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ACCURACY OF VIRTUAL PLANNING USING THREE-DIMENSIONAL COMPUTER-AIDED SIMULATION OF ORTHOGNATHIC SURGERY

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Abstract:

Introduction: *The extent of improvement in accuracy of orthognathic surgery depend on many factors such as used technology, type of orthognathic surgery and patients' characteristics. This article aimed to review the literature regarding the accuracy of virtual planning using three-dimensional computer assisted technology in bimaxillary orthognathic surgery.*

Methods: *The electronic MEDLINE search was conducted and the resultants studies were subjected into two types of screening, to identify eligibility. The primary screening was done based on abstracts of the articles and secondary screening based on the full texts of primarily eligible article. The articles should meet the inclusion criteria of being human in-vivo study, aimed to evaluate accuracy of virtual planning of hard tissue in bimaxillary surgery using 3-dimensional and computer assisted technology.*

Results: *The electronic search resulted in 39 studies which have been subjected for primary and secondary screening when 11 studies met the inclusion criteria. The accuracy of virtual planning was found accurate when compared to the postoperative results in five included studies, while no significant results found in three included studies.*

Conclusion: *There was a satisfactory accuracy of virtual planning using 3-dimensional and computer-assisted technology in conduction of bimaxillary orthognathic surgery. In particular, when a combination of 3-dimensional scanning, CBTC imaging and surgical splint guiding were used.*

Keywords: *Virtual planning, CAD, CAM, Bimaxillary, Surgery.*

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INTRODUCTION:

Conventional planning of orthognathic operative interventions used two-dimensional analysis of x-rays and dental models in articulator for modeling of the surgical plan to predict jaws occlusion and movements [1]. The limitations of two-dimensional approach include the overlapping of reference points and difficulty in identification of landmarks particularly in asymmetrical profile of the patient's face. The accuracy of virtual planning in orthognathic surgery has been improved by introducing of three-dimensional imaging and scanning technologies [2].

The production of craniofacial skeleton model in three-dimensional view using cone-beam computed tomography (CBCT) are recently used in orthognathic surgery [3]. Combination of CBCT and three-dimensional scanning with computer-aided designing and manufacturing technology can dramatically increase the accuracy of virtual surgical plan and improve the outcomes of the surgery [4]. Additionally, a skull-dental model can be produced which can be used by the surgeon to simulate the surgery using software such as Dolphin Imaging (Dolphin Imaging and Management Solutions,Chatsworth, CA, USA) and modification of initial plan can be implemented if there are concerns about movement harmony or facial symmetry [5]. After that, the surgeon can transfer the virtual plan into real operation using certain guidance intra-operatively. These guidance include surgical splints, jaws repositioning planes, and real time navigator [5]. The extent of improvement in accuracy of orthognathic surgery depend on many factors such as used technology, type of orthognathic surgery and patients' characteristics. This article aimed to review the literature regarding the accuracy of virtual planning using three-dimensional computer assisted technology in bimaxillary orthognathic surgery.

METHODS:

The electronic MEDLINE search was conducted based on the keywords ("Bimaxillary surg*") AND (Dolphin OR ProPlan OR CMF OR 3 d OR three dimensional OR 3-dimensional Computer aided surgical simulation OR CASS OR computer-aided OR computer designed OR computer assisted OR computer -manufactured OR CAD/CAM) AND (accuracy OR reliability). The resultants studies were subjected into two types of screening, to identify eligibility. The primary screening was done based on abstracts of the articles and secondary screening based on the full texts of primarily eligible articles. The articles should meet the inclusion criteria of being human in-vivo study, aimed to evaluate accuracy of virtual planning of hard tissue in bimaxillary surgery using 3-dimensional and computer assisted technology. Any study used 2-dimensional CBCT, conventional surgery, modeling of soft-tissues, or feasibility studies were excluded. The data were collected from the included studies regarding study features and accuracy of virtual planning of bimaxillary surgery.

RESULTS:

The electronic search resulted in 39 studies which have been subjected for primary screening based on inclusion criteria where 19 ineligible studies were excluded. Then full text studies were read by tow investigators and further 9 studies were excluded for causes such as studies conducted simulation of soft tissue only [6-9], being feasibility studies [10,11], studies used two-dimensional planning [4,12], or study aimed to follow the complications of bimaxillary surgery not assessing the accuracy of virtual planning [13]. Finally, 11 studies were included in this review as they met the inclusion criteria (table 1).

Four included studies were case series [14-17] and 4 studies conducted the retrospective review of patients' records [18-21], while tow prospective clinical trials [22,23], and one case report study [24]. The number of patients underwent bimaxillary surgery ranged from one case in the study of Hatamleh *et al*. [24] to 55 cases in a clinical trial conducted by Kim *et al*.[23]. Indications of bimaxillary orthognathic surgery were mainly to correct malocclusion or skeletal deformities in maxilla, mandible or both. Three included studies used optical scanning and then merging the scans with CBCT images [16,20,23], while other studies used software to create 3-deminsional images of the skeleton and facial profile. The included studies conducted computer assisted technologies to transfer the surgery from virtual planning to actual bimaxillary surgery such as intermediate surgical splints [18-21], wafers [23,24] and real time navigation [15]. Only three studies reported comparison of virtual planning intervention to conventional surgical modeling [19,20,24].

Regarding the main outcome of the studies, the accuracy of virtual planning was found high when compared to the postoperative results in five included studies [14-16,21,22], while there were no significant differences found in three included studies [17,18,23]. De Riu et al. reported that virtual planning was overall accurate, however some reference points such as SNA, SNB, and anterior facial height transferred to the surgery with significant differences from virtual points [18]. When the accuracy of virtual planning compared with the accuracy of other interventions, a significant superior accuracy of virtual planning over CMS was found by Hatamleh et al. [24]. Conversely, a non-significant difference between virtual planning and CMS was found by Ritto et al. [20]. The method to assess the accuracy of virtual planning among all included studies was by calculating the mean difference, correlation coefficients, or mean errors of comparison between measurements of virtual planning and postoperative findings.

Figure (1): Flow diagram of the included studies in the systematic review

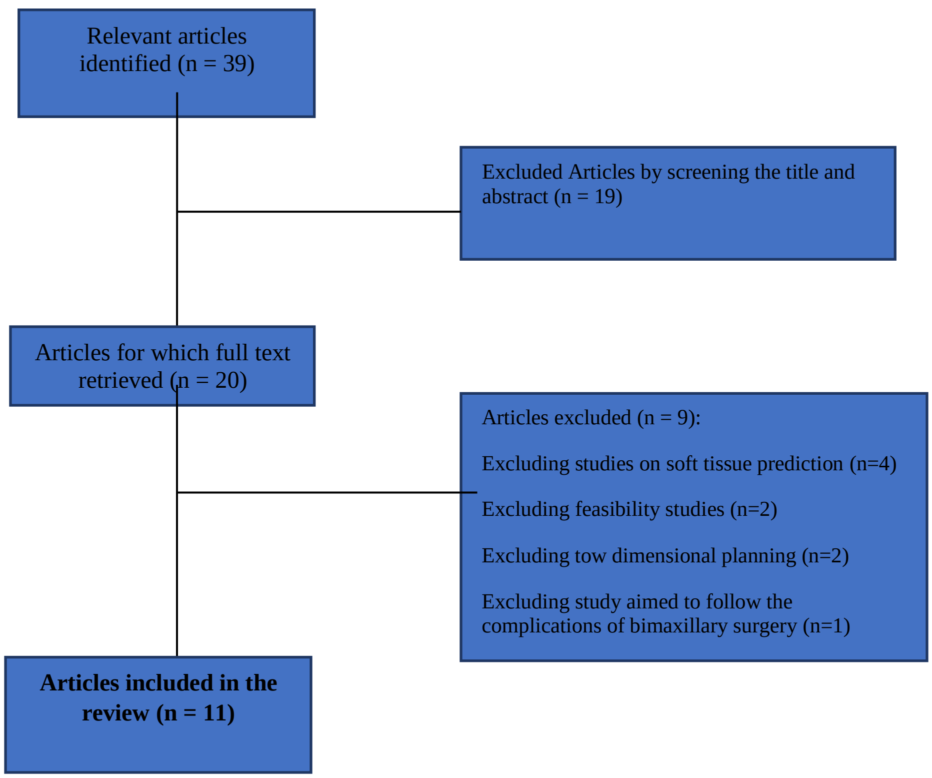

Table (1): The accuracy of the virtual planning of bimaxillary orthognathic surgery reported by the included studies.

Study	Study design	Sample size	Patients characteristics	Indication of the intervention	Comparison (if present)	Accuracy of virtual planning	Method of outcome assessment	Conclusion
[20]	A retrospective study of patients' records	30	In the VSP group, one patient presented a skeletal class I malocclusion, 2 presented class II, and 12 presented class III. The CMS group, 4 patients presented a skeletal class II malocclusion and 11 presented class III.	To assess the accuracy of virtual planning in positioning of the maxilla	CMS	The mean linear difference between planned and obtained movements for CMS was 1.20±1.08 mm	Mean linear difference between planned vertical movements and the actual postoperative position was assessed. The success criterion adopted was a mean linear difference of <2 mm.	With CMS, 80% of overlapping reference points had a difference of <2 mm, while for VSP this value was 83.6%. There was no statistically significant difference between the two techniques regarding accuracy
[18]	A retrospective study of patients' records	49	Patients had to have undergone bimaxillary orthognathic surgery due to abnormal growth of the jaws. Patients excluded if they were diagnosed with a TMD, those with a history of facial bone conditions.	To evaluate the difference between the planned and the actual movements of the jaws	Not-reported	Virtual surgical planning presented a good degree of accuracy for most of the parameters assessed, with an average error of 1.98 mm for linear measures and 1.19° for angular measures.	The accuracy of the virtual planning method was determined by comparing planned movements of the osteotomised jaws with the actual surgical movements.	The overall results were deemed accurate, and differences among 12 the of 15 parameters were considered non-significant. Significant differences were reported for SNA, SNB, and anterior facial height.
[22]	A prospective study	22	Patients undergoing bimaxillary osteotomy for the correction of dento-facial deformities.	For waferless maxillary positioning using CAD/CAM fabricated customized surgical guides and patient specific osteosynthesis.	Not-reported	The median deviation of the maxilla position between the preoperative plan and the surgical result was 0.39 mm.	The virtual plan was compared with the postoperative surgical result	The results demonstrate the high predictability of maxillary positioning by CAD/CAM fabricated customized surgical guides and patient specific osteosynthesis.

[24]	A case report	1	A male patient, 26-year old, presented with a Class III incisor relationship on a Skeletal III base with pan facial asymmetry complicated by 4mm reverse overjet and 5mm anterior open bite.	To set back the occlusion to class 1 incisor relationship	CMS	The lower midline rotated to the left 2.5mm so it is coincident with the upper dental and facial midlines, and there was a mandibular set back to class 1 incisor relationship.	Superimpositio n of pre- and postsurgical lateral cephalograms on cranial base confirms surgical movements	Three-dimensional planning showed great accuracy and treatment outcome and reduced laboratory time in comparison with the conventional method.
[14]	Case series	10	Patients with non-syndromatic dysgnathia requiring bimaxillary osteotomy for skeletal Class II profile.	To validate the OrthoGnathi cAnalyser, in patients who underwent bimaxillary osteotomies	Not - reported	The left/right translation showed the lowest absolute mean difference for both the maxilla and mandible, 0.49 mm and 0.71 mm respectively.	The 3D planned maxillary and mandibular segments were segmented and superimposed upon the postoperative maxillary and mandibular segments.	The left/right translation showed the least discrepancy followed by anteroposterior or sagittal translation
[21]	A retrospe ctive clinical trial	30	Patients underwent bimaxillary surgery due to abnormal growth of the jaws. Patients who were diagnosed with a TMD.	To evaluate Bimaxillary surgery, bimaxillary surgery with segmentatio n of the maxilla, bimaxillary surgery	Not-reported	Measuremen t errors were all within 0.1 mm in 17 patients, with accurate dental reference points in the mediolateral dimension.	The virtual surgical plan was compared with the postsurgical outcome by using three linear and three rotational measurements	A high degree of linear accuracy between planned and postsurgical outcomes was found, but with a large standard deviation. Rotational difference showed an increase in pitch, mainly affecting the maxilla.

[19]	A retrospective clinical trial	26	Patients referred for surgical correction of dentofacial deformity requiring bimaxillary surgery with any superior maxillary impaction 3 mm or greater.	Maxillary repositioning	Occlusal splint	The majority of cases showed a <0.5-mm difference between predicted and actual horizontal and vertical positions of the maxilla	Group A showed excellent correlation between the planned and actual maxillary positions in vertical and horizontal dimensions.	Group A showed excellent correlation between the planned and actual maxillary positions in vertical and horizontal dimensions. In Group B, the maxilla tended to move anteriorly than planned.
[15]	Case series	17	Patients underwent bimaxillary surgery	Real time navigation intraoperative maxillary positioning in sagittal, vertical, and mediolateral directions	Not-reported	The differences in movement of the maxilla, were 0.44 - 0.35 mm in the sagittal, 0.50 -0.35 mm in the vertical, and 0.56 - 0.36 mm (P = 0.81) in the mediolateral direction.	A postoperative CBCT scan was taken and registered to the preoperative cone-beam computed tomography scan to identify the actual surgical movement of the maxilla.	Intraoperative computer navigation is a promising tool for measuring the surgical change of the maxilla in bimaxillary surgery.
[16]	Case series	15	Patients underwent bimaxillary surgery between	To discuss use of computer-assisted surgical planning for bimaxillary surgery and intermediate splint fabrication.	Not reported	The difference at the edge of the upper central incisor was 0.50 - 0.22 mm in sagittal, 0.57 - 0.35 mm in vertical, and 0.38 -0.35 mm in horizontal direction	The differences between planned and actual surgical change in sagittal, vertical, and horizontal direction.	In conclusion, under clinical circumstances, the accuracy of the designed intermediate splint satisfied the requirements for bimaxillary surgery.

[23]	One arm prospective study	55	Patient need treatment of maxillofacial dysmorphosis with malocclusion.	To assess the accuracy of digitally printed wafers for maxillary movement during the bimaxillary orthognathic surgery	Not-reported	A mean error of 0.00-0.09 mm. The mean errors confirmed by the model remounting procedure with the printed wafer by DMS were 0.18-0.40 mm	The error in moving reference points using DMS	The accuracies of the wafers by DMS were similar to those for wafers produced by manual model surgery,
[17]	Case series	16	Patients should be adult, and have skeletal Class III combined with an open-bite or vertical maxillary extrusion. Patients with cleft-lip or palate, or both, were excluded.	To use surgical navigation supplemented by an IGVD to transfer virtual maxillary planning	Not reported	Transfer of preoperative planning to the surgical environment for the maxilla (<0.67 mm, <0.41◦)	A metric cephalometric analysis was used to assess the difference between the virtual planning and the postoperative position of the maxilla	An interactive IGVD complemented surgical navigation, augmented virtual and real-time reality, and provided a precise technique of waferless stereotactic maxillary positioning

*Virtual surgical planning (VSP), conventional articulator model surgery (CMS), temporomandibular joint disorder (TMD), cone-beam computed tomography (CBCT), natural head position (NHP), bilateral sagittal split osteotomy (BSSO), digital model surgery (DMS), image-guided visualization display (IGVD)

DISCUSSION:

This review aimed to investigate the scientific evidence supporting the use of virtual 3-dimensional computer-aided planning to simulate the orthognathic bimaxillary surgery. After successful implementation of computer-aided technology in dental implants [25] and dental prosthesis [26], the use of these advanced technology in maxillofacial surgery have been conducted by several studies [5]. In this review, we found a satisfactory accuracy of virtual computer-aided planning of bimaxillary surgery when compared to actual outcomes or conventional surgical approach. However, The accuracy of the wafers generated by DMS were close to those for wafers fabricated by manual model surgery as shown by Kim et al. [23]. There were many sources of errors inherited in the digital wafers production included errors in the digital mounting onto virtual articulator, errors generated during and after digital dental model performing. Many included studies reported the accurate virtual planning when intermediate splint used as guide for transferring plan into actual surgery [18,19,24]. The use of external reference point can improve the accuracy in measuring the sagittal dimension during maxillary repositioning. However, in the surgery the sagittal repositioning of the maxilla depends on the operator skills and the measurement devices. The positioning of condyles remains a potential source of imprecision during bimaxillary surgery and conventional surgical splints may not assist in the stabilization of condyles. However, computer-designed surgical splint can help in condylar seating [27].

Limitations of this review were the lack of randomized controlled trials with adequate statistical power and consistent methods and technology used. This heterogeneity in methods of surgery conduction and outcome assessment can affect the findings of the review.

CONCLUSION:

We can conclude that based on the included studies there was a satisfactory accuracy of virtual planning using 3-dimensional and computer-assisted technology in conduction of bimaxillary orthognathic surgery. In particular, when a combination of 3-dimensional scanning, CBTC imaging and surgical splint guiding were used. However, there is a need of randomized controlled trials with consistent methods and outcomes to prove the superiority of the virtual planning over the conventional surgical modeling.

CONFLICT OF INTERESTS:

The authors declared no conflict of interest

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