Research Article

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The Role of Virtual Surgical Planning in Increasing the Predictability in Orthognathic Surgery

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Abstract

Purpose: To evaluate our surgical outcomes by comparing our surgical plan to the outcome of the surgery and evaluate our efficacy using Virtual Surgical Planning and Medical Modeling software. Our aim is to determine the quality and validity of Virtual Surgical Planning when comparing pre-surgical plans with post-surgical outcomes.

Patients and Methods: A cohort study was conducted for patients who underwent orthognathic surgery at a single institution. Utilizing virtual plans and models, select points for the virtual plans were compared and superimposed with that of the actual surgical movements. The primary predictor variable were the pre-surgical virtual plans of movements; the outcome variable consisted of the actual post-surgical movements. Statistical analysis was computed via IBM SPSS Version 25 software utilizing a paired t-test assuming equal variance with alpha ($p < 0.05$). The sample of patients included those who had pre-operative and post-operative cone beam computed tomography scans, a virtual surgical plan, CAD/CAM splints, and LeFort I osteotomy and bilateral sagittal split osteotomy.

Results: The study consisted of ten patients between the ages of 18-51 years old. Pre and post surgical plans were superimposed and four points of measurement were compared along 3 dimensional planes. There were no statistical significant associations between the virtually planned and post surgical planned values.

Conclusion: Our results suggest that the use of virtual surgical planning in orthognathic surgery yields favorable and accurate surgical outcomes regarding rotational movements with minor degrees of discrepancies.

Keywords: Orthognathic surgery, Virtual surgical planning (VSP), Computer-assisted surgery, Three-dimensional imaging

Introduction

Orthognathic surgery is a procedure commonly performed to correct dentofacial deformities and malocclusion. Approximately 18% of the United States population have dental malocclusion issues that potentially justify surgical intervention [1]. Orthognathic surgery is most commonly a procedure surgically planned

to reposition the maxilla and/or mandible via LeFort I or intraoral vertical ramus osteotomy (IVRO) and/or bilateral sagittal split osteotomy (BSSO) balancing form and function through the use of precise measurements for optimal results.

Since the 1960s and 1970s, surgical planning methods

have not drastically changed for orthognathic surgery [2]. A series of steps is used to plan the surgery with each step adding an additional opportunity for error. The goal of any pre-surgical work-up is to minimize error in order for the actual surgery to yield favorable results. Traditionally, the conventional approach to surgical modeling utilizes two-dimensional cephalometric radiographs for planning operative movements to be utilized during surgery [3,4]. Recently, more surgeons are utilizing Virtual Surgical Planning (VSP) as opposed to hand tracing the surgical treatment objective and stone models. This is because VSP potentially minimizes time, cost, and human error that can arise when performing preliminary work-ups [3,5-7]. For example, VSP laboratory work for orthognathic surgery saves approximately two hours of laboratory time, money, and resources needed to fabricate splints and enact model surgery [5,6]. The purpose of this study was to evaluate the efficacy and utility in using VSP and Medical Modeling software in regards to orthognathic surgery. Our aim is to determine the quality and validity of VSP when comparing pre-surgical plans with post-surgical outcomes. Our null hypothesis is that there is no statistical significance for those who received orthognathic surgery when comparing surgical outcomes with the pre-surgical virtual plans.

Materials and Methods

Our cohort consists of ten patients between the ages of 18-51 years old who underwent orthognathic surgery at Case Western Reserve University, University Hospitals in Cleveland, Ohio between June 2009 and February 2015. All surgeries were performed with the same attending along with a resident. This retrospective study was approved by the Institutional Review Board (IRB). Inclusion criteria included, 1) pre-operative CBCT scans, 2) a virtual surgical plan, 3) CAD/CAM splint fabrication, 4) LeFort I osteotomy and bilateral sagittal split osteotomy, and 5) post-operative CBCT scanning within one week post-surgery. Patients who required prosthetic joint replacement were excluded. All patients at the institution received both standard and CAPP (computer aided surgical simulation) (Figure 1).

A standard orthognathic workup included alginate impressions with stone models mounted on a semi-adjustable articulator in centric relation, intraoral and extraoral photographs, and extraoral soft & hard tissue measurements and facial analysis. The software utilized for the surgical plans was VSP Medical Modeling and Dolphin Imaging.

Before surgery begins, a cone beam computed tomography (CBCT) scan is taken of the patient and

uploaded with stone models to Medical Modeling Software systems that allows manipulation of jaw movements and simulation of the surgery in three dimensions. The surgery is completed and within a week, a post-operative CBCT is taken so that statistical data can be acquired by superimposing pre-and post-surgical outcomes. By doing so, we can quantitatively assess the predictive value of VSP in our own institution.

Figure 1: A schematic diagram of the stages for preliminary outpatient work-up and simulation for surgical planning of orthognathic surgery.

Scanning was completed using CB Mercury from Hitachi with 0.37 voxel size of 512 slices. All scans were completed at the same facility with the same operator. Stone models were sent and photographs with CBCT scans were uploaded to the medical modeling technicians. A virtual meeting was held to discuss the surgical plan. Bite splints were fabricated by medical modeling and used perioperatively. Post-surgical imaging was obtained at the one-week follow up appointment and comparison of predicted outcomes to post-surgical outcomes were completed by superimposition according to standard medical modeling protocol (Figure 2).

Outcome data was assessed by calculating accuracy using Box and Whisker plots of the superimposed scans determining difference planned to post-operative. Null hypothesis was assessed by using paired t-test comparing virtually planned to post-operative values. The points that were assessed for mean distance difference were the following: A-point, midline upper central incisor, B-point, and the midline lower central incisor. Measurements were obtained for the anteroposterior (A/P), superio-inferior (S/I), and yaw dimensions. Only data points from hard tissue structures were measured.

Success criteria for linear movement mean differences were set to be less than 2 mm and mean distance difference (MDD) set at less than 0.5 mm. These set points were chosen as Tucker et al. has demonstrated that obtaining a

Figure 2: 3D superimposition of planned surgical outcome (Green) and actual surgical outcome (Red).

difference of less than 2 mm is not clinically significant [8] and due to the standard of error of the CBCT scan's spatial resolution to be 0.5 mm.

Results

We utilized 3-dimensional imaging to collect data points of hard tissue landmarks from cone-beam computed tomography (CBCT) scans that were taken within one week following the surgical operation. We superimposed pre-surgical and post-surgical scans; from here, we gathered the difference of the hard tissue landmarks enabling us to have a quantitative measure of how much our predicted surgical outcomes correlated with our actual surgical outcomes. Four measurements were selected for data analysis: A-point, Midline upper incisor, B-point, and Midline lower incisor were measured. Data analysis included the comparison of the planned virtual surgical movements to postsurgical outcomes using points of measurement along the Antero-Posterior, Superior-Inferior, and Yaw dimensions. Data from the planned and post-operative values recorded by Medical Modeling were extracted and organized into a Microsoft Excel spreadsheet to include the patient and his/her four measured points in the three spatial movements.

Outcome data was assessed by calculating accuracy using Box and Whisker plots of the superimposed scans determining difference planned to post-operative. Our mean differences of A-point were 0.027 mm (SD=1.83), -0.12 mm (SD=1.04), -0.064 mm (SD=1.12) for A/P, S/I, Yaw, respectively (Figure 3,4 and 5).

Figure 3: A visual reference of the difference between the planned to post-operative measurements in the Antero-Posterior dimension.

Figure 4: A visual reference of the difference between the planned to post-operative measurements in the Superior-Inferior dimension.

Figure 5: A visual reference of the difference between the planned to post-operative measurements in the Yaw dimension.

Our findings indicate that there is neither statistical nor clinical significance of our surgical plan and the outcome of our surgery. Consistent values were calculated for all landmark points in both the maxilla and mandible with values being less than 2 mm in difference. As noted in the literature, a standard deviation of 2 mm is consistent with our findings [2,8,9].

We also used the IBM SPSS Statistics Version 25 software for statistical analysis. A two sample *t*-test assuming equal variance with alpha ($p < 0.05$) was used. Along the A/P dimension: A-point, $p = 0.66$, Midline Upper Incisor, $p = 0.91$, B-point, $p = 0.59$, and Midline Lower Incisor, $p = 0.90$. The S/I dimension obtained *p*-values of A-point, $p = 0.72$, Midline Upper Incisor, $p = 0.98$, B-point, $p = 0.46$, and Midline Lower Incisor, $p = 0.39$. The *p*-values for Yaw

were as follows: A-point, $p = 0.11$, Midline Upper Incisor, $p = 0.13$, B-point, $p = 0.76$, and Midline Lower Incisor, $p = 0.49$ (Tabel 1).

The mean differences we obtained for A-point in all three rotations of movement (A/P, S/I, and Yaw) were: 0.27mm (SD=1.83), -0.12mm (SD=1.04), and -0.64mm (SD=1.12). The mean differences obtained for the Midline Upper Incisor in all three rotational movements were: A/P = 0.07mm (SD=1.75), S/I = -0.01mm (SD=1.11), and Yaw = -0.73mm (SD=1.39). The mean differences obtained for B-point in all three rotations (A/P, S/I, and Yaw): -0.36mm (SD=2.07), -0.32mm (SD=1.22), and -0.17mm (SD=1.54). The mean differences for Midline Lower Incisor for A/P, S/I, and Yaw rotations were: 0.08mm (SD=1.95), -0.36mm (SD=1.24), and -0.30 (SD=1.30) (Table 2).

Discussion

This study was conducted because post-surgical outcomes may not always reflect the pre-surgical plans, thus there is a need to assess accuracy. Unlike traditional methods of planning orthognathic surgery, virtual surgical planning utilizes computer software to simulate the surgery in three-dimensional technology. The basic sequence of VSP are as follows: (1) outpatient work-up and data acquisition, (2) pre-surgical planning and splint fabrication, (3) surgery and intraoperative navigation, and (4) post-operative analysis and assessment. The development of three dimensional radiographic scans and computer-assisted technology provides us with tools to analyze our outcomes. The findings of our surgical outcomes performed for ten patients who underwent orthognathic surgery at

Table 1: The average of planned virtual movements and actual surgical movements of four anatomical points (A-point, Midline Upper Incisor, B-point, and Midline Lower Incisor) in three planes of rotation (Pitch, Roll, and Yaw).

Anatomical Landmark points		Mean of Planned Movements (mm) $\pm$ SD	Mean of Actual Movements (mm) $\pm$ SD
A point	Antero-posterior (A/P)	4.57 $\pm$ 3.39	4.31 $\pm$ 2.14
	Supero-inferior (S/I)	-0.62 $\pm$ 0.93	-0.50 $\pm$ 1.68
	Yaw	0.12 $\pm$ 1.72	0.75 $\pm$ 1.20
Midline Upper Incisor	Antero-posterior (A/P)	4.20 $\pm$ 3.25	4.14 $\pm$ 2.35
	Supero-inferior (S/I)	-0.45 $\pm$ 1.05	-0.44 $\pm$ 1.84
	Yaw	0.21 $\pm$ 1.15	0.93 $\pm$ 1.27
B point	Antero-posterior (A/P)	-1.60 $\pm$ 4.19	-1.23 $\pm$ 4.78
	Supero-inferior (S/I)	-1.07 $\pm$ 2.93	-0.65 $\pm$ 3.74
	Yaw	-0.07 $\pm$ 2.49	0.17 $\pm$ 3.41
Midline Lower Incisor	Antero-posterior (A/P)	-1.45 $\pm$ 2.73	-1.53 $\pm$ 3.54
	Supero-inferior (S/I)	-1.11 $\pm$ 3.24	-0.76 $\pm$ 4.08
	Yaw	0.01 $\pm$ 2.24	0.31 $\pm$ 3.14

Table 2: Comparison of virtual surgical planned values with that of actual surgical outcomes of four anatomical points in three dimensions of movement.

Anatomical Landmark Point of Reference		Mean Distance Difference (mm)	Standard Deviation (SD)	Standard Error (SE)	P-value
A point	Antero-posterior (A/P)	0.027	1.83	0.58	0.659
	Supero-inferior (S/I)	-0.12	1.04	0.33	0.722
	Yaw	-0.64	1.12	0.35	0.105
Midline Upper Incisor	Antero-posterior (A/P)	0.07	1.75	0.55	0.906
	Supero-inferior (S/I)	-0.01	1.11	0.35	0.982
	Yaw	-0.73	1.39	0.44	0.133
B point	Antero-posterior (A/P)	-0.36	2.07	0.65	0.593
	Supero-inferior (S/I)	-0.43	1.2	0.38	0.292
	Yaw	-0.24	1.47	0.47	0.626
Midline Lower Incisor	Antero-posterior (A/P)	0.08	1.95	0.62	0.901
	Supero-inferior (S/I)	-0.36	1.24	0.39	0.388
	Yaw	-0.3	1.3	0.42	0.487

Case Western Reserve University - University Hospitals were assessed for accuracy. The accuracy of bi-maxillary surgery was assessed using linear measurements in the Antero-Posterior (A/P) dimension, the Supero-Inferior (S/I) dimension, and yaw. The linear measurements were assessed by superimposing pre-surgical virtual imaging with that of post-surgical CBCT imaging and calculating the difference of selected anatomical points.

Tucker et al., has demonstrated that obtaining a difference of less than 2 mm is not clinically significant [3]. Thus, based on our findings and with the support of previous studies, virtual surgical planning is an accurate and useful tool when we compare pre-surgical plans with post-surgical outcomes. In accordance with the literature, this computer-aided approach better enables the surgical team to visualize all aspects of the craniofacial skeleton which ultimately yields more precise surgical planning, removes the likelihood of errors, and offers the ability to easily modify movements to suit the patient via the predictability of outcome assessment [3,10].

The clinical evaluation of our study determines that the minor differences between our values are clinically insignificant. There is a slight increase in deviation among mandibular values with a standard deviation moderately greater than 2.00 mm for the A/P dimension of B-point for our study. This may be due to more variability and greater discrepancy among mandibular measurements with a minor greater degree of difficulty in locating reproducible landmark points on the mandible when compared to point landmark selection designated on the maxilla [9].

There is unpredictability with any surgery, however, virtual surgical planning is a promising approach that enables the surgeon and surgical team to have more predictability and optimal success in post-surgical outcomes without compromising the quality or validity of surgical plans. In addition, previous studies have also shown that VSP saves time, as well as money [5,6]. In 2006, Xia et al utilized a computer-aided surgical simulation technique that required four hours less for surgical planning and saved approximately \$1,500 in materials and scanning costs; furthermore, the patient's time was reduced to half in regards to planning outpatient work-ups [7]. Virtual surgical planning also allows different scenarios to be discussed and simulated by the surgical team. Consequently, several treatment planning options are able to be presented simultaneously due to the virtual repositioning and construction. An added benefit to VSP is the instantaneous evaluation of dental arches, occlusion, and dento facial skeletal structures.

There are current limitations that exist with our study. Due to the nature of it being a retrospective study, we are not able to determine causation. Therefore, we cannot determine that virtual surgical planning directly causes our results to have better outcomes, only that our outcomes correlate with the use of virtual surgical planning. In addition, this is a single center study with limited patient population. In the future, to better solidify our findings, we must gather a larger patient population sample size.

There is no definitive protocol for this surgical approach on how data should be presented, hence the variability among reports in the literature [3,4,9,11]. Systematic

reviews do exist, however, meta analysis is not able to be performed due to the variability among computer algorithms which negate standardization across the field [8]. We hope that this study can provide another way to analyze and present our findings.

Conclusion

In conclusion, the novel approach of utilizing virtual surgical planning in orthognathic surgery yields favorable and accurate surgical outcomes in regards to rotational movements. Even with minor degrees of discrepancies, the virtual planned values coincide to a negligible degree with the actual outcomes obtained post-surgery. Based on our findings, virtual surgical planning is an accurate and useful tool for the planning of orthognathic surgeries.

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