Accuracy of Computer-Aided Surgical Simulation (CASS) Planning Program for Orthognathic Surgery in Skeletal Type III Relationship

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Abstract

Nowadays, the surgical prediction for orthognathic surgery using Computer-Aided Surgical Simulation (CASS) planning program has become the main trend in three-dimensional (3D) applications for patients with skeletal discrepancies. So, this study was aimed to assess the accuracy of surgical prediction by CASS planning program to treat two-jaw orthognathic surgery in skeletal type III non-growing patients. Nineteen participants were treated by orthodontic-orthognathic surgery. The first CBCT scans and 3D virtual model scans were presurgical recorded 2-4 weeks (T0). The simulation plans were generated by software, Simplant O & O, and were transferred to the operating room by 3D splints. The second CBCT scans were postsurgical recorded 2-6 weeks after surgical procedures or splint-off period. (T1). The differences between T0 and T1 were compared by linear and angular measurements relative to 3 planes, Frankfort Horizontal Plane (FHP), Midsagittal Plane (MSP), and Coronal Plane (CP), respectively, and statistically analyzed by one-sample t-test and intraclass correlation coefficient (ICC). For repeated measurement, ICC showed an excellent correlation (0.787–0.998). Statistically significant differences were found in U6L to FHP, L6R to MSP, PP to FHP, MP to FHP, and MP to MSP with P-value less than 0.05. The overall mean linear and angular differences were 0.57 mm and 0.93 degrees. The overall linear and angular differences were within the acceptable criteria which could be interpreted as clinical insignificance. The mean intraclass correlation coefficient was 0.94 for the simulation plans and 0.95 for the actual outcomes. The application of CASS planning program for two-jaw orthognathic surgery in skeletal class III patients had acceptable accuracy which facilitated diagnosis and surgical planning effectively.

***Keywords**: Skeletal Type III/ Orthognathic Surgery/ CASS*

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Introduction

Treatment of skeletal discrepancies in adult patients requires combined treatment of orthodontic and surgical procedures. The aims are not only for achieving normal occlusion but also for improving facial esthetics.[1,2] Because of the complex 3D anatomy of dentofacial structures, orthognathic surgery usually requires sophisticated presurgical planning to allow patients to be familiar with sudden and dramatic alterations brought by orthognathic surgery. Conventional planning methods for orthognathic surgery have a number of problems causing a less than ideal surgical result.[3-9] The development of CASS planning program shifts a paradigm in surgical planning for patients with skeletal discrepancies. Up to date, it has been reported in a prospective multicenter study to apply surgical guides as a template to properly transfer the designed simulation planning into the actual surgical positioning, thereby increasing the accuracy of the surgical result.[10]

In 2013, Chang et al.[11] assessed the accuracy of simulation and prediction of the computerized method of 3D simulation and prediction in orthognathic surgery (CASPOS) that they have

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developed which did not only enable clinicians to plan and simulate the surgical procedures, but also provides a bony guiding splint to allow surgeons to precisely position the bony segments into the planned location. Their CASPOS technique provides a novel approach for orthodontists and surgeons to accurately remedy patients with complex craniofacial discrepancies.

Nowadays, the development of 3D technology has increased use for diagnosis, analysis, data documentation, surgical planning for orthognathic surgery, and research. The application of 3D surgical prediction has now become the main trend in the 3D application for orthognathic planning. Nevertheless, no meta-analysis of the accuracy of CASS was reported due to the different prediction software, different landmark, and data interpretation. So, this study was aimed to assess the accuracy of CASS planning program (Simplant O&O™, Materialise Dental NV, Leuven, Belgium) in comparison with the actual outcomes in patients treated by bimaxillary orthognathic surgery.

Materials and Methods

Participants

The inclusion criteria were: 1) Thai patients who were older than 19 years at the Department of Orthodontics and Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Mahidol University; 2) skeletal type III relationship; 3) no congenital craniofacial deformities or trauma, and no history of head and neck surgery; and 4) required bimaxillary orthognathic surgery operated by one surgeon. The exclusion criteria were: 1) previous orthognathic surgery; 2) active temporomandibular joint disorder; and 3) periodontal disease. This study was approved by Mahidol University Institutional Review Board (MU-IRB) with COA. No. MU-DT/PY-IRB2016/035.

Nineteen patients (5 males and 14 females) were included which was calculated from the study of Chang et al.[11] (mean 1 = 0.74 ± 0.30, mean 2 = 1.15 ± 0.23). All patients were undergone bimaxillary orthognathic surgery which included bilateral sagittal split osteotomy (BSSRO) for mandibular setback and Le fort I osteotomy for maxillary advancement. All patients were older than 19 years at the time of surgery. Four to six weeks before surgery, a high-resolution CBCT scan (Planmeca Promax 3D Mid, Helsinki, Finland), and a 3D virtual model scan (R900 3D Scanner, 3Shape, Copenhagen, Denmark) of the plaster model were performed. Heads of participants were positioned with the Frankfort plane parallel to the floor, the midsagittal plane perpendicular to the floor, and teeth were occluded in centric relation. The CBCT data will be exported in a Digital Imaging and Communication in Medicine (DICOM) format on a CD-ROM for each patient. Postoperative CBCT scans were performed 2 - 6 weeks after orthognathic surgery on the day that the surgical splint was off.

Virtual surgical planning

The traditional assessment tools, such as clinical examination (history taking, extraoral examination, intraoral examination, and primary impression) and standardized photographs (intra-oral and extra-oral pictures, including dental occlusion and oblique, frontal, and profile views of the face) were used for planning. In addition, presurgical CBCT scans (T0) were performed 2-4 weeks before surgery and presurgical orthodontic preparation was completed with stabilizing wire. A postsurgical CBCT scan (T1) was performed 2-6 weeks after surgery. (Table 1)

Table 1 Time schedule for data collection

Period	Time	Data collection	Outcome from CASS
T0	2-4 weeks presurgically	CBCT, dental model scan	Surgical prediction (Prepared surgical outcome)
T1	2-6 weeks postsurgically	CBCT	Actual outcome

Three-dimensional virtual models were generated from CBCT data by segmentation using CASS planning program, Simplant O&O™ (Figure 1) as follows:

1. Presurgical CBCT scans were transferred to the planning software and were fused with 3D virtual dental models scanned from the R900 3D scanner by surface-based matching methods (Figure 2).

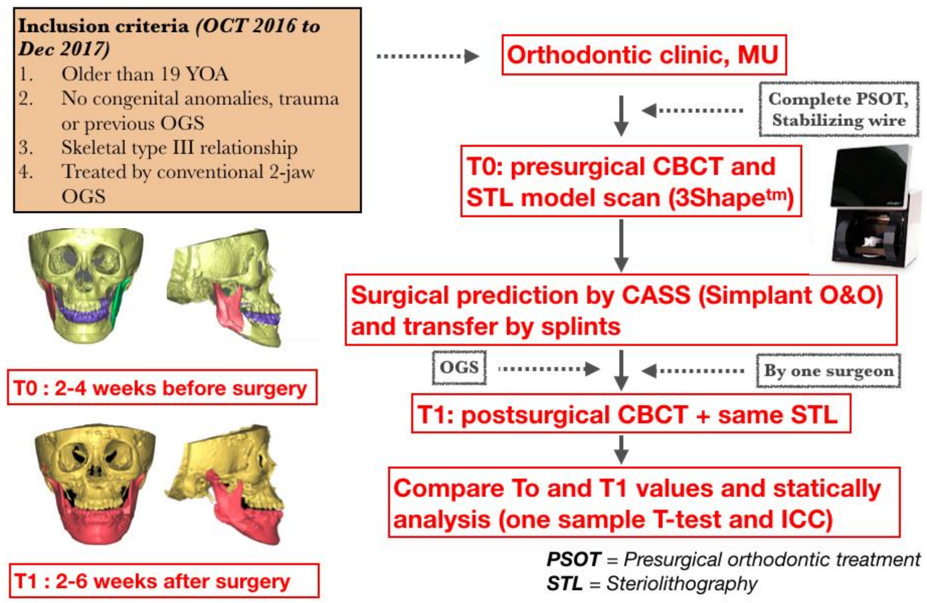

Figure 1 Overall processes of this study (YOA : year of age, OGS : Orthognathic Surgery)

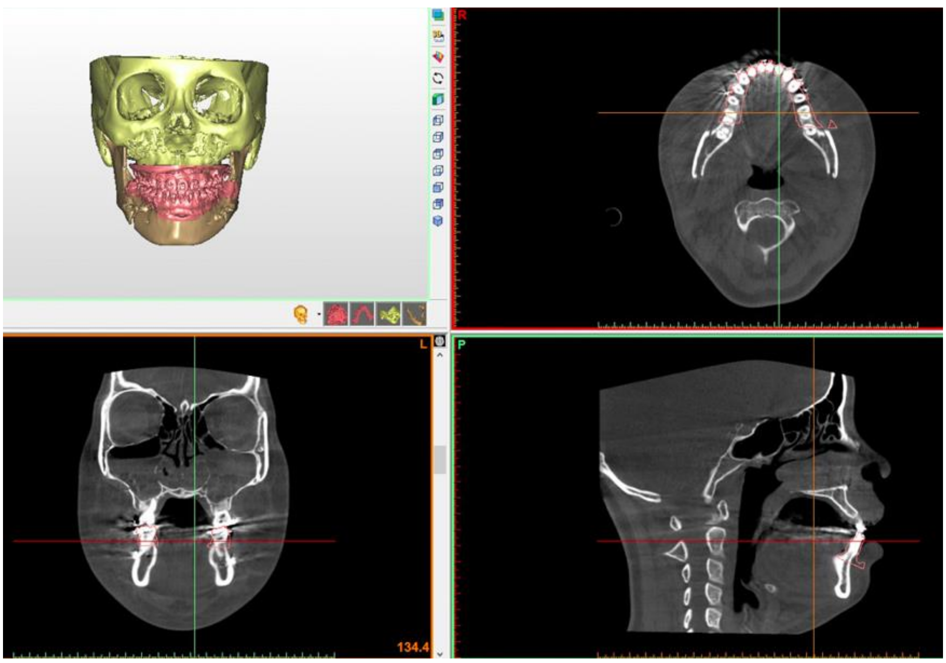

Figure 2 STL dental model scan was fused to virtual 3D skull by surface-based matching methods in 3 facial reference planes before identifying all selected landmarks.

Table 2 The definition of Landmarks and planes for measurement on T0 and T1

Point	Description
UI	Midpoint between upper central incisors
LI	Midpoint between lower central incisors
U6R	Mesiobuccal cusp of upper right first molar
U6L	Mesiobuccal cusp of upper left first molar
L6L	Mesiobuccal cusp of lower left first molar
L6R	Mesiobuccal cusp of lower right first molar
A	The deepest midline point in the curved bony outline from base to the alveolar process of maxilla
ANS	The tip of the bony anterior nasal spine in the median plane
B	The most posterior point in the outer contour of the mandibular process in the median plane
Pog	The most anterior point of the bony chin in the median plane
PP	Palatal plane (ANS to PNS)
FOP	Functional occlusal plane (L6R and L6L to LI)
MP	Mandibular plane (GoR and GoL to Me)
FHP	Frankfort horizontal plane (OrR and OrL to PoR)
MSP	Plane through S and N and normal to FHP
CP	Plane through S and normal to MSP and FHP

2. Six landmarks on 3D virtual dental models (Figure 3) were identified for the linear and angular measurement (T0) relative to three facial planes (Figure 4) including Frankfort Horizontal Plane (FHP), Midsagittal Plane (MSP), and Coronal Plane (CP). Four landmarks (A, ANS, B, and Pog) on the 3D virtual skull were also identified for the linear measurement (T0) relative to the Nasion perpendicular line (Nperp). Virtual surgical simulation planning was performed by one surgeon. The final simulation plans were sent to the CAD/CAM center and surgical splints (Dental LT Clear, Formlabs™) were fabricated by means of a 3D rapid-prototyping machine.

3. Postsurgical CBCT scans were performed 2-6 weeks after surgery on the day that the splint was off. The 3D virtual dental model was fused by surface-based matching methods and the same measurement of linear and angular differences (T1) relative to the same 3 planes.

Outcome evaluation

Twenty-two linear parameters and six angular parameters of T0 and T1 were obtained when comparing 6 dental landmarks (UI, LI, U6R, U6L, L6R and L6L) to 3 reference planes (FHP, MSP, and CP), 4 bony landmarks (A, ANS, B, and Pog) to Na perpendicular line (Nperp) and 3 planes (FOP, PP, and MP) to 2 reference planes (FHP and MSP), respectively. The discrepancies of individual landmarks and planes between simulation plans (T0) and actual outcomes (T1) were assessed by the difference in geographical locations and reported in terms of the differences in linear and angular measurement as shown in Table 3.

Statistical analysis

The accuracy of CASS planning program was evaluated by calculating the differences in linear and angular measurement of 22 linear parameters and 6 angular parameters between T0 and T1 and statistically analyzed by the one-sample t-test in order to assess the presence of significant differences between T0 and T1 of participants. Intraclass correlation coefficient (ICC) was done to evaluate the intra-observer reproducibility of the measurements.

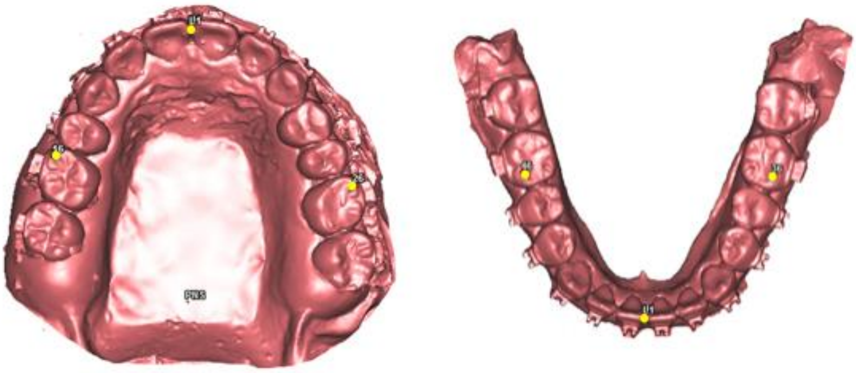

Figure 3 Six landmark identifications in 3D virtual dental model as UI, U6R, U6L, LI, L6R and L6L for 3D comprehensive evaluation of linear and angular measurement relative to three facial planes

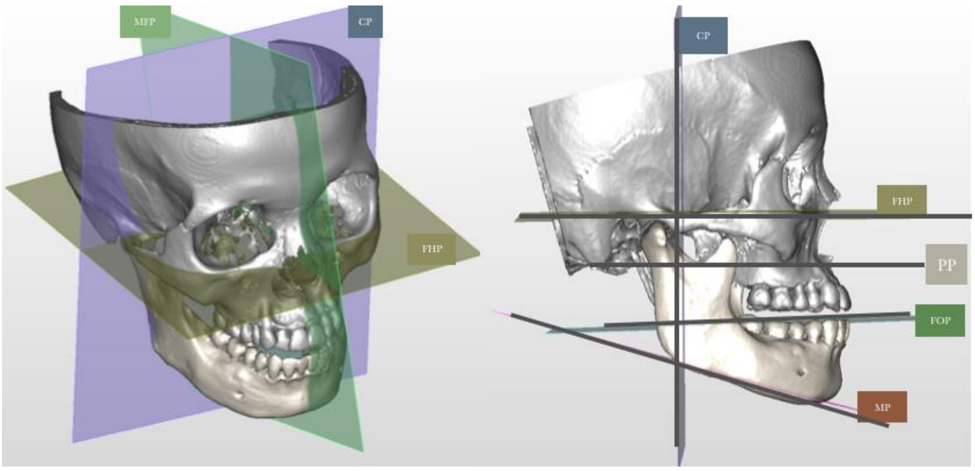

Figure 4 Three facial reference planes (MSP, CP and FHP)

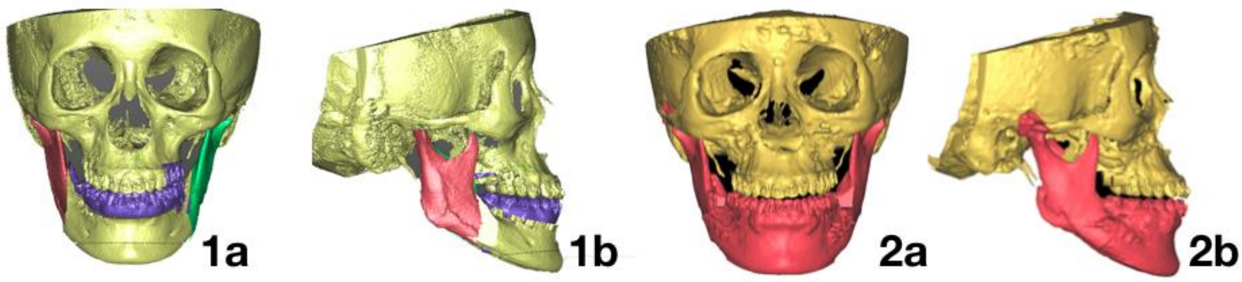

Figure 5 illustrated one sample underwent conventional 2-jaw orthognathic surgery in this study. The simulation plan (To) in frontal (1a) and lateral view (1b) and the actual outcome in frontal (2a) and lateral (2b) view, respectively.

Table 3 Mean differences of T0 and T1 measurement (* mean statistically significant different)

Linear and angular parameters	Mean difference (T1-T0)	SD	P-value	95% Confidence Interval	
				Lower	Upper
UI to FHP (mm)	0.51	2.84	0.448	-0.87	1.88
LI to FHP (mm)	1.09	3.31	0.178	-0.50	2.68
U6R to FHP (mm)	0.48	1.68	0.227	-0.33	1.29
U6L to FHP (mm)	0.95	1.76	*0.031**	0.98	*1.80*
L6R to FHP (mm)	0.56	2.36	0.316	-0.58	1.70
L6L to FHP (mm)	0.51	2.02	0.284	-0.46	1.49
UI to MSP (mm)	0.31	2.65	0.615	-0.96	1.59
LI to MSP (mm)	-0.19	2.47	0.741	-1.38	1.00
U6R to MSP (mm)	-0.44	3.01	0.532	-1.89	1.01
U6L to MSP (mm)	-0.63	2.23	0.233	-1.70	0.44
L6R to MSP (mm)	-0.95	1.75	*0.030**	-1.79	*-0.10*
L6L to MSP (mm)	0.04	2.21	0.943	-1.03	1.10
UI to CP (mm)	0.94	2.38	0.103	-0.21	2.09
LI to CP (mm)	0.39	2.12	0.434	-0.63	1.41
U6R to CP (mm)	-0.35	2.45	0.540	-1.53	0.83
U6L to CP (mm)	0.74	2.14	0.148	-0.29	1.78
L6R to CP (mm)	0.66	1.69	0.108	-0.16	1.47
L6L to CP (mm)	0.45	1.97	0.336	-0.50	1.40
A to Nperp (mm)	-0.09	2.67	0.884	-1.38	1.20
ANS to Nperp (mm)	0.92	2.53	0.131	-0.30	2.14
B to Nperp (mm)	0.78	2.95	0.267	-0.65	2.20
Pog to Nperp (mm)	0.62	4.17	0.525	-1.39	2.63
FOP to FHP (degree)	1.10	2.77	0.100	-0.23	2.44
PP to FHP (degree)	0.84	1.74	*0.049**	-0.01	*1.68*
MP to FHP (degree)	0.91	1.26	0.006*	0.30	1.52
FOP to MSP (degree)	0.65	2.03	0.182	-0.33	1.62
PP to MSP (degree)	-0.53	1.11	0.050	-1.07	0.00
MP to MSP (degree)	1.56	2.38	0.011*	0.41	2.71

Results

Nineteen participants with 5 males and 14 females with a mean age of 30 years and 3 months (from 20 to 57 years of age). Fourteen participants were operated on by Le Fort I osteotomy and BSSRO and 5 participants were operated on by Le Fort I osteotomy, BSSRO and advanced genioplasty. The simulation plan and actual outcome of one participant were illustrated in figure 5.

The results of prediction variations were all within either less than 1.5 mm. for linear parameters or 2 degrees for angular parameters. Most of the linear and angular parameters were not statistically significant different except U6L to FHP, L6R to MSP, PP to FHP, MP to FHP, and MP to MSP with *P*-values were 0.031, 0.030, 0.049, 0.006, and 0.011, respectively, (Table 3) which interpreted that the simulation plans were different from the actual outcomes in these parameters.

The mean linear differences in the distance between UI, U6R, U6L, LI, L6R, and L6L to FHP, MSP, and CP were 0.68, 0.42, and 0.58 mm, respectively. (Table 4) The mean linear difference of maxillary and mandibular landmarks was 0.59 mm. and 0.54 mm., respectively. The overall mean angular difference was 0.93°. The mean angular differences relative to FHP and MSP were 0.95° and 0.91°, respectively. (Table 3)

Thirteen out of 19 participants had a mean linear difference of less than 2 mm and 19 out of 19 participants had a mean angular difference of fewer than 4 degrees which meant that CASS planning program for orthognathic surgery in this study had an accuracy for linear and angular measurement as 69% and 100%, respectively. (Figure 6)

The repeated measurements of simulation plans and actual outcomes were done 1 month after the first measurements. The mean intraclass correlation coefficient was 0.94 (range from 0.727 to 0.997) for the simulation plans and 0.95 (range from 0.144 to 0.999) for the actual outcomes, respectively. So, the data indicated an excellent correlation between both repeated measurement. (Table 5)

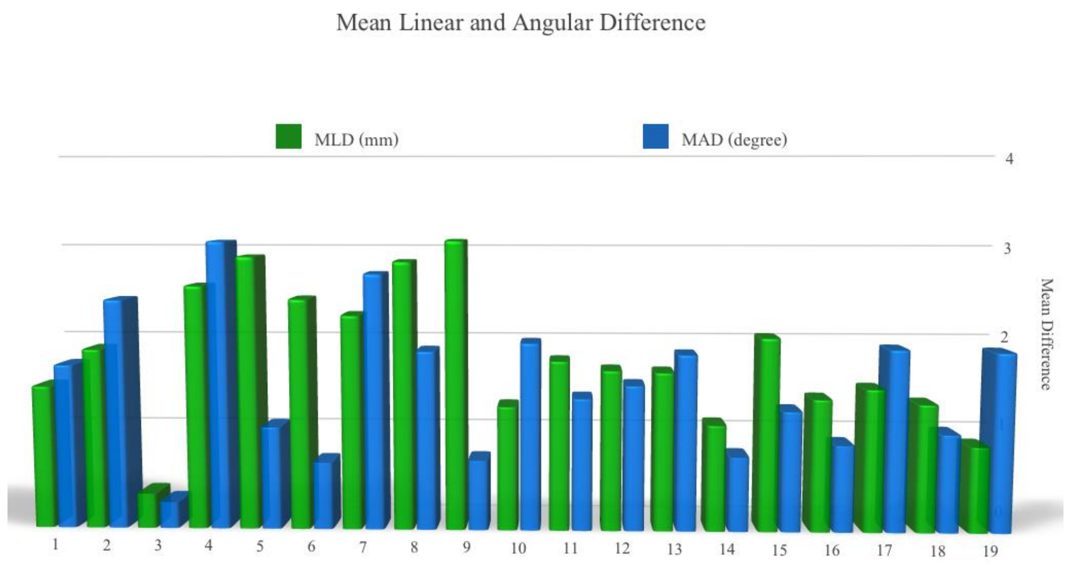

Figure 6 Mean Linear Difference (MLD) and Mean Angular Difference (MAD) for all participants.

Table 4 Mean differences on 6 dental landmarks compared to 3 facial reference planes

Dental Landmarks	Mean difference (mm)			
	FHP	MFP	CP	Average
UI	0.51	0.31	0.94	0.59
LI	1.09	-0.19	0.39	0.56
U6R	0.48	-0.44	-0.35	0.42
U6L	0.95	-0.63	0.74	0.77
L6R	0.56	-0.95	0.66	0.72
L6L	0.51	0.04	0.45	0.33
Average	0.68	0.42	0.58	

Table 5 ICC of the repeated measurement between simulation plan (T0) and actual outcome (T1)

Measurement	Intraclass Correlation Coefficient (r)	
	Simulation Plan (T0)	Actual Outcome (T1)
UI to FHP	0.998	0.995
LI to FHP	0.996	0.978
U6R to FHP	0.994	0.990
U6L to FHP	0.993	0.994
L6R to FHP	0.994	0.970
L6L to FHP	0.992	0.982
UI to MSP	0.987	0.821
LI to MSP	0.987	0.899
U6R to MSP	0.940	0.973
U6L to MSP	0.924	0.973
L6R to MSP	0.976	0.862
L6L to MSP	0.987	0.992
UI to CP	0.997	0.997
LI to CP	0.999	0.991
U6R to CP	0.998	0.992
U6L to CP	0.996	0.992
L6R to CP	0.999	0.993
L6L to CP	0.999	0.997
A to Nperp	0.995	0.928
ANS to Nperp	0.970	0.940
B to Nperp	0.997	0.958
Pog to Nperp	0.994	0.843
FOP to FHP	0.991	0.956
PP to FHP	0.991	0.972
MP to FHP	0.994	0.994
FOP to MSP	0.787	0.727
PP to MSP	0.114	0.855
MP to MSP	0.987	0.808

Discussion

Lin et al[12] reviewed the published studies of CASS in orthognathic surgery over the past 10 years and summarized that the surgical prediction by CASS was accurate and clinically acceptable in transferring the simulation plan to the operating room which, finally, produced the optimal functional and esthetic outcomes.

Statistical significant differences were observed in U6L to FHP, L6R to MSP, PP to FHP, MP to FHP and MP to MSP (Table 3). The errors in U6L to FHP and L6R to MSP could be from the extrusion effect of the fixation technique. The error in PP to FHP could be from the unintentional destruction of ANS during the operation in some cases and the error of MP to FHP and MP to MSP could be from the immediate premature contact after the splint was off. Another consideration was that minor surgical relapses could affect the differences between the prepared and the actual outcomes. However, most of the results had no significant differences and were within the clinical acceptableness. Moreover, the simulation plan allowed superior control of the deviation from MSP (0.42 mm) than CP (0.59 mm) and FHP (0.68 mm), respectively. So, CASS planning program in bimaxillary orthognathic surgery was considered accurate for this study.

Due to the previously published studies,[13-16] success criteria for the mean systematic difference of linear and angular measurement of this study were set as 2 mm and 4°, respectively (Table 6). If errors of orthognathic surgery were within these criteria, a minor postsurgical relapse could be properly manage by postsurgical orthodontic treatment. This study selected only skeletal type III subjects treated by bimaxillary orthognathic surgery which utilized the different software compared to Peterman et al.[16] and different surgical techniques compared to Trans et al.[18] When compared to the previous studies[17-19] the results of this study were consistent with the study of Tran et al.[18] which evaluated the accuracy of 3D planning in surgery first orthognathic approach (SFA) by using the same software and method for interpretation.

The keys to success for transferring the simulation plan to the operating room of this study were the development of a CBCT scan, single-center study, bimaxillary procedures were performed by one surgeon, and selected participants were in the same skeletal relationship which was different from the previous studies.[17-19] So, precise treatment outcomes can be accomplished by utilizing these advanced technologies.

Table 6 Results of recently reported studies compared to this present study (CA = Conventional Approach, SFA = Surgery First Approach and NR = no report).

Study	Skeletal pattern	Surgical technique	N	Software	Mean Systematic Difference (MSD)	
					Linear (mm)	Angular (Degree)
Peterman et al, 2016[18]	III	CA (2 jaws)	14	Dolphin Imaging	+/- 2	NR
Zhang et al, 2016[19]	II, III	CA (2 jaws)	30	Dolphin Imaging	0.81	0.95
Tran et al, 2018[17]	III	SFA (2 jaws)	15	Simplant O&O	0.88	1.16
This study	III	CA (2 jaws)	19	Simplant O&O	0.57	0.93

Conclusion

Statistically significant differences were found in 5 from 28 parameters (18%) including U6L to FHP, L6R to MSP, PP to FHP, MP to FHP, and MP to MSP ($P < 0.05$). Overall mean linear and angular differences relative to 3 facial reference planes were 0.57 mm and 0.93 degrees which were consistent with the previous studies. CASS planning program for bimaxillary orthognathic surgery in skeletal type III relationship was clinically acceptable and facilitated the surgical-orthodontic team to effectively deal with patients who underwent combined orthodontic-orthognathic treatment for predictable treatment outcomes. However, further investigation is still required to prove whether CASS planning program could accurately transfer the simulated surgical plan to the other class of skeletal relationships and the other surgical technique.

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Ethical Approval

This study was approved by Mahidol University Institutional Review Board (MU-IRB) with COA.No.MU-DT/PY-IRB2016/035.

Conflicts of Interest

We hereby declare that we have no financial or personal relationships with other people, commercial, public funding agencies or organizations that could inappropriately influence or bias this study.

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ความแม่นยำของโปรแกรมวางแผนจำลองการผ่าตัดกระดูกขากรรไกรในผู้ป่วยที่มีความผิดปกติของกระดูกขากรรไกร ประเภทที่ 3

รยพัทห์ บัวผัน ศรินนา ตันติธนเศรษฐ์** สมชาติ เราเจริญพร*** พาสน์ศิริ นิสาลักษณ์** พีรพงศ์ สันติวงศ์** กรกมล กรีฑาภิรมย์*****

บทคัดย่อ

ปัจจุบันการวางแผนสำหรับการผ่าตัดกระดูกขากรรไกรด้วยโปรแกรมวางแผนจำลองการผ่าตัดกระดูกขากรรไกรได้รับความนิยมมากขึ้นในผู้ป่วยที่มีความผิดปกติของการสบฟันและกระดูกขากรรไกร งานวิจัยนี้มีวัตถุประสงค์เพื่อประเมินความแม่นยำของโปรแกรมจำลองการผ่าตัดกระดูกขากรรไกรในการรักษาผู้ป่วยที่มีความสัมพันธ์ของกระดูกขากรรไกร ประเภทที่ 3 ตัวอย่างในการศึกษานี้คือผู้ป่วยที่รับการรักษาจัดฟันร่วมกับการผ่าตัดกระดูกขากรรไกร จำนวน 19 ราย ผู้ป่วยได้รับการถ่ายภาพกะโหลกศีรษะสามมิติและสแกนช่องปากก่อนผ่าตัดกระดูกขากรรไกร 2-4 สัปดาห์ เพื่อนำข้อมูลไปวางแผนจำลองการผ่าตัดกระดูกขากรรไกรและทำเฝือกสำหรับการผ่าตัด หลังผ่าตัด 2-6 สัปดาห์ ผู้ป่วยจะได้รับการถ่ายภาพกะโหลกศีรษะสามมิติอีกครั้งเพื่อนำข้อมูลไปวัดผลและวิเคราะห์ทางสถิติถึงความแตกต่างเชิงเส้นและเชิงมุมเปรียบเทียบกับระนาบแฟรงค์เฟิร์ต ระนาบมิดแซกจิทอล และระนาบโคโรนอล ตามลำดับ ผลการศึกษาพบว่าสัมประสิทธิ์สหสัมพันธ์ภายในชั้นมีค่าความน่าเชื่อถือสูงสุด (0.787-0.998) และพบความแตกต่างอย่างมีนัยสำคัญทางสถิติที่บริเวณฟันกรามบนซ้ายซี่ที่ 1 เทียบกับระนาบแฟรงค์เฟิร์ต ฟันกรามล่างขวาซี่ที่ 1 เทียบกับระนาบมิดแซจิทอล ระนาบเพดานเทียบกับระนาบแฟรงค์เฟิร์ต ระนาบขากรรไกรล่างเทียบกับระนาบแฟรงค์เฟิร์ต และระนาบขากรรไกรล่างเทียบกับระนาบมิดแซจิทอลตามลำดับ ผลรวมความแตกต่างเชิงเส้นและเชิงมุมมีค่าเท่ากับ 0.57 มม. และ 0.93 องศา ตามลำดับ จึงสรุปว่า การใช้โปรแกรมวางแผนจำลองการผ่าตัดกระดูกขากรรไกรเพื่อวางแผนการรักษาผู้ป่วยที่มีความสัมพันธ์ของกระดูกขากรรไกรประเภทที่ 3 นั้นมีความแม่นยำที่ยอมรับได้และยังช่วยในการวินิจฉัยและวางแผนผ่าตัดกระดูกขากรรไกรได้อย่างมีประสิทธิภาพ

คำไขรหัส: *ความสัมพันธ์ของกระดูกขากรรไกรประเภทที่ 3/ การผ่าตัดกระดูกขากรรไกร/ การวางแผนการผ่าตัดกระดูกขากรรไกร*

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