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Systematic Review
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Virtual planning in orthognathic surgery

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Abstract. Numerous publications regarding virtual surgical planning protocols have been published, most reporting only one or two case reports to emphasize the hands-on planning. None have systematically reviewed the data published from clinical trials. This systematic review analyzes the precision and accuracy of three-dimensional (3D) virtual surgical planning of orthognathic procedures compared with the actual surgical outcome following orthognathic surgery reported in clinical trials. A systematic search of the current literature was conducted to identify clinical trials with a sample size of more than five patients, comparing the virtual surgical plan with the actual surgical outcome. Search terms revealed a total of 428 titles, out of which only seven articles were included, with a combined sample size of 149 patients. Data were presented in three different ways: intra-class correlation coefficient, 3D surface area with a difference <2 mm, and linear and angular differences in three dimensions. Success criteria were set at 2 mm mean difference in six articles; 125 of the 133 patients included in these articles were regarded as having had a successful outcome. Due to differences in the presentation of data, meta-analysis was not possible. Virtual planning appears to be an accurate and reproducible method for orthognathic treatment planning. A more uniform presentation of the data is necessary to allow the performance of a meta-analysis. Currently, the software system most often used for 3D virtual planning in clinical trials is SimPlant (Materialise). More independent clinical trials are needed to further validate the precision of virtual planning.

Key words: virtual surgical planning; computer-assisted surgery; computer-assisted image processing; three-dimensional imaging user–computer interface.

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The success of orthognathic surgery depends on the surgical technique and the accuracy of the surgical plan. Virtual planning combined with computer-aided surgery are rapidly emerging and increasingly important areas of research. Computer-aided surgery describes various forms of surgical planning or execution that incorporate advanced imaging, software analysis, virtual planning, rapid prototyping technology, robotics, and image-guidance systems. Virtual planning is performed on a virtual model composed of a three-dimensional (3D) scan of the maxillofacial skeleton and a 3D scan of the dental arch (3shape, Copenhagen, Denmark), merged into a 3D virtual model as close to reality as possible.[1–3] Additional digital data can be added for soft tissue rendering of the face by laser scanners or stereophotography.[4] The two major software systems for 3D virtual planning are SimPlant (Materialise, Leuven, Belgium) and Dolphin 3D (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA). The systems have been developed from different origins. SimPlant originated from 3D-guided surgery in implant dentistry, whereas Dolphin 3D originated from conventional lateral two-dimensional (2D) cephalometric tracing and planning.

Virtual planning offers new possibilities to visualize the relationship between the dental arches and the surrounding bony structures in a single virtual model. This approach offers several advantages compared to conventional planning, including: (1) A diagnostic evaluation performed on a 3D virtual model; this diagnostic tool makes it possible to detect and quantify dental cant, yaw deformities, and other facial asymmetries that would have been undetected by physical examination, 2D lateral cephalometric analysis, and plaster cast dental models mounted on a semi-adjustable articulator.[3,5–7] (2) 3D virtual planning provides the surgeon with freedom to simulate different surgical procedures to obtain the best possible outcome for the patient. (3) 3D virtual planning facilitates the evaluation and correction of centric relation in the temporomandibular joint (TMJ).[8] Thus, discrepancies in centric relation can be identified and corrected prior to surgery. This preoperative correction may minimize the strain on the TMJ after orthognathic surgery and facilitate accurate transfer of the virtual surgical plan to the patient.[9–11] Since both displacement and resorption of the condylar process postoperatively have been reported following orthognathic surgery,[12–15] optimizing the accurate transfer of the virtual plan to the patient is still critical in the successful implementation of new planning protocols.

In computer-aided surgical simulation systems, the virtual plan is transferred to the patient using surgical splints, which can be fabricated directly from the virtual plan using computer-aided design and computer-aided manufacturing (CAD/CAM) techniques.[8,16,17] In addition, virtual planning provides new opportunities to incorporate intraoperative navigational systems that can assist in the correct positioning of the bony segments independently of the opposite maxillary position.[1,18,19] This independent positioning minimizes the intraoperative error due to the inconsistencies in condylar position. Finally, the postoperative soft tissue changes can be predicted with increasing accuracy, and new software algorithms are rapidly being developed to predict the change in soft tissue in response to movement of the underlying bony segments.

Virtual surgical planning, coupled with a method of transferring the plan to the patient, enables the surgeon to make an accurate diagnosis, provides a predictable means of 3D reconstruction, and facilitates the analysis of postoperative changes in both hard and soft tissue. Several articles have described 3D virtual surgical planning protocols.[3,5,6,19–21] Most authors have included only one or two case reports to support the hands-on planning. Additionally, no papers have systematically reviewed the data published from clinical trials.

Therefore, the main focus of this systematic review was to examine the publication of clinical trials evaluating the precision of 3D virtual surgical planning used in orthognathic surgery, and if possible to perform a meta-analysis of the results. The precision is evaluated as the difference between the 3D virtual surgical plan and the actual surgical outcome.

Materials and methods

The precision and accuracy of the virtually planned orthognathic surgery compared with the actual postoperative surgical outcome was assessed in this systematic review. The review protocol was prospectively registered with PROSPERO (registration CRD42013004090).

The inclusion criteria for this review were the following: a relevant sample size of five patients or more in order to encompass all performed clinical trials larger than case studies; conventional orthognathic surgery to correct dentofacial development abnormalities; the precision and accuracy evaluated by a comparison of the 3D virtual surgical plan with the actual surgical outcome in 3D. The exclusion criteria were the following: case reports with fewer than five patients; surgery performed with distraction apparatus; surgery due to trauma, cancer, or cleft palate.

A systematic, computerized database search was conducted using the National Center for Biotechnology Information (NCBI) to search MEDLINE (PubMed), Embase, and the Cochrane Library. The search included only articles published in English, from the year 2000 until the search date, June 2012. The search was conducted using the medical subject heading (MeSH) terms given below, divided into two groups regarding orthognathic surgery and virtual planning. The search was intentionally wide to encompass all surgeries using 3D virtual surgical planning. (1) Group 1, orthognathic surgery: ''Orthognathic Surgery'', ''Orthognathic Surgical Procedures'', ''Craniofacial Abnormalities'', ''Osteotomy, Maxillary'', ''Osteotomy, Le Fort'', or ''Osteotomy, Sagittal Split Ramus''. (2) Group 2, virtual planning: ''Surgery, Computer-Assisted'', ''Computer-Aided Surgical Simulation'', ''User–Computer Interface'', or ''Imaging, Three-Dimensional''.

The search was supplemented by a search of the bibliographies of included articles and a hand-search of the relevant journals. Screening was carried out according to the inclusion and exclusion criteria. Initially, headlines were screened for inclusion or exclusion criteria. If included, the abstract was screened for inclusion or exclusion criteria. Finally, if the abstract was included or incomplete, the full article was reviewed.

Data from the articles were extracted into an Excel spreadsheet with regard to year, author, sample size, type of surgery, mean difference between planned and actual outcome, success criteria, and the number of successful operations. The articles included were evaluated regarding risk of bias due to financial interests. Also, the Cochrane Collaboration tool for assessing the risk of bias was used to evaluate selection, performance, detection, attrition, and reporting risk of bias (Table 1).[22]

If possible, a meta-analysis would be performed, where the weighted mean of the difference between virtual surgical plan and actual surgical outcome were evaluated and visualized by a forest plot.

Results

The search created a database of 428 articles with at least one MeSH term in both groups 1 and 2 (see Fig. 1). The titles were screened initially with regard to relevance, and 259 were excluded since the headlines indicated that the articles did not discuss either virtual planning or orthognathic surgery. The remaining 169 abstracts were assessed, and 128 were excluded since the abstract indicated that the article did not discuss virtual planning, orthognathic surgery, or involvement of patients. If the abstract was not published, the article was included for full text assessment. In total, 41 articles were selected for full text analysis. Out of these 41 articles, six did not meet the inclusion criteria, 12 described planning protocols, 12 were case reports with one or two patients, and four exclusively assessed soft tissue outcomes. Only seven articles met the inclusion criteria and were included in this review. An additional search through the bibliographies of these seven articles created another database of 140 articles, of which 114 were not in the previous search. The titles were screened, and 20 were selected for abstract assessment, but none met the inclusion criteria. Relevant journals from 2005 to May 2013 were searched for additional articles, but none were found.

The seven articles included in this review were published between January 2006 and May 2013.[1,8,16,17,23–25] The sample size of each article ranged from five to 65 patients, with a combined sample size