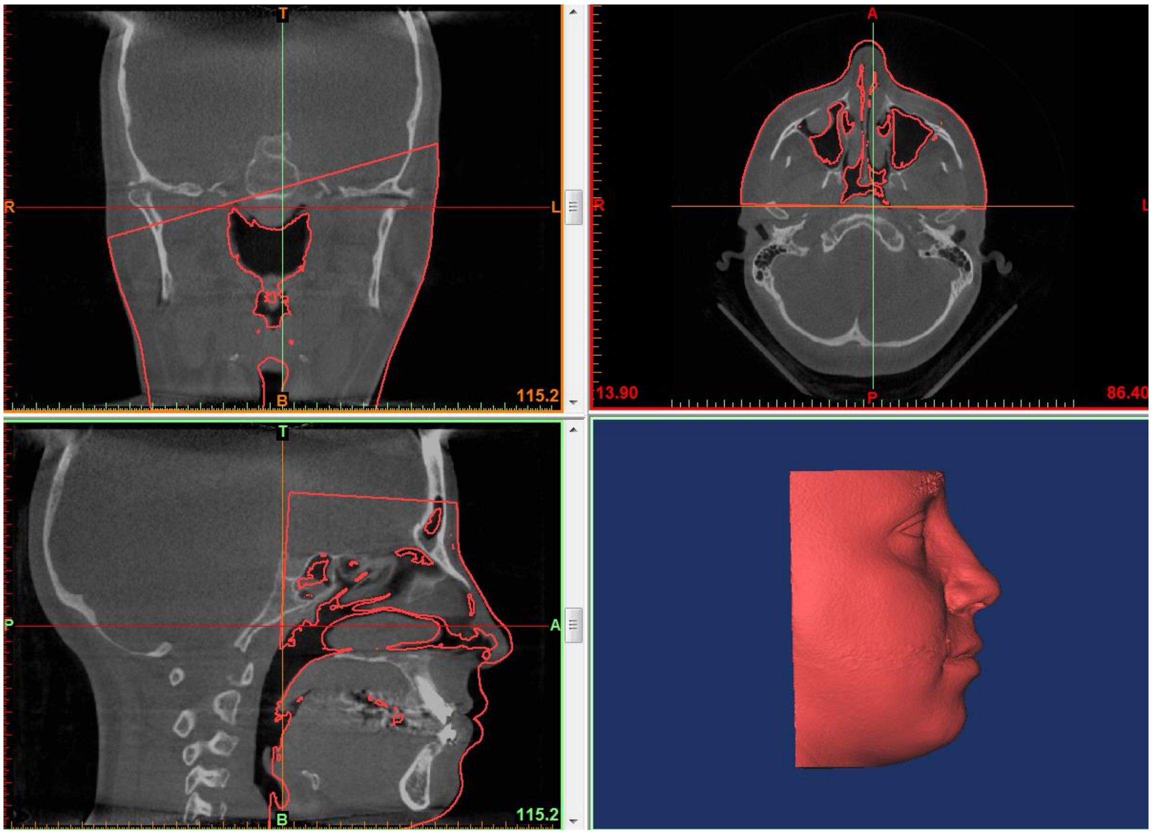


Figure 3-3: Post-Surgical Hard and Soft Tissue Alignment

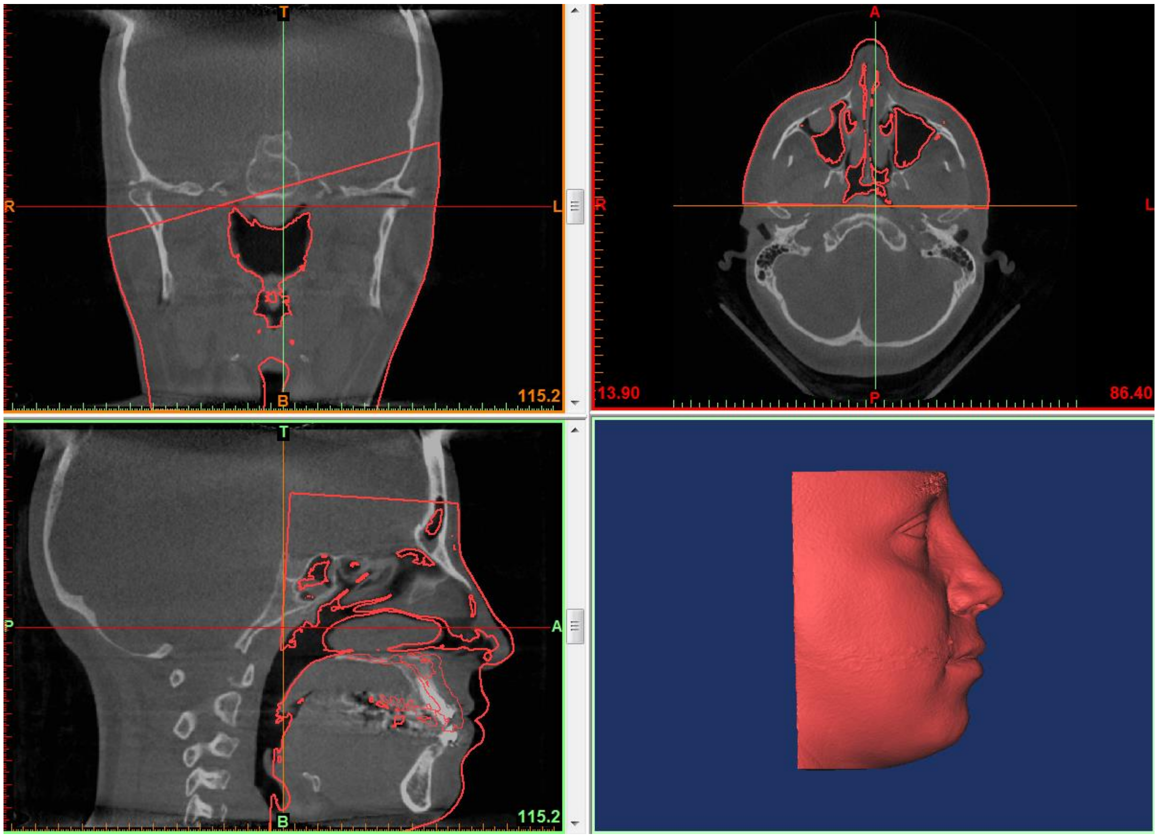


Figure 3-4: Pre-surgical Maxillary Fragment

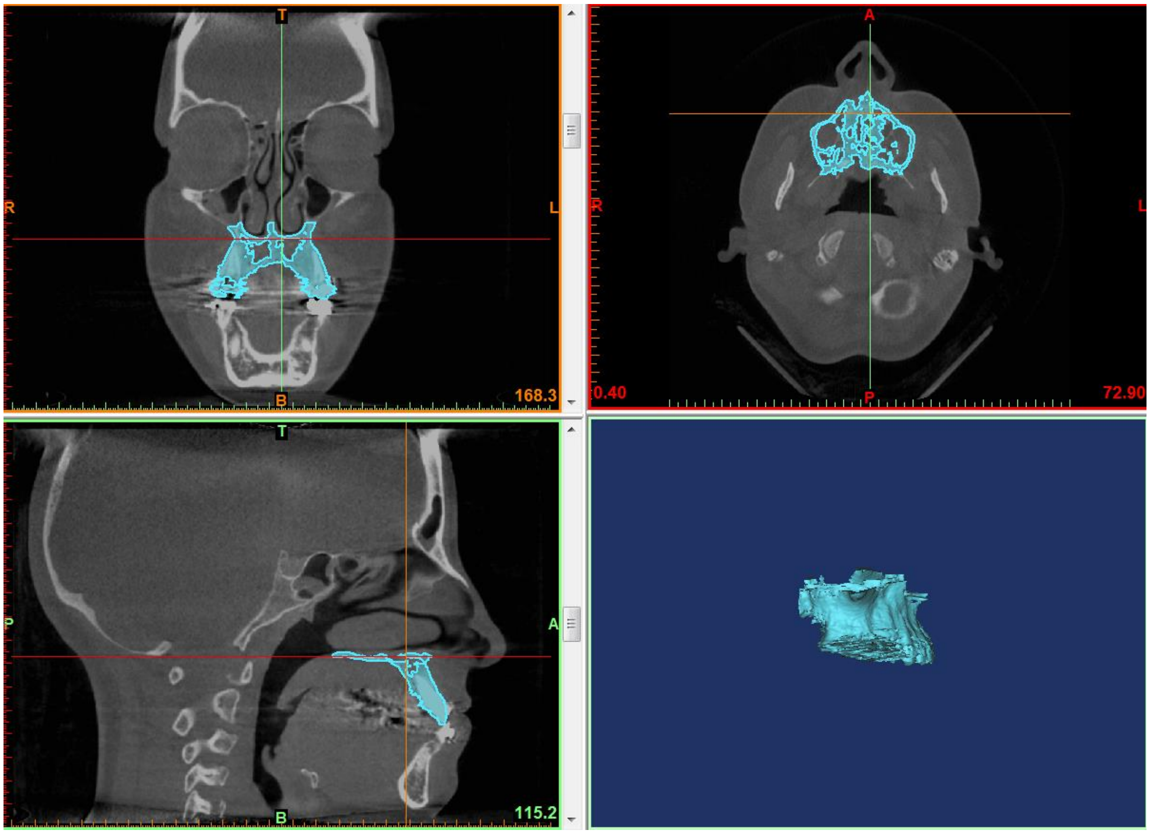


Figure 3-5: Pre-Surgical Soft Tissue

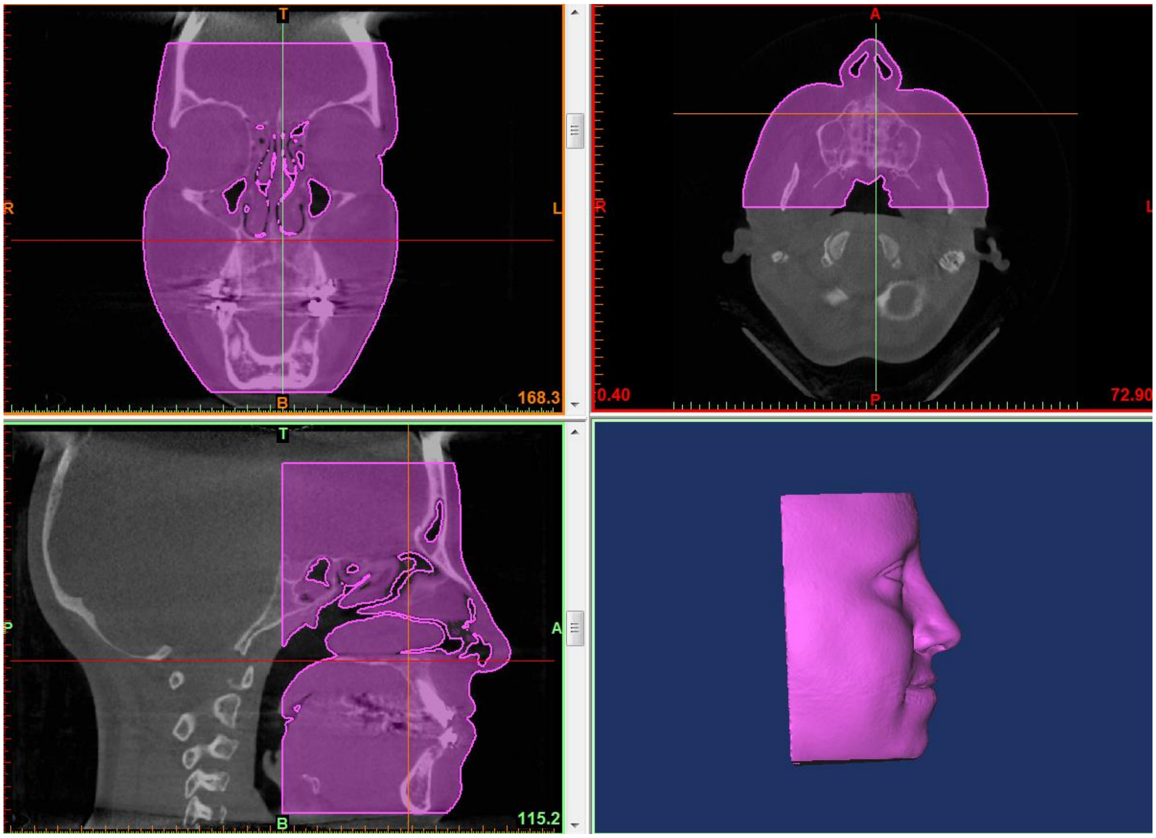


Figure 3-6: Pre-Surgical and Post-Surgical Hard Tissue Alignment

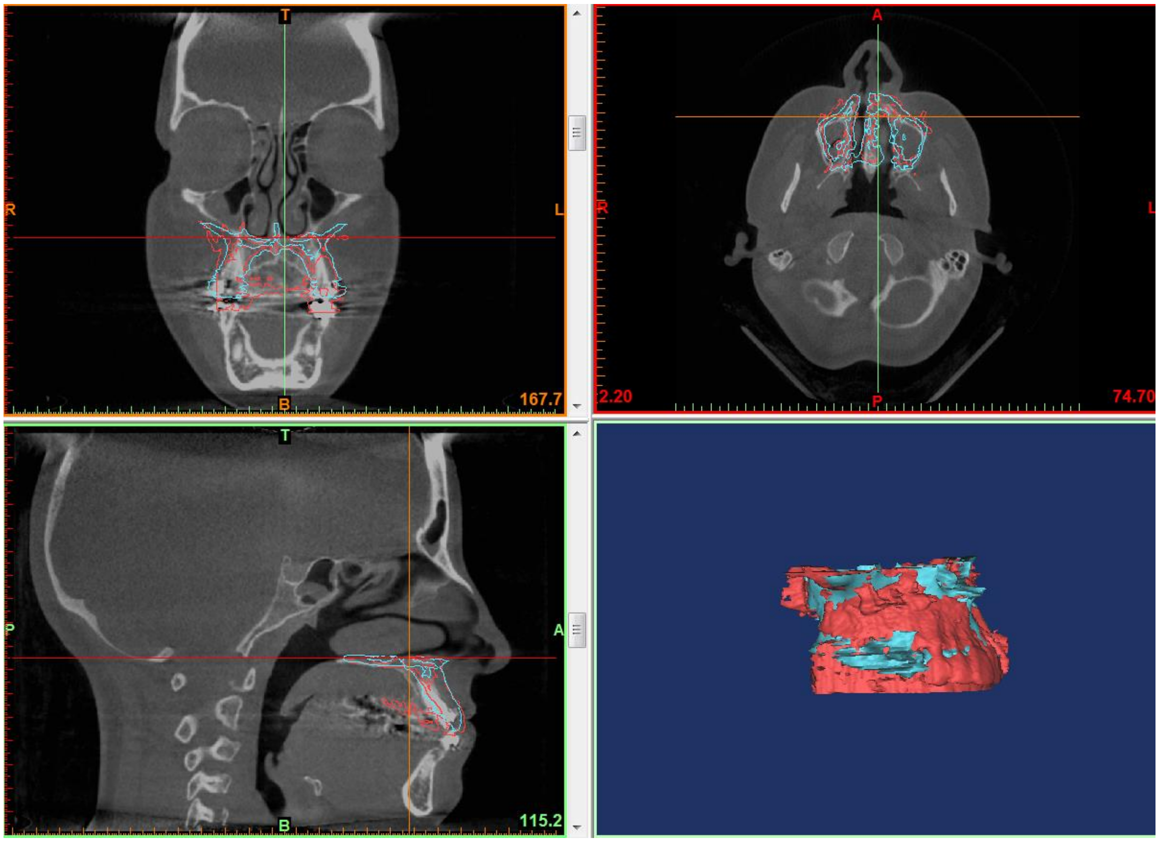


Figure 3-7: Simulation Set-up

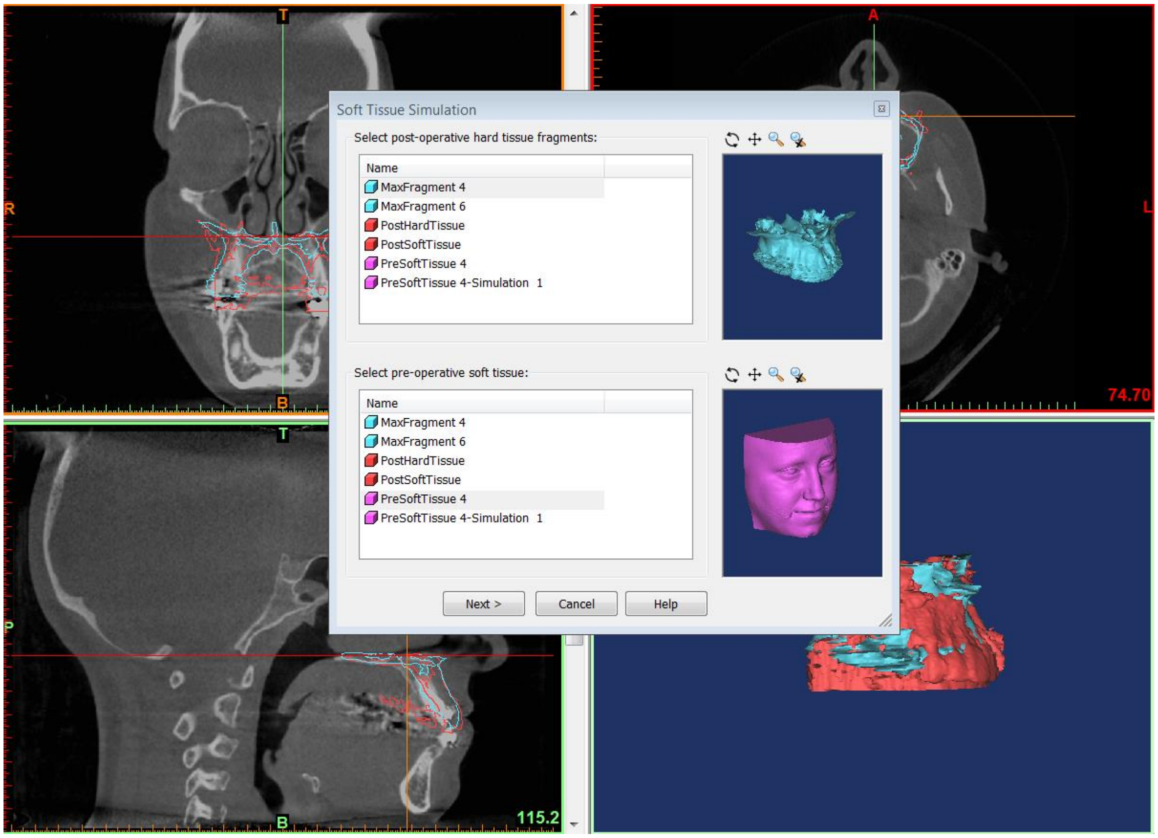


Figure 3-8: Execution of the Soft Tissue Simulation

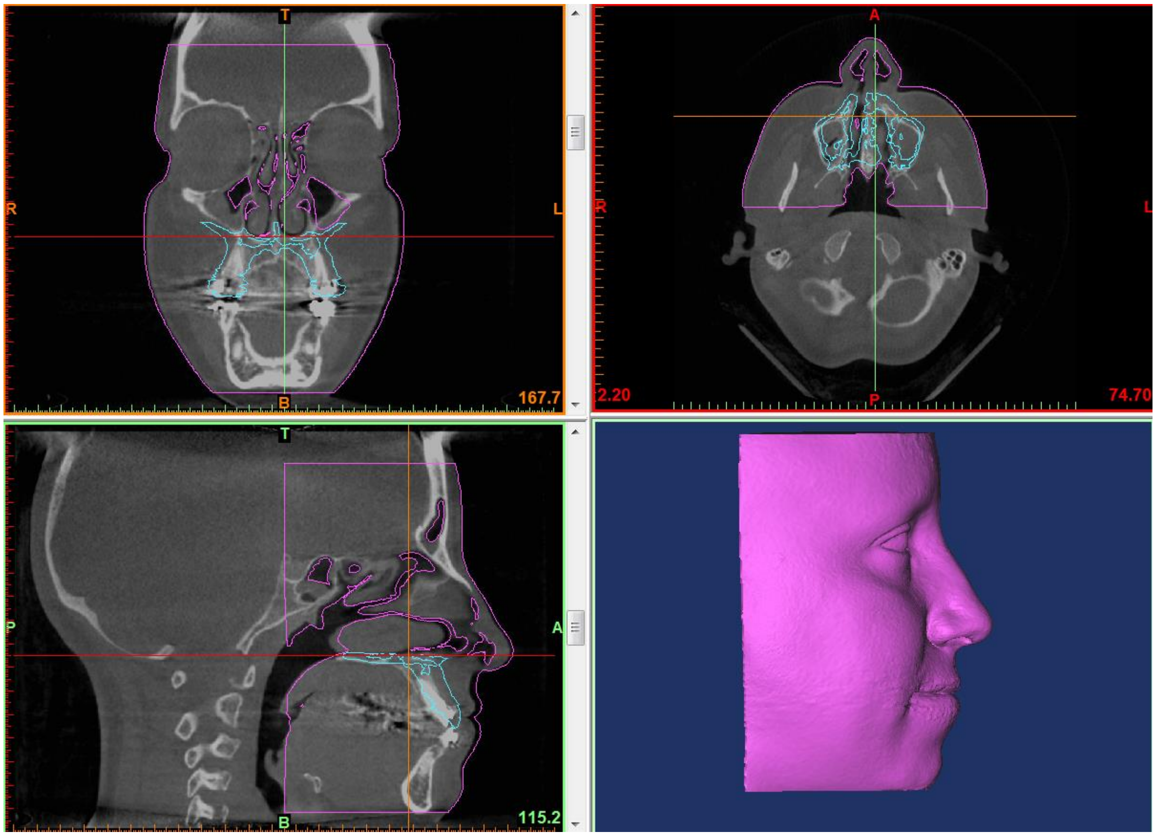
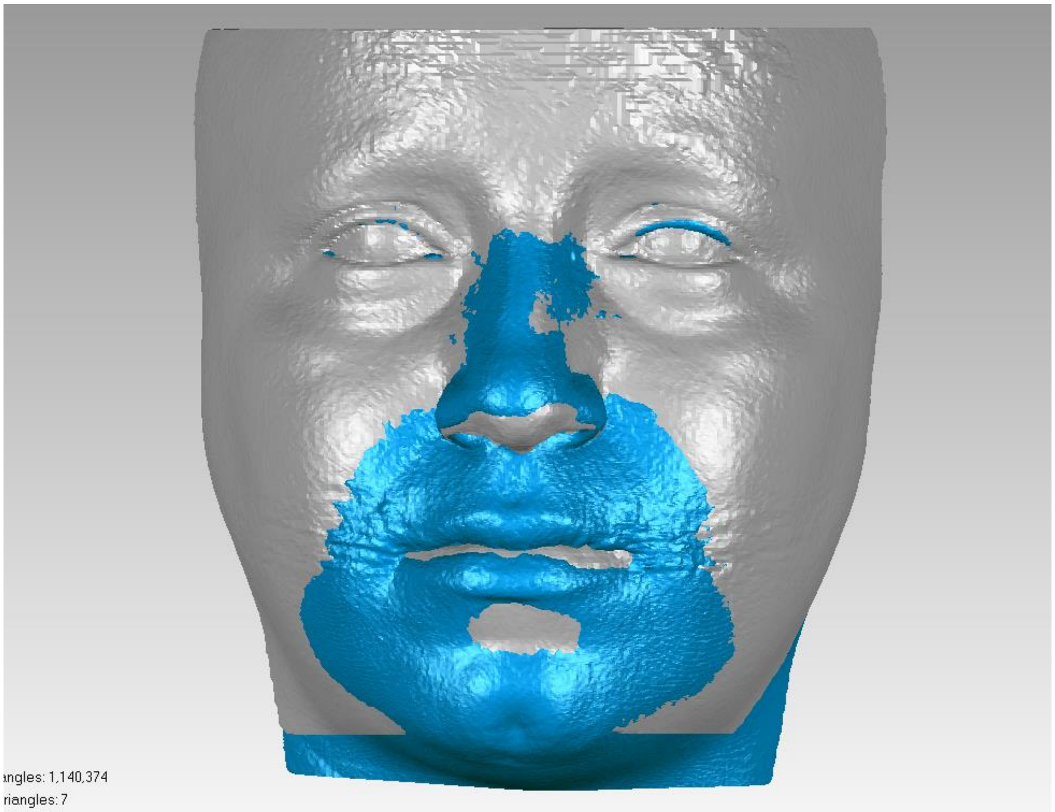


Figure 3-9: Soft Tissue Scans in Geomagic Studio®



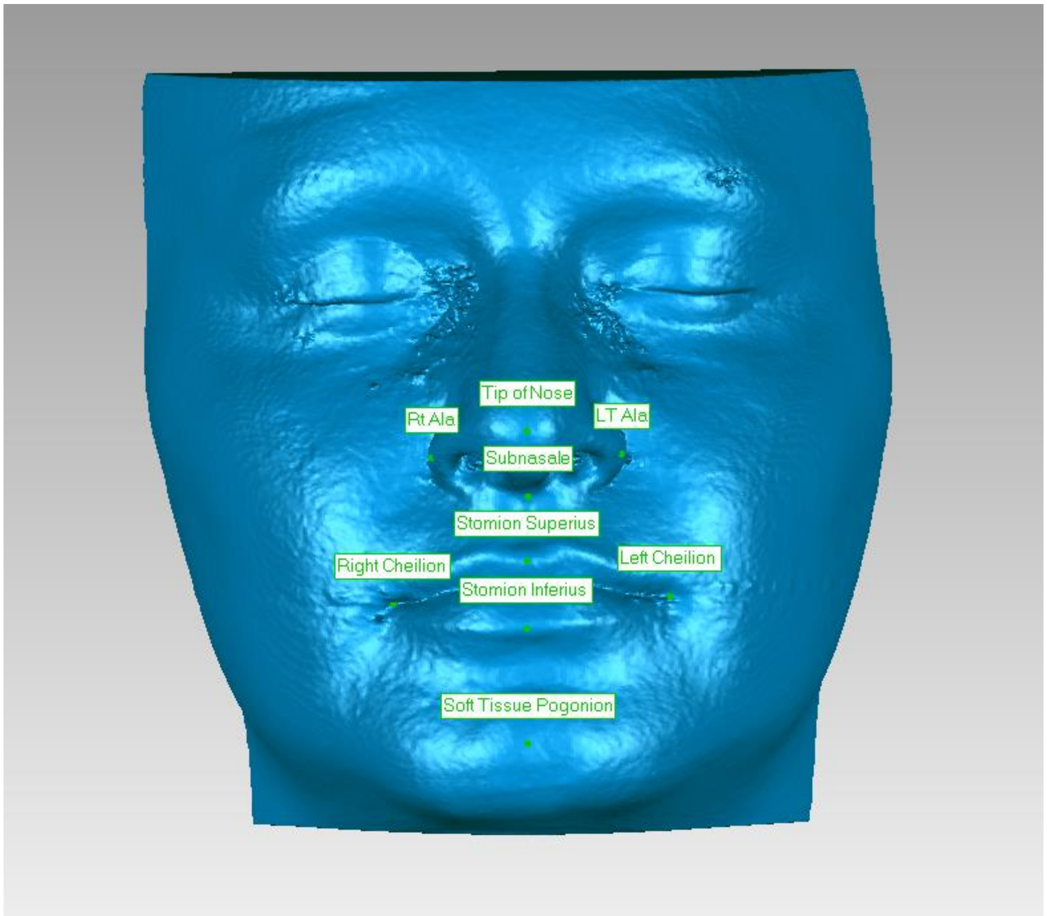
C. Quantitative Evaluation

Validation of Mimics® accuracy will be 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 nine soft tissue landmarks:

Table 3-2: 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
Tip of nose	Most anterior point of the nose
Subnasale (Sn)	Point at which nasal columella merges with the upper cutaneous lip in the midsagittal plane
Soft Tissue Pogonion (Pog’)	Most anterior point on the anterior curve of the soft tissue chin
Right Ala	Most lateral point of the right nostril
Left Ala	Most lateral point of the right nostril

Figure 3-10: Plotted Soft Tissue Landmark Example



The Primary Investigator (PI) selected these points for each patient based on what is known about soft tissue change after maxillary advancement. Geomagic® was used to calculate the three-dimensional distance between the actual and predicted landmarks.

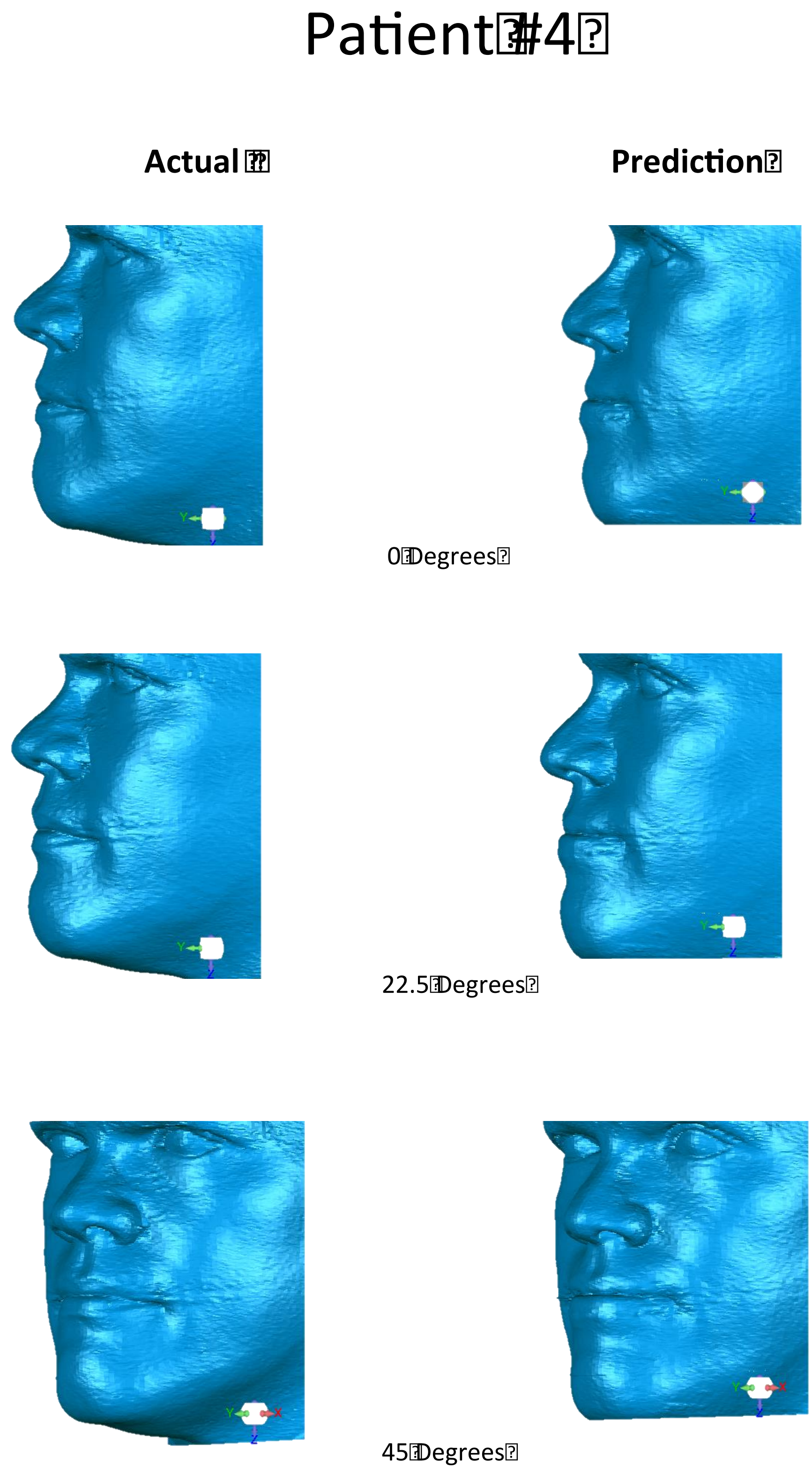
D. Qualitative Evaluation

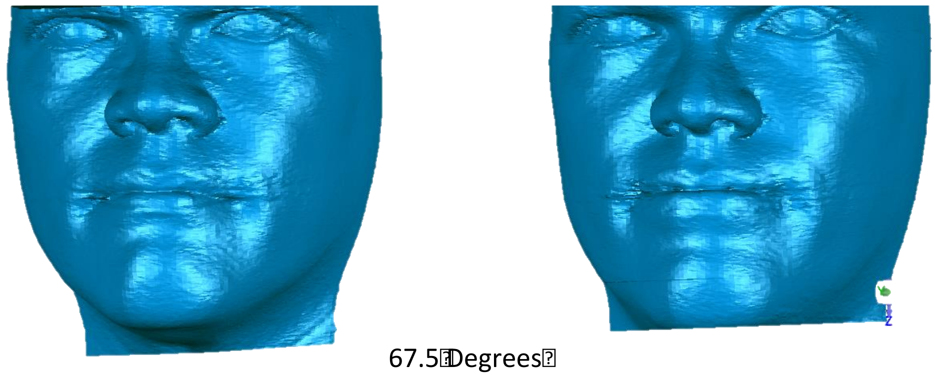
A panel of orthodontists qualitatively assessed the accuracy of the pre-surgical predictions generated by Mimics®. The PI provided a PowerPoint® presentation that contained side-by-side comparisons of 3-D soft tissue surface representations of the post-surgical actual result and the pre-surgical prediction. Each panelist individually viewed a progressive series of 9 screen shots for each patient, which was taken at 22.5 degree intervals rotating about the y-axis (Figure 3-10). The panelists recorded their assessments and indicated which depiction for each patient was more esthetic; the actual result or the surgical prediction. The presentation was projected on a SMARTboard™ (SMART Technologies, Calgary, Canada) 800ixe-SMP with a UX60 projector in a dimly lit room. The only lighting provided was from the projector screen and a small desk lamp in the back corner of the room to allow the panelists to see their assessment worksheets. The PI read a script of instructions (Appendix A) prior to the presentation.

During the presentation, each screen shot was available for 10 seconds and automatically transitioned to the next slide. At the end of each patient, the panelist was allotted one more minute of time to view the screen shot of their choice. However, no panelist was allowed to return to a previously completed patient. Using a Visual Analog Scale (VAS) from 0-10 (0-no resemblance, 10-excellent resemblance), each panelist was asked to provide an overall assessment of the prediction to the actual result. In addition, each panelist specifically assessed the following regions on the same VAS: 1. Upper Lip, 2. Lower Lip, 3. Corners of the mouth, 4. Tip of the nose, and 5. Subnasale. Answers were recorded by marking an “X” for each category. Lastly, each panelist was asked to judge which image was overall more esthetic; the actual result or the surgical prediction.

Each VAS was scaled to exactly 10cm and each “X” was assigned a numerical value based on measurement with a ruler to a tenth of a centimeter.

Figure 3-11: Example of Comparisons Viewed by Panel of Orthodontists





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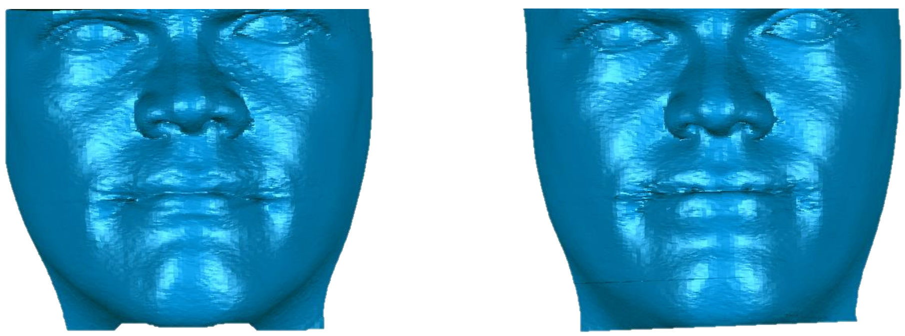
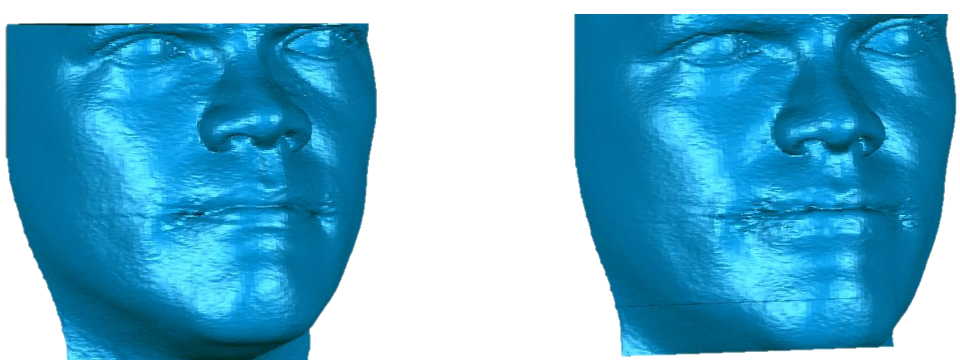
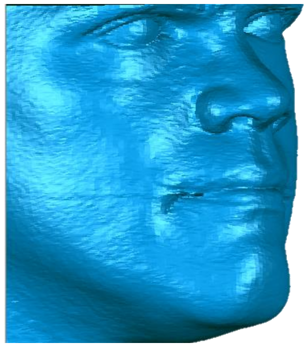
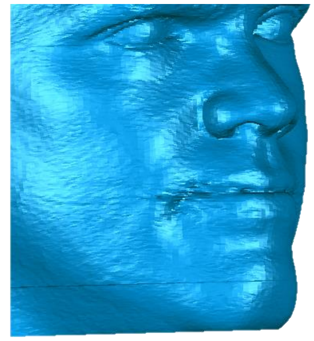


90 Degrees



112.5 Degrees

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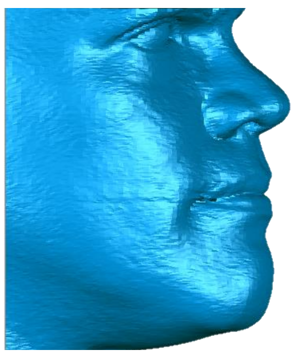
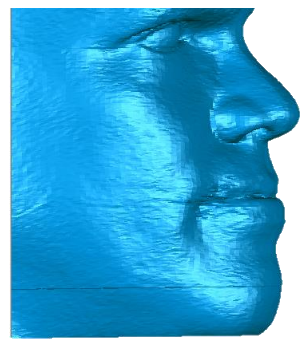
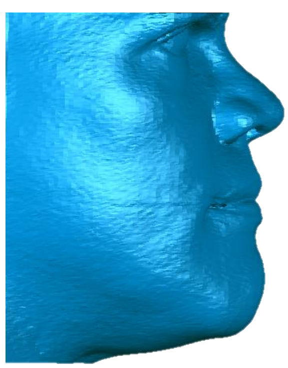
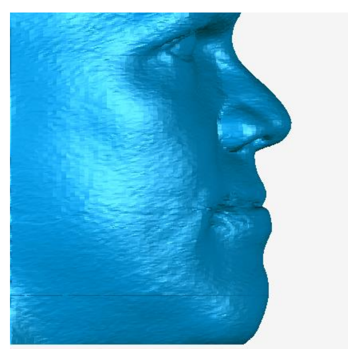



157.5 Degrees

180 Degrees

IV. RESULTS

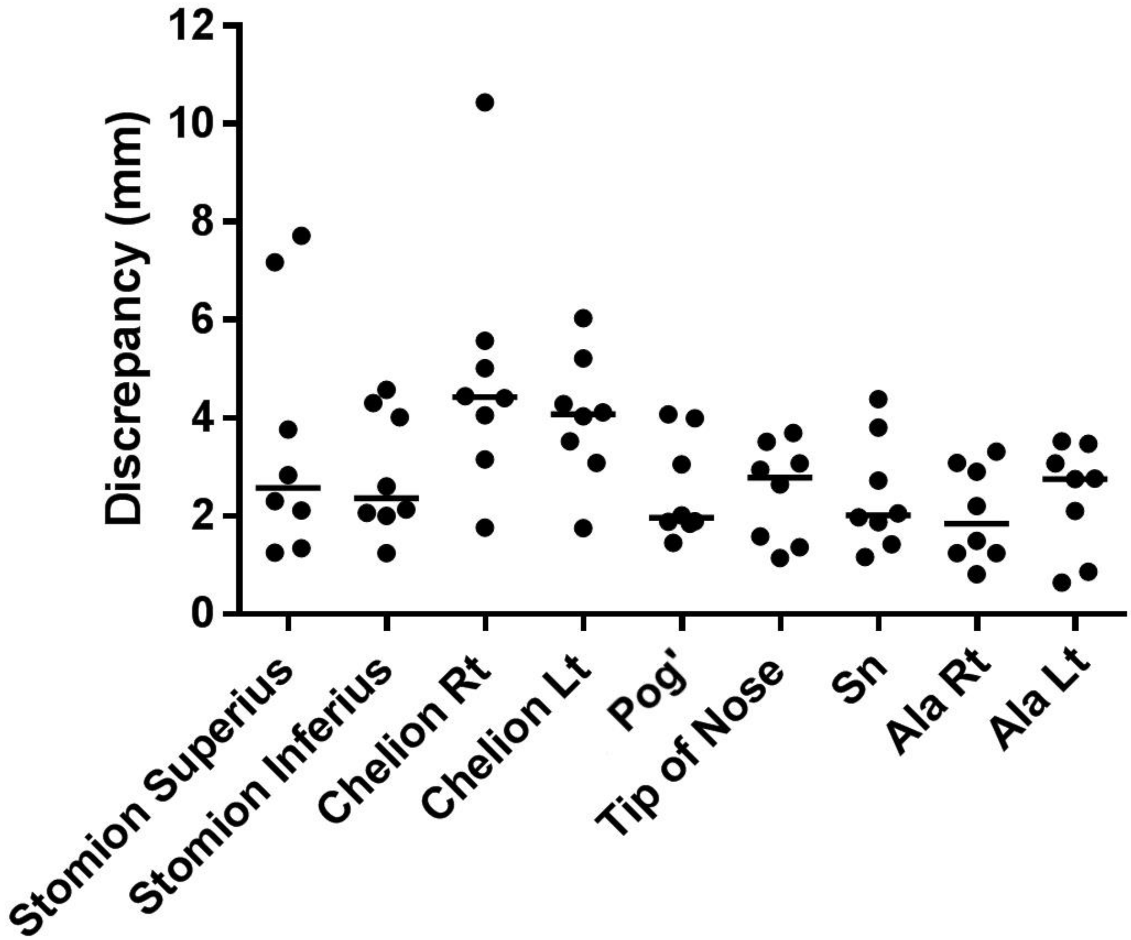
A. Quantitative Results

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

Table 4-1: Raw Data – Quantitative Measurements for Soft Tissue Landmark Discrepancies Between Predicted and Actual Outcomes

Pt #	Stomion Superius	Stomion Inferius	Chelion Rt	Chelion Lt	Pog’	Tip of Nose	Sn	Ala Rt	Ala Lt
1	3.77	2.61	4.41	5.22	1.45	1.15	2.72	1.24	0.65
2	2.31	4.58	5.58	6.03	1.89	1.58	1.17	2.90	2.75
3	1.34	1.24	3.15	3.09	1.84	2.94	1.97	1.49	2.11
4	1.26	2.07	4.06	3.53	2.02	3.69	1.43	2.20	2.77
5	2.12	2.13	1.77	1.75	4.07	1.36	1.87	0.81	0.86
6	7.18	4.30	10.44	4.29	3.06	3.52	3.81	3.09	3.08
7	2.84	2.01	4.45	4.12	3.99	3.08	2.06	1.24	3.47
8	7.72	4.02	5.02	4.04	1.90	2.64	4.38	3.32	3.53

Figure 4-1: Dotplot - Quantitative Measurements for Soft Tissue Landmark Discrepancies Between Predicted and Actual Outcomes



The mean measurements for the landmarks, as well as the standard deviations, are listed in the table below:

Table 4–2: Mean Discrepancies and Standard Deviations Among Subjects Between Surgical Predictions and Final Results for Specific Landmarks

	Stomion Superius	Stomion Inferius	Chelion Rt	Chelion Lt	Tip of Nose	Sn	Pog'	Ala Rt	Ala Lt
MEAN	3.57	2.87	4.86	4.01	2.53	2.50	2.43	2.04	2.40
STD DEV	2.53	1.25	2.54	1.30	1.03	1.00	1.14	0.97	1.11

Based on the mean measurements for the individual soft tissue landmarks, the right ala displayed the lowest average discrepancy at 2.04 mm +/- 0.97mm, followed by the left ala (2.40 mm +/- 1.11 mm), soft tissue pogonion (2.43 mm +/-1.14 mm), subnasale (2.50 mm +/- 1.00 mm), and the tip of the nose (2.53 mm +/-1.03 mm). A series of one-sample t tests were performed comparing the average discrepancy to a hypothetical value of 2.0 mm. Discrepancies for all of the landmark locations were significantly greater than 2 mm (so by extension, they were significantly greater than zero) and were statistically significant.

To obtain a more comprehensive view of the regional discrepancies of each patient, color maps were produced by superimposing the pre-surgical soft tissue prediction with the actual surgical soft tissue result (Figures 4-1 through 4-8). The color map key correlates the amount of discrepancy with the color of the area; i.e. green indicates less than 1.5 mm of discrepancy and dark red indicates 6 mm of discrepancy.

Figure 4-2: Color map of discrepancy for patient #1

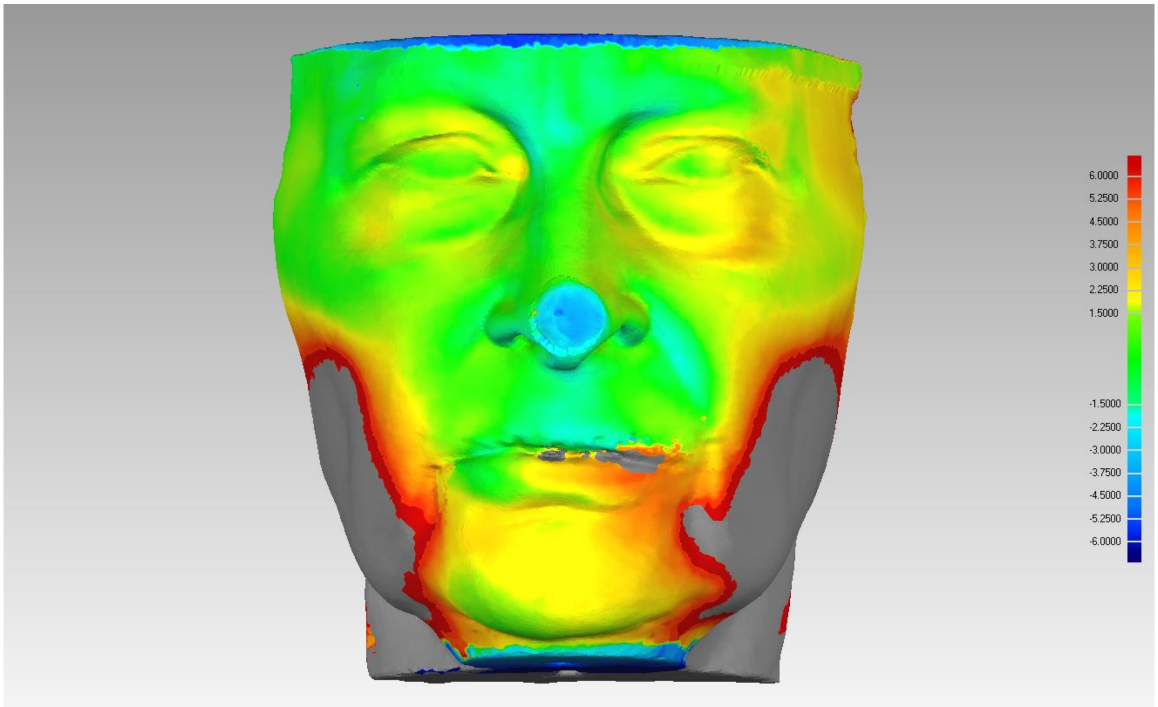


Figure 4-3: Color map of discrepancy for patient #2

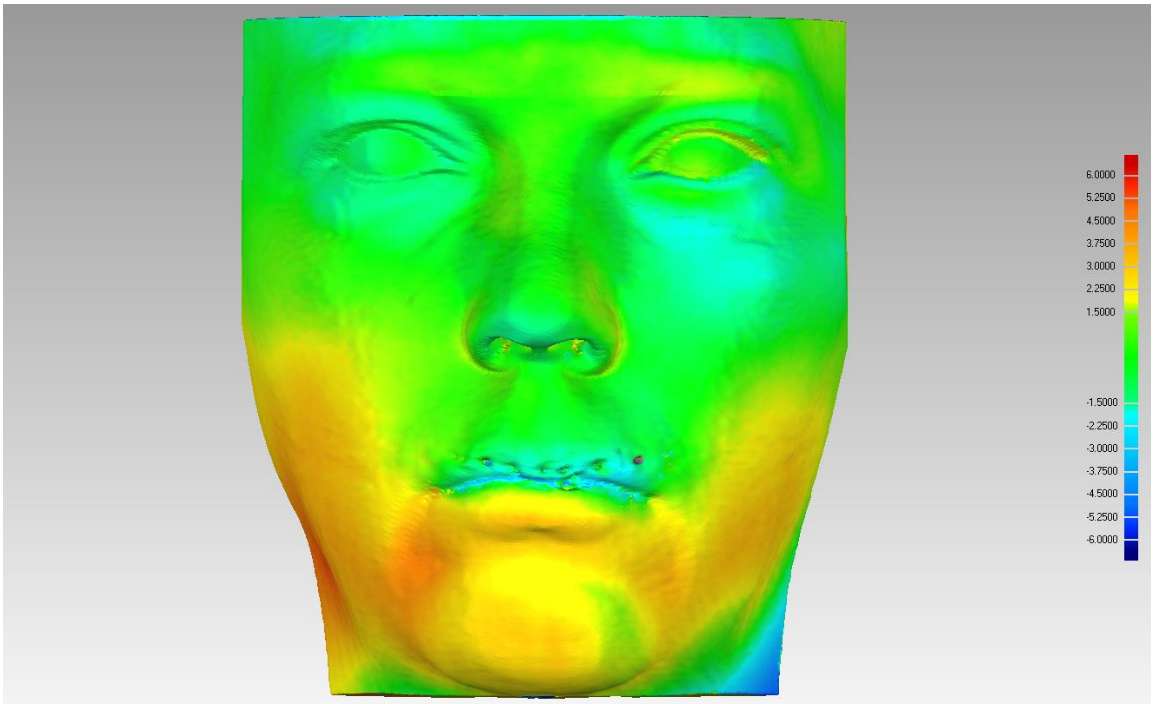


Figure 4-4: Color map of discrepancy for patient #3

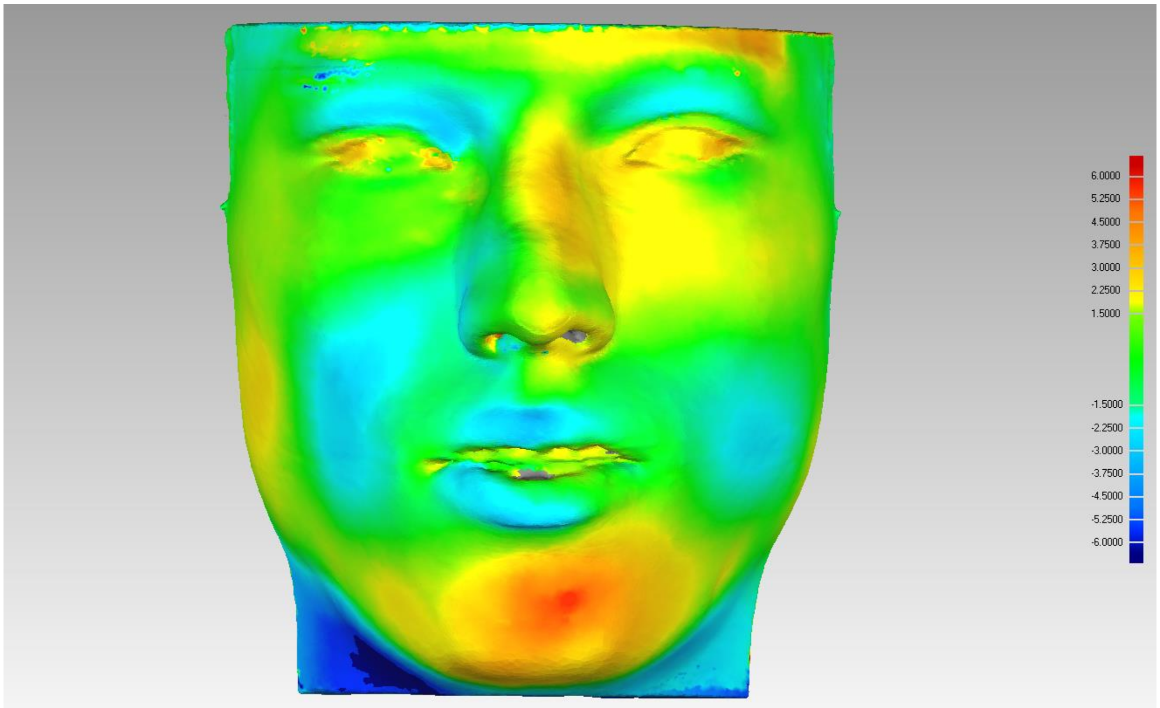


Figure 4-5: Color map of discrepancy for patient #4

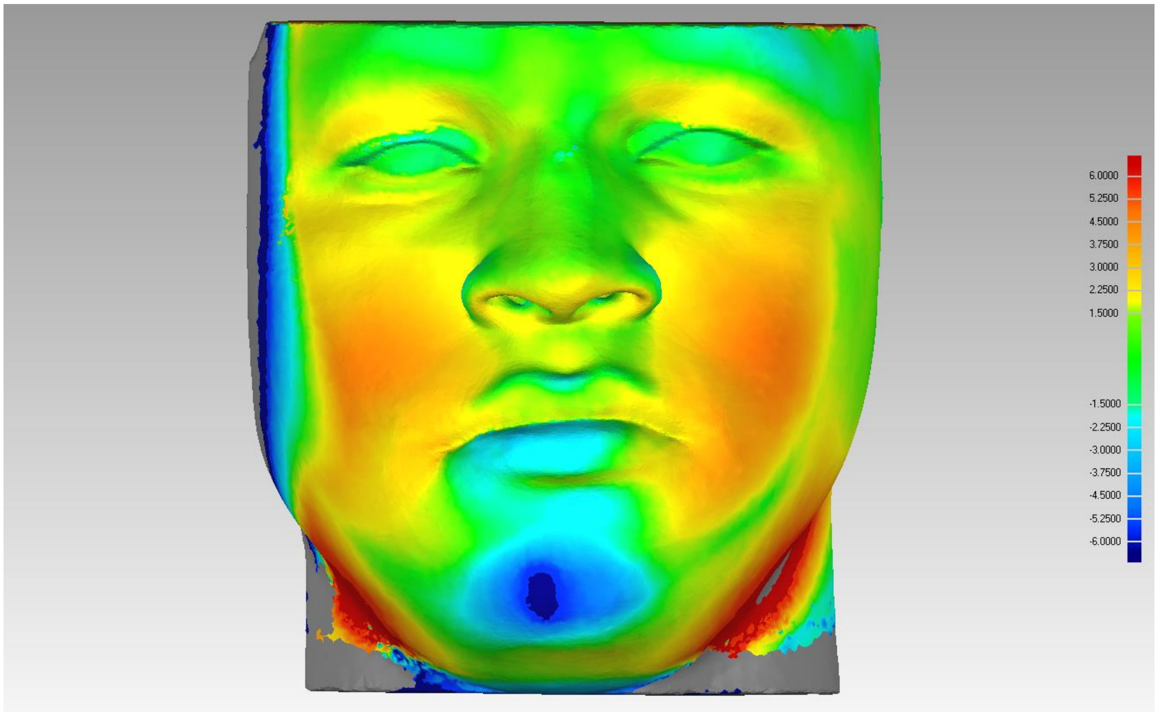


Figure 4-6: Color map of discrepancy for patient #5

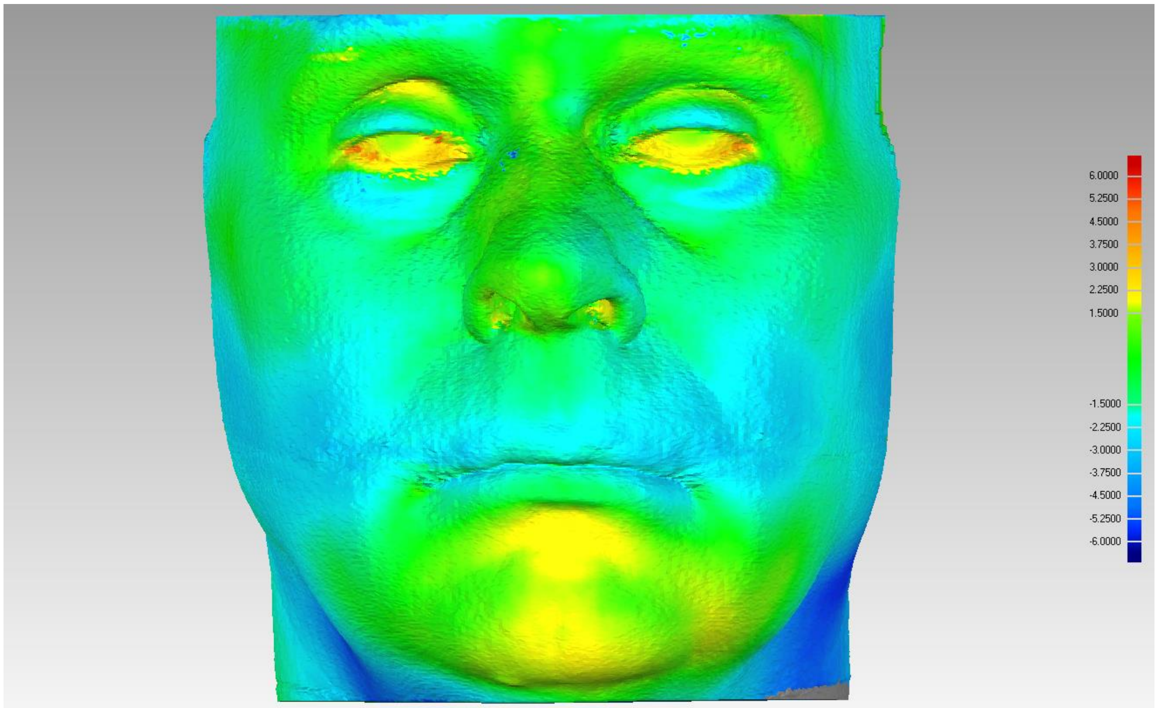


Figure 4-7: Color map of discrepancy for patient #6

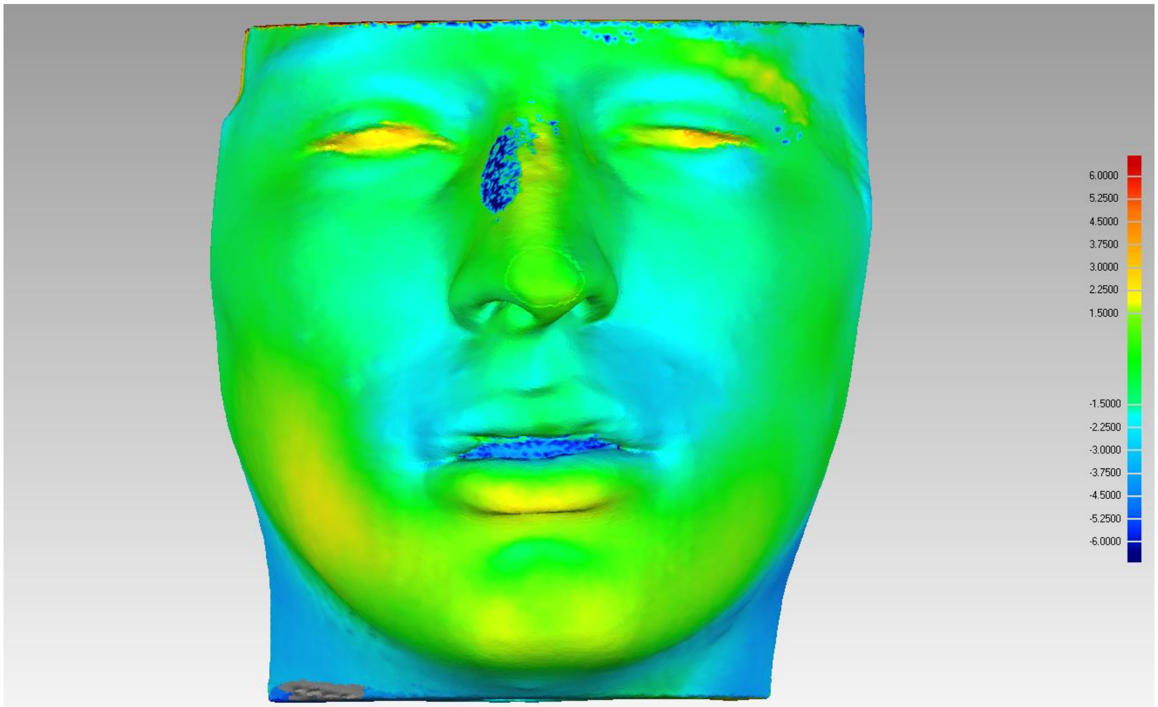


Figure 4-8: Color map of discrepancy for patient #7

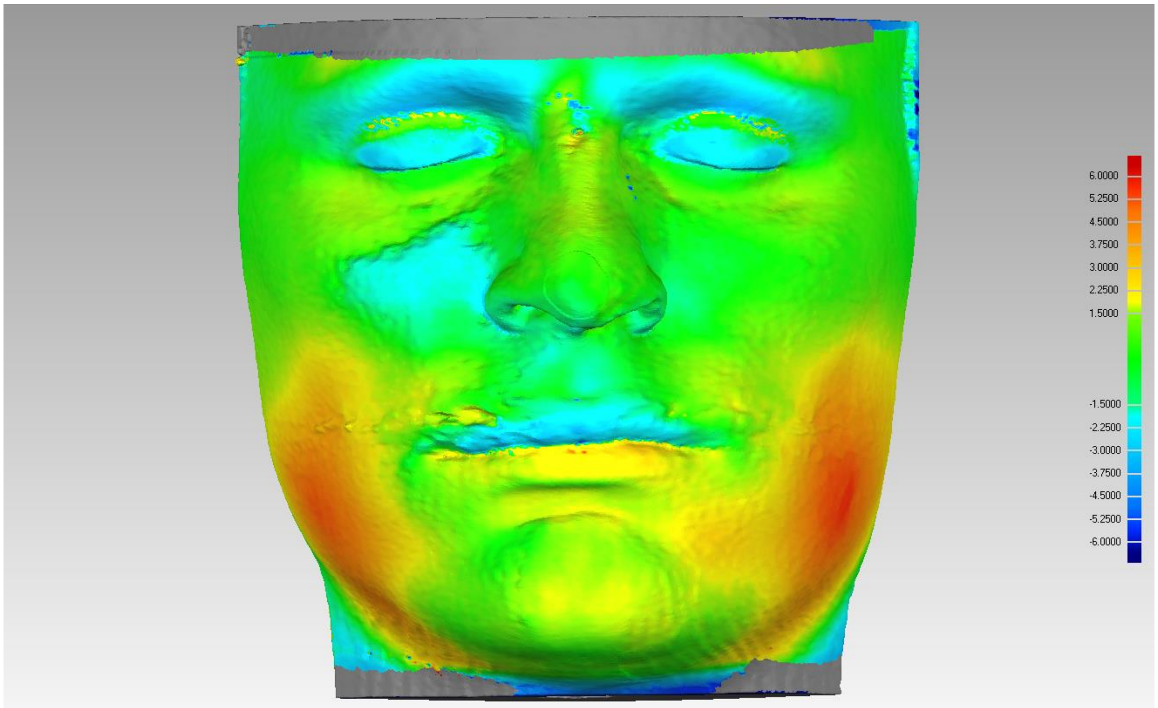
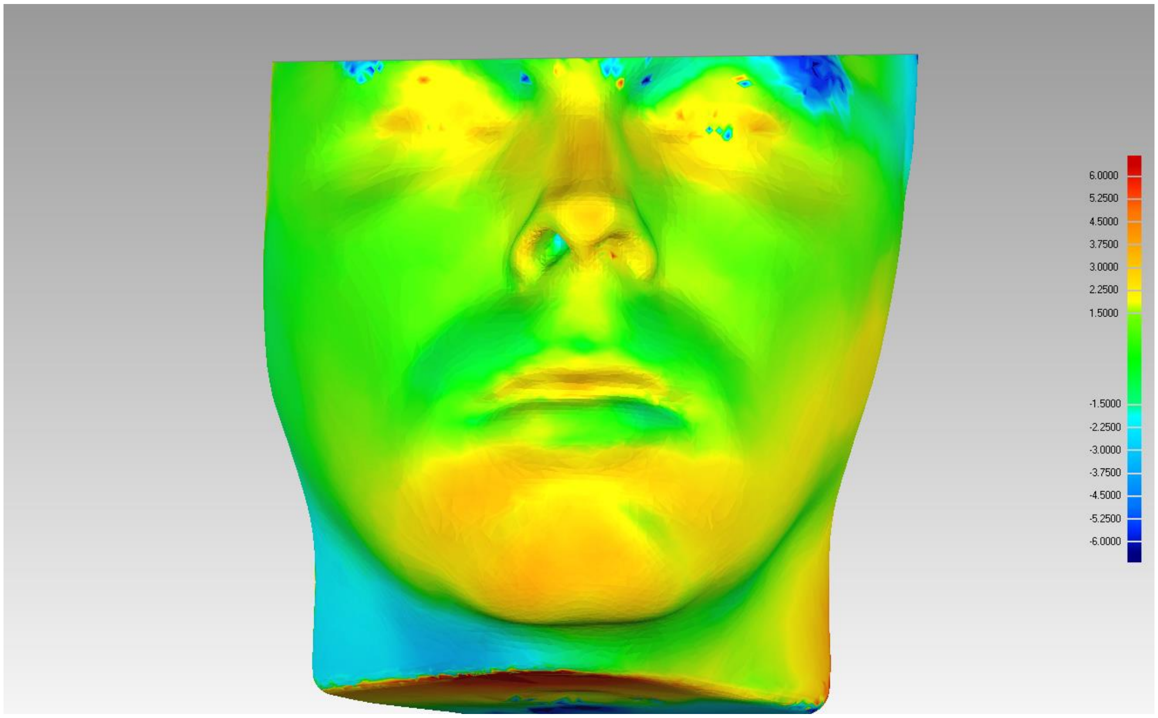


Figure 4-9: Color map of discrepancy for patient #8



B. Qualitative Results

A panel of five orthodontists assessed the resemblance of the pre-surgical prediction with the actual result. Their overall and specific landmark assessments were recorded (Appendix C). The individual mean Visual Analog Scale (VAS) scores (Table 4-3), overall mean VAS (Table 4-4), as well as the respective standard deviations are summarized in the tables below:

Table 4-3: Subjective Assessment Individual Means

Patient #	Overall	Stomion Superius	Stomion Inferius	Chelion	Tip of Nose	Subnasale
1	5.3	6.0	3.2	4.8	6.9	7.5
2	4.0	6.2	1.9	4.9	6.7	7.4
3	6.3	6.0	6.6	6.7	7.2	7.6
4	5.5	5.5	4.7	6.1	6.8	7.8
5	7.7	7.3	7.8	8.0	8.4	7.9
6	4.5	3.9	3.7	5.5	3.4	3.4
7	3.7	2.6	4.0	4.9	4.1	3.8

Table 4-4: Subjective Assessment Overall Means and Standard Deviations

	Overall	Stomion Superius	Stomion Inferius	Chelion	Tip of Nose	Subnasale
Mean VAS	5.3	5.4	4.6	5.8	6.2	6.5
STD DEV	1.4	1.6	2.0	1.2	1.8	2.0

The panel assigned a mean overall VAS score of 5.3, a fairly neutral result. The panel found the most concordance between the prediction and the final result in the region of subnasale, assigning a VAS score of 6.5, followed by the tip of the nose, with a VAS score of 6.2. The panel was most critical of the position of the lower lip, followed by that of the upper lip. Individually, the predictions for Patient #7 (3.7) and #3 (4.0) were scored as the most inaccurate while the predictions for Patient #5 (7.7) and #3 (6.3) were the most accurate. The panel preferred the actual surgical result over the soft tissue prediction in 77% of the cases.

V. DISCUSSION

In this study, predictions with Mimics® software proved to be inaccurate with only 31% of points falling within 2 mm and 44% within 3 mm of discrepancy between the prediction and actual result. There was difficulty in accurately predicting the right chelion (4.86 mm average discrepancy), left chelion (4.01 mm average discrepancy) and stomion superius (3.57 mm average discrepancy). The panel of experts gave an average overall rating of 5.3, indicating a moderate resemblance and was most critical of the lower lip, followed by the upper lip. As Dr. Cummins mentioned in his thesis, it is possible that the panel's assessment was more impacted by differences in lip morphology caused by the surgery than the bodily position of the lips alone (2014).

There were a number of factors that contributed to some of the soft tissue findings. This study altered the superimposition process performed by Dr. Cummins, which could be an explanation of why 68% of the previous study's points versus only 31% of the current study's points fell within 2 mm. The virtual objects were created in a similar manner, but the previous study only measured the antero-posterior distance between the landmarks (Cummins, 2014). The current study's algorithm calculated the distance between the landmarks in all three planes of space, which proved to be a larger distance.

An important point is that many of the patient's post-operative CBCT's were taken within a month of the surgery date, which would have exhibited more edema than those taken farther from surgery (the CBCT scans varied from 1 week to one year). In fact, the PI opted to exclude Patient #8 from the Qualitative Assessment shown to the panelists due to the incredible amount of residual edema (one week post-surgery). Since each patient's individual physiology responds differently to surgical trauma, this could contribute to the variability of post-operative healing.

Also, not all of the patients in both the pre-surgical and final CBCT scan may have been in natural repose and there were various degrees of mentalis and lip strain that could have influenced soft tissue position. Although the goal is natural head position, some of the patients may have changed their head position and lip posture due to their respective surgeries (Moorrees and Kean, 1958). In addition, because this was a retrospective study, there was no known uniformity among the radiology technicians, so techniques and patient coaching may have differed.

Another factor that could have impacted the discrepancy averages was the potential for operator error while placing the landmark points in Mimics®. The software is not easily manipulated and in order for any points to be adjusted or changed, the operator must place all points again; i.e. one may not manipulate individual points as needed. Also, it was especially difficult to place points at the corners of the mouth and at the upper and lower lip because of surface discrepancies. A majority of CBCT's made for pre-surgical records before orthognathic surgery had increased scatter due to the presence of appliances on their teeth at this time point. As most orthodontists have seen in their radiographs and CBCT's, blurriness appears in areas where metal may be located in the image. The surface artifacts could also be caused by lower quality scans, but scatter is apparent in these scans, as well. The scatter would diminish the ability to clearly see and accurately indicate landmarks.

It is also important to note that soft tissue changes accompanying maxillary surgery has proved to be more difficult to predict than mandibular surgery, regardless of the magnitude of the movement or the type of surgery. Much of the variability of the nasolabial angle and the upper lip come from the neuromuscular tone and any adjunctive soft tissue procedures that may accompany the surgery (eg. rhinoplasty, V-Y cheiloplasty). The vermilion border of the upper lip typically advances horizontally with both a rotational and a translational movement around subnasale in a ratio of soft tissue to bone that ranges from 0.33:1 to 0.9:1. Thinning and shortening of the upper lip, nasolabial angle decrease, widening of the alar base, nasal tip rotation, and autorotation of the mandible that influence the lower lip and chin are all soft tissue changes that may be seen in a maxillary advancement, each uniquely contributing to the outcome and confounding the results (Miloro *et al*., 2004).

Lastly, a larger, more ideal sample size may have allowed the exclusion of patients who had their post-surgical CBCT taken less than six months after surgery, patients who had lower quality scans, or patients who exhibited any lip strain on the CBCT.

Although there was a significant difference between the actual and predicted soft tissue outcomes, it is important to ask if these results are clinically significant. Would these predictions still be useful for patients? Orthodontists are trained experts in their field and are accustomed to detecting millimeter differences, but it would be interesting to get both a general dentist and layperson perspective as an additional qualitative measure. The expert panel preferred the actual outcome, and it is possible that the patient would gain an understanding of the surgery with the prediction but would reap even more satisfaction from the actual outcome. In a randomized clinical trial, Phillips et al. found that patients who viewed a pre-surgical prediction prior to surgery had greater overall satisfaction with their surgical outcome, as well as a feeling of better communication with their respective doctors (Phillips *et al*., 1995). Sarver *et al*. found that 72% of orthognathic surgery patients who viewed pre-surgical predictions in the planning stages indicated that the actual results were as good as or better than the generated two-dimensional prediction (1998). Even with the perceived inaccuracies, these predictions may still be valuable for patient education.

VI. CONCLUSIONS

1. In this study, predictions with Mimics® software were inaccurate. Only 31% of landmarks identified among subjects exhibited a discrepancy of 2 mm or less between the predictions and the final outcomes. However, 44% of landmarks exhibited a discrepancy of 3 mm or less between the predictions and the final outcomes.
2. The panel of experts gave an average overall rating of 5.3, indicating a moderate resemblance and was most critical of the lower lip, followed by the upper lip. It is possible that the panel's assessment was more impacted by differences in lip morphology caused by the surgery than the bodily position of the lips alone. The software may be able to more correctly predict the morphology of the soft tissue rather than the tissue's bodily position
3. There was weakness in accurately predicting the right chelion, left chelion, and stomion superius.
4. Experts preferred the overall esthetics of the post-surgical actual result 77% of the time when compared to the pre-surgical prediction.
5. Experts perceived the lower lip to be the least accurate region in the pre-surgical prediction.
6. Additional studies utilizing post-surgical CBCT's that are at least six months post-surgery would be beneficial.

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 7 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 seven soft tissue regions:

1.)Upper Lip

2.)Lower Lip

3.)Corners of the mouth

4.)Tip of Nose

5.)Subnasale

To assess each of the 7 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 ____ 10

No resemblance   Excellent resemblance

You will be given one and a half minutes to assess each subject, though if you feel as if you need more time to give 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. Lastly, 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 to record your assessments. Please let the presenter know if you have any additional questions prior to the start of the presentation. "

Appendix B. Qualitative Assessment Visual Analog Scale Worksheet

Patient 1

Overall Similarity

No resemblance (0) ———————————————— Excellent resemblance (10)

Upper Lip

No resemblance (0) ———————————————— Excellent resemblance (10)

Lower Lip

No resemblance (0) ———————————————— Excellent resemblance (10)

Corners of the mouth

No resemblance (0) ———————————————— Excellent resemblance (10)

Tip of nose

No resemblance (0) ———————————————— Excellent resemblance (10)

Subnasale

No resemblance (0) ———————————————— Excellent resemblance (10)

Indicate with an "X" which representation you believe to be more esthetic:
Actual Final Result_____
Presurgical Prediction _____

Appendix C. Raw Data – Qualitative Assessments

Judge_1	Overall	Upper Lip	Lower Lip	Chelion	Tip of Nose	Sn	Actual or Pred
1	4.0	5.5	2.0	2.6	6.3	5.6	Actual
2	1.9	5.7	2.1	2.2	6.2	6.3	Actual
3	4.3	6.2	4.3	3.1	6.3	6.3	Actual
4	4.4	5.9	4.3	3.4	5.3	7.0	Actual
5	6.9	6.9	6.8	5.7	7.3	7.3	Actual
6	3.0	3.4	3.7	4.1	3.6	2.7	Actual
7	3.1	3.2	3.2	3.1	3.5	3.8	Predicted
Judge_2							
1	6.7	6.6	5.7	2.7	5.2	8.4	Actual
2	5.2	8.2	2.1	5.3	7.6	7.5	Actual
3	8.4	7.6	8.3	8.4	8.1	8.4	Actual
4	8.6	7.3	8.7	7.4	7.3	8.1	Actual
5	9.5	8.9	9.4	8.4	9.2	8.3	Predicted
6	7.1	4.1	5.1	6.3	4.8	4.0	Actual
7	4.5	3.5	7.3	7.4	5.3	2.8	Predicted
Judge_3							
1	5.1	3.2	2.3	7.7	8.7	8.5	Actual
2	2.4	2.2	0.5	2.9	6.0	7.5	Actual
3	3.2	2.2	7.8	6.4	7.7	9.3	Actual
4	4.1	1.8	1.9	9.1	8.0	9.0	Actual
5	7.1	7.3	6.3	9.1	8.7	7.9	Predicted
6	6.0	3.9	4.3	8.3	4.4	6.1	Actual
7	6.2	1.9	3.6	6.8	4.3	4.7	Predicted
Judge_4							
1	7.0	6.8	3.0	3.8	5.9	6.8	Actual
2	7.8	7.4	2.5	7.1	5.9	7.7	Actual
3	9.1	8.3	6.1	8.2	8.4	8.2	Actual
4	7.0	6.8	5.9	5.6	5.9	6.8	Actual
5	7.8	5.9	8.3	8.0	8.4	8.0	Actual
6	3.3	2.4	1.7	5.8	1.8	1.5	Actual
7	0.4	0.6	0.6	1.0	0.7	0.5	Predicted
Judge_5							
1	3.5	7.8	2.9	7.4	8.4	8.3	Actual
2	2.9	7.5	2.3	7.2	7.6	7.8	Actual
3	6.6	5.9	6.6	7.2	5.4	5.9	Actual
4	3.6	5.8	2.6	4.8	7.5	8.1	Actual
5	7.3	7.5	8.1	8.6	8.5	7.9	Predicted
6	2.9	5.6	3.6	3.0	2.2	2.5	Actual
7	4.3	3.9	5.5	6.0	6.9	7.0	Predicted

Appendix D. Software Script Used for Calculating Landmark Delta

Two scripts were written in Python® to accomplish the repetitive task of placing points on the pre- and post-surgical models, calculating the distance, and then recording the deltas between corresponding points. The Python® programming language that was utilized for this project is embedded in the Geomagic Studio 2014® application program interface (API) from 3D Systems®.

Corresponding points from both of the models were called into a function that calculated the delta of the points in three-dimensional space. The delta was calculated using the following formula that was a built in function in the Geomagic API:

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

As the delta for each pair of points was calculated, it was paired with an appropriate label and written to a .clv (constant linear velocity) spreadsheet file.

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