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THE PRECISION OF 3D PRINTED CAD/CAM OCCLUSAL SPLINTS IN ORTHOGNATHIC SURGERY

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ABSTRACT

Purpose: To validate the accuracy of orthognathic 3D Printed final occlusal splints produced with in office desktop 3D Printer and comparing the accuracy with the conventional acrylic resin splints.

Subjects & Methods: 10 Orthognathic Surgery patients were included in this study. All surgeries were performed by the same Surgeon. Computer virtual planning for Orthognathic Surgery for all cases was performed in Pro- Plan Software version 3.0 (Materialise, Leuven, Belgium) with the proper work flow ending with splint design. Final Splint with 3D Printed with an In Office Desktop Printer (Formlabs), also conventional work up was performed on all cases and acrylic resin conventional splint was fabricated. The final splints were clinically evaluated; also the 3D Printed splint image was superimposed on the virtual splint image and distance errors recorded from 3 landmarks on the upper dental model. This superimposition was repeated with the conventional splint and compared with the virtual splint and distance errors recorded.

Results: All final splints (3D Printed and Conventional) accuracy was reflected as clinically acceptable. The distance error (Absolute) ranged from 0.17 – 0.82 mm and an overall mean distance error of 0.44 mm with respect to the 3D Printed splint (Final Splint2) when superimposed on the virtual design splint (Final Splint1). The distance error (Absolute) ranged from 0.26 – 0.75mm and an overall mean distance error of 0.39 mm with respect to the conventional splint when superimposed on the virtual splint (Final Splint1)

Conclusion: This study has validated the accuracy of the 3D printed final splint as the mean distance error of 0.44 mm lies within the clinically acceptable range. In addition, the conventional splint design still proved highly accurate with a distance error of 0.39 mm.

Keywords: Orthognathic Surgery – Occlusal Splints – Wafer - Accuracy – Validity – 3D Printer – CAD/CAM – Rapid Prototype

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INTRODUCTION

Orthognathic surgery is the surgery used for correction of maxillary and mandibular deformities, dental malocclusion along with improvement of facial appearance. Successful orthognathic surgery requires accurate treatment planning with detailed clinical, radiographic and model analyses to achieve facial harmony, ideal skeletal positioning and correct occlusal relationship. [1, 2]

Stokbro et al., stated that success of the orthognathic surgery is governed by the surgical technique used as well as the precision of the surgical planning.[2] surgical planning has developed greatly during the past decades. The conventional technique was considered to be the golden standard for accurate treatment planning. It implies the use of cephalometric analysis and mock surgery on plaster casts that are mounted on semi-adjustable articulator.[3]

With the evolution of surgical planning and imaging techniques, many authors reported limitations encountered using conventional methods. They described cast model planning as a time consuming & complex procedure, carrying the risk of incorporating errors during transfer of the occlusal plane, which in turn results in errors in the treatment plan.[4,5,6,7,8,9] Others reported the difficulty of accurate diagnosis & correction of occlusal cant and asymmetric deformity of the bony skeleton.[4,10,11] Theses many problems my lead to less than ideal surgical outcome. Significant effect is expected when they are add together.[12]

The current improvements in the field of three-dimensional (3D) imaging with cone-beam computed tomography (CBCT) introduced the development of computer-assisted orthognathic surgery. This provided a detailed presentation of the craniofacial complex with improved analysis of surgical planning & enhanced predictability of surgical outcomes.[13,14,15, 16, 17,18]

Zinser et al., 2012 stated that the improvement of computer-aided surgical simulation presented a paradigm shift for surgical planning in cranio-maxillofacial deformities and overcome the limitations encountered with the conventional method.[19] Authors described protocol in which a computerized skull models of the patient are generated. These models precisely represent the skeleton, the dentition, and the facial soft tissue of the patient.[20,21, 22, 14]

This enabled the Surgeon to perform virtual osteotomies on the computer and simulate orthognathic surgery.[23,24,25] Furthermore, surgical splints & templates are then processed virtually and fabricated via rapid prototyping machine. These splints are used during surgery for accurate positioning of the bony segments.[26, 27]

The past 10 years witnessed a great progress of 3D printed models and patient-specific guides that facilitate surgical planning and treatment outcome. A progressively increasing number of studies investigated and reported the feasibility of virtual planning & computer aided orthognathic surgery.[28,29,30]

Many studies on virtual surgical planning were directed to emphasize the potential advantages of this technique over conventional methods.[31,32,33] other studies were directed to compare the precision of specific software used for orthognathic planning and production of rapid prototype models to those constructed via conventional manual planning of model surgery.[34] Some reported mean value rather than absolute errors which underestimate the actual magnitude of errors.[35]

Splints are utilized to transfer the proposed surgical plan, position the jaws in correct relationship and provide the optimal occlusal relationship. The conventional method of fabricating the splint involved mounting the dental models on a semi-adjustable articulator, simulating the proposed move on the articulator and fabricating an acrylic resin splint. This technique has multiple uncontrollable errors. [27,32,35]

The aim of this study was to validate the accuracy of orthognathic 3D Printed final occlusal splints produced with in office desktop 3D Printer and comparing the accuracy with the conventional acrylic resin splints.

PATIENTS AND METHODS

10 Orthognathic Surgery patients were included in this study with six patients planned for bilateral sagittal split osteotomy surgery (BSSO) and four patients prepared for Bimaxillary surgery (Le Fort I and BSSO). All surgeries were performed by the same Surgeon. Computer virtual planning for Orthognathic Surgery for all cases was undertaken in Pro- Plan Software version 3.0 (Materialise, Leuven, Belgium). The precise workflow for Pro-plan software was followed; the Preoperative Cone Beam CT (CBCT) scan of the patients were imported into each individual Pro-plan project. All CBCT were performed on Newtom Giano CBCT Machine (Newtom, Verona, Italy). Then thresholding was performed to identify the bone from soft tissue and remove artifacts and segmentation of the skull, Maxilla and mandible was completed.

The dental Stone models of upper and lower teeth were optically scanned (Figure 1) with a high resolution optical scanner (Open Technologies, Brescia, Italy)(figure 2) and the files saved as sterolithography (STL). These files were imported into the pro-plan project, then point based registration method was utilized to superimpose the dental models on the upper and lower jaw CBCT image.

The Dental stone models of the upper and lower teeth were placed into the final occlusion position by the surgeon after adjusting midline, canine relation and achieving tripod stable occlusion. The occlusion casts were optically scanned and file saved as STL.

Virtual osteotomy cuts were performed and the final occlusion relation STL file was imported and superimposed via point based registration and the desired move of the mandible and maxilla with the final occlusion established. The final step of splint fabrication was performed to adapt to the upper and lower contact areas of the teeth in the final occlusion and the desired splint thickness chosen. This virtual splint prior to fabrication with the dental models in occlusion was recorded and saved as STL (Final Splint 1). The final splint was saved as STL and exported from pro-plan and imported into Preform software for 3 D printing the splint into a bio-compatible material using our in office Formlabs Printer (Formlabs, USA) (Figure 3).

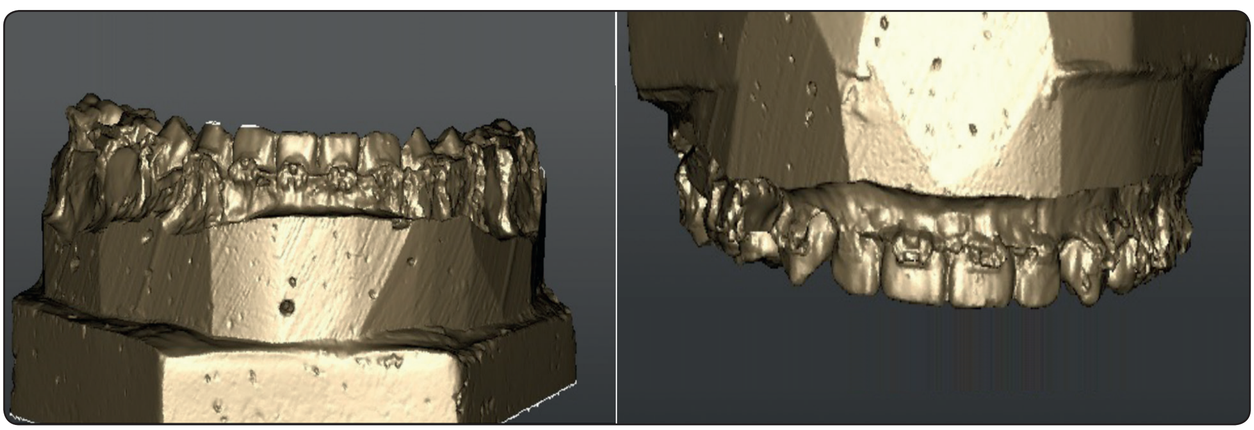

Fig. (1) Optical Scans of Orthognathic dental stone Models

Fig. (2) Optical Scanner – Open Technologies while scanning a dental model

Fig. (3) In office 3D Printer - Formlabs used to 3D Print the final Occlusal Splint

Conventional Orthognathic Surgery workup was also performed for all patients included in the study undergoing Orthognathic Surgery with mounting of the Dental stone models on a semi-adjustable articulator, facebow record, performing the surgical move on the models, measurement and fabrication of the final acrylic resin splint.

For each individual orthognathic case, the dental stone models used for final splint fabrication were mounted on the 3D printed final splint, sticky wax was used to hold models in place and then optically scanned (Final splint 2), which was imported into the software, final splint 2 data were registered onto the lower jaw image of final splint 1 data with point based registration and compared to Final splint 1. Both STL should be identical and any difference in superimposition is considered errors of fabrication. Three different landmarks were recognized on each Maxillary dental model: Anterior, Right posterior and left posterior. The distance among each landmark on the maxillary dental model in Final splint 2 STL and the same landmark on the virtual splint model (Final Splint 1) results in distance errors. This method was repeated with the conventional acrylic resin splint (conventional splint) and any difference in superimposition is considered as errors.

RESULTS

All 10 Orthognathic Cases were assessed clinically by the surgeon and the final splints accuracy was reflected as clinically acceptable. After superimposition of the lower dental models of final splint 2 (3D printed) over the lower dental model of final splint 1 (Virtual) using point based registration, the distance errors on the 3 landmarks of the upper dental models were recorded (Table 1). The distance error (Absolute) ranged from 0.17–0.82mm and an overall mean distance error of 0.44mm.

Then superimposition of the lower dental model of Conventional splint image over the lower dental model of final splint 1 (virtual) and distance errors on the 3 landmarks of the upper dental models were recorded (Table 1). The distance error (Absolute) ranged from 0.26 – 0.75 mm and an overall mean distance error of 0.39 mm.

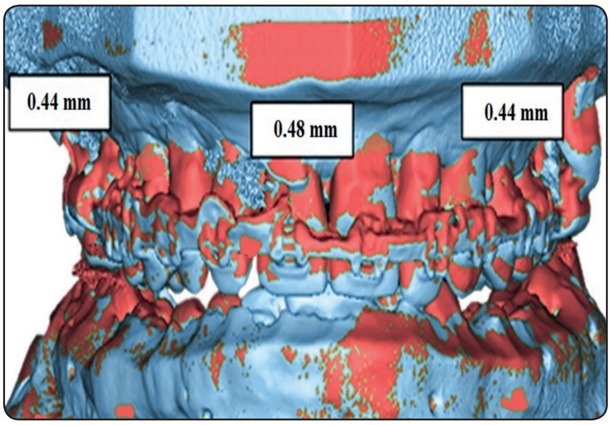

Fig. (4) The virtual Splint Models (blue) with the 3 D Printed Final Splint models (Red) were superimposed based on lower models. Distance errors from 3 Maxillary landmarks recorded

TABLE (1) Mean Distance Errors (Standard deviation) for all cases of the 3 Upper model Landmarks between Virtual Splint 1 and 3 D Printed splint, and between virtual Splint 1 and conventional splint

Mean Distance Errors	Anterior	Right Posterior	Left Posterior
3D Printed Splint	0.48 mm (0.16)	0. 40 mm (0.18)	0.44 mm (0.19)
Conventional Splint	0.43 mm (0.18)	0.38 mm (0.15)	0.36 mm (0.14)

DISCUSSION

The success of orthognathic surgery requires the development of the correct occlusal relationship along with facial balance and harmony. Splints are employed during orthognathic surgery for transferring the preoperative surgical plan & repositioning of the jaws into the required optimized occlusion.[36] The current advances in maxillofacial imaging using computed tomography (CT) and cone beam CT (CBCT) introduced computer aided designing and virtual planning for orthognathic surgery with a variety of algorithms.[27, 21] Furthermore, the recent progresses of 3D printers unlocked new opportunities for fabrication of patient-specific devices constructed from patient's 3D digital models.[30]

Lauren et al. introduced the first computer-based design & fabrication of occlusal splints. They used full coverage flat occlusal splints with guiding ramps. The technique was admired for time saving and for quantitative control over articulation.[37] Many researchers evaluated the accuracy of computer based occlusal splints employing variable measures including; difference of 3D surface area, linear & angular differences in three dimensions.[38,39]

A study presented by ***Gateno et al.***[27] used impression material to record the airspaces between the occlusal surface and the "fitting" surface of the rapid prototyped wafer in a small group of non-surgical patients. The accuracy of the wafer was then calculated from the thickness of the impression material. They reported an average difference between the conventional and rapid prototyped wafer 0.24±0.23mm^2. In this study, we studied the accuracy of the 3D Printed final Splint in articulating both the upper and lower dental models in the final occlusion with the virtual (digital) splint and compared this with the conventional splint.

Shqaidef et al.[35] evaluated the accuracy of rapid prototype surgical splints in comparison to conventional wafers. Authors reported absolute mean distances ranging between 0.04mm & 1.73mm, with an absolute mean error of 0.94mm, a value that considered clinically acceptable. In contrast our study showed distance error (Absolute) ranged from 0.17 – 0.82mm and an overall mean distance error of 0.44mm with respect to the 3D Printed splint (Final Splint2) when superimposed on the virtual design splint (Final Splint1). The distance error (Absolute) ranged from 0.26 – 0.75mm and an overall mean distance error of 0.39mm with respect to the conventional splint when superimposed on the virtual splint (Final Splint1) Our study was in accordance with a recent study by ***Shaheen et al.***[40] presented the steps for designing and fabricating surgical occlusal splints and their results showed an absolute distance error ranged from 0.12 to 0.88 mm, with mean absolute distance error of 0.4 mm when comparing 3D Printed splint with the conventional splint. In our study, we did not compare the 3D Printed splint with the conventional splint as both splints should have fabrication errors, but we used the virtual design splint as the gold standard to compare these splints.

CONCLUSION

This study has shown that there is a mean distance error in the 3D printed splint of 0.44 mm when compared with virtual splint which lies within the clinically acceptable error range confirming and validating the accuracy of the in-office 3 D printed Splint. Also the conventional splint fabrication method proved clinically acceptable with a distance error of 0.35mm.

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