Journal of Research Administration
Society of Research Administrators International

COMPARATIVE EVALUATION OF CONVENTIONAL SURGICAL PLANNING AND VIRTUAL SURGICAL PLANNING IN ORTHOGNATHIC SURGERY: A SYSTEMATIC REVIEW

Dr Raj Madhani
Third Year Post Graduate Student, Department of Oral and Maxillofacial Surgery, Ahmedabad Dental College and Hospital, Ahmedabad, Gujarat, India

Dr Neha Vyas
Professor and Head, Department of Oral and Maxillofacial Surgery, Ahmedabad Dental College and Hospital, Ahmedabad, Gujarat, India

Dr Prashant Malik
Reader, Department of Oral and Maxillofacial Surgery, Ahmedabad Dental College and Hospital, Ahmedabad, Gujarat, India

Dr Kartik Vadhel
Senior Lecturer,Department of Oral and Maxillofacial Surgery, Ahmedabad Dental College and Hospital, Ahmedabad, Gujarat, India

***Corresponding author:** Dr Raj Madhani,
*Department of Oral and Maxillofacial Surgery, Ahmedabad Dental College and Hospital, Ahmedabad, Gujarat, India

Abstract
Background and Aim: In the 20th century, the rapid development of three-dimensional (3D) technology, such as computer-aided design/computer-aided manufacturing (CAD/CAM) and 3D computer-aided design systems, has led to the rapid rise of Virtual surgical planning (VSP) in oral and maxillofacial surgery. The main purpose of this systematic review is to determine whether Virtual surgical planning is superior to the Conventional surgical planning in terms of surgical accuracy for hard tissue and predicting precision for soft tissue. In addition, this study attempted to explore the comparative advantages of the techniques regarding the time required for surgery, planning and cost.
Material and Methods: A comprehensive electronic and manual search of the literature without date or language restriction was performed, i.e., PubMed, Google scholar from 2010 to 2022. The searched terms were Orthognathic Surgery, Conventional Surgical Planning in Orthognathic Surgery, Virtual Surgical Planning in Orthognathic Surgery, Conventional vs Virtual Surgical Planning in Orthognathic Surgery.
Results: After the title and abstract evaluation 600 studies were included. From that, 52 full text articles were assessed for eligibility and were selected. After evaluating the inclusion and exclusion criteria, 14 suitable articles were taken for the study. Six retrospective study (RS) were included in the systematic review in terms of planning time and surgical planning time. In total, 194 patients were enrolled in six studies comparing CSP (n =81) to VSP (n =73). For Accuracy for Hard Tissue and Soft tissue, eight studies were included which consisted of five RCT, one prospective, one CCT, one Retrospective studies. In total 261 patients enrolled in this study out of which CSP (n=130) and VSP (n=131).
Conclusion: This systematic review summarisesthat VSP shortens the planning time and gives more predictable outcomes as far as hard and soft tissue accuracy is concerned however the financial expenses were increased with three-dimensional virtual surgical planning.

Keywords: Conventional Surgical Planning, Orthognathic Surgery,PubMed,Virtual Surgical Planning

Introduction

The word 'orthognathic' comes from the Greek word 'orthos' which means to straighten and 'gnathos' which means jaw. Orthognathic surgery thus means to a procedure that realigns the upper and lower jaws. Orthognathic surgery is defined as 'the art and science ofdiagnosis, treatment planning and execution of treatment to correct musculoskeletal, dento osseous and soft tissue deformities of the jaws and associated structures'.[1,2]

The success of orthognathic surgery depends on preoperative planning,accurate implementation and prevention of postoperative relapse. The proper amalgamation ofthe planning technique and the technique to transfer the plan on to the patient ensures the correct diagnosis and analysis, as well as accurate implementation of orthognathic surgery. A preoperative plan is the most important step in process of orthognathic surgery. Conventional surgical planning has been the cornerstone of preoperative preparation. Conventional surgicalplanning is based on clinical recordings, two-dimensional (2D) radiographs, photographs and model surgeries.Though this approach has been effective, it has its own setbacks.[3-5]

The limitations observed in CSPare such as the complexity of preoperative preparation, which may lead to errors, a lack of control in the third dimension, more operator time, the absence of the evaluation of temporomandibular joint position changes,insufficient control of movements, such as rotation, with regard to the whole cranial situation.[6-8]

In conventional planning the movements are limited to linear antero posterior, medio lateral and inferiosuperior translations suitable for articulator surgery. This limitation of conventional planning restricts the detailed analysis of facial asymmetries which compromises the predictability and accuracy of orthognathic surgery in patients with severe dentofacial asymmetries and occlusal canting.[7]

In the 20th century, the rapid development of three-dimensional (3D) technology, such ascomputer-aided design/computer-aided manufacturing (CAD/CAM) and 3D computer-aided design systems, has led to the rapid rise of Virtual surgical planning (VSP) in oral and maxillofacial surgery. Virtual surgical planning is being used more frequently in orthognathic surgery. It not only corporate a powerful communication tool between the surgeon, the orthodontist and the patient, but also it adds value in diagnosis and planning of orthognathic surgery.[8]

The advent of three-dimensional technologies and computer software programs has facilitated novel methods for three-dimensional virtual surgical planning (VSP) of dentofacial deformities without the need of facebow registration and plaster dental models. VSP is anticipated to diminish treatment planning inaccuracies and significantly improve the surgical accuracy specifically in cases involving dentofacial deformities, occlusal cant correction where CSP is not accurate enough to produce better results in patient.[9]VSP is based on a 3D virtual model that simulates the patient's actual craniofacial structure, including the skeleton and dental. The software developed is able to generate the treatment outcome evaluation possible through techniques of voxel-based rigid registration and superimposition on a 3D reference system.[10] These recent software tools allow an optimal alignment of 3D CBCT or CT scan data sets, avoiding observer-dependent traditional techniques based on overlapping of anatomic landmarks. Thus, with the help of this advanced software we are able to create a virtual patient.

The osteotomy simulated and predictions done by the software is helpful for the surgeon and helps the surgeon to simulate different surgical approaches to determine the most favorable outcomes. Surgical splints manufactured via CAD /CAM can accurately transfer the virtual planning on to the patients intra operatively.Thesplintswhich are created according to the software reinforce intraoperative accuracy of the osteotomy performed in the virtual plan and support in orienting and positioning of bony segments.[11,12]

The main purpose of this systematic review is to determine whether Virtual surgical planning is superior to the Conventional surgical planning in terms of surgical accuracy for hard tissue and predicting precision for soft tissue. In addition, this study attempted to explore the comparative advantages of the techniques regarding the time required for surgery, planning and cost.

Material and Methods

A comprehensive electronic and manual search of the literature without date or language restriction was performed, i.e., PubMed, Google scholar from 2010 to 2022. The searched terms were Orthognathic Surgery,Conventional Surgical Planning in Orthognathic Surgery,Virtual Surgical Planning in Orthognathic Surgery, Conventional vs Virtual Surgical Planning in Orthognathic Surgery. Reference lists of all included studies and any published systematic reviews were searched to identify any additional studies. Earlier references were obtained by back-referencing and from the authors' files.

Randomised controlled trials, quasi-randomised controlled trials, clinically controlled trials, non-randomised cohort studies and retrospective studies employing either Conventional Surgical Planning, Virtual Surgical planning and Conventional vs Virtual Surgical planning in subjects undergoing orthognathic surgery which mainly included Le fort 1 osteotomy, Bilateral Sagittal Split Osteotomy and Genioplasty were eligible to be part of this systematic review.

Inclusion criteria

- Cross sectional studies, observational studies, prospective studies, retrospective studies, randomized control trials.
- Case control and cohort studies.
- Controlled clinical trials.
- English language.
- 3D manufactured Splints.
- Bi max surgery,Genioplasty.

Exclusion criteria

- Inaccurate data for analysis.
- Incomplete data for analysis.
- In vitro studies.
- Animal studies.
- Biomechanical studies.
- Model studies.
- Orthognathic surgery in operated patients of cleft lip and cleft palate.

Selection of Studies and Data Extraction

Studies retrieved from the databases were selected after reading the abstracts and titles, following a calibration exercise with 10% of the studies read by reviewers to determine interexaminer agreement (Kappa: 0.68 to 0.97). Disagreements were resolved by consensus. Reviews were included, and their reference lists were searched in turn for any studies not retrieved by the electronic search. However, this process yielded no further studies.

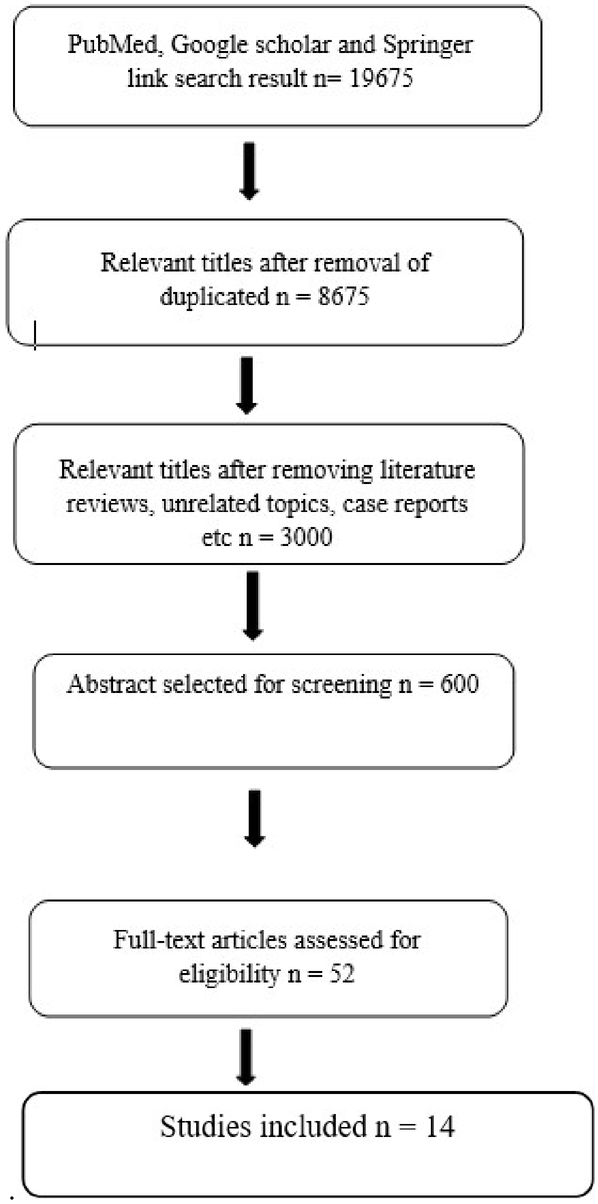
Study selection and data collection process

Investigator screened all collected findings and registered title, author and whole reference in two Excel files (one for included and one for excluded findings, according to eligibility criteria) using a screening guide created on eligibility criteria. Kind of source was registered as reason for exclusion. Duplicates from different electronic databases were excluded. The full text of all studies judged potentially eligible in at least one screening were retrieved. Then, investigator screened the full text for inclusion using a screening guide and all findings.

Evaluation of scientific articles

The articles relevant for study which met inclusion criteria were rated as strong, moderate, weak and very weak. Validity scores indicated whether a study met the reviewer`s criteria for research rigour.

Flow diagram 1: Search Strategy



Flow diagram depicts the process of final selection of studies.

R. XU. et al (2020)[13] conducted a study to evaluate the postoperative and follow-up accuracy of using an intermediate occlusal splint between articulatormodel surgery (AMS) and virtual surgical planning (VSP) in double-jaw operations. Thirty skeletal class III patients were randomly allocated to have AMS or VSP. In the AMS group surgical planning was done through conventional articulator model surgery and an intermediate occlusal splint made of acrylic resin was used. In the VSP group the surgical simulation was done virtually and the same intermediate splint was used in the software and then fabricated using rapid prototyping technology. Preoperatively, one week postoperatively and 1~2-yearslater we obtained follow-up cone-beam computed tomographic (CT) images of each patient. Absolute linear differences between planned and actual outcomes, as well as planned and follow-up outcomes, were evaluated. There was no significant difference in either postoperative accuracy or follow-up accuracy between the methodsand there was no significant difference in the rate of skeletal relapse. Planning transfer by intermediate splint might therefore be the dominant factor in the final inaccuracies. The potentially greater accuracy of VSP may be realisedwith the help of new positioning devices instead of an intermediate splint.

Si-Yeon Park(2021)[10] did this study to measure the time of the conventional surgical planning (CSP) and virtual surgical planning (VSP) in orthognathic surgery and to compare them in terms of cost. This is a retrospective study of the patients who underwent orthognathic surgery at the Pusan University Dental Hospital from December 2017 to August 2018. All the patients were analysed through both CSP and VSPand all the surgical stents were fabricated through manual and 3-dimensional (3D) printing. The predictor variables were the planning method (CSP vs. VSP) and the surgery type (group I: Le Fort I osteotomy bilateral sagittal split osteotomy [LFI+BSSO] or group II: only bilateral sagittal split osteotomy and the outcomes were the time and cost. The results were analysed using paired t test. Thirty patients (12 females, 18 males) met the inclusion criteriaand 17 patients were excluded from the study due to missing or incomplete data. There were 20 group I patients and 10 group II patients. The average time of CSP for group I was 385±7.8 minand that for group II was 195±8.33 min. The time reduction rate of VSP compared with CSP was 62.8% in group I and 41.5% in group II. On the other hand, there was no statistically significant cost reduction. The study concluded that the time investment in VSP in this study was significantly smaller than that in CSPand the difference was greater in group I than in group II.

Results

Study selection process

The eligible studies were searched using electronic databases, i.e., PubMed, google scholar from 2010 to 2023. The search terms were Orthognathic Surgery, Conventional Surgical Planning, Virtual Surgical Planning. A total of 3000 studies of potential interests were identified in the initial database search. After the title and abstract evaluation 600 studies were included. From that, 52 full text articles were assessed for eligibility and were selected. After evaluating the inclusion and exclusion criteria, 14 suitable articles were taken for the study.

Characteristics of the included studies

The extracted data and the characteristics of the studies were included in the final analysis. It includes 14 studies, from which 7 studies were retrospective, 6 studies were randomised control trial,1 was prospective study and 1 was controlled clinical trials.

In total 562 patients underwent orthognathic surgery, Lefort 1 osteotomy, bilateral sagittal split osteotomy and genioplasty were the most commonly performed surgeries on these patients.

There are total 562 patients in this study out of which200were male while 232 were female. All the patients from various age group were included in this study. The main surgical techniques used for surgery where also mentioned in this study.

Planning Time for CSP & VSP

Six retrospective studies (RS)were included in the systematic review in terms of planning time and surgical planning time. In total, 194 patients were enrolled in six studies comparing CSP (n =81) to VSP (n =73).

As the planning time was compared for CSP, H.C. Schwartz et al[4],in his study, he stated that it took 10.25 hrs, M.K Wrzosek et al[5] (7.52 ± 1.97) hr, Cory Resnick et al[11] (9.16) hr. When planning time for VSP was compared, H.C. Schwartz et al[4] (9.25) hrs, M.K Wrzosek et al[5] (5.12 ± 0.99) hr,

Out of 5 studies, all the 5 studies concluded that VSP took less time than CSP to plan the orthognathic surgery.

Out of 6 studies, surgery time was recorded in 2 studies,for CSP, H.C. Schwartz et al[4] (4.17) hr and Daniel Schneider et al[8] (3.02) hr, as for VSP, H.C. Schwartz et al (4.17) and Daniel Schneider et al (2.7) hr. In these 2 studies, the surgery time was same in 1 study,while 1 study stated that surgery planned via VSP took lesser time than surgery planned by CSP.

Cost Difference for CSP & VSP

The table consisted of four studies in the systematic review in which three were retrospective and one RCT. In total, 151 patients were enrolled in four studies comparing cost of CSP (n = 51) to VSP (n = 43).

As regards for CSP, Resnick et al[11] ($3537), Schneider et al[4] ($524.17), Bengtsson et al[3] ($330.76), Si Yeon Park et al[10] ($613.80) and for VSP, Resnick et a[11] ($2883), Schneider et al ($521.99), Bengtsson et al ($1889.34), Si Yeon Park et al ($675.48). Out of 4 studies, 2 studies suggests that VSP has less cost than CSP, while in the remaining 2 CSP has less cost than VSP. Thus, we can say that VSP and CSP have same cost .

Accuracy for Hard Tissue and Soft tissue

In this systematic review eight studies were included which consisted of fiveRCT, one prospective, one CCT, one Retrospective studies. In total 261 patients enrolled in this study out of which CSP (n=130) and VSP (n=131). Giacomo De Riu et al[1]. calculated the linear and angular measurements for alignment of midline in which lower interincisal point (P = 0.03), mandibular sagittal plane (P = 0.01) and centering of the dental midlines (P = 0.03) compared with TSP.

Geert Van Hemelen et al[6] studied the differences between the achieved surgical outcome and planned position were analyzed using cephalometric landmarks in another study. Difference in the anterior posterior and vertical dimension were 1.42 and 1.44 mm with TVSP. Corresponding measurements were 1.71 mm and 1.69 mm for TSP.

Cheng-Ting Ho et al[9]. studied roll, pitch, yaw, changes in ramus inclination via x,y,z axis.Absolute angular differences of planes in the 2D and 3D plans in which Frontal ramus inclination hadthe largest correction of 3.37°, followed by yaw (1.88°), pitch (1.73°) and roll (1.06°).

Daniel Schneider et al[4] planned surgical outcome and planned position were analysed using angular measurements including sella-nasion to A point (SNA), sella-nasion to B point (SNB) and A point to B point (ANB). Differences in the anterior posterior dimension using TVSP were 0.6 degrees (SNA), 0.7 degrees (SND) and 0.5 degrees (ANB). Corresponding measurements for TSP were 1.8 degrees (SNA), 1.9 degrees (SND) and 1.6 degrees (ANB). The difference was statistically significant at SNA (P < 0.001), SNB (P = 0.002) and ANB (P < 0.001)

Bengtsson et al[2] studied differences between the achieved surgical outcome and planned position were analysed using superimposition of cephalometric landmarks. VSP and CSP disclosed comparable outcomes in the anterior posterior dimension for most of the cephalometric landmarks. Difference in A point position was 1.86 mm and 2.75 mm with VSP and CSP.

M Hanafy et al[14]. studied the differences between the achieved surgical outcome and planned position were analysed using dental reference points and angular deviation of the dental occlusion and maxilla. Difference in the anterior posterior, vertically and mediolaterally dimension were 0.17 mm, 0.26 mm and 0.07 mm with VSP. Corresponding measurements were 1.31 mm, 1.45 mm and 0.71 mm for CSP.

R. XU. et al[13] differences between the achieved surgical outcome and planned position were analysed using linear measurements on skeletal landmarks including subspinale and the last midpoint on the hard palate. Differences in the horizontal, vertical and transverse dimension using TVSP were 0.95 mm, 0.69 mm and 0.51 mm, respectively. Corresponding measurements for TSP were 0.89 mm, 0.77 mm and 0.42 mm, respectively. There were no statistically significant differences between VSP and CSP.

H. Chen et al[15] studied the differences between the achieved surgical outcome and planned position were analysed using linear measurements on eight selected points on the surface of the maxillary teeth. The difference was 2.15 (SD 1.12) mm using VSP compared with 2.55 (SD 0.95) mm with CSP.

VSP seems to beneficially improve the hard tissue accuracy between the planned position and the achieved surgical outcome compared with CSP.

Table 1: The study design of included studies

Sr no.	Author	Year of publication	Study design
1	Giacomo De Riu et al.	2013	RCT
2	H.C. Schwartz et al.	2013	Retrospective
3	Geert Van Hemelen et al.	2015	Prospective
4	M. K. Wrzosek	2016	Retrospective
5	Cory M. Resnick et al.	2016	Retrospective
6	Thomas Steinhuber et al.	2017	Retrospective
7	Cheng-Ting Ho et al.	2017	CCT
8	M. Bengtsson et al.	2018	RCT
9	M. Bengtsson et al.	2019	RCT
10	Daniel Schneider et al.	2018	Retrospective
11	M. Hanafy et al.	2019	RCT
12	R. XU. et al.	2020	RCT
13	H. Chen et al.	2020	RCT
14	Si-Yeon Park et al.	2021	Retrospective

Table 2: Number of patients and male female ratio

Sr no.	Author	Year of publication	Number of patients	Male patients	Female patients	Male Female ratio
1	Giacomo De Riu et al.	2013	8	_	_	_
2	H.C. Schwartz et al.	2013	60	34	26	1.30
3	Geert Van Hemelen et al.	2015	66	29	35	0.83
4	M. K. Wrzosek	2016	41	_	_	_
5	Cory M. Resnick et al .	2016	43	_	_	_
6	Thomas Steinhuber et al.	2017	40	15	25	0.6
7	Cheng-Ting Ho et al.	2017	30	8	22	0.37
8	M. Bengtsson et al.	2018	57	30	27	1.11
9	M. Bengtsson et al.	2019	57	30	27	1.11
10	Daniel Schneider et al.	2018	21	_	_	_
11	M. Hanafy et al.	2019	18	9	9	1
12	R. XU. et al.	2020	30	10	20	0.5
13	H. Chen et al.	2020	61	17	44	0.39
14	Si-Yeon Park et al.	2021	30	18	12	1.5

Table 3: Employed Surgical Techniques

Sr no.	Author	Year of publication	Surgical techniques employed
1	Giacomo De Riu et al.	2013	Bimaxillary osteotomy surgery, Genioplasty
2	H.C. Schwartz et al.	2013	Bimaxillary osteotomy surgery, Genioplasty
3	Geert Van Hemelen et al.	2015	Bimaxillary osteotomy surgery, Genioplasty
4	M. K. Wrzosek	2016	Bimaxillary osteotomy surgery
5	Cory M. Resnick et al .	2016	Bimaxillary osteotomy surgery
6	Thomas Steinhuber et al.	2017	Bimaxillary osteotomy surgery, Genioplasty
7	Cheng-Ting Ho et al.	2017	Bimaxillary osteotomy surgery
8	Daniel Schneider et al.	2018	Bimaxillary osteotomy surgery
9	M. Bengtsson et al.	2018	Bimaxillary osteotomy surgery, Genioplasty
10	M. Bengtsson et al.	2019	Bimaxillary osteotomy surgery, Genioplasty
11	M. Hanafy et al.	2019	Bimaxillary osteotomy surgery, Genioplasty
12	R. XU. et al.	2020	Bimaxillary osteotomy surgery
13	H. Chen et al.	2020	Bimaxillary osteotomy surgery
14	Si-Yeon Park et al.	2021	Bimaxillary osteotomy surgery, Genioplasty

Table 4: Age range and mean of included patients

Sr no.	Author	Year of publication	Age range(years)	Mean age ± SD
1	Giacomo De Riu et al.	2013	21-54	_
2	H.C. Schwartz et al.	2013	16-54	28.3
3	Geert Van Hemelen et al.	2015	_	_
4	M. K. Wrzosek	2016	_	_
5	Cory M. Resnick et al .	2016	_	_
6	Thomas Steinhuber et al.	2017	15-57	24.6± 7.6
7	Cheng-Ting Ho et al.	2017	18-26	22.4
8	M. Bengtsson et al.	2018	18-28	21
9	Daniel Schneider et al.	2018	23-52.1	32.6
10	M. Bengtsson et al.	2019	18-28	21
11	M. Hanafy et al.	2019	19-24	21.22
12	H. Chen et al.	2020	19-32	23
13	R. XU. et al.	2020	-	-
14	Si-Yeon Park et al.	2021	_	_

Table 5: No. Of Patients in CSP and VSP

Sr no.	Author	Year of publication	No. of patients in CSP	No. of patients in VSP
1	Giacomo De Riu et al.	2013	10	10
2	H.C. Schwartz et al.	2013	12	9
3	Geert Van Hemelen et al.	2015	35	31
4	M. K. Wrzosek	2016	41	41
5	Cory M. Resnick et al.	2016	-	-
6	Thomas Steinhuber et al.	2017	-	-
7	Cheng-Ting Ho et al.	2017	-	-
8	M. Bengtsson et al.	2018	29	28
9	Daniel Schneider et al.	2018	12	9
10	M. Bengtsson et al.	2019	29	28
11	M. Hanafy et al.	2019	9	9
12	R. XU. et al.	2020	15	15
13	H. Chen et al.	2020	20	21
14	Si-Yeon Park et al.	2021	-	-

Table 6: Planning time for VSP & CSP

Sr no.	Author	Year of publication	Surgical Planning (in hours)		Time taken for Surgery (in hours)	
			CSP	VSP	CSP	VSP
1	H.C. Schwartz et al.	2013	10.25	9.25	4.17	4.17
2	M. K. Wrzosek et al.	2016	7.52 ± 1.97	5.12 ± 0.99		
3	Cory M. Resnick et al .	2016	9.16	3.28		
4	Thomas Steinhuber et al.	2017	3.44	2.29		
5	Daniel Schneider et al.	2018			3.02	2.7
6	Si-Yeon Park et al.	2021	6.41 ± 0.2	2.38 ± 0.2		

Table 7: Cost Comparison for VSP & CSP

Sr no.	Author	Year of publication	Cost of CSP	Cost of VSP
1	Cory M. Resnick et al .	2016	$3537	$2883
2	Daniel Schneider et al.	2018	$524.17	$521.99
3	M. Bengtsson et al.	2019	$330.76	$1889.34
4	Si-Yeon Park et al.	2021	$613.80	$675.48

Table 8: Accuracy for hard and soft tissue

Sr. No	Author	Year of publication	Assessment methods	Type of Surgery	Hard Tissue Accuracy				Soft Tissue Accuracy	
1	Giacomo De Riu et al.	2013	Linear and angular measurements for alignment of midline		Rate of Alignment (%)				Rate of Alignment (%)	
					LIPFM	MSPFM	CDM		Soft tissue menton/facial midline	
				VSP	88.2	80.2	92.6		76.7	
				CSP	50.8	42.7	58.5		79.7	
2	Geert Van Hemelen et al.	2015	Linear measurements on cephalometric radiographs		Difference planned/ achieved (mm)					
					Horizontal	Vertical			Horizontal	Vertical
				VSP	1.42 (SD 0.78)	1.44(SD 0.61)			1.48(SD 0.73)	1.46(SD 0.53)
				CSP	1.71 (SD 0.87)	1.69(SD 0.76)			2.29(SD 1.06)	2.07(SD 0.95)
3	Cheng-Ting Ho et al.	2017	Roll, Pitch, Yaw, changes in ramus inclination via x, y, z axis		Difference planned/ achieved (angle)				No Result	
					Roll	Pitch	Yaw	Ramus inclination		
				VSP	0.37	15.23 (4.03)	1.88	0.78(1.47)		
				CSP	1.43(1.17)	13.50 (4.04)	0.00	4.15 (3.06)		
4	Daniel Schneider et al.	2018	SNA, SNB and ANB angle		Difference planned and achieved				No Result	
					SNA	SNB	ANB			
				VSP	0.6	0.7	0.5			
				CSP	1.8	1.9	1.6			
5	M. Bengtsson et al.	2018	Linear measurements on cephalometric radiographs		Difference planned and achieved				No Result	
					First Incisor /NSL		A-point (mm)			
				VSP	0.23		1.86			
				CSP	3.95		2.75			
6	M. Hanafy et al.	2019	Linear and angular dental measurements		Difference planned and achieved (mm)				No Result	
					Horizontal	Vertical	Transverse			
				VSP	0.17	0.26	0.07			
				CSP	1.31	1.45	0.71			
7	R. XU. et al.	2020	Maxillary position assessed by three skeletal points		Difference planned and achieved (mm)				No Result	
					Horizontal	Vertical	Transverse			
				VSP	0.89	0.77	0.42			
				CSP	0.95	0.69	0.51			
8	H. Chen et al.	2020	Maxillary position assessed by eight skeletal points		Difference planned and achieved (mm)				No Result	
				VSP	2.15					
				CSP	2.55					

Discussion

Hargis coined the term “orthognathic surgery” (ortho-straight, gnathic -jaw). Orthognathic surgery is a vibrant part of the health care system offering patients an opportunity to improve their situation. As the functional, aesthetic and psychosocial benefits of surgery have been realized, its popularity has increased. Although orthognathic surgery is associated with certain risks and challenges, it has become a more refined and less traumatic procedure.

Combined orthodontic and surgical correction is considered the best treatment modality for dentoskeletal imbalances once growth has ceased. The remarkable facial changes created by improved skeletal relationships have become an important factor in treatment goal-setting.

Unlike most surgical procedures, orthognathic surgery involves not just the thorough medical assessment of the patient but also precise preoperative dental, radiographic and facial aesthetic planning. The surgeon must carry out a detailed face-to-face examination of the patient to determine variations from normal. The clinical decision making regarding the preferred aesthetic reorientation and repositioning of the jaws in the operating room remains both an art and a science, the technical aspects of planning should be precise and consistent. Analytic model planning and the use of prefabricated splints continue to represent the standard of care for bimaxillary and segmental maxillary osteotomies.[16,17]

The success of orthognathic (CMF) surgery depends not only on surgical techniques, but also on an accurate surgical plan. The adoption of computer-aided surgical simulation (CASS) is creating a paradigm shift in surgical planning for patients undergoing orthognathic surgeries. There are various programs which has specifically designed protocol for orthognathic surgeries only .In this protocol, a three-dimensional (3D) composite skull model of a patient is generated to accurately represent the maxillofacial skeleton, the dentition and the facial soft tissue.In addition, an anatomic reference frame is created for the 3D composite skull model.Virtual osteotomies are then performed and orthognathic surgery is simulated.Finally, surgical splints and templates are designed in the computer, fabricated by a rapid prototyping machine and used during surgery to accurately position the bony segments. The protocol has been proven to be more accurate and efficient than the traditional planning methods. Presurgical model surgery allows the surgeon to carry out the planned osteotomies and movements ex vivo. This exercise enables the surgeon to plan and preview the exact surgical movements and outcome prior to entering the operating room. The model surgery allows for fabrication of rigid interdental splints to replicate the planned surgical movements intraoperatively. These splints relate the teeth and corresponding skeletal segments in their planned positions during application of rigid internal fixation.[18]

In 1898, Edward Angle, Jr. published an article in The Dental Cosmos suggesting the use of presurgical model surgery for "double resection of the lower maxilla." In his article, he recommended the use of plaster models to replicate the intended osteotomies and then fabrication of a vulcanite or metal splint to be used during surgery to achieve more accurate results. Since that time, the uses of model surgery and surgical splints for orthognathic surgery have become the gold standard. Model surgery has increased the precision of surgery, decreased intraoperative time and resulted in predicable and repeatable surgical results. Now this method is also known has the conventional surgical planning. There are customary steps which have been laid down or are to be performed before surgery to ensure optimal results.

The first step in conventional planning is taking photosfor documentation, treatment planning and medico-legal purposes. These photos can assist in verifying accuracy of mounting the casts as well. Obtaining photographs prior to impressions is recommended. For single jaw surgery, only one set of impressions for the maxilla and mandible is necessary. For a double jaw surgery, two sets of impressions are necessary: one set for the final occlusion and one set for the model surgery.

The bite registration should be recorded in centric relation (CR), with the condyles in the most posterior superior position in the glenoid fossa, to create a repeatable position in the operating room. Each patient requires either a cone beam CT (CBCT) reconstruction or three plain films: orthopantogram, PA cephalometric (PA ceph) and lateral cephalometric (lateral ceph) radiographs.For single jaw surgery (maxilla only or mandible only), the final occlusal relationship is the only cast mount needed, which can be mounted on a hinge or Galetti articulator. A final splint is fabricated from the mounted final occlusion.[19,20]

For double jaw surgery or other complex cases, mounting the casts on a semi adjustable articulator is indicated to replicate the movements of the condyle .The patient's maxillofacial and occlusal relationships are accurately replicated on the semi-adjustable articulator, the previously marked occlusal surfaces on the maxillary teeth are recorded on a worksheet as starting reference points in the AP, vertical and transverse dimensions.Double jaw surgery may be performed by starting with either the maxilla or the mandible. Regardless of the sequence of osteotomies, the primary role for model surgery is to replicate correct maxillary repositioning as determined during the initial clinical and cephalometric evaluation. The position of the mandible is dictated by the maxillary position and previously determined final occlusion.[15]

The intermediate splint is imperative for intraoperative use during double jaw surgery. After the osteotomy of the first jaw, this splint helps position the cut jaw in relation to the uncut jaw. Once this position is established intraoperatively, the cut jaw is secured with internal fixation.

The advent of the semi-adjustable articulator, facebow, Erickson Model Table, acrylic, PVS and various dental stones, all have led to improvements in accuracy and precision of model surgery.

For virtual surgical planning three-dimensional (3D) composite skull model of a patient is generated to accurately represent the maxillofacial skeleton, the dentition and the facial soft tissue. In addition, an anatomic reference frame is created for the 3D composite skull model.Virtual osteotomies are then performed and orthognathic surgery is simulated. Finally, surgical splints and templates are designed in the computer, fabricated by a rapid prototyping machine and used during surgery to accurately position the bony segments. The protocol has been proven to be more accurate and efficient than the traditional planning methods.[15]

CT scans can be used to create 3D models of the facial skeleton, teeth and soft tissues. However, the teeth ofthese 3D CT models are not sufficiently accurate for surgicalplanning. The protocol solves this problem byreplacing the inaccurate teeth of the CT with accurate digitaldental models that are created by scanning stone dentalmodels.[20]This facial model created by aligning and mergingdigital dental models into a maxillofacial CT is called a composite model. This aligning and merging process iscalled registration. The registration is done by aligning corresponding features that are presentedin both images. The fiducial markers can be part of theanatomic structures being imaged, or easy to identify partsthat are added in, on, or around the objects.[21]

The major advantage of VSP is, once the planning is completed in the software the final result is then shown to the patient. The patient can have perspective of the outcomes of the surgery in virtual planning while in conventional planning this cannot be done. In conventional planning the outcome of model surgery cannot perceive by the patient.

The major steps of 3D planning include the following steps

Eight steps are followed in this: (1) Taking and pouring dental impressions; (2) Fabricating a bite-jig; (3) Taking clinical measurements; (4) Clinical photographing of the patient; (5) Recording the patient's NHP; 6) Testing the fit of the bite-jig on the stone dental models; (7) Acquiring a CT scan; and (8) Establishing final occlusion.

The second major step of VSP is data processing. This takes place after all the preoperative records have been gathered. The first step in data processing is to create a virtual model that displays an accurate rendition of the skeleton, the soft tissues and the teeth. Four separate but correlated3D CT models are generated: a mid-face model, a mandibular model, a soft tissue model and a fiducial marker model.This is completed by using specialized planning software. Digital dental modelsare then generated by scanning the stone dental models with the fiducial registration frame in place, either with a high-resolution laser scanner, or with aCBCT. Next, the digital dental models are incorporated into the 3D CT models by registering thefiducial markers of the digital dental models to the markers of the 3D CT.[13]

The second step in data processing is to establish an anatomic reference frame for the head model. An accurate anatomic reference frame is critical for planning. The recordedNHP is used to orientthe computer head model to the NHP. Using the fiducialfacebow as reference, the NHP of the computer model is established by applying the recorded pitch, roll and yaw tothe facebow frame.Once the virtual head model is in the NHP, the construction of a referenceframe is straightforward. The mid-sagittal plane is the vertical plane that best divides the head into right and left halves.The axial plane is the horizontal plane that isperpendicularto the mid-sagittal plane, passing closest to the right andleft portion. The coronal plane is the vertical plane that isperpendicular to the other planes, aligned with the coronalsuture.The third data processing step is to digitize all the cephalometriclandmarks and to perform a cephalometric analysis.

The surgeon may request any cephalometric analysis but he/she should take into consideration that 3D cephalometryis significantly more complex than its 2D counterpart.Simply adapting 2D cephalometric measurements to 3D space may cause diagnostic errors.If necessary, landmark digitization can be altered later in the planningphase.The fourth data processing step is to perform virtual osteotomies. At this stage, all the osteotomized segmentsremain in their original position. Their movements are completed later in the planning phase.[15]

The last step of data processing step is to establish virtual final occlusion. This is done by copying the final occlusion which was established by the surgeon on the stone dental models. First, the upper and lower stone models are articulated into final occlusion using the bite registration provided by the surgeon. Next, the models are scanned together, using a high-resolution optical surface scanner or a CBCT scanner.[24] Finally, the scan is segmented to create a 3D image of the upper and lower teeth in final occlusion. This image, the final occlusal template, is imported into the planning software and is used as a guide to articulate the jaws in final occlusion. The virtual final occlusion is established in the following manner: First, the upper teeth of the final occlusion template are aligned to the upper teeth of the Le Fort I segment. Then, the distal mandibular segment is moved until its lower teeth are aligned to the lower teeth of the template

The third major step of the protocol is surgical planning. It is done in the computer using virtual planning software. It is important to note that planning an orthognathic surgery using virtual planning is conceptually different from planning the same operation using traditional planning methods. In stone dental model surgery, one intuitively executes all transformations, includingrotations, as linear translations of particular points. It has six degrees of freedom, enabling the measurements of inclinations in degrees and positions in millimetres, independently of each other.The final occlusion is established first and then both jaws are moved together into the final alignment while they are occluded in final occlusion.[22]

The final step of this protocol is to prepare the tools necessary for transferring the computerized surgical plan to the patient at the time of the surgery. Moreover, surgical splints are designed in the computer and fabricated using a rapid prototyping machine.Genioplasty and other bone templates and cutting and drilling guides can also be fabricated as needed.

The planning techniques for virtual surgical technique may vary from surgeon to another surgeon, but certain steps do remain the same, many authors did compare the cost , time taken for the surgery , while some studied about the accuracies for the same.[23]

The purpose of the present study was to identify outcomes of the cost, planning time and accuracy for soft tissue and hard tissue for patients undergoing orthognathic surgery .Thirteen studies were included in this systematic review to compare the virtual surgical planning and conventional surgical planning by analyzing the database. The primary variables are bimaxillary surgery and genioplasty, other variables are study design, number of patients, male-female ratio and age. The systematic review showed a significant difference between the planning time, cost and accuracy.

In this systematic review,outcome of hard tissue accuracy was compared; we found that hard tissue accuracy was more post VSP when compared to CSP. The difference between the accuracy was measured with the help of linear measurements and dental midline, while for maxilla roll, yaw and pitch were used to measure the accuracy.In this systematic review, eight studies were included to measure the outcome of hard tissue accuracy.Out of the eight studies, the five studies showed that there is significantly more accuracy of Virtual Surgical Planning then conventional surgical planning, while three studies did not find significant difference between the results of VSP and CSP. These studies compared the difference between the planned outcome and the final outcome. Two studies conducted the soft tissue accuracy in which the results were conflicting, as one study showed no change in the accuracy while one study concluded that soft tissue accuracy was more in VSP then CSP.[25,26]The outcomes of time taken to plan the surgery and perform the surgery were compared in this systematic review.In our systematic review we found that time taken in planning the surgery conventionally was more when compared to planning the surgery virtually. While for time taken to perform the surgery with the help of virtually created splints was less when compared to conventionally created splints. According to Steinhuber (2016) et al[7] who did a retrospective study found that the time taken to plan the surgery via VSP for single jaw surgery or double jaw surgery was significantly lesser than CSP. Schneider et al (2018)[8] concluded that surgical time was reduced in cases where the splints are prepared by VSP when compared to the splint prepared by CSP. Park et al (2021)[10] in his study observed that in terms of the total time, VSP was much shorter than that of CSP. Schwartz et al (2013)[4] observed that planning in VSP takes less time when compared to CSP, he also compared the surgical time which were similar in both VSP and CSP.In terms of cost in our systematic review we did find that planning the surgery with the help of VSP was similar when compared to CSP. M. Bengtsson et al. (2019)[3] is his study observed that the software for VSP was expensive and hence concluded that VSP had more cost than CSP, when the patient workflow is less. According to Schneider et al (2018) VSP had more cost than CSP, but when the cost of 3d printed models was eliminated it was the same. Resnick et al (2016)[11] in his study observed that in each group VSP was more cost effective than CSP.This all favours that Virtual Surgical Planning is better than Conventional Surgical Planning in respect to hard tissue and soft tissue accuracy, when planning time is considered Virtual Surgical Planning is better than Conventional Surgical Planning, while in cost it still remains non conclusive.

Conclusion

This systematic review summarizes that VSP shortens the planning time and gives more predictable outcomes as far as hard and soft tissue accuracy is concerned however the financial expenses were increased with three-dimensional virtual surgical planning. With the improvements and newer developments in software for virtual surgical planning the cost can be reduced significantly in the coming time. Further development of three-dimensional virtual surgical planning techniques involving cutting guides and patient-specific osteosynthesis plates will probably improve the predictability of orthognathic surgical planning. To conclude the finalstudy moreevidence-based studies are required.

Conflict of interest: None declared.

Sources of funding: Nil.

References

1. De Riu G, Meloni SM, Baj A, Corda A, Soma D, Tullio A. Computer-assisted orthognathic surgery for correction of facial asymmetry: results of a randomised controlled clinical trial. British Journal of Oral and Maxillofacial Surgery. 2014 Mar 1;52(3):251-7.
2. Bengtsson M, Wall G, Becktor JP, Rasmusson L. A comparison of cost-effectiveness of computer-assisted 2-and 3-dimensional planning techniques in orthognathic surgery. British Journal of Oral and Maxillofacial Surgery. 2019 May 1;57(4):352-8.
3. Bengtsson M, Wall G, Greiff L, Rasmusson L. Treatment outcome in orthognathic surgery—A prospective randomized blinded case-controlled comparison of planning accuracy in computer-assisted two-and three-dimensional planning techniques (part II). Journal of Cranio-Maxillofacial Surgery. 2017 Sep 1;45(9):1419-24.
4. Schwartz HC. Does computer-aided surgical simulation improve efficiency in bimaxillary orthognathic surgery?. International Journal of Oral and Maxillofacial Surgery. 2014 May 1;43(5):572-6.
5. Wrzosek MK, Peacock ZS, Laviv A, Goldwaser BR, Ortiz R, Resnick CM, Troulis MJ, Kaban LB. Comparison of time required for traditional versus virtual orthognathic surgery treatment planning. International journal of oral and maxillofacial surgery. 2016 Sep 1;45(9):1065-9.
6. Van Hemelen G, Van Genechten M, Renier L, Desmedt M, Verbruggen E, Nadjmi N. Three-dimensional virtual planning in orthognathic surgery enhances the accuracy of soft tissue prediction. Journal of Cranio-Maxillofacial Surgery. 2015 Jul 1;43(6):918-25.
7. Steinhuber T, Brunold S, Gärtner C, Offermanns V, Ulmer H, Ploder O. Is virtual surgical planning in orthognathic surgery faster than conventional planning? A time and workflow analysis of an office-based workflow for single-and double-jaw surgery. Journal of Oral and Maxillofacial Surgery. 2018 Feb 1;76(2):397-407.

8. Schneider D, Kämmerer PW, Hennig M, Schön G, Thiem DG, Bschorer R. Customized virtual surgical planning in bimaxillary orthognathic surgery: a prospective randomized trial. Clinical oral investigations. 2019 Jul 1;23:3115-22.
9. Ho CT, Lin HH, Liou EJ, Lo LJ. Three-dimensional surgical simulation improves the planning for correction of facial prognathism and asymmetry: A qualitative and quantitative study. Scientific reports. 2017 Jan 10;7(1):40423.
10. Park SY, Hwang DS, Song JM, Kim UK. Comparison of time and cost between conventional surgical planning and virtual surgical planning in orthognathic surgery in Korea. Maxillofacial plastic and reconstructive surgery. 2019 Dec;41(1):1-7.
11. Resnick CM, Inverso G, Wrzosek M, Padwa BL, Kaban LB, Peacock ZS. Is there a difference in cost between standard and virtual surgical planning for orthognathic surgery?. Journal of Oral and Maxillofacial Surgery. 2016 Sep 1;74(9):1827-33.
12. Wu TY, Lin HH, Lo LJ, Ho CT. Postoperative outcomes of two-and three-dimensional planning in orthognathic surgery: a comparative study. Journal of Plastic, Reconstructive & Aesthetic Surgery. 2017 Aug 1;70(8):1101-11.
13. Xu R, Ye N, Zhu S, Shi B, Li J, Lai W. Comparison of the postoperative and follow-up accuracy of articulator model surgery and virtual surgical planning in skeletal class III patients. British Journal of Oral and Maxillofacial Surgery. 2020 Oct 1;58(8):933-9.
14. Hanafy M, Akoush Y, Abou-ElFetouh A, Mounir RM. Precision of orthognathic digital plan transfer using patient-specific cutting guides and osteosynthesis versus mixed analogue–digitally planned surgery: a randomized controlled clinical trial. International journal of oral and maxillofacial surgery. 2020 Jan 1;49(1):62-8.
15. Chen H, Bi R, Hu Z, Chen J, Jiang N, Wu G, Li Y, Luo E, Zhu S. Comparison of three different types of splints and templates for maxilla repositioning in bimaxillary orthognathic surgery: a randomized controlled trial. International Journal of Oral and Maxillofacial Surgery. 2021 May 1;50(5):635-42.
16. Chin SJ, Wilde F, Neuhaus M, Schramm A, Gellrich NC, Rana M. Accuracy of virtual surgical planning of orthognathic surgery with aid of CAD/CAM fabricated surgical splint—A novel 3D analyzing algorithm. Journal of Cranio-Maxillofacial Surgery. 2017 Dec 1;45(12):1962-70.
17. Zhang N, Liu S, Hu Z, Hu J, Zhu S, Li Y. Accuracy of virtual surgical planning in two-jaw orthognathic surgery: comparison of planned and actual results. Oral surgery, oral medicine, oral pathology and oral radiology. 2016 Aug 1;122(2):143-51.
18. Hua J, Aziz S, Shum JW. Virtual surgical planning in oral and maxillofacial surgery. Oral and Maxillofacial Surgery Clinics. 2019 Nov 1;31(4):519-30.
19. Alkhayer A, Piffkó J, Lippold C, Segatto E. Accuracy of virtual planning in orthognathic surgery: a systematic review. Head & face medicine. 2020 Dec;16(1):1-9.
20. Zinser MJ, Sailer HF, Ritter L, Braumann B, Maegele M, Zöller JE. A paradigm shift in orthognathic surgery? A comparison of navigation, computer-aided designed/computer-aided manufactured splints, and "classic" intermaxillary splints to surgical transfer of virtual orthognathic planning. Journal of oral and maxillofacial surgery. 2013 Dec 1;71(12):2151-e1.
21. Wu TY, Lin HH, Lo LJ, Ho CT. Postoperative outcomes of two-and three-dimensional planning in orthognathic surgery: a comparative study. Journal of Plastic, Reconstructive & Aesthetic Surgery. 2017 Aug 1;70(8):1101-11.
22. Alkaabi S, Maningky M, Helder MN, Alsabri G. Virtual and Traditional Surgical Planning in Orthgnathic Surgery–Systematic Review and Meta-analysis. British Journal of Oral and Maxillofacial Surgery. 2022 Jul 29.
23. Lo L-J, Weng J-L, Ho C-T, Lin H-H (2018) Three-dimensional region-based study on the relationship between soft and hard tissue changes after orthognathic surgery in patients with prognathism. 13(8): e0200589.
24. Liao YF, Chen YA, Chen YC, Chen YR. Outcomes of conventional versus virtual surgical planning of orthognathic surgery using surgery-first approach for class III asymmetry. Clinical Oral Investigations. 2020 Apr;24:1509-16.

25. Raymond Fonseca Oral and Maxillofacial Surgery ,Volume 3 ,Third edition
26. Starch-Jensen T, Hernández-Alfaro F, Kesmez Ö, Gorgis R, Valls-Ontañón A. Accuracy of Orthognathic Surgical Planning using Three-dimensional Virtual Techniques compared with Conventional Two-dimensional Techniques: a Systematic Review J Oral Maxillofac Res 2023;14(1):e1