Journal of Cranio-Maxillo-Facial Surgery 43 (2015) 918–925

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

Three-dimensional virtual planning in orthognathic surgery enhances the accuracy of soft tissue prediction

Geert Van Hemelen [a], Maarten Van Genechten [a], Lieven Renier [a], Maria Desmedt [b], Elric Verbruggen [c], Nasser Nadjmi [a,*]

[a] Department of Cranio-Maxillofacial Surgery, University of Antwerp, AZ MONICA Antwerp, Harmoniestraat 68, 2018 Antwerp, Belgium
[b] Department of Mund-, Kiefer- und Gesichtschirurgie, Fachklinik Hornheide, Dorbaumstraße 300, 48157 Münster, Germany
[c] Department of Medical Informatics, Military Hospital Queen Astrid, Bruynstraat 1, 1120 Brussels, Belgium

A R T I C L E I N F O

Article history:
Paper received 7 November 2014
Accepted 1 April 2015
Available online 30 April 2015

Keywords:
Virtual surgery
3D planning
2D planning
Orthognathic surgery
Soft tissue prediction

A B S T R A C T

Introduction: Throughout the history of computing, shortening the gap between the physical and digital world behind the screen has always been strived for. Recent advances in three-dimensional (3D) virtual surgery programs have reduced this gap significantly. Although 3D assisted surgery is now widely available for orthognathic surgery, one might still argue whether a 3D virtual planning approach is a better alternative to a conventional two-dimensional (2D) planning technique. The purpose of this study was to compare the accuracy of a traditional 2D technique and a 3D computer-aided prediction method.

Methods: A double blind randomised prospective study was performed to compare the prediction accuracy of a traditional 2D planning technique versus a 3D computer-aided planning approach. The accuracy of the hard and soft tissue profile predictions using both planning methods was investigated.

Results: There was a statistically significant difference between 2D and 3D soft tissue planning ($p < 0.05$). The statistically significant difference found between 2D and 3D planning and the actual soft tissue outcome was not confirmed by a statistically significant difference between methods.

Conclusions: The 3D planning approach provides more accurate soft tissue planning. However, the 2D orthognathic planning is comparable to 3D planning when it comes to hard tissue planning. This study provides relevant results for choosing between 3D and 2D planning in clinical practice.

1. Introduction

Evolution in medical imaging has produced an emerging trend of 3D virtually assisted computer planning programs. Virtual 3D computer-aided planning is becoming more and more important in orthognathic surgical treatment planning. It not only embodies a powerful communication tool between the surgeon, the orthodontist, and the patient, but it is also considered to have an added value in diagnosis and planning of orthognathic surgery. As the terminology implies, classical 2D planning is a profile planning which does not sufficiently control the third dimension (Chabanas et al., 2004). The third dimension is often of crucial importance, such as when treating facial asymmetry. Face bow registration combined with anthropometrical analysis generates additional control of the third dimension, but theoretical errors and inaccuracies easily occur (Olszewski and Reychler, 2004). There are scientific literature reports on the accuracy of 3D computer-aided planning, but this has not yet led to widespread use of 3D virtual planning of orthognathic surgery in common clinical practice (Chabanas et al., 2004; Kaipatur and Flores-Mir, 2009; Marcheti et al., 2011; Mollemans et al., 2007; Shafi et al., 2013; Westermark et al., 2005; Xia et al., 2009; Zinser et al., 2013).

In this study, we focused on the accuracy of the hard and soft tissue profile predictions and the time-consuming aspects of both planning approaches in routine daily practice, which we consider important from a clinical perspective. The design of this study was set up to compare the accuracy of 2D and 3D orthognathic planning in their 2 common directions (depth and height).

* Corresponding author. Department of Cranio-Maxillofacial Surgery, University of Antwerp, AZ MONICA Campus Antwerpen, Harmoniestraat 68, 2018 Antwerp, Belgium. Tel.: +32 3 240 26 11; fax: +32 3 238 04 89.
E-mail address: nasser@nadjmi.com (N. Nadjmi).

http://dx.doi.org/10.1016/j.jcms.2015.04.006
1010-5182/

2. Materials and methods

The study protocol was approved by the local ethics committee (Dirsec/EC/134The, AZ Monica, Antwerp, Belgium). The study included 66 patients (29 males, 37 females) who were operated on by the same surgeon. 58 patients had an Angle Class II malocclusion, and 8 patients had an Angle Class III malocclusion. 46 Patients underwent a bimaxillary osteotomy, of which 21 patients also received a genioplasty. 17 Patients underwent a bilateral sagittal split osteotomy of the lower jaw, of which 6 patients also received a genioplasty. 3 Patients underwent a Le Fort I osteotomy, of which 1 also received a genioplasty (Table 1). No counter clockwise rotations were performed. 31 Patients were treated according to the 3D planning scenario, and 35 patients were treated according to the 2D planning protocol. Both the 2D and 3D approaches required a specific input of data.

2.1. Data collection

2.1.1. Data acquisition and pre-processing

To perform the 2D planning, a clinical facial examination was performed, and a lateral cephalogram, frontal cephalogram, orthopantomogram (OPT) (CRANEX® D, Soredex, Tuusula, Finland), clinical slides, and plaster models with a wax-bite in central relation (CR) were taken. Face bow registration completed the 2D data collection (Artex facebow Rotofix 218600, Artex transfer table 216240, Artex articulator type CN 217310 calibrated with Splitex plates 216100C).

To enable 3D computer-aided planning, a virtual skin and skull model with detailed dental information is required. Therefore, an augmented model procedure was applied (Swennen et al., 2009). This method allows the generation of a detailed occlusion on a virtual skull model using a triple scan procedure (Olszewski and Reychler, 2004). First, a full extended height Cone beam CT (CBCT) was performed in a vertical sitting position biting down on a thin wax bite in CR position (i-CAT™, Imaging Sciences International, Inc., Hatfield, USA; field of view: 17-cm diameter/22-cm height; scan time: 2 × 20 s; voxel size: 0.4 mm). Next, a limited-dose CBCT scan of the patient biting down on a double-sided impression was carried out (field of view: 17-cm diameter/8-cm height; scan time: 1 × 10 s; voxel size: 0.4 mm). Finally, a high-resolution scan of the double-sided impression was performed (field of view: 17-cm diameter/6-cm height; scan time: 40 s; voxel size: 0.2 mm). By combining the image data of these three CBCT scans, an augmented model was generated in Maxilim software (Medicim NV, Mechelen, Belgium).

Digital photographs of the patient biting down in CR on the same wax bite were taken and mapped on the 3D soft tissue model (Swennen et al., 2009). A virtual head was finally computed, including a 3D skull model with coloured overlying soft tissue.

Table 1
Demographic and clinical characteristics of 2D and 3D patients.

Demographic characteristics			
Average age			19.78
Seks	M		29
	F		37
Clinical characteristics	**2D**	**3D**	**Total**
BSSO	6	5	11
BSSO + chin	2	4	6
LFI	1	1	2
LFI + chin	0	1	1
Bimax	15	10	25
Bimax + chin	11	10	21
Angle 2	26	32	58
Angle 3	3	5	8
Planning	35	31	66

2.1.2. Pre-operative planning

Before surgery, 2D and 3D planning of the orthognathic surgery was prepared. All 2D planning procedures were performed based on the data collection described above. The lateral cephalogram allowed for analysis of the dentofacial skeleton from a sagittal perspective. The frontal cephalogram allowed for analysis of the facial asymmetry. The position of the maxilla and the mandible were related to each other and to the skull base. Further facial analysis included the determination of the key cephalometric landmarks, as described in the most widely used analyses, as well as a clinical facial evaluation, which offers an objective quantification of the clinically most important anthropometric landmarks. The treatment planning abides by a paradigm shift that favours anthropometric planning over cephalometric planning. The planned jaw repositioning is therefore not solely focused on cephalometric analysis, but also takes the anthropometric landmarks into account. After marking the jaw movements and defining the final occlusion on cast models, surgical splints were fabricated by a dental laboratory.

All 3D computer-aided planning was executed in Maxilim software. This software package allows for the performance of virtual osteotomies, the definition of movements of the osteomised bone fragments in three dimensions, and the definition of a good post-operative occlusal relation (Nadjmi et al., 2010). In addition, the software calculates the predicted post-operative facial outlook of the patient in 3 dimensions based on the defined bone movements using a biomechanical soft tissue simulation model (Mollemans et al., 2007). This model imitates the deformational behaviour of facial tissues and maps the calculated 3D deformations to the facial skin surface. Based on the defined 3D virtual planning, intermediate and final surgical splints were virtually constructed and produced using a milling technique (Swennen et al., 2009).

2.1.3. Surgical intervention

A set of closed envelopes with 2D and 3D cards (50/50) were provided to a secretary who pulled an envelope in response to a phone call just prior to the surgical intervention. Depending on the selected outcome of the envelope pulling, either the 2D or the 3D surgical plan was used. If for any reason the selected surgical splints could not be used, we switched to the other available surgical plan. The patient was then eliminated from the study.

2.1.4. Post-operative follow-up

The post-operative anatomy of the patient was documented 4 months after surgery with orthodontic brackets still present. If the patient was treated using the surgical splints generated from the 2D planning, a new lateral post-operative cephalogram was taken. In case the patient was assigned to the 3D planning group, a full-extended height cone beam CT was acquired (field of view: 17 cm diameter/22 cm height; scan time: 2 × 20 s; voxel size: 0.4 mm).

2.2. Validation procedure

To validate the predictive accuracy of the 2D and 3D planning approaches, specific cephalometric landmarks were analysed. 17 and 16 landmarks were respectively selected for the 3D and 2D planning approaches (soft A-point was not determined in the 2D study) (Figs. 1 and 2).

The 'drawn-on-paper' postoperative predictions and post-operative lateral cephalograms were digitized. These data were imported into Onyx Ceph Version 3.1.111 (Image Instruments,