Accuracy of Orthognathic Surgical Planning using Three-dimensional Virtual Techniques compared with Conventional Two-dimensional Techniques: a Systematic Review

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ABSTRACT

Objectives: The objective was to assess the accuracy of orthognathic surgical planning using three-dimensional virtual planning compared with conventional two-dimensional planning.
Material and Methods: MEDLINE (PubMed), Embase and Cochrane Library search combined with hand-search of relevant journals was conducted to identify randomized controlled trials (RCTs) published in English through August 2nd, 2022. Primary outcomes included postsurgical accuracy of hard and soft tissue. Secondary outcomes included treatment planning time, intraoperative time, intraoperative blood loss, complications, financial expenses, and patient-reported outcome measures (PROMs). Quality and risk-of-bias assessment were evaluated by Cochrane risk of bias tool and GRADE system.
Results: Seven RCTs characterised by low, high, and unclear risk of bias fulfilled inclusion criteria. Included studies disclosed conflicting results regarding accuracy of hard and soft tissue as well as treatment planning time. The intraoperative time was shortened, and financial expenses were increased with three-dimensional virtual surgical planning (TVSP), while no planning-related complications were revealed. Comparable improvement in PROMs were reported with TVSP and two-dimensional planning.
Conclusions: Future orthognathic surgical planning will indisputable be performed by three-dimensional virtual planning. The financial expenses, treatment planning time, and intraoperative time will therefore probably decrease due to further development of three-dimensional virtual planning techniques. The hard and soft tissue accuracy between planned position and achieved surgical outcome seems to be improved by three-dimensional virtual planning compared with two-dimensional planning, although results are inconsistent. Further development of three-dimensional virtual planning involving cutting guides and patient-specific osteosynthesis plates are therefore needed to improve the accuracy of orthognathic surgical planning.

Keywords: orthognathic surgery; review; surgery; treatment; virtual planning.

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INTRODUCTION

Pronounced malocclusion combined with a dentofacial deformity are commonly treated by orthognathic surgery involving either single jaw or bimaxillary surgery. Previous published systematic reviews have demonstrated significant improvement in facial aesthetics, masticatory function, obstructive sleep apnoea and oral health-related quality of life (OHRQoL) following orthognathic surgery [1-5]. However, a predictable and successful treatment outcome following orthognathic surgery necessitates a meticulous and detailed preoperative treatment plan including clinical and radiographic transmission of the dentition and dentofacial deformity with high accuracy. Moreover, predictable implementation of the treatment plan to the surgical setting is a prerequisite for accurate intraoperative repositioning of the bony segments to obtain a satisfying functional outcome and aesthetic [6-8]. Ensuring predictable and accurate transmission of the preoperative treatment plan to the operating theatre is thus crucial to achieve the planned postsurgical outcome.

Conventional surgical planning of dentofacial deformities involves reproduction of the occlusal discrepancy on a fully or semi adjustable articulator through facebow transfer of cast model, two-dimensional cephalometric analysis, mock surgery, and manual fabricated acrylic occlusal splints. However, two-dimensional surgical planning (TSP) using mock surgery contain potential risk of errors and inaccuracies related to the impression, facebow transfer, radiographic distortion, surgical simulation, and intraoperative repositioning of the bony segments [9,10]. Moreover, TSP is inadequate for detailed analysis of facial asymmetries, which compromises the predictability and accuracy of orthognathic surgery in patients with severe dentofacial asymmetries and occlusal canting [11-13].

Emerging of three-dimensional technologies and computer software programs has facilitated novel methods for three-dimensional virtual surgical planning (TVSP) of dentofacial deformities without the need of facebow registration and plaster dental models. Computed tomography (CT) and cone-beam computed tomography (CBCT) combined with computer-assisted technology enables acquisition of three-dimensional images of the craniofacial complex and detailed implementation of a three-dimensional treatment plan, virtual surgeries, and manufacturing of computer-generated occlusal splints. Application of three-dimensional technologies for orthognathic surgical planning of dentofacial deformities is therefore anticipated to diminish treatment planning inaccuracies and significantly improve the surgical accuracy [12].

Previous published systematic reviews assessing surgical precision of hard and soft tissue following orthognathic surgery have demonstrated comparable or higher accuracy with TVSP compared with TSP [12-14]. However, the required time for treatment planning, operating theatre time, intraoperative blood loss, intra- and postoperative complications, financial expenses, and patient-reported outcome measures (PROMs) are also important considerations when assessing the best applicable treatment planning technique for correction of dentofacial deformities. Recent published systematic reviews concluded that TVSP shorten the overall treatment planning time compared with TSP [15-17]. Moreover, equivalent financial expenses and comparable improvement in OHRQoL have been reported with TVSP and TSP [13]. Thus, TVSP seems too beneficial improve the predictability and accuracy of hard and soft tissue as well as other parameters in orthognathic surgery compared with TSP. However, discrepancies of more than 2 mm between the planned and the actual surgical outcome following orthognathic surgery have been reported with TVSP and TSP, respectively [18,19]. Moreover, inaccuracies of up to 5 mm between the planned and the postsurgical position of the maxilla have been described following TSP using mock surgery [20]. Consequently, a systematic comparison of TVSP and TSP concerning the predictability and accuracy of the preoperative treatment plan to accomplish the planned postsurgical outcome is needed. The primary objective of the present systematic review is therefore to assess the predictability and accuracy of orthognathic surgical planning using TVSP techniques compared with TSP.

MATERIAL AND METHODS

Protocol and registration

The present systematic review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement for reporting systematic reviews [21]. The methods of the analysis and inclusion criteria were specified in advance and documented in a protocol and registered in PROSPERO, an international prospective register of systematic reviews.

Registration number: CRD42022350881

The protocol can be accessed at:

https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42022350881.

Focus question

The focus question was created according to the Patient, Intervention, Comparison and Outcome (PICO) framework as described in Table 1.

Eligibility criteria for considering studies for this review

Randomized controlled trials assessing the predictability and accuracy of orthognathic surgical planning using TVSP techniques compared with TSP were included.

Types of outcome measures
Primary outcome

Surgical accuracy of hard and soft tissue as evaluated by the difference in treatment plan measurements and actual surgical outcome based on cephalometric radiograph, CT, CBCT, photos or other valid assessment methods.

Secondary outcome

- Treatment planning time including total required time for the treatment planning procedure as well as preparing necessary material or other specified time periods.
- Time in the operating theatre, from beginning of the surgical procedure to the end of the surgical procedure or other specified intraoperative time periods.
- Intraoperative blood loss.
- Complications related to preparation, transmission, and implementation of the surgical treatment plan.
- Financial expenses including cost-effectiveness as well as required length of treatment planning time, occupation of the operating theatre, and length of hospitalization.
- PROMs including OHRQoL assessment as evaluated by interview, questionnaire, or visual analogue scale.

Information sources

The search strategy incorporated examinations of electronic databases, supplemented by a thorough hand-search page by page of relevant journals including “British Journal of Oral and Maxillofacial Surgery”, “International Journal of Oral and Maxillofacial Surgery”, “Journal of Oral & Maxillofacial Research”, “Journal of Craniofacial Surgery”, “Journal of Cranio-Maxillo-Facial Surgery”, “Journal of Oral and Maxillofacial Surgery”, “Medicina Oral Patologia Oral y Cirugia Bucal”, “Oral and Maxillofacial Surgery” and “Oral Surgery Oral Medicine Oral Pathology Oral Radiology”. The manual search also included the bibliographies of all articles selected for full-text screening as well as previously published reviews relevant for the present systematic review. Two reviewers (T.S-J and Ö.K.) independently performed the search. In the event of disagreement, another reviewer was consulted (A.V.O.)

Search strategy for identification of studies

A MEDLINE (PubMed), Embase, and Cochrane Library search was conducted. Human studies published in English through August 2nd, 2022 were included. Grey literature, unpublished literature as well as other databases like Scopus, Google Scholar, or Research Gate were not included in the search strategy of the present systematic review. Search strategy was performed in collaboration with a librarian and utilized a combination of Medical subject heading (MeSH) and free text terms. A detailed description of the search strategy is presented in Appendices 1 to 4.

Table 1. PICOS guidelines

Patient and population (P)	Healthy patients older than 18 years with severe dental malocclusion combine with dentofacial deformities necessitating orthognathic surgery.
Intervention (I)	Three-dimensional virtual surgical planning of orthognathic surgery.
Comparator or control group (C)	Two-dimensional surgical planning of orthognathic surgery using cephalometric analysis and model surgery.
Outcomes (O)	Primary outcomes included surgical accuracy of hard and soft tissue. Secondary outcomes included required treatment planning time, time in the operating theatre, intraoperative blood loss, intra- and postoperative complications, financial expenses, and patient-reported outcome measures.
Study design (S)	Randomized controlled trials.
Focused question	Are there any differences in the predictability and accuracy of orthognathic surgical planning using three-dimensional virtual surgical planning techniques compared with two-dimensional surgical planning?

Selection of studies

PRISMA flow diagram presents an overview of the selection process (Figure 1). Titles of identified reports were initially screened with duplicates removed. Abstracts were assessed when titles indicated that the study was relevant. Full-text analysis was obtained for those with apparent relevance or when the abstract was unavailable. References of papers identified and previously published systematic reviews assessing TVSP and TSP in conjunction with orthognathic surgery were cross-checked for unidentified articles. Study selection was performed by two reviewers (T.S-J. and Ö.K.). In the event of disagreement between the reviewers, another reviewer was consulted (A.V.O.). The level of agreement between the reviewers was tested using the Cohen's kappa coefficient (k).

Inclusion criteria

Randomized controlled trials in humans assessing the predictability and accuracy of orthognathic surgical planning using TVSP and TSP were included by addressing the previously described outcome measures. Moreover, at least ten patients should be included, and the used treatment planning technique should be clearly specified.

Exclusion criteria

Studies including syndromic craniosynostosis, cleft-palate, surgical-first approach or skeletal deformities resulting from trauma or tumour resection were excluded. Moreover, letters, editorials, PhD theses, letters to the editor, case reports, abstracts, technical reports, conference proceedings, cadaveric studies, animal or in vitro studies, and literature review papers were also excluded.

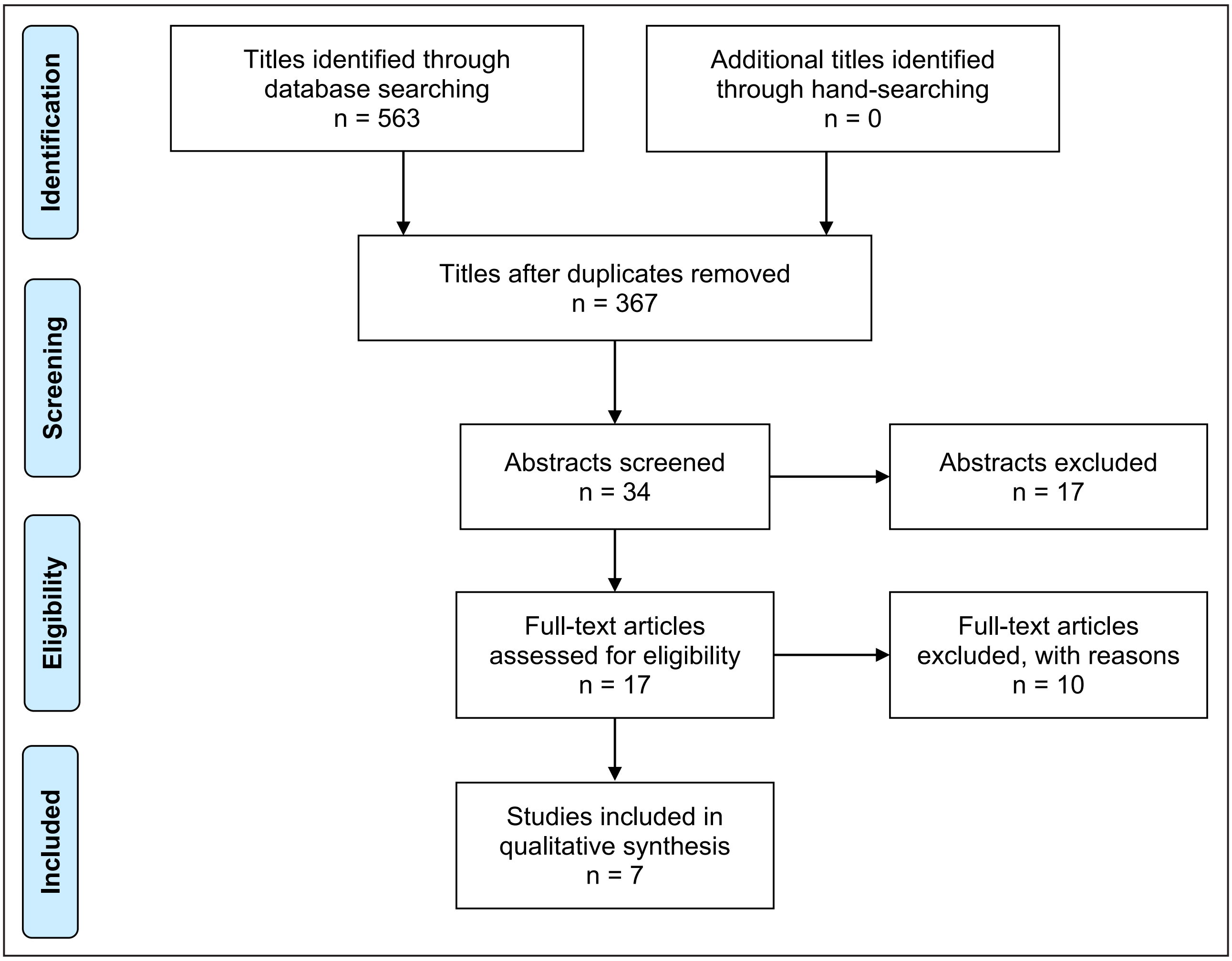

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram demonstrating results of systematic literature search. Electronic search resulted in 563 entries.
No articles were identified through hand-searching.
Of these 563 articles, 196 were excluded because they had been retrieved in more than one search.
A total of 34 abstracts were reviewed and full-text analysis included 17 articles.
Seven randomized controlled trials were finally included.

Data extraction

Data were extracted by one reviewer (T.S-J.) according to a predefined data-collection form ensuring systematic recording of the outcome measures. In addition, relevant characteristics of the study were recorded. Corresponding authors were contacted by e-mail in the absence of important information or ambiguities.

Data items

Following items were collected and arranged in following fields: author, number of patients, dentofacial deformity, treatment planning technique, planning instrument, surgical procedure, assessment methods, observation period, surgical accuracy of hard and soft tissue, treatment planning time, time in operating theatre, intraoperative blood loss, intra- and postoperative complications, financial expenses, and PROMs.

Quality and risk-of-bias assessment

Quality assessment was undertaken by two review authors (R.G. and T.S-J.) as part of the data extraction process. Cochrane Collaboration's tool for assessing the risk of bias suggested in the Cochrane Handbook for Systematic Reviews of Interventions was used for included randomized controlled trials (version 5.1.0) [22]. Following items were evaluated:

- Random sequence generation;
- Allocation concealment;
- Blinding of participants and personnel;
- Blinding of outcome assessment;
- Incomplete outcome data addressed;
- Selective reporting.

Publications were grouped into the following categories [23]: low risk of bias (possible bias not seriously affecting results) if all criteria were met, high risk of bias (possible bias seriously weakening reliability of results) if one or more criteria were not met, and unclear risk of bias when too few details were available for classification as high or low risk.
Moreover, the GRADE system (Grading of Recommendations, Assessment, Development and Evaluations) was used for evaluation of the included studies [24].

Statistical analysis

The outcome measures were evaluated by descriptive statistics. Parametric data involving surgical accuracy of hard and soft tissue, treatment planning time, and time in operating theatre are presented as mean and standard deviation (M [SD]) in the tables.
Meta-analysis was conducted if the included studies were of similar comparison and reporting identical outcome measures.

RESULTS

Study selection

Search results are outlined in Figure 1. Electronic search resulted in 563 entries. No articles were identified through hand-searching. Of these 563 articles, 196 were excluded due to being retrieved in more than one search. A total of 34 abstracts were reviewed and full-text analysis included 17 articles. Finally, seven randomized controlled trials were included [25-31]. The level of agreement between the two authors (T.S-J. and Ö.K) in selecting abstracts and studies to be read in full text were measured at k = 0.97 and 0.94, indicating almost perfect reliability of agreement.

Exclusion of studies

Reasons for excluding 10 studies after full-text assessment were: not a randomized controlled trial (n = 2) [32,33], TSP was not used in the study (n = 2) [34,35], identical patient sample were reported in one of the included studies (n = 5) [36-40], conference abstract (n = 1) [41].

Quality assessment

The quality of the included studies is summarized in Figures 2 and 3. Two studies were characterised by low risk of bias [27,31], one study with high risk of bias [30], and four studies with unclear risk of bias [25,26,28,29].
According to the GRADE system, two studies displayed a high grade [27,31], while the other five studies displayed a low grade [25,26,28-30]. The reason for downgrading was mainly the lack of blinding.

Characteristics of the studies included

The included studies of the present systematic review consisted of seven randomized controlled trial [25-31]. Adult patients (≥ 18 years) with malocclusion and a dentofacial deformity in need of orthognathic surgery were enrolled [25-31]. Detailed description of the used power analysis and sample size calculation, in which the mean linear distance between the planned

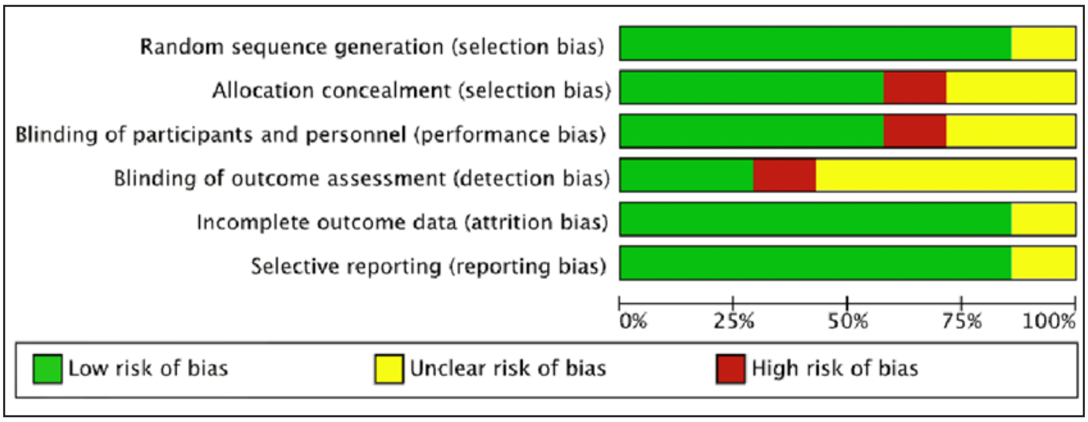

Figure 2. Risk of bias graph.

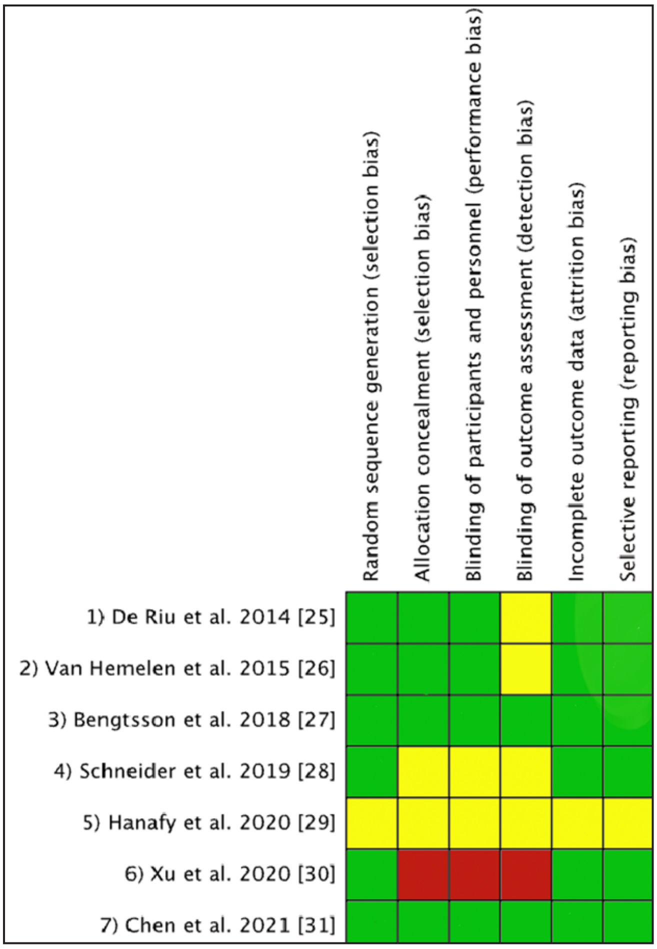

Figure 2. Risk of bias summary.

and actual postoperative position was chosen as the primary outcome variable was described in one of the included studies [31]. Consolidated Standards of Reporting Trials (CONSORT) were followed in two studies [27,31]. A single-blind [27,31] or double-blind study design [27] were applied, while no information of blinding was provided in studies [25,26,28-30]. Age and gender distribution as well as inclusion criteria and exclusion criteria were specified in all the included studies [25-31]. The surgical procedures included bimaxillary surgery [25-31], bimaxillary surgery with or without genioplasty [25,26], vertical ramus mandibular osteotomy [27], or single jaw procedure with or without genioplasty [26,27]. The sequencing of bimaxillary surgery included maxilla-first approach [25,27-29,31], mandibel-first approach [25] or the sequence were not reported [26,30]. The surgical procedure was performed by the same experienced surgeon [25,26,28,31], seven surgeons [27], or an unknown number of surgeons [29,30]. TVSP was performed using the treatment planning software Maxilim® (Medicim - Nobel Biocare Group; Mechelen, Belgium) [25], Maxilim (Medicim NV, Mechelen, Belgium) [26], Simplant® Pro version 12.02 OMS (Materialise Corp.; Leuven, Belgium) [27], Dolphin 3D Imaging® (Dolphin Imaging 11.9 Premium and Management Solution®; Chatsworth, California, USA) [28], and Mimics Research version 19.0 or 19.0 (Materialise NV; Leuven, Belgium) [29-31]. TVSP was conducted using computer-generated surgical splints [25,26,30,31], computer-generated surgical splints and pre-bent osteosynthesis plates [28] or computer-generated surgical guides and patient-specific titanium plates for maxillary positioning [29]. TSP was conducted involving two-dimensional tracing of radiographs, semi- or fully adjustable articulator through facebow transfer of cast model, mock surgery, and manual fabricated acrylic occlusal splints [25-31]. All measurements were performed by calibrated investigators [27,29,30], while no information was provided about examiner, training, or calibration [25,26,28,31]. Numbers of dropouts including plausible explanation were reported in two studies [27,30].

Data synthesis

The included studies of the present systematic review revealed considerable heterogeneity including use of different software planning system, single jaw surgery or bimaxillary surgery combined with genioplasty, sequencing of the surgical procedure, use of cutting guides and patient-specific osteosynthesis, different outcome measures, and assessment of hard and soft tissue accuracy by dissimilar clinical or radiographic landmarks. A well-defined meta-analysis was therefore not applicable.

Outcome measures

Primary and secondary outcomes measures are presented below and outlined in Table 2 and 3. All reported numerical values are presented as mean values combined with standard deviation. For each outcome measure, a short summary is finally provided including concluding remarks. Intraoperative blood loss was not reported in any of the included studies and therefore not described in the following section or outlined in Table 2 and 3.

Primary outcome measures

Hard tissue accuracy

Hard tissue accuracy was compared in all the included studies [25-31]. Results from each of the included studies are presented below in numerical order [25-31].

The percentage of linear and angular alignment of selected anatomical landmarks were assessed in patients with facial asymmetries [25]. TVSP revealed a statistically significantly improvement in alignment of the lower interincisal point (P = 0.03), mandibular sagittal plane (P = 0.01), and centring of the dental midlines (P = 0.03) compared with TSP [25].

The differences between the achieved surgical outcome and planned position were analysed using cephalometric landmarks in another study [26]. Difference in the anteriorposterior and vertical dimension were 1.42 and 1.44 mm with TVSP. Corresponding measurements were 1.71 mm and 1.69 mm for TSP. There were no statistically significant differences between TVSP and TSP [26].

The differences between the achieved surgical outcome and planned position were analysed using superimposition of cephalometric landmarks, after 12 months [27]. TVSP and TSP disclosed comparable outcomes in the anteriorposterior dimension for most of the cephalometric landmarks. Difference in A point position was 1.86 mm and 2.75 mm with TVSP and TSP. The difference was statistically significant (P = 0.035). Difference in the axis of the upper incisor and the nasion-sella line was 0.23 degrees and 3.95 degrees with TVSP and TSP. The difference was statistically significant (P < 0.001) [27].

The differences between the achieved 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) [28]. Differences in the anteriorposterior 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) [28].

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 [29]. Difference in the anteriorposterior, vertically, and mediolaterally dimension were 0.17 mm, 0.26 mm, and 0.07 mm with TVSP. Corresponding measurements were 1.31 mm, 1.45 mm, and 0.71 mm for TSP. The differences were statistically significant (P < 0.05) [29].

The 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 [30]. 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 TVSP and TSP [30].

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 [31]. The difference was 2.15 (SD 1.12) mm using TVSP compared with 2.55 (SD 0.95) mm with TSP. There were no statistically significant differences between TVSP and TSP (P < 0.05) [31].

Summary

The hard tissue accuracy following orthognathic surgical planning using TVSP compared with TSP is inconsistent. However, various studies revealed a statistically significant improvement in hard tissue accuracy with TVSP compared with TSP. Thus, TVSP seems to beneficially improve the hard tissue accuracy between the planned position and the achieved surgical outcome compared with TSP.

Soft tissue accuracy

Soft tissue accuracy was compared in two studies [25,26].

Table 2. Primary outcome measures following three-dimensional virtual surgical planning compared with two-dimensional surgical planning

Study	Year of publication	P	Dentofacial deformity	TVSP/TSP	Planning instrument	Surgical procedure	Assessment methods	OP	Hard tissue accuracy	Soft tissue accuracy	Conclusion
		Materials and Methods							Primary outcome measures		
De Riu et al. [25]	2014	20	Canting of occlusal plane of > 3° or midline discrepancies > 2.5 mm	TVSP: 10	Maxilim	Bimaxillary	Linear and angular measurements define alignment of midlines/cant	IAS	Rate of alignment (%): LIPFM 88.2[a]; MSPFM 80.2[b]; CDM 92.6[c]	Rate of alignment (%): Soft tissue menton/facial midline 76.7	Hard tissue accuracy improved with TVSP
				TSP: 10	Articulator				LIPFM 50.8; MSPFM 42.7; CDM 58.5	79.7	
Van Hemelen et al. [26]	2015	66	Class II/III	TVSP: 31	Maxilim	Bimaxillay: 20 Single jaw: 11	Linear measurements on cephalometric radiographs	4	Difference planned/achieved (mm): Horizontal 1.42 (SD 0.78); Vertical 1.44 (SD 0.61)	Horizontal 1.48 (SD 0.73)[d]; Vertical 1.46 (SD 0.53)[e]	No difference in hard tissue accuracy between TVSP and TSP. Soft tissue accuracy improved with TVSP
				TSP: 35	Articulator	Bimaxillay: 26 Single jaw: 9			Horizontal 1.71 (SD 0.87); Vertical 1.69 (SD 0.76)	Horizontal 2.29 (SD 1.06); Vertical 2.07 (SD 0.95)	
Bengtsson et al. [27]	2018	62	Class III and overjet > 5 mm	TVSP: 28	Simplant	Bimaxillary:15 Single jaw: 13	Linear and angular measurements on cephalometric radiographs	12	Difference planned and achieved: First incisor/NSL 0.23°[f]; A-point (mm) 1.86[g]	NR	Hard tissue accuracy improved with TVSP. TVSP improved outcome in asymmetric facial appearance and malocclusion
				TSP: 29	Facad	Bimaxillay:14 Single jaw: 15			First incisor/NSL 3.95°; A-point (mm) 2.75		
Schneider et al. [28]	2019	21	Class II	TVSP: 9	Dolphin	Bimaxillary	SNA, SNB and ANB angle	NR	Difference planned and achieved: SNA 0.6°[h]; SNB 0.7°[i]; ANB 0.5°[j]	NR	Hard tissue accuracy was improved with TVSP
				TSP: 12					SNA 1.8°; SNB 1.9°; ANB 1.6°		
Hanafy et al. [29]	2020	18	Dentofacial disharmony and mis-alignment	TVSP: 9	Mimics	Bimaxillary	Linear and angular dental measurements	IAS	Difference planned/achieved (mm): Horizontal 0.17[k]; Vertical 0.26[k]; Transverse 0.07[k]	NR	Hard tissue accuracy was improved with TVSP
				TSP: 9	Articulator				Horizontal 1.31; Vertical 1.45; Transverse 0.71		
Xu et al. [30]	2020	30	Class III. No severe asymmetry	TVSP: 15	Mimics	Bimaxillary	Maxillary position assessed by three skeletal points	IAS	Difference planned/achieved (mm): Horizontal 0.89; Vertical 0.77; Transverse 0.42	NR	No difference in hard tissue accuracy between TVSP and TSP
				TSP: 15	Articulator				Horizontal 0.95; Vertical 0.69; Transverse 0.51		
Chen et al. [31]	2021	51	Dentomaxillofacial deformity requiring bimaxillary surgery	TVSP: 21	Mimics	Bimaxillary	Maxillary position assessed by eight selected points on the teeth	7 days after surgery	Difference planned/achieved (mm): 2.15 (SD 1.12)	NR	No difference in hard tissue accuracy between TVSP and TSP
				TSP: 20	Articulator				2.55 (SD 0.95)		

[a]P = 0.03 (Student's test); [b]P = 0.01 (Student's test); [c]P = 0.03 (Student's test); [d]P = 0.002 (unpaired Student's t-test); [e]P = 0.005 (unpaired student t-test); [f]P < 0.001 (Fisher's Exact test), [g]P = 0.035 (Fisher's exact test); [h]P < 0.001 (unpaired Student's t-test and Fisher's exact test); [i]P = 0.002 (unpaired Student's t-test and Fisher´s exact test); [j]P < 0.001 (unpaired Student's t-test and Fisher's exact test); [k]P < 0.05 (unpaired Student's t-test, Mann-Whitney U-test).
ANB = A point to B point angle; CDM = centring of the dental midlines; IAS = immediately after surgery; LIPFM = lower interincisal point to facial midline; MSPFM = mandibular sagittal plane to facial midsagittal plane; P = number of patients; SD = standard deviation; SIA = semi-individual articulator; SNA = sella-nasion to A point angle; SNB = sella-nasion to B point angle; TSP = two-dimensional surgical planning; TVSP = three-dimensional virtual surgical planning.

Table 3. Secondary outcome measures following three-dimensional virtual surgical planning compared with two-dimensional surgical planning

Study	TVSP/TSP	Assessment methods	Treatment planning time (minutes)	Operating theatre time (minutes)	Complications	Financial expenses	PROMs	Conclusions
	Materials and Methods		Secondary outcome measures					
Van Hemelen et al. [26]	TVSP: 31	Total time spent on treatment planning. Patient appreciation scale questionnaire	38	NR	NR	NR	Patient appreciation scale questionnaire: 4.65	TVSP associated with increased treatment planning time
	TSP: 35		20				4.67	
Bengtsson et al. [27]	TVSP: 28	Time for radiographic examination/preparation/planning. Financial expenses OHIP-49, JFLS and OES questionnaire	34.1	NR	NR	156.1 $US[a]	OHIP-49 Pre 53.98, Post 26.67; JFLS Pre 33.28, Post 9.97; OES Pre 35.07, Post 59.72	Similar treatment planning time. TVSP associated with lower financial expenses. Comparable improvement PROMs
	TSP: 29		32.2			211.9 $US	OHIP-49 Pre 61.26, Post 37.64; JFLS Pre 37.54, Post 16,03; OES Pre 38.33, Post 60.5	
Schneider et al. [28]	TVSP: 9	Intraoperative time from start to end. Fixed cost including laboratory device	NR	162 (96 - 215)[b]	NR	884 €	NR	TVSP associated with shorter intraoperative time. TVSP associated with higher cost
	TSP: 12			202 (164 - 304)		481.8 €		
Hanafy et al. [29]	TVSP: 9	Planning related complications. Intraoperative time from maxillary incision to fixation	113	49	No planning-related complications	780 $US	All patients were satisfied with the clinical outcome	TVSP associated with shorter treatment planning time and intraoperative time. TVSP associated with higher cost
	TSP: 9		192	72		280 $US		
Chen et al. [31]	TVSP: 21	Duration of the operation from Le Fort I osteotomy to maxilla fixation	NR	39.1 (SD 15)	NR	NR	NR	No difference in intraoperative time
	TSP: 20			41.7 (SD 13.1)				

[a]P < 0.001 (Fisher's exact test); [b]P = 0.041 (unpaired Student's t-test and Fisher's exact test).
JFLS = jaw functional limitation scale; NR = not reported; OES = orofacial aesthetic scale; OHIP = oral health impact profile; OHRQOL = oral health-related quality of life; PROMs = patient-reported outcome measures; SD = standard deviation; TSP = two-dimensional surgical planning; TVSP = three-dimensional virtual surgical planning.

There was no statistically significant difference in the percentage rate of alignment of the soft tissue menton to the facial midline between TVSP and TSP (P = 1.00) [25].
Differences between the achieved surgical outcome and planned position were analysed using cephalometric landmarks [26]. Difference in the anteriorposterior and vertical dimension were 1.48 and 1.46 mm using TVSP. Corresponding measurements were 2.29 mm and 2.07 mm for TSP. The differences were statistically significant (P = 0.002, P = 0.005) [26].

Summary

The soft tissue accuracy following orthognathic surgical planning using TVSP compared with TSP is inconsistent. However, TVSP seems to beneficially improve the soft tissue accuracy between the planned position and the achieved surgical outcome compared with TSP.

Secondary outcome measures
Treatment planning time

The required treatment planning time was compared in two studies [26,29].
The treatment planning time was 38 minutes using TVSP, while 20 minutes were used for TSP [26]. The used method for assessment of treatment planning time was not specified and no statistical method was applied [26].
The treatment planning time from the end of the virtual plan to stereolithography (STL) export was 113 minutes using TVSP, while 192 minutes were used for TSP [29]. No statistical method was applied [29].

Summary

The required treatment planning time for orthognathic surgical planning with TVSP and TSP is inconsistent.

Time in the operating theatre

Time in the operating theatre was compared in three studies [28,29,31].
The intraoperative time from the start to the end of the operation was 162 minutes (range: 96 to 215 minutes) using TVSP and pre-bent osteosynthesis plates compared with 202 minutes (range: 164 to 304) for TSP. The difference was statistically significant (P = 0.041) [28].
The intraoperative time from maxillary incision to fixation was 49 minutes using TVSP with cutting guides and patient-specific osteosynthesis, while 72 minutes were used for TSP and conventional osteosynthesis [29]. No statistical method was applied [29].
The intraoperative time from Le Fort I osteotomy, placement of intermediate splint, and maxilla fixation was recorded using a stopwatch [31]. The recorded time was 39.1 (SD 15) minutes for TVSP and 41.7 (SD 13.1) minutes for TSP, respectively. The difference was not statistically significant (P > 0.05) [31].

Summary

TVSP seems to shorten the required time in the operating theatre compared with TSP.

Complications

Complications related to preparation, transmission, and implementations of the treatment plan were compared in one study [29].
No planning-related complications were reported following orthognathic surgical planning using TVSP and TSP [29].

Summary

TVSP and TSP seems to be associated with no surgical planning-related complications.

Financial expenses

Financial expenses were compared in three studies [27-29].
Financial expenses for radiographic examination, purchase of software, and annually software licence combined with time calculated cost following orthognathic surgical planning using TVSP or TSP were 211.88 $ (US dollars) and 156.12 $, respectively [27]. The difference was statistically significant (P = 0.041) [27].
Financial expenses following orthognathic surgical planning using TVSP or TSP was 884 € (Euros) and 481.8 €, respectively [28]. However, the cost of TVSP was reduced to 479 € without osteotomy models. No statistical method was applied [28].
Financial expenses for patient-specific cutting guides and plates were approximately 780 $ compared with 280 $ for conventional plates [29]. No statistical method was applied [29].

Summary

TVSP increases the financial expenses following orthognathic surgical planning compared with TSP.

Moreover, the use of cutting guides and patient-specific osteosynthesis plates in conjunction with TVSP further increases the financial expenses compared with TSP using conventional plate osteosynthesis.

Patient-reported outcome measures

PROMs were compared in three studies [26,27,29].
Patient appreciation scale revealed good satisfaction following orthognathic surgical planning with TVSP (4.65) and TSP (4.67), after four months [26]. No statistical method was applied [26].
OHRQoL was assessed by Oral Health Impact Profile 49 (OHIP-49), Jaw Functional Limitation Scale (JFL), and Orofacial Esthetic questionnaire (OES) following orthognathic surgical planning with TVSP and TSP [27]. A significant improvement in OHRQoL was reported with both treatment planning techniques. There was no statistically significant difference in total OHIP-49 score ($P = 0.65$), JFL score ($P = 0.83$), and OES score ($P = 0.64$) following orthognathic surgical planning with TVSP and TSP, after 12 months [27].
High patient satisfaction with the clinical outcome were reported with TVSP and TSP, after four months [29]. The applied method for assessment of PROMs were not described [29].

Summary

Comparable patient satisfaction and improvement in OHRQoL were reported following orthognathic surgical planning with TVSP and TSP.

DISCUSSION

The primary objective of the present systematic review was to assess the predictability and accuracy of orthognathic surgical planning using TVSP techniques compared with TSP. Seven randomized controlled trial characterized by various risk of bias as well as high or low grade fulfilled the inclusion criteria [25-31]. The hard and soft tissue accuracy between the planned position and achieved surgical outcome seems to be beneficially improved by TVSP compared with TSP, although the results of the included studies are inconsistent. The reported required treatment planning time with TVSP and TSP was opposing, while the intraoperative time was shortened, and the financial expenses were increased with TVSP. No planning-related complications were reported with TVSP and TSP. Comparable patient satisfaction and improvement in OHRQoL were revealed with TVSP and TSP. The included studies of the present systematic review revealed conflicting results according to the primary and secondary outcome measures. Synthesising inconsistent outcomes in reliable clinical recommendations attributes several limitations. Conclusions provided from the results of the present systematic review is therefore supplemented by the authors' considerations and should be cautiously interpreted.
Systematic reviews summarize and analyse the current scientific knowledge within a specific topic to answer a well-defined research question. Systematic reviews based on randomized controlled trials are generally considered as the highest quality evidence for assessing the effectiveness of a particular intervention due to an unbiased study design and diminished risk of systematic errors. Systematic reviews are frequently combined with a meta-analysis, which is a statistic method that combines data from several comparable studies into a single quantitative estimate or summary effect size. The present systematic review tried to answer the research question, whether TVSP led to improved predictability and accuracy of orthognathic surgical planning compared with TSP based on randomized controlled trials. However, severe methodological heterogeneity, dissimilar risk of bias, and various confounding factors prevented application of well-defined meta-analyses. Conclusion of the present systematic review is therefore based on descriptive data leading to the conclusion that none of the used orthognathic surgical planning techniques could be considered better than the other. Further well-conducted randomized controlled trials including comparable clinical and radiographic assessments methods, observation periods, and uniform data presentation are therefore needed to answer the focus question of the present systematic review.
Preoperative planning of orthognathic surgery has evolved substantially during the last decade from two-dimensional analysis on lateral cephalograms combined with manual model surgery and manufacturing of acrylic splints towards three-dimensional computer-assisted techniques using high-resolution CT or CBCT scans and computer software [42]. These novel treatment planning options poses new possibilities in orthognathic surgery including virtual surgeries, computer-generated surgical splints, cutting guides and patient-specific osteosynthesis, which is anticipated to improve the predictability and accuracy of the treatment plan and the actual surgical outcome [6]. However, the improved predictability and accuracy of TVSP compared with

TSP have been questioned [32]. Moreover, a recent systematic review concluded that the scientific literature lacks consensus regarding the accuracy of TVSP following orthognathic surgery [7]. From the author's point of view, it is indisputable that future orthognathic surgical planning will be performed by TVSP and computer-generated surgical splints possibly combined with cutting guides and patient-specific osteosynthesis. Moreover, detailed analysis and planning of facial asymmetries in patients with severe dentofacial asymmetries and occlusal canting is significantly enhanced by using TVSP compared with TSP. The focus question of improved predictability and accuracy of orthognathic surgical planning between TVSP and TSP therefore seems immaterial since TVSP has proven comparable or enhanced accuracy without significantly prolonging the required treatment planning time, intraoperative time or increased the financial expenses substantially. Further development of the TVSP technique to improve the transmission accuracy and implementation of the treatment plan to the surgical setting is therefore today´s challenge.

A difference of maximum 2 mm between the treatment plan and the actual surgical outcome is generally considered as a success criterion following orthognathic surgery [6]. Most of the included studies of the present systematic review revealed less than 2 mm discrepancy between the treatment plan and the actual surgical outcome with TVSP and TSP [26,29,30], whereas more than 2 mm discrepancy was reported with TSP [27], or both treatment planning techniques [31]. The surgical accuracy of positioning the maxilla following TVSP with the use of cutting guides and patient-specific osteosynthesis have been assessed in various studies demonstrating a mean difference less than 1 mm between the treatment plan and the actual surgical outcome [43-45]. Moreover, a resent systematic review reported that the required treatment planning and intraoperative time were shortened by approximately one third following TVSP involving cutting guides and patient-specific osteosynthesis compared with TSP and conventional plate osteosynthesis [46]. Consequently, TVSP with the use of cutting guides and patient-specific osteosynthesis seems to beneficially improve the predictability and accuracy of orthognathic surgical planning.

A recent published systematic review concluded that the financial expenses were significantly increased following orthognathic surgical planning using TVSP, cutting guides, and patient-specific osteosynthesis compared with TSP and conventional plate osteosynthesis [46]. The higher financial expenses may possibly restrict routine use of TVSP in orthognathic surgery. However, shortening of the required treatment planning time, operating theatre time, and hospitalization could justify the additional financial expenses following TVSP with the use of cutting guides and patient-specific osteosynthesis. Moreover, further development of software programs for orthognathic surgical planning will probably decreases the financial expenses associated with TVSP. In addition, a newly published study reported a higher incidence of reoperations following Le Fort I osteotomy with conventional plate osteosynthesis compared with patient-specific osteosynthesis due to insufficient advancement or postsurgical malocclusion [47]. Consequently, reliable comparison of financial expenses following orthognathic surgical planning using TVSP, cutting guides and patient-specific osteosynthesis compared with TSP and conventional plate osteosynthesis is multifaceted and various aspects such as frequency of reoperations, time savings, and length of hospitalization should be included in future studies assessing financial expenses following orthognathic surgery.

A recent published systematic review concluded that orthognathic surgery generates a positive impact on OHRQoL [1]. Improved satisfaction with facial appearance, masticatory function, and postsurgical OHRQoL are important considerations for orthognathic surgery patients. PROMs using self-administrated questionnaires, interviews or visual analogue scale are therefore valuable tools to evaluate whether health care services or a surgical intervention improve patients' health status or OHRQoL, including symptoms and functionality as well as physical, mental, and social health. The included studies of the present systematic review reported comparable improvement in OHRQoL following orthognathic surgical planning with TVSP and TSP [26,27,29]. However, PROMs were assessed by few questionnaires [26,27] or reported as a statement that all patients were satisfied with the clinical outcome [29]. Consequently, further studies assessing PROMs following orthognathic surgery with TVSP or TSP are needed.

CONCLUSIONS

The predictability and accuracy of orthognathic surgical planning using three-dimensional virtual surgical planning techniques compared with conventional two-dimensional surgical planning was assessed in the present systematic review.

The included studies disclosed conflicting results regarding accuracy of hard and soft tissue as well as required treatment planning time. The intraoperative time was shortened, and the financial expenses were increased with three-dimensional virtual surgical planning, while no planning-related complications and comparable improvement in oral health-related quality of life were reported with the two treatment planning techniques. Synthesising inconsistent outcomes in reliable clinical recommendations attributes several limitations. Nevertheless, it seems that the hard and soft tissue accuracy between the planned position and achieved surgical outcome are improved by three-dimensional virtual surgical planning, although the results are inconsistent. However, from the authors' point of view, it is indisputable that future planning of orthognathic surgery will be performed by three-dimensional virtual surgical planning techniques. The increased financial expenses, treatment planning time, and intraoperative time following orthognathic surgical planning with three-dimensional virtual surgical planning will probably be reduced due to further software development. Moreover, further development of three-dimensional virtual surgical planning techniques involving cutting guides and patient-specific osteosynthesis plates will probably improve the accuracy of orthognathic surgical planning, especially in patients with severe facial asymmetries and occlusal canting. However, theses aspects must be assessed in future studies.

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Appendix 1. Search history. Accuracy of Orthognathic Surgical Planning using Three-dimensional Virtual Techniques compared with Conventional Two-dimensional Techniques: a Systematic Review

Database	Interface	Result	Date
PubMed	PubMed.gov	178	02.08.2022
Embase	Embase.com	297	02.08.2022
Cochrane Library	Wiley	88	02.08.2022
All		**563**	
After duplicate-removal with Endnote		**367**	

Appendix 2. PubMed search until the 2nd of August, 2022

Search	Query	Items found
#1	(((((((((((((((((((((((((((((“Maxillofacial Abnormalities”[Mesh]) OR (“Orthognathic Surgery”[Mesh] OR “Orthognathic Surgical Procedures”[Mesh])) OR (“Osteotomy, Le Fort”[Mesh])) OR (“Osteotomy, Sagittal Split Ramus”[Mesh])) OR (Facial deformit*[Text Word])) OR (Orthognatic surg*[Text Word])) OR (orthognathic surg*[Text Word])) OR (Maxillofacial Surg*[Text Word])) OR (Corrective jaw Surg*[Text Word])) OR (Maxillary osteotom*[Text Word])) OR (Mandibular osteotom*[Text Word])) OR (Mandibular Reconstruct*[Text Word])) OR (Maxillofacial osteotom*[Text Word])) OR (Le Fort osteotom*[Text Word])) OR (Sagittal split*[Text Word])) OR (BSSO[Text Word])) OR (Dentofacial Deformit*[Text Word])) OR (Dentofacial Abnormalit*[Text Word])) OR (Dentofacial Malformation*[Text Word])) OR (Maxillofacial Abnormalit*[Text Word])) OR (Maxillofacial Deformit*[Text Word])) OR (Maxillofacial Malformation*[Text Word])) OR (orthognathic osteotom*[tw])) OR (Maxillary surger*[tw])) OR (Mandibular surger*[tw])) OR (Le Fort I[tw])) OR (Le Fort 1[tw])) OR (LF1[tw])) AND ((((((((((((“Computer Simulation”[Mesh]) OR (“Imaging, Three-Dimensional”[Mesh])) OR (“Surgery, Computer-Assisted”[Mesh])) OR (“User-Computer Interface”[Mesh])) OR (Virtual surgical plan*[tw])) OR (virtual plan*[tw])) OR (Three-dimensional*[tw])) OR (Threedimensional*[tw])) OR (Computer-assisted surg*[tw])) OR (3-dimensional*[tw])) OR (3dimensional*[tw])) OR (3D[tw]))) AND ((((((((((((Conventional*[tw]) OR (Conventional surgical plan*[tw])) OR classic*[tw] OR (Traditional*[tw])) OR (Traditional plan*[tw])) OR (Two-dimensional*[tw])) OR (Twodimensional*[tw])) OR (2-dimensional*[tw])) OR (2dimensional*[tw])) OR (2D[tw])) OR (Model surg*[tw])) OR (Mock surg*[tw]))) AND ((“randomized controlled trial”[Publication Type] OR “controlled clinical trial”[Publication Type] OR “randomized”[tw] OR “placebo”[tw] OR randomis*[tw] OR “drug therapy”[MeSH Subheading] OR “randomly”[tw] OR “trial”[tw] OR “groups”[tw]) NOT (“animals”[MeSH Terms] NOT “humans”[MeSH Terms])))	178

Appendix 3A. Embase search until the 2nd of August, 2022

Search	Query	Items found
#226	((‘face malformation’/exp OR ‘orthognathic surgery’/exp OR ((fac* OR dentofacial* OR maxillofacial) NEAR/3 (deformit* OR abnormalit* OR malformation*)):ti,ab,kw OR ((orthognatic OR orthognathic OR maxillofacial OR ‘corrective jaw’ OR maxillary OR mandibular OR ‘le fort’) NEAR/3 (surg* OR osteotom* OR reconstruct*)):ti,ab,kw OR (‘le fort i’:ti,ab,kw OR ‘le fort 1’:ti,ab,kw OR ‘lf1’:ti,ab,kw) OR ‘sagittal split*’:ti,ab,kw OR ‘bsso’:ti,ab,kw) AND (‘computer simulation’/exp OR ‘three dimensional computer aided design’/exp OR ‘three-dimensional imaging’/exp OR ‘computer assisted surgery’/exp OR (‘virtual surgical plan*’:ti,ab,kw OR ‘virtual plan*’:ti,ab,kw OR ‘three-dimensional*’:ti,ab,kw OR threedimensional*:ti,ab,kw OR ‘computer-assisted surg*’:ti,ab,kw OR ‘3-dimensional*’:ti,ab,kw OR ‘3dimensional*’:ti,ab,kw OR 3d:ti,ab,kw)) AND ((conventional*:ti,ab,kw OR classic*:ti,ab,kw OR traditional*:ti,ab,kw OR ‘two dimensional*’:ti,ab,kw OR twodimensional*:ti,ab,kw OR ‘2 dimensional*’:ti,ab,kw OR 2dimensional*:ti,ab,kw OR 2d:ti,ab,kw OR ‘model surg*’:ti,ab,kw OR ‘mock surg*’:ti,ab,kw) OR ‘two-dimensional imaging’/exp)) AND ((‘controlled clinical trial’/exp OR ‘randomized controlled trial’/exp OR ‘randomization’/exp OR (randomized:ti,ab,kw OR placebo:ti,ab,kw OR randomis*:ti,ab,kw OR randomly:ti,ab,kw OR trial:ti,ab,kw OR groups:ti,ab,kw)) NOT (‘animal experiment’/de NOT (‘human experiment’/de OR ‘human’/de)))	297
#25	(‘controlled clinical trial’/exp OR ‘randomized controlled trial’/exp OR ‘randomization’/exp OR (randomized:ti,ab,kw OR placebo:ti,ab,kw OR randomis*:ti,ab,kw OR randomly:ti,ab,kw OR trial:ti,ab,kw OR groups:ti,ab,kw)) NOT (‘animal experiment’/de NOT (‘human experiment’/de OR ‘human’/de))	4584838
#24	‘animal experiment’/de NOT (‘human experiment’/de OR ‘human’/de)	2448644
#23	‘controlled clinical trial’/exp OR ‘randomized controlled trial’/exp OR ‘randomization’/exp OR (randomized:ti,ab,kw OR placebo:ti,ab,kw OR randomis*:ti,ab,kw OR randomly:ti,ab,kw OR trial:ti,ab,kw OR groups:ti,ab,kw)	4988632

Appendix 3B. Embase search until the 2nd of August, 2022

Search	Query	Items found
#22	randomized:ti,ab,kw OR placebo:ti,ab,kw OR randomis*:ti,ab,kw OR randomly:ti,ab,kw OR trial:ti,ab,kw OR groups:ti,ab,kw	4783897
#21	'randomization'/exp	94761
#20	'randomized controlled trial'/exp	723775
#19	'controlled clinical trial'/exp	900729
#18	('face malformation'/exp OR 'orthognathic surgery'/exp OR ((fac* OR dentofacial* OR maxillofacial) NEAR/3 (deformit* OR abnormalit* OR malformation*)):ti,ab,kw OR ((orthognatic OR orthognathic OR maxillofacial OR 'corrective jaw' OR maxillary OR mandibular OR 'le fort') NEAR/3 (surg* OR osteotom* OR reconstruct*)):ti,ab,kw OR ('le fort i':ti,ab,kw OR 'le fort 1':ti,ab,kw OR 'lf1':ti,ab,kw) OR 'sagittal split*':ti,ab,kw OR 'bsso':ti,ab,kw) AND ('computer simulation'/exp OR 'three dimensional computer aided design'/exp OR 'three-dimensional imaging'/exp OR 'computer assisted surgery'/exp OR ('virtual surgical plan*':ti,ab,kw OR 'virtual plan*':ti,ab,kw OR 'three-dimensional*':ti,ab,kw OR threedimensional*:ti,ab,kw OR 'computer-assisted surg*':ti,ab,kw OR '3-dimensional*':ti,ab,kw OR '3dimensional*':ti,ab,kw OR 3d:ti,ab,kw)) AND ((conventional*:ti,ab,kw OR classic*:ti,ab,kw OR traditional*:ti,ab,kw OR 'two dimensional*':ti,ab,kw OR twodimensional*:ti,ab,kw OR '2 dimensional*':ti,ab,kw OR 2dimensional*:ti,ab,kw OR 2d:ti,ab,kw OR 'model surg*':ti,ab,kw OR 'mock surg*':ti,ab,kw) OR 'two-dimensional imaging'/exp)	1753
#17	(conventional*:ti,ab,kw OR classic*:ti,ab,kw OR traditional*:ti,ab,kw OR 'two dimensional*':ti,ab,kw OR twodimensional*:ti,ab,kw OR '2 dimensional*':ti,ab,kw OR 2dimensional*:ti,ab,kw OR 2d:ti,ab,kw OR 'model surg*':ti,ab,kw OR 'mock surg*':ti,ab,kw) OR 'two-dimensional imaging'/exp	1896928
#16	'two-dimensional imaging'/exp	5518
#15	conventional*:ti,ab,kw OR classic*:ti,ab,kw OR traditional*:ti,ab,kw OR 'two dimensional*':ti,ab,kw OR twodimensional*:ti,ab,kw OR '2 dimensional*':ti,ab,kw OR 2dimensional*:ti,ab,kw OR 2d:ti,ab,kw OR 'model surg*':ti,ab,kw OR 'mock surg*':ti,ab,kw	1895169
#14	'computer simulation'/exp OR 'three dimensional computer aided design'/exp OR 'three-dimensional imaging'/exp OR 'computer assisted surgery'/exp OR ('virtual surgical plan*':ti,ab,kw OR 'virtual plan*':ti,ab,kw OR 'three-dimensional*':ti,ab,kw OR threedimensional*:ti,ab,kw OR 'computer-assisted surg*':ti,ab,kw OR '3-dimensional*':ti,ab,kw OR '3dimensional*':ti,ab,kw OR 3d:ti,ab,kw)	675647
#13	'virtual surgical plan*':ti,ab,kw OR 'virtual plan*':ti,ab,kw OR 'three-dimensional*':ti,ab,kw OR threedimensional*:ti,ab,kw OR 'computer-assisted surg*':ti,ab,kw OR '3-dimensional*':ti,ab,kw OR '3dimensional*':ti,ab,kw OR 3d:ti,ab,kw	479336
#12	'computer assisted surgery'/exp	34976
#11	'three-dimensional imaging'/exp	117028
#10	'three dimensional computer aided design'/exp	209
#9	'computer simulation'/exp	155308
#8	'face malformation'/exp OR 'orthognathic surgery'/exp OR ((fac* OR dentofacial* OR maxillofacial) NEAR/3 (deformit* OR abnormalit* OR malformation*)):ti,ab,kw OR ((orthognatic OR orthognathic OR maxillofacial OR 'corrective jaw' OR maxillary OR mandibular OR 'le fort') NEAR/3 (surg* OR osteotom* OR reconstruct*)):ti,ab,kw OR ('le fort i':ti,ab,kw OR 'le fort 1':ti,ab,kw OR 'lf1':ti,ab,kw) OR 'sagittal split*':ti,ab,kw OR 'bsso':ti,ab,kw	158683
#7	'bsso':ti,ab,kw	494
#6	'sagittal split*':ti,ab,kw	2453
#5	'le fort i':ti,ab,kw OR 'le fort 1':ti,ab,kw OR 'lf1':ti,ab,kw	2554
#4	((orthognatic OR orthognathic OR maxillofacial OR 'corrective jaw' OR maxillary OR mandibular OR 'le fort') NEAR/3 (surg* OR osteotom* OR reconstruct*)):ti,ab,kw	36990
#3	((fac* OR dentofacial* OR maxillofacial) NEAR/3 (deformit* OR abnormalit* OR malformation*)):ti,ab,kw	12343
#2	'orthognathic surgery'/exp	11778
#1	'face malformation'/exp	113082

Appendix 4. Cochrane Library search until the 2nd of August, 2022

Search	Query	Items found
#1	MeSH descriptor: [Maxillofacial Abnormalities] explode all trees	485
#2	MeSH descriptor: [Orthognathic Surgery] explode all trees	52
#3	MeSH descriptor: [Orthognathic Surgical Procedures] explode all trees	222
#4	MeSH descriptor: [Osteotomy, Le Fort] explode all trees	88
#5	MeSH descriptor: [Osteotomy, Le Fort] explode all trees	47
#6	((fac* OR dentofacial* OR maxillofacial) NEAR/3 (deformit* OR abnormalit* OR malformation*)):ti,ab,kw	329
#7	((orthognatic OR orthognathic OR maxillofacial OR “corrective jaw” OR maxillary OR mandibular OR ‘le fort’) NEAR/3 (surg* OR osteotom* OR reconstruct*)):ti,ab,kw	2829
#8	“le fort i”:ti,ab,kw OR “le fort 1”:ti,ab,kw OR “lf1”:ti,ab,kw	203
#9	“sagittal split*”:ti,ab,kw	245
#10	‘bsso’:ti,ab,kw	75
#11	#1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9 or #10	3557
#12	MeSH descriptor: [Computer Simulation] explode all trees	2218
#13	MeSH descriptor: [Imaging, Three-Dimensional] explode all trees	1205
#14	MeSH descriptor: [Surgery, Computer-Assisted] explode all trees	1282
#15	MeSH descriptor: [User-Computer Interface] explode all trees	1294
#16	“virtual surgical plan*”:ti,ab,kw OR “virtual plan*”:ti,ab,kw OR “three-dimensional*”:ti,ab,kw OR threedimensional*:ti,ab,kw OR “computer-assisted surg*”:ti,ab,kw OR “3-dimensional*”:ti,ab,kw OR “3dimensional*”:ti,ab,kw OR 3d:ti,ab,kw	10238
#17	#12 or #13 or #14 or #15 or #16	14262
#18	conventional*:ti,ab,kw OR classic*:ti,ab,kw OR traditional*:ti,ab,kw OR “two dimensional*”:ti,ab,kw OR twodimensional*:ti,ab,kw OR “2 dimensional*”:ti,ab,kw OR 2dimensional*:ti,ab,kw OR 2d:ti,ab,kw OR “model surg*”:ti,ab,kw OR “mock surg*”:ti,ab,kw	120484
#19	#11 and #17 and #18	88