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RESEARCH ARTICLE

# Virtually Planned Surgical Guides to Optimize Orthognathic Surgery

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## Abstract

This article aims to introduce a brief *in vitro* report on development of surgical guides planned virtually for orthognathic surgery and its validation. Orthognathic surgery is a process first developed back on 19th century, and its methods have been updated ever since. The aim of the surgery is to reposition the jaw to achieve an ideal dental occlusion and facial symmetry. Traditionally, planning was conducted by a set of clinical and dental models, using mechanical articulators and analysis that allowed a simulation of what would be an ideal repositioning of the facial skeleton, but there are many problems with this method, resulting in a less desirable surgical outcome. With the development of Computer Tomography Scans (CT), patient's 3D representations were available and allowed surgeons to analyze anatomical patterns of patients in a customized way. Added to that, imaging software tools enabled the clinicians to investigate and analyze the procedures that needed to be made in a much more accurate way than the one done conventionally. This virtual planning was translated to surgical execution due to the development of 3D printers, which granted the production of surgical guides that allowed the execution of orthognathic osteotomies at the anatomical position planned virtually since it's an accurate and fast method of manufacturing splints for orthognathic surgeries. Thus, we present in this report a proof of concept for 3D virtual planning and maxilla repositioning in an experimental set-up with accuracy for the positional differences between the planned and postoperative outcomes less that 0.53 mm.

## Keywords

Orthognathic, Surgery, Virtual, Planning, 3D printing, Guides

## Purpose

To present a proof of concept for 3D virtual planning and maxilla repositioning in an experimental set-up with accuracy for the positional differences between the planned and postoperative outcomes less that 0.53 mm.

## Background

Orthognathic surgery is defined as a surgery process that aims to correct congenital or acquired jaws deformities. This surgical process consists essentially of a series of osteotomies to reposition all the displaced parts of the jaw to achieve an ideal static and dynamical dental occlusion and facial symmetry [1,2]. Besides the obvious functional and esthetical gain, which impacts directly on quality of life and self-esteem, the benefits of orthognathic surgery are wide, providing effects on the speech, chewing, smile and patient respiratory parameters, such as oxygen saturation [3].

Since the description of this surgical technique, planning was conducted by a set of clinical and dental models, using mechanical articulators, analysis that allowed a simulation of what would be an ideal repositioning of the facial skeleton. Despite the usefulness of this technique, the process of occlusal plane transfer from patient to dental articulator has numerous of non-controllable errors, such as plaster contraction, that are inherent to the technique [4,5]. With the development of Computer Tomography Scans (CT), patient's 3D representations created important anatomical evidence for surgical applications, as well as for others areas of dentistry [6,7] and medicine [8]. This 3D images analysis allowed surgeons to analyze anatomical patterns of each patient in a customized way. Apart of the patient

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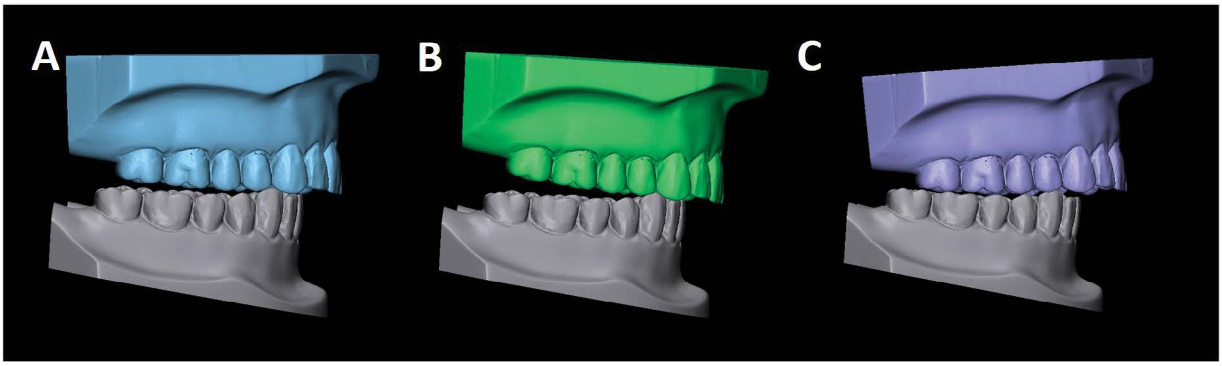


**Figure 1:** Virtual planning surgery were conducted using the Mimics Software (Materialize).

customization, the 3D representations enable the surgeon to interact with the 3D images and simulate the surgery and, therefore, predict the postoperative results on both soft and hard tissues [9].

Imaging software tools provided an evolution of this concept, defined as virtual surgical planning. This evolution enabled the clinicians to investigate and analyze the procedures that needed to be made, such as treatments for micrognathism, prognathism, laterognathism, maxillary atresia and corrections required on frontal occlusal plane and on upper dental midline in a much more accurate way than the one done conventionally [10]. This pre-evaluation allowed the surgical team to establish rational strategies to achieve the aim of orthognathic surgery mainly because it became possible to save the virtual treatment in a viewer format, allowing discussions over the patients' treatment with orthodontist and patients themselves. This possibility optimized and individualized treatment to each patient's case [11].

Recently, this virtual planning was translated to surgical execution due to the development of 3D printers, which granted the production of surgical guides that allowed the execution of orthognathic osteotomies at the exactly anatomical position planned virtually. The surgical guides are customized pieces that are fundamental to transform results of virtual planning in reality, since it's a fast, accurate and cheap method of manufacturing splints for orthognathic surgeries. Therefore, the objective of this article is to present an *in vitro* proof of concept for virtual planning and surgical guide's production to improve orthognathic surgeries execution and patient outcomes.

## Methodology

For the experimental model surgery, mandibular and maxillary acrylic models (Roic©, Brazil) were used. The virtual 3D models representation was obtained by scanning them with an infrared scanner 3Shape TRIOS TP12 after coating the models surface with the opt spray CEREC, to optimize the scanning images captures. After scanning, the virtual models files were save as *.dcm* and then converted to a *.stl* files to proceed with the virtual movements for surgical planning using Computer-aided Design (CAD). Then the Frankfort Horizontal Plane was utilized as a reference point to perform our proof of concept movements, where three virtual planning surgeries were conducted using the Mimics Software (Materialize), as following:

- Virtual Surgery 1 - forward advance of 5 mm and a superior reposition of 2 mm of the maxilla, represented by the Figure 1A.
- Virtual Surgery 2 - forward advance of 5 mm on the maxilla, 1 mm of superior reposition on the central incisor teeth and a 3 mm superior reposition on the first molar teeth, providing a clockwise spin, represented by the Figure 1B.
- Virtual Surgery 3 - forward advance of 7 mm of the maxilla, 3 mm of superior reposition on the central incisor teeth and 1 mm of superior reposition on the first molar teeth, providing an anticlockwise spin, represented by the (Figure 1C).

After the virtual movements, surgical guides with the intermediary and final surgery positions were designed using 3-Matic Software. The designed guides were then printed in a 3D printer (Conex 500- Stratasys) using MED610- Stratasys Ltd. to evaluate the planning accuracy.

In order to compare the planned and executed surgery, the movements mentioned before were recorded again with the infrared scanner and the initial and final position were virtually compared. A colored scale image comparing the congruent and non-congruent points of the planned and executed surgery were produced in order to facilitate the result interpretation with the software 3-Matic, that automatically presents the error scale (maximum and minimum) in mm, represented on the (Figure 2A, Figure 2C and Figure 2E). The more greenish the color, more congruent the parts. Utilizing the software Cloud Compare, that detects changes between sequentially gathered cloud points, in our evaluation those virtually planned and the ones printed and scanned, the accuracy of the surgical guides planned and the surgical guide printed were evaluated, ensuring that the surgical guides virtually planned could be translated to the printed acrylic surgical guides. The Cloud

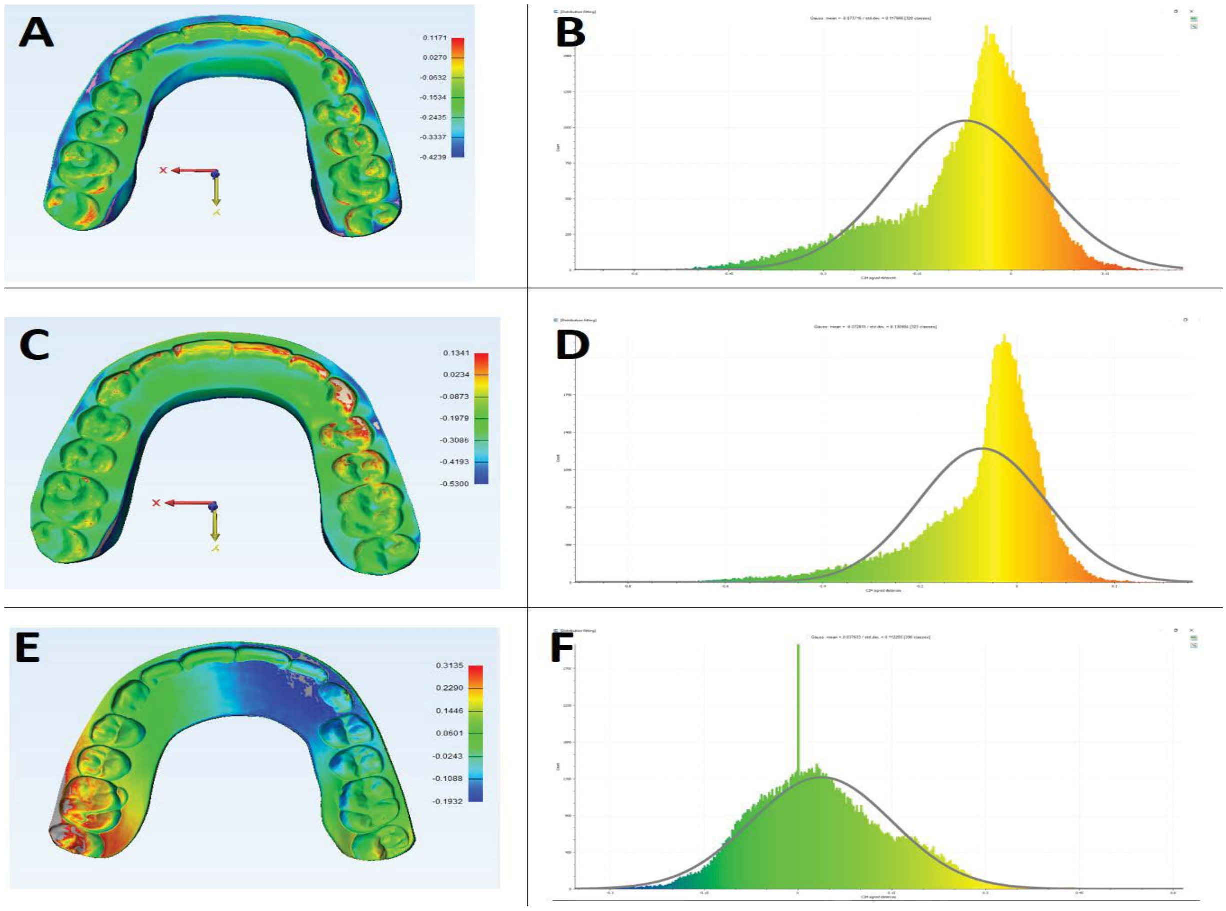


**Figure 2:** Schematic representation of congruent and non-congruent parts of the comparison between the planned design and printed models A, C and E and their respective Gaussian distribution.

Compare analysis provided the Gaussian distribution, as known as Normal distribution, as statistical analysis, presented in our study in the (Figure 2B, Figure 2D and Figure 2F).

## Results and Discussion

Corrective jaw or orthognathic surgery is a surgical procedure used to correct bone skeleton, jaws and face, and its relationship with dental occlusion, being the last one the most important and necessary aspect of the orthognathic surgery [1]. Despite functional rehabilitation, which impacts decisively on the patients' life quality, a series of psychological issues are involved in this surgical procedure due to facial anatomical modifications directly related with this kind of rehabilitation. In general, if surgery is satisfactory, patient self-image is improved. However, in some cases there is a gap between patient expectation and surgery outcome. Thus, development of virtual 3D planning of orthognathic surgery was fundamental to bring together patient expectation and reality. In addition, surgery becomes safer, more efficient and faster using these types of virtual planning [2].

In general, literature shows that a good outcome between the planned and postoperative positional differences in orthognathic surgeries would be an accuracy of measurements for the maxilla, mandible and chin limited to less than 2 mm [4,12,13]. This metric limit is influenced not only by bone reposition procedures, but also to post-operative soft tissue accommodation, that influences the final self-image perception. This means that minimal errors during planning and surgery execution can be amplified in the postoperative periods.

In our *in vitro* orthognathic model, three different experimental models for surgery were planned. In each one of them different moves were virtually made and then reproduced on the physical models using the printed surgical guides. As mentioned before, the Frankfort Horizontal Plane was utilized as reference point for the movements to be made. The first move was the forward advance of 5 mm and a superior reposition of 2 mm of the maxilla. The second one had an advance of 5 mm on the maxilla as well, 1 mm of superior reposition on the central incisor teeth and a 3 mm superior reposition on the first molar teeth, providing a clockwise spin. The third move was an anticlockwise spin with advance of 7 mm of the maxilla, 3 mm of superior reposition on the central incisor teeth and 1 mm of superior reposition on the first molar teeth. The movements are represented on the (Figure 2A, Figure 2C and Figure 2E), respectively.

As the reproducibility of the surgical procedures depends mainly by the surgical guide accuracy, our analysis where focused in the differences of the planned and printed surgical guides. For the first validation case (Surgical Guide 1 - Figure 2A), the result of the experimental procedure had a maximum repositioning error of 0.42 mm and a minimum repositioning error of 0.11 mm, that can be observed on the error bar presented on the right side of the figure, a Gaussian Distribution of the congruent and non-congruent parts is presented on the Figure 2B. On the second case of validation (Surgical Guide 2- Figure 2C), a maximum error of 0.53 mm was observed on the error bar presented on the right side of the figure, and the minimum error was 0.13 mm. The Gaussian distribution of this movement accuracy can be observed on the Figure 2D. The third case of validation (Surgical Guide 3 - Figure 2E) was analyzed as well, and the minimal and maximum error of 0.1932 and 0.3135 were observed, respectively, and their normal distribution can be observed on Figure 2F. On the Figure 3 we present a different analysis proposed, made with the second case of validation, where the splint was printed and placed on the surgical model and both were scanned. The resulting image was overlapped on the one virtually planned, enabling a comparison between the CAD and the CAM results we observe the error (plan vs. executed) detected in the model surgery in section. On this validation, the minimum and maximum error observed were 0.1929 mm and 0.2858 mm, respective-

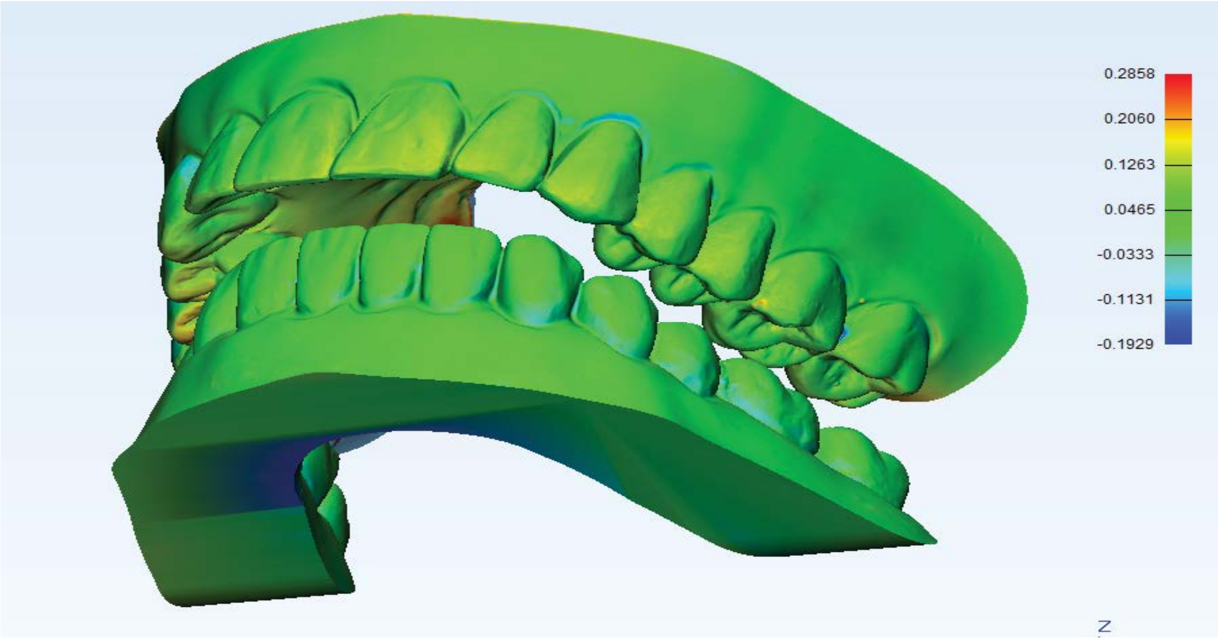


**Figure 3:** Schematic representation of the 3D-printed splint overlapped over the model.

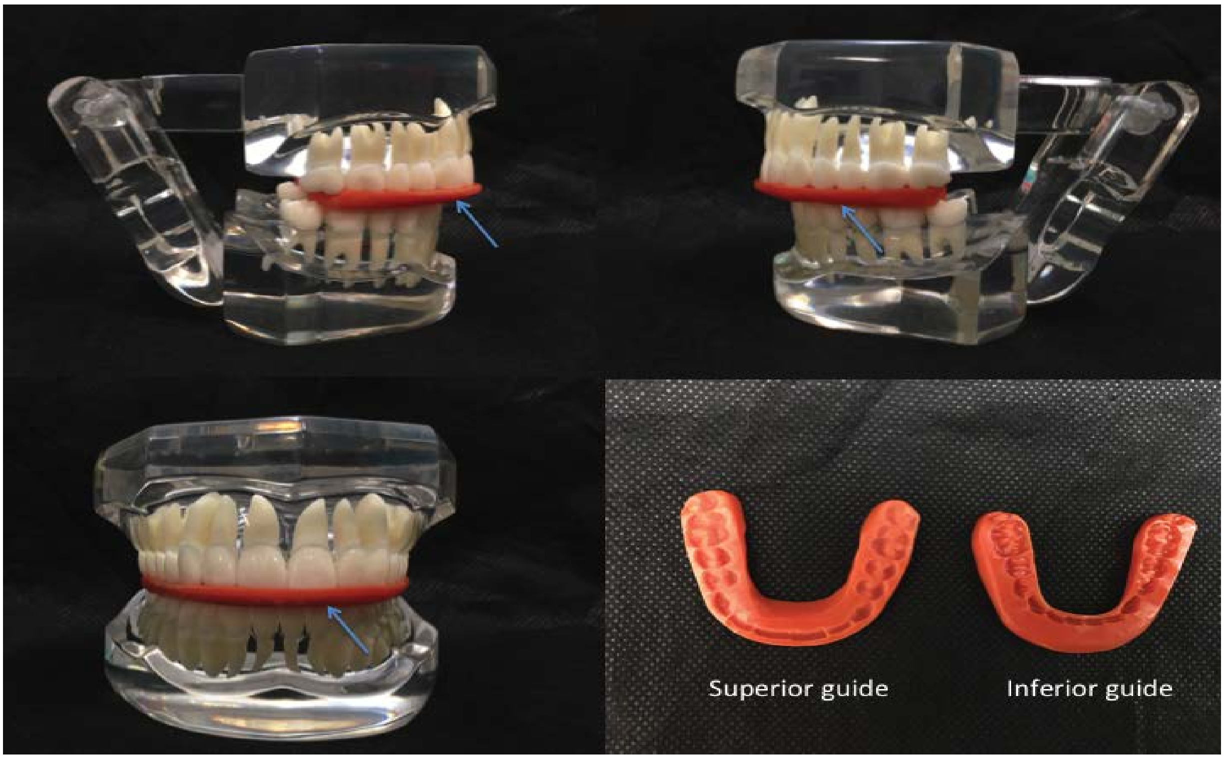


**Figure 4:** Surgical guide's representation.

**Table 1:** Quantitative error (maximum/minimum) observed among the planned and printed surgical guides.

| Virtual Planning | Maximum repositioning error | Minimum repositioning error | Qualitative (colored) image |
|---|---|---|---|
| 01 | 0.4239 mm | 0.1171 mm | Figure 1A |
| 02 | 0.5300 mm | 0.1341 mm | Figure 1C |
| 03 | 0.3135 mm | 0.1932 mm | Figure 1E |

ly. In the Figure 4, we observe the physical appearance of the surgical guide positioned. We would like to highlight this result due to the importance of the accuracy in this kind of surgery.

The quantitatively error (maximum/minimum) detected in each of the different surgical guides printed were summarized in Table 1. The qualitative representation of these surgical guides is presented in Figure 2. The colored scale images represent the comparison of the congruent or non-congruent points of the planned and executed guides. Greenish colored areas represent the most congruent areas, while the reddish and bluish areas represent respectively the maximum and minimum errors of the planned and printed surgical guides. As observed, most of the images area are colored in greenish color, which represents the accuracy of the planning procedure for this specifically application. In addition to the qualitative images, the Gaussian distribution of the planned to executed surgical guides (n = > 320 points) points is presented in Figure 2B, Figure 2D and Figure 2E, respectively. It's possible to observe that the errors detected had a narrow normal distribution, proving that the applied technique is useful for Orthognathic surgery planning.

Another aspect that must be taken in consideration is the accuracy of the scanner utilized to obtain the 3D models representation. The infrared scanner captured images can be influenced by external light illumination and unwanted reflection that can interfere with the device accuracy [7,14]. Thus, it is possible that this minimal errors observed in our results could be reduced with real patient computed tomography images.

In our study model, we used surgical guides virtually planned and printed to stabilize the final position of the maxilla model. However, the virtual planning can also be applied to prepare guides for precise osteotomy positioning or to plan titanium splints for final bone positioning. Technically, the surgical guides are kind of physical products used to transfer the virtual planned reality to the surgical moment [15]. It is possible that in near future different types of surgical guides can be developed using planning techniques to reduce risks and improve patient outcome.

Another important advantage that almost all papers claim for virtual planning is the time used during the orthognathic surgical procedure. As the surgeon already knows patient anatomy, and surgical guides fit easily, the time used for surgery is, in general, reduced. In addition to that, recently, some authors had calculated the time invested to plan an orthognathic surgery using conventional and virtual planning techniques. In this study, authors observed in 43 surgical planning that, in average conventional planning expend 540 minutes, while virtual planning is executed in 190 minutes [16]. Time investment is directly correlated to costs of surgical planning. Thus, virtual planning provides not only safety for both patient and surgeons, but is also executed in less time, is reproducible and cost less than conventional planning.

Therefore, we present in this report, a proof of concept for 3D virtual planning and maxilla repositioning in an experimental set-up with an accuracy for the positional differences between the planned and postoperative outcomes of 0.8 mm, which is a expressive improved result, once compared to the ones on the literature (2 mm) as previously mentioned [4,12,13]. In addition, we provide some discussion related to the possible advantages of virtual planning to improve Orthognathic surgery outcome.

## Conclusions

Virtual planning, with the production of intermediated and final position surgical guides can improve the accuracy and security of orthognathic surgeries as well as for others types of surgery, making the process less willing to mistakes.

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