COMPUTER AIDED DESIGN OF CUSTOM-MADE MINIPLATES FOR VIRTUAL PLANNING IN ORTHOGNATHIC SURGERY

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Abstract Maxillofacial deformities cause the facial asymmetry and the patients also are exposed to malocclusions due to the undesired position of the jaws. Conventional preoperative planning takes a long time for orthognathic surgery and includes a series of steps which should be carried out in a precise and most convenient way. Osteosynthesis plates which are commonly used in orthognatic surgery are manufactured in standard shapes and sizes in consistent with patient jaws anatomy. Nowadays, various software has been developed for transforming two dimensional CBCT (Cone Beam Computed Tomography) data into three dimensional (3D) solid model. Benefitting these software, surgical operations could be simulated and planned before the actual surgical intervention. The designed solid models can be obtained in dimensions of the tissues to be examined. In addition, the problems that are likely encountered during the operation also could be explored in such virtual approach in the preoperative stage. Proper surgical methods can be tested in the virtual planning and, pros and cons can be evaluated in silico. Computer-based design of miniplates for orthognatic surgery enables to save a significant amount of time and to reduce the labor cost. Accordingly, to be able to perform a preoperative stage for a patient with maxillary deformity, two-dimensional CBCT data of the skull of the patient were converted to three-dimensional solid model. Le Fort I osteotomy was simulated benefitting from the software to plan the surgery process. Later, custom-made miniplates were designed such that they would be compatible for osteotomy line and curvature of bone surface.

Key words: Oral and maxillofacial surgery, virtual planning, preoperative prepatrations.

1. INTRODUCTION

Maxillofacial deformities can be caused by congenital or accidental traumas due to a variety of reasons. Patients are adversely affected by psychological, cosmetic and chewing functions originating from facial asymmetry and dentoskeletal deformities [1]. The treatment of patients with maxillofacial deformities may require careful and precise surgical interventions to gain acceptable outcomes. Orthognathic surgery is an operation for reconstruction of maxilla and/or mandible. Maxillary deformities are treated by Le Fort I osteotomy. Preoperative planning takes a long time for orthognathic surgery with the traditional method, since diagnosis of the dentoskeletal deformities needs obtaining data from various sources including photographs, cephalograms, and surgical simulation in which the movement measurement of plaster model belonging to teeth and jaws on articulator is carried out [2].

Three dimensional (3D) virtual planning in orthognathic surgery is performed to obtain a simulation resembling real-world surgery implementation conditions of osteotomies for acceptable surgical results. This method also provides to position the maxilla and mandible on the virtual model before the surgery. By means of virtual planning facilities, complex problems in surgery could be detected and it represents a different way of preoperative planning unlike the traditional approaches which require production of modeling and production of partial jaw structure with different materials. 3D preoperative planning of orthognathic surgery can be practically utilized thanks to the development of various digitization and modeling software [3]. Cone beam computed tomography (CBCT) scans are generally employed and processed within available software solutions that remarkably simplifies diagnosis, analysis, and pre-operative surgical planning. This approach is based on the 3D visualization, modeling and analysis of bone. Two-dimensional CBCT scan data can be converted into 3D virtual models benefitting the capabilities of the computer programs. Advances in 3D technologies have enabled surgeons to perform complex surgical procedures with reduced operating time and optimal outcomes [4]. After the surgical operation, fixation is carried out by osteosynthesis miniplates and screws which are made mostly of resorbable materials or titanium. Typically, titanium L-plates are used in Le Fort I osteotomy. Design of the miniplates could be achieved with various computer programs.

In this study, the skull of a patient with maxillary deformity was scanned with CBCT scanner. The CBCT data were converted to digital imaging and communications in medicine (DICOM) format. After 3D data conversion, the virtual solid body model was generated by DICOM data in an open sources software. The model was in stereolithography (STL) format which enables to modify the targeted structure. Le Fort I osteotomy, however, was simulated benefitting from three dimensional virtual solid model with a open source software. Moreover, a new type of miniplate system was designed to use in the process of virtual surgery planning based on the solid body model of a patient's dentoskeletal structure. This design of miniplates was implemented to reach the most appropriate and acceptable shape for a proper osteotomy. General shape of the custom-made miniplates and screw sizes were inspired by the conventional titanium L-plates. By doing so, it was aimed to facilitate the tasks of the maxillofacial surgeons during complex surgeries and provide precise execution of the osteotomy with exact positioning and fixation.

2. MATERIAL AND METHOD

In this study, CT data of a 18 years old male patient with class III divison incisor relationship was selected to apply the virtual planning method (Fig. 1). The subject was informed about the whole details of procedures and the consent was taken. Detailed virtual model composed of skull, mandible and teeth was generated converting the two-dimensional CBCT data into 3D model using an open source software 3D slicer [5] (Fig. 2). It is important to notice that a series of critical operations such as simplifications, modifications, smoothness and healing were implemented to construct the model. Then, the Le Fort I osteotomy was simulated on the 3D virtual model. The maxilla was horizontally cut, detached from the skull and, advanced 5 mm along the anteroposterior axis by means of tools presented in the software [6]. The magnitude of advancement is specified measuring the distance between the actual and desired positions. Maxilla was then fixed to its new position and osteosynthesis miniplates were designed. Major design considerations of miniplates were providing *i)* a sufficient match between surfaces of the zygomatic and paranasal buttresses and the miniplates surface and also *ii)* a proper connection site between the maxilla and skull (Fig. 3). The process was modified according to surgeon's demands and directions which are explained below in details.

Fig. 1. Computed tomography (CT) scan data of the patient with maxillary deformity.

Since osteosynthesis miniplates are manufactured with standard shapes and sizes, Ti6AL4V and pure titanium materials are commonly selected for implants. The Ti6Al4V alloy and pure titanium protect the passive oxide layer formed on the surface. This stabilized and adherent passive oxide film protects the parts against implant pitting and intergranular corrosions and provides biocompatibility. In addition to those properties, the mechanical properties of titanium alloys ensure the necessary rigidity and stiffness in order to sustain appropriate conditions especially for bone-implant interactions.

Surgeons generally need to modify the shape of the miniplates by applying external loads during surgery in such a way that the surface geometry of the miniplates perfectly match the soft and hard tissues of the maxillofacial regions. Surgeons seek the most appropriate shape of miniplates for osteotomy line and curvature of bone surface in order to meet the natural jaw functions such as the opening/closing, chewing and biting motions. Three-dimensional simulation of orthognathic surgery takes a shorter time than traditional preoperative planning which requires, mostly, manual manipulations of miniplates. The previously highlighted procedures are suitable to apply for primary and secondary reconstruction of the hard tissue defects including the balancing facial asymmetry, orbital floor, zygoma and cranial bones.

In order to perform a successful preoperative planning for maxillofacial surgeries, design and production of miniplates should be precisely and moderately managed. Design process could also be conducted by employing only open source and non-commercial software such as 3D Slicer, Autodesk Meshmixer and FreeCad, thereby providing economical advantages and enabling modifications on models easily. CAD based methodology enables easier modifications of models and miniplates than the classical techniques . By means of this novel approach, the unique and patient-specific miniplates could be designed. In addition, production of miniplates is easier and more applicable than the traditional implants benefitting from the additive manufacturing process such as 3D printing or laser sintering technology.

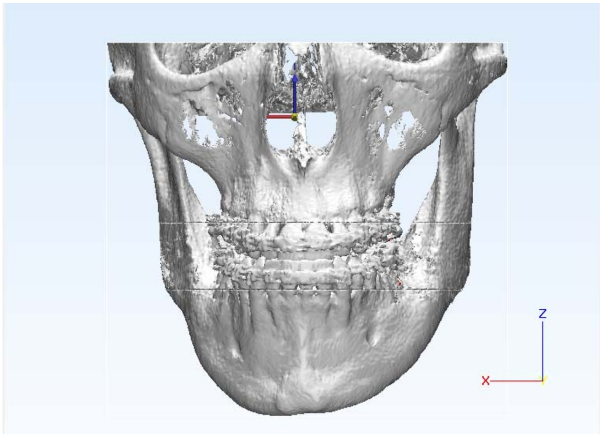

Fig. 2. Three-dimensional skull model used in the pre-operative planning created from computed tomography (CT) data.

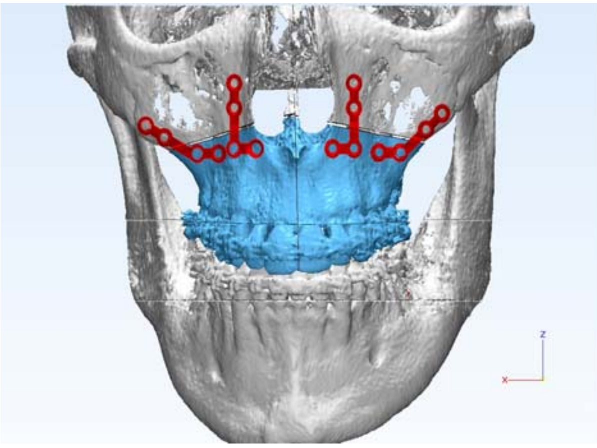

Fig. 3. Simulation of Le Fort I osteotomy and design of customized miniplates.

3. RESULTS AND DISCUSSION

Virtual planning of orthognathic surgery provides various useful outcomes. Imaging of maxillofacial region provides diagnosis of the dentoskeletal deformities. Preoperative planning in orthognathic surgery utilizing the improvement of CBCT technology is a novel and promising method to simulate the bone-implant interaction and surgical interventions before the real operations [7, 8]. Various software are used for converting CBCT scans to 3D surface model. In this study, 3D Slicer software was employed to obtain the solid body model of dentoskeletal structure and the model provided acceptable accuracy and compatibility according to surgeon's feedbacks. The program, Autodesk Meshmixer, used to obtain reconstructed model of the jaw bone enabled to reposition of maxilla and to simulate the osteotomies on surface models in consistent with anatomical obligations, as well.

Preoperative planning is highly important for orthognathic surgery. Conventional planning of surgical procedures is applied by cast model on semi-adjustable articulator. This method takes a long time, since first diagnosis of dentoskeletal deformities is carried out by cephalograms to prepare dental cast model of teeth. Unlike the conventional planning, virtual planning of orthognathic surgery is a time effective method since such a computer aided approach does not require to collect data from different sources. Anatomical, diagnostic and treatment data can be saved, validated, simulated and displayed [9].

In this study, we simulated Le Fort I osteotomy on 3D model which responded the clinical demands. Osteotomy line created in the region which is far from the root of teeth to provide a realistic simulation of the surgery. By employing the virtual reality method, it was achieved to reduce the surgery time duration and to design the custom miniplates.

Computer aided design of custom miniplates is efficient and critical part of the virtual planning besides the positioning and rigid fixation processes in othognathic surgery [10]. Customized shape and size determination of the miniplates ensures the proper match and fixation between the anatomical structures and dental instruments. The miniplate system is also compatible for bones and osteotomy lines. Furthermore, other maxillofacial deformities or fractures could also be planned and simulated with the virtual planning method and, treatment could be observed in virtual space using this miniplates systems.

Virtual planning of orthognathic surgery provides the realistic simulation of osteotomies and preoperative planning. Also, patient-specific miniplates can be designed by taking the feedback from the virtual planning into account and can also be fabricated using additive manufacturing techniques.

Preopertaive planning of orthognathic surgery with CAD provides the examine the 3D surface model of maxillofacial structures. Computer aided design of custom miniplates provides easier fixation, shorter surgical intervention and anestesia periods exposing to the patients than the traditional surgery planning. Aboul-Hosn Centenero and Hernández-Alfaro reported that three points at which conventional model surgery can lead to error [11]. These occurs *i)* when transferring the models to the articulator, *ii)* when drawing the vertical and horizontal lines of reference in the models, and *iii)* when repositioning the models, when transferring and rotating. The method presented in this study provided time saving, labor reduction and the most appropriate miniplates in size and shape. Additionally, virtual planning method significantly decreased the cost of preoperative planning. Feedback from the surgeon for the subject showed that the method presents remarkable advantages and promising performance. Benefitting the method presented in this study, clinicians or surgeons could perform any scenarios on the solid body models without collecting information from traditional cast models. Thus, complex surgical operations could be planned and simulated utilizing with various open-source and non-commercial software.

4. CONCLUSION

Virtual planning of orthognathic surgery is a very helpful tool for both patients' needs and surgeons' demands. Traditional planning methods are time consuming and expensive besides not to provide the desired functionality. Virtual planning of osteotomy in human jaw region could be simulated and the implants could be designed on the virtual models. The virtual planning has the potential to provide satisfactory outcomes and promising performance.

5. REFERENCES

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