A Practical Guide to Virtual Planning of Orthognathic Surgery and Splint Design Using Virtual Dentoskeletal Model

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Abstract

The present work is a manual that describes the practical aspects of optimizing dental precision by virtual dentoskeletal modeling, use the precises model in virtual planning, and splint design of orthognathic surgery. A single case study is used to demonstrate the stages involved in this approach, which include acquiring CBCT scan data and digital dental models, incorporating this data into developing a virtual dentoskeletal model using superimposition process to replace the unclear teeth. Utilizes virtual assessment and three-dimensional cephalometry to diagnose the maxillofacial deformity of the patient correctly. The results of the diagnosis played a crucial role in formulating a comprehensive plan for dental alignment, which involved osteotomy and correction of bone positions. The final step is to create a personalized splint. The importance of virtual tools is highlighted in our work to optimizing dental precision, diagnose and treat maxillofacial deformities. Present a virtual planning methodology for orthognathic surgeons as well as researchers.

Keywords: Digital Dental Model, CBCT Scan, Structure-From-Motion Photogrammetry Method, Virtual Dentoskeletal Model, Virtual Planning of Orthognathic Surgery, Splint Design.

دليل عملي لتخطيط الجراحة الافتراضية وتصميم قالب باستخدام نموذج افتراضي للهيكل

ريم شاكر محمود، صادق جعفر حمندي، اكرام حمدي المهدي

الخلاصة:

تقدم هذه المخطوطة دليلًا شاملاً يصف الجوانب العملية للتخطيط الجراحي، وتصميم القالب، وبناء نموذج الرأس الافتراضي في مجال جراحة العظام. يتم استخدام دراسة حالة واحدة لإظهار المراحل التي ينطوي عليه هذا النهج، والتي تشمل الحصول على بيانات مسح CBCT ونماذج الأسنان الرقمية، ودمج هذه البيانات في تطوير نموذج الرأس الافتراضي الدقيق، وخلق خطة افتراضية لجراحة تقويم العظام، وتصميم القالب الجراحي. يستخدم النهج أيضًا التقييم الافتراضي وقياس رأسي ثلاثي الأبعاد لتشخيص الانحراف او العيوب بالفك العلوي والسفلي للمريض بشكل صحيح. تلعبت نتائج التشخيص دورًا حاسمًا في صياغة خطة شاملة لرصف الأسنان وتعديلها، والتي تتضمن قص العظام وتصحيح مواقع العظام. تستخدم مواقع العظام بعد التعديل كدليل لإنشاء القالب الجراحي. يتم تسليط الضوء على أهمية الأدوات الافتراضية في تشخيص وعلاج انحرافات او عيوب الوجه من خلال عملنا، مما يقدم منهجية متكاملة لجراحين تقويم العظام والباحثين.

1. Introduction

Orthognathic surgery is a procedure performed on patients with severe malocclusion to correct the misalignments of dental or skeletal. In the past, they relied heavily on two-dimensional cephalometric X-rays and plaster models in oral and maxillofacial surgery planning [1]. The use of three-dimensional technology in scanning and photographing the oral and maxillofacial anatomical structures to create digital three-dimensional models of these anatomical structures allows orthodontists and maxillofacial surgeons to use computer software for virtual surgery planning. This software facilitates surgery simulation and predicts the outcome before the actual surgical procedure, particularly for complex cases. It makes it easier to imagine and understand the complicated relationship between jaws, teeth, and facial structures. And finally, ensure effective communication between surgeons and patients [2-4].

Cone-beam computed tomography (CBCT) scan is an X-ray machine that provides three-dimensional images of the patient's head, neck anatomy, and dental structures [5, 6]. The CBCT scan is especially useful in dentistry. The quality of the resulting CBCT images can be affected by noises. The noise in a CBCT scan can arise from various sources, including patient motion, beam hardening, and scatter radiation [7]. The presence of noise can make it challenging to interpret the small size of the teeth and surrounding anatomical structures. So, the noise in the CBCT scan, particularly in the dental region, can lead to distorted teeth in the images, decreased image quality, and poor reconstruction of the three-dimensional models [8, 9]. This reduction in image quality can negatively impact the accuracy of three-dimensional virtual surgery planning. It can affect diagnosis, the display of dental occlusion, cephalometric analysis, and treatment planning [10]. One strategy that can be employed to reduce noise in the dental region for the CBCT scan is to construct three-dimensional models from the CBCT scan, specifically for the maxilla and mandible. Replace the dental region in the CBCT model (maxillary and mandibular) with a different dental region for the digital dental model [11-15]. The digital dental model represents a digital copy of teeth and oral structures [16]. The digital dental model can be created using different methods, such as intraoral or extraoral scans. The intraoral scan directly scans the teeth inside the mouth, while the extraoral scan scans the dental cast [17-19].

Medical three-dimensional imaging technology and computer software development allow visualization and analysis of the complicated human anatomy. This combination of inventions reinforces diagnostic imaging and allowed three-dimensional surgical planning. Many studies explained the various stages of the digital workflow procedure for routine three-dimensional virtual orthognathic surgery planning, and some studies call it a computer-aided surgical simulation (CASS) system [2-4, 20-23]. In the three-dimensional protocol of virtual orthognathic surgery planning, three-dimensional cephalometry was developed to overcome the problems of two-dimensional cephalometry. Many essential parameters cannot be determined, and measurements in facial asymmetry are inaccurate. Swennen et al. proposed the Swennen Protocol for three-dimensional virtual orthognathic surgery planning. This method uses a triple scan procedure without markers or dental plaster casts and without facial soft-tissue deformation. First, a CBCT scan of the patient's head in the natural head position (NHP) with central occlusion and relaxed lips. Second, a CBCT scan (low-dose) for the patient with an impression tray in place. Third, CBCT scan (high-resolution) for tray impression. Create a composite patient skull model with detailed occlusal using triple voxel-based rigid registration. This protocol was validated and assessed on ten orthognathic patients. The steps involved in the three-dimensional workflow of the Swennen Protocol include data acquisition, data processing to generate a three-dimensional virtual model of the patient's head, virtual diagnosis and treatment planning, patient communication, surgical dental wafer manufacture, actual surgery, and outcome evaluation [3, 24, 25]. Hernández-Alfaro et al. presented a new clinical protocol for three-dimensional surgical planning of orthognathic surgery. The protocol includes a CBCT scan of the patient's head, scanning the dental arches using an intraoral scanner to create the virtual composite skull, and using computer-aided design and computer-aided manufacturing (CAD/CAM) technology to design the surgical dental splint [26]. The Charlotte Protocol was developed by Bobek et al. to represent an alternative three-dimensional protocol for VSP of orthognathic surgery. Utilizing a CBCT scan for the patient, with an intraoral fiducial marker included in a wax bit, radiopaque markers were placed on the true horizontal and vertical lines of the patient's face. The markers used during the CBCT scan to ensure obtaining the centric relation bite and NHP. The second CBCT scan was for the dental cast with the same wax bit in place. Data processing includes merging the skeletal and occlusal models by superimposing the fiducial markers to create a virtual patient with detailed occlusal. Orient the resulting virtual model in the NHP by aligning the radiopaque marker to the virtual horizontal, vertical, and median planes. This Charlotte protocol was successfully utilized for 25 patients in the planning CBCT scan with no lip distortion [27, 28].

Some studies use the swennen approach for virtual treatment planning of orthognathic surgery, Shaheen et al. apply the virtual planning on CBCT scan without integration with other imaging technology, used the materialize software [29]. Elnagar et al. and Donaldson et al. build composite model using the CBCT scan and dentition scan (intra-oral scan) as well as photograph and video of the face to scan the face texture [25, 30].

The related literature focuses on the virtual planning of orthognathic surgery, utilizing various methods to acquire data, including CBCT scans, CT scans, intraoral or extraoral scans, photographs, dental plaster casts, and videos. Each study creates a composite virtual model based on the acquired data. Applying the Structure-from-Motion (SfM) photogrammetry method in forming composite virtual skull model (dentoskeletal model) remains relatively limited. Despite various proposed methods for generating a composite three-dimensional skull model, none have used the SfM photogrammetry technique for digitizing dental casts to create the dentoskeletal model.

The aim of this research, applied the virtual orthognathic surgical planning by using the swennen's approach of virtual diagnosis and virtual treatment planning on the created virtual dentoskeletal model. With the aid of the ProPlan CMF software for virtual surgical planning, and others computer software required for processing during the study.

This research created the digital dental model by digitizing the dental cast using the SfM photogrammetry method. This technique captures a set of overlapping sequences of two-dimensional images that can be converted into three-dimensional structures of dental cast using photogrammetry software. This set of images must cover all parts of the dental cast at multiple levels and angles to create a three-dimensional mesh surface of the dental cast [16]. The purpose of digitizing the dental cast combines it with the CBCT to create a virtual dentoskeletal model for virtual treatment planning of orthognathic surgery and surgical dental splint designs. The digital dental cast model can be integrated with CBCT images through a superimposition process by replacing the dentition area of the maxillary and mandibular three-dimensional model of the CBCT with the corresponding area in the digital dental cast model.

Our previous study evaluated the efficiency and accuracy of virtual dentoskeletal models [11]. Additionally, explore the three-dimensional cephalometric analysis of virtual dentoskeletal Models [10]. Furthermore, there is an urgent need for more research to discover the limitations and potential benefits of these virtual dentoskeletal models in various aspects of dentistry, including virtual surgical planning and splint design. Thus, there is a need for a study to determine the role of virtual models in various dental procedures. This manuscript aims to outline comprehensive practical steps of virtual surgical planning and splint design in the context of orthognathic surgery by using virtual dentoskeletal models.

2. Materials and Methods

A single case is used to explain the virtual planning steps of orthognathic surgery. Fig. 1 illustrates the workflow of the virtual orthognathic surgery planning.

2.1 Data acquisition and processing

The patient's head is scanned using a CBCT scan. The patient's dental cast images are taken [1, 3, 24]. After collecting the medical imaging data, the digital image processing begins.

2.1.1 The acquisition of a digital dental model

Indirect scanning of the patient's plaster dental cast can be performed using SfM Photogrammetry technology [16, 31]. Involves capturing a series of high-resolution photographs of a dental cast from different angles and then using specialized software (Agisoft Metashape Professional version 1.8.3) to create a digital three-dimensional model of the cast. Digitize the maxillary and mandibular dental cast Severally, saving all models in Stereolithography (STL) format [16], as shown in Fig. 2. Before the superimposition process, the digital dental model undergoes a trimming process to remove unwanted regions in the model using Meshmixer software [10], as shown in Fig. 3. The SfM Photogrammetry technique serves as an alternative way for dentists to convert dental casts to digital three-dimensional models, using smartphones, simple hardware and computer software but required more time than alternative methods [16].

2.1.2 The acquisition of maxillary and mandibular CBCT models

The CBCT scan (KaVo machine) was performed while the patients' lips and tongues were at rest, and their heads were fixed with head and chin support in centric occlusion. The digital imaging and communication in medicine (DICOM) file obtained from the CBCT scan was reconstructed into three-dimensional images using Materialise Mimics software to read and interpret the scan data. Reconstruct different structures in the scan, such as the maxillary mandibular models. Create a surface three-dimensional mesh that can be edited and manipulated. Clean up the mesh to remove any artifacts or errors that may have resulted from the scanning process. This may involve smoothing, filling in gaps, and removing unwanted structures. It is essential to split the skull model into maxillary and mandibular models severally to see all the teeth of the upper and lower jaw and to facilitate the registration process, saving all models in STL format [10, 11]. See the maxillary and mandibular models in the Fig. 3.

2.2 Prepare for planning

The digital dental model is the output of the SfM Photogrammetry technique used with CBCT scan in the virtual planning to build the virtual dentoskelektal model.

2.2 Create Maxillary and Mandible Composite Mode

Generate the digital three-dimensional models from the patient's data, transferring the teeth area of the digital dental cast to the skull model to create the composite model (the virtual dentoskeletal model) by using the Superimposition process [32]. as shown in Fig. 3, which explain the steps doing through superimposition process, which is done separately for the maxillary and mandibular models by using the ProPlan CMF 3.0 software.

2.3 Three-dimensional Cephalometric Analysis

The first step is to position the skull in a Standardized Virtual Positioning. Four landmark points (PoL, PoR, OrR, OrL) based on the Frankfort horizontal plane were indicated to set the natural head position as a Standardized Virtual Positioning [33-35]. Next, an anatomical Cartesian coordinate system was set up to represent the skull's axes (x, y, and z). This point on the axis is known as the Sella at (0, 0, 0). Movement in all three axes was presented by the x-axis as left and right direction, the y-axis as forward and reverse direction, and lastly z-axis as going up and down direction, which had +/- signs respective to each direction. This ensured that the right skull measurements were taken to analyze the different structures [36]. They are shown in Tables 1 and 2, respectively [24, 37, 38].

Using three-dimensional cephalometry will allow us to diagnose the patient's skeletal structure and select the needed type of osteotomy. The surgeon will analyze the patient's skeletal structure using three-dimensional cephalometry to know where some abnormalities or malocclusions may require correction [3, 24, 39, 40]. A single observer performed a three-dimensional cephalometric analysis. The observer was adequately trained to use a standardized measurement tool and protocol to ensure the reliability of the measurements [24].

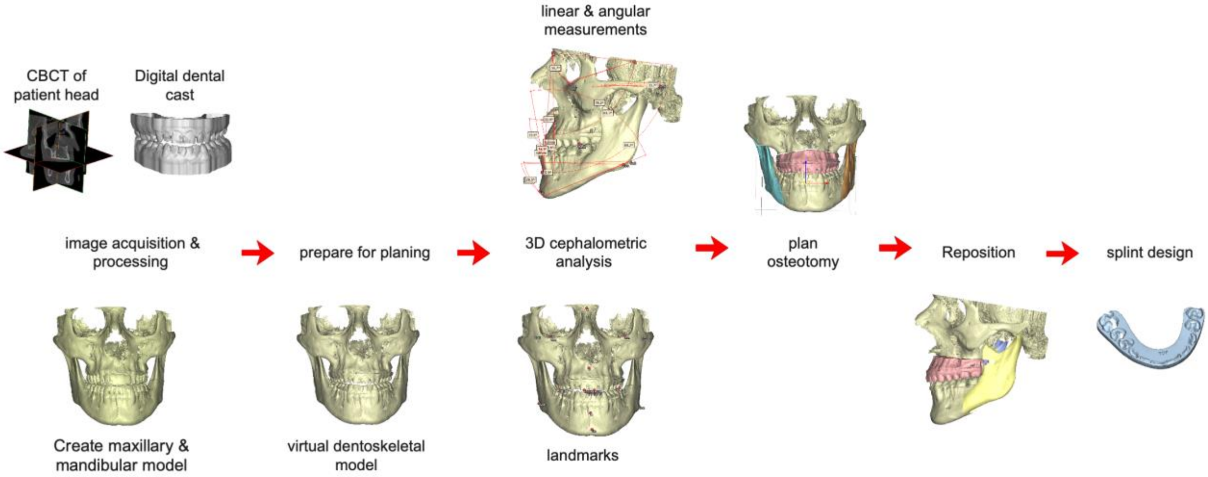


Figure (1): Workflow of the virtual planning of the orthognathic surgery

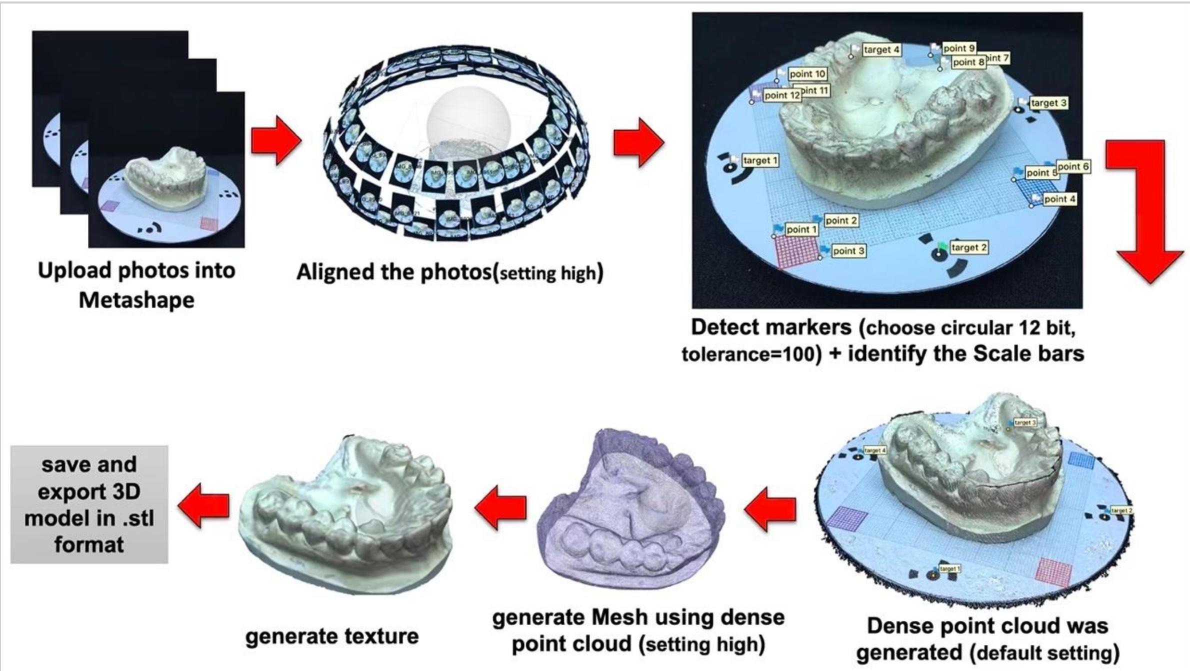


Figure (2): Agisoft Metashape workflow used for three-dimensional model generation [16]

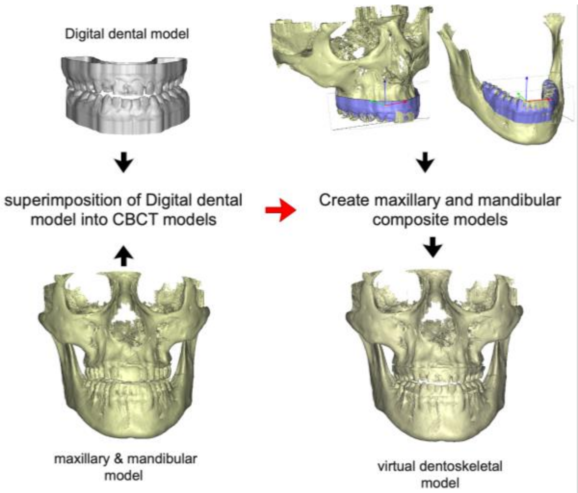


Figure (3): Superimposition process of maxillary and mandibular teeth with upper and lower jaw

2.4 Plan Osteotomy

Based on the three-dimensional cephalometric analysis of the patient, the most suitable osteotomy procedure should be chosen. Using the three-dimensional virtual dentoskeletal model, identify the specific bone that needs to be cut and reshaped, such as the upper jaw, the lower jaw, or the chin.

Identify the specific landmark points on the bone where the cuts will be made. Virtually simulate the cuts and reshaping of the bone to achieve the desired alignment. Fine adjustments to ensure that the cuts are precise and that the bone is reshaped as desired [1, 3, 4, 22, 23, 25].

2.5 Reposition

Repositioning in the virtual planning of orthognathic surgery refers to virtually moving the bones in the three-dimensional model to achieve the desired alignment and occlusion. This process is crucial in determining the final surgical plan and ensuring the surgical outcome meets the patient's expectations [1, 4, 18, 24, 31].

During orthognathic surgery, the bone pieces can be moved in various directions using translational and rotational movements. Translational movements involve moving the bone pieces up or down, forward or backward, or left or right. Rotational movements, on the other hand, involve changing the orientation of the bone pieces around different axes. Three rotational movements are illustrated in Table 3 [1]. Combining these different movements, the surgeon can reposition the bone pieces to correct functional and aesthetic issues with the patient's bite and facial structure.

Table (1): Definitions and Abbreviations of Landmarks and Plane [24]

Abbreviation	Landmark	Definition
N	Nasion	The middle point of the frontonasal suture
A	A Point	Deepest midline concavity on maxilla between anterior nasal spine and prosthion
B	B Point	Deepest midline concavity on mandibular symphysis between pogonion and infra-dental
OrL	Left orbitale	The most inferior point of the left infraorbital rim
OrR	Right orbitale	The most inferior point of the right infraorbital rim
PoL	Left porion	The highest points of the left external acoustic meatus
PoR	Right porion	The highest points of the right external acoustic meatus
S	Sella turcica	Point representing midpoint of pituitary fossa on skull
U1	The midpoint of upper central incisor	Point as midpoint of points U1L & U1R
U1L	upper left central incisor	The incisal edge of upper left central incisor
U1R	upper right central incisor	The incisal edge of upper right central incisor
MoL	First upper left molar	Mesio-buccal cusp of the first upper left molar
MoR	First upper right molar	Mesio-buccal cusp of the first upper right molar
FH	Frankfort horizontal plane	defined by Point OrL, point OrR and point PoL

2.6 Splint Design

Once the virtual planning is complete, create a surgical guide based on the virtual model, which can be used during the actual surgery that fits precisely over the teeth and can guide the movement of the bones to achieve the desired outcome. The splint's design is critical for ensuring the accuracy and predictability of the surgical outcome. The splint must be designed to provide adequate support to the bones during surgery and ensure that the desired bone movements are achieved [41].

3. Result

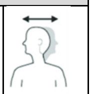
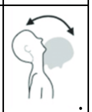
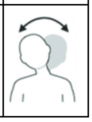
The patient is a 25-year-old male who is experiencing a Class III maxillofacial deformity caused by both midfacial hypoplasia and mandibular hyperplasia. The Class III malocclusion is indicated by an ANB angle of -5.8º and an overjet of 4.5mm. In this condition, the lower teeth and jaw are positioned further forward than the upper teeth and jaw, resulting in an underbite or a protruding lower jaw. This malocclusion is also known as "prognathic" or "mandibular prognathism" malocclusion. The hard tissue of the patient's head is shown in Fig. 3 and Fig. 4, representing a virtual dentoskeletal model.

The dentoskeletal model was evaluated virtually, and it was determined that the maxillary occlusal plane was tilted 0.2 degrees from the horizontal plane, see Fig. 5 (a). The maxillary occlusal plane, which connects three points (U1, MoR, MoL), was assessed in relation to the horizontal reference plane (HP), and no correction was needed. The three-dimensional cephalometric analysis revealed that the SNA angle value was within the normal range, see Fig. 6. However, the SNB and ANB angle values indicated a Class III malocclusion, necessitating Bilateral sagittal split osteotomy (BSSO) orthognathic surgery to correct the mandibular protrusion.

Table (2): Definitions and Abbreviations of Angular and Linear Measurements [42].

Name	*Unit*	*Description*	*Normal range*
SNA	*degree*	*Angle from point S via point N to point A*	*82 ± 2°*
SNB	*degree*	*Angle from point S via point N to point B*	*80 ± 2°*
ANB	*degree*	*Angle from point A via point N to point B*	*2 ± 2°*
overjet	*mm*	*Horizontal distance between upper and lower incisor*	*2-4mm*

Table (3): Rotational movements

Rotational movements	*description*	
Yaw	*This movement involves rotating the bone pieces around a vertical axis (turning head left or right)*	
Pitch	*This movement involves rotating the bone pieces around a horizontal axis,(nodding head up or down)*	
Roll	*This movement involves rotating the bone pieces around a longitudinal axis, (tilting head from side to side)*	

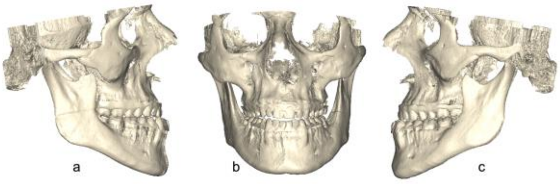


Figure (4): Preoperative: a three-dimensional model of the patient Virtual dentoskeletal model (a) right, (b) frontal, and (c) left profile

During the BSSO procedure, see Fig. 7, the lower dental midline will be corrected by repositioning the mandibular body with a translational movement to the right to align it with the upper dental midline, see Fig. 8 (a). In addition to correcting the lower dental midline, a mandibular setback of 6mm is necessary during the BSSO procedure to treat the Class III malocclusion and rectify the protrusion of the mandible, see Fig. 8 (b). This procedure involves cutting the mandibular bone and moving it backward. The exact amount of setback will depend on the patient's unique anatomy and treatment objectives and should be determined by a skilled orthodontic or oral and maxillofacial surgeon.

Fig. 9 illustrate the three-dimensional cephalometric analysis of the patient after accomplish the treatment plan. After completing the virtual treatment planning, a splint can be designed to transfer the planned movements of the upper and lower teeth to the patient's mouth. This splint is an appliance placed over the teeth and intended to guide them to their correct positions, as shown in Fig. 8. The using of a splint to ensure the movement and stabilizing of teeth in their planned location and achieving the desired treatment outcome.

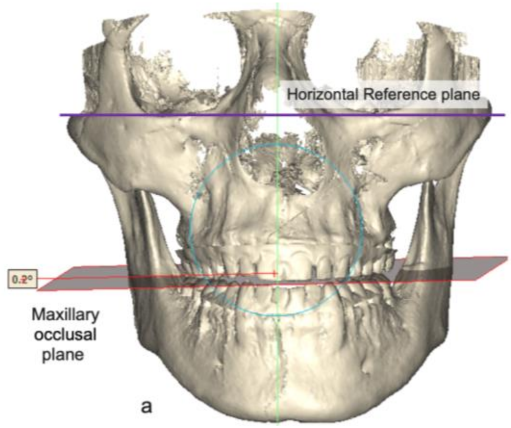


Figure (5): Virtual evaluation of the dentoskeletal model: The maxillary occlusal plane tilts 0.2 °s from the horizontal plane.

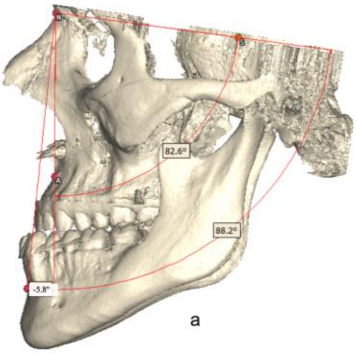


Figure (6): Three-dimensional cephalometric analysis: preoperative SNA= 82.6°, SNB= 88.2°, ANB= -5.8°

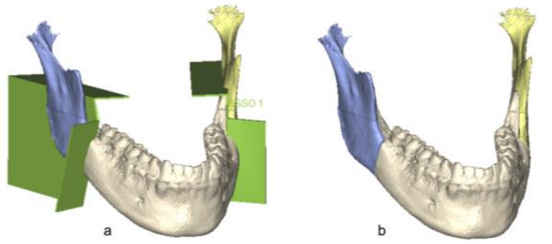


Figure (7): BSSO osteotomy (a) indicates landmark points to indicate cutting plane (b) mandible cutting into three pieces

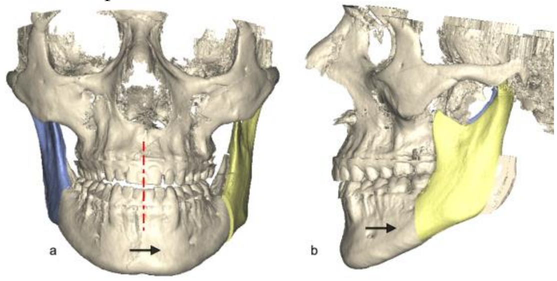


Figure (8): Mandibular Repositioning: (a) the translational adjustment of the mandibular body until the lower dental midline aligns with the upper dental midline, and (b) a mandibular setback of 6mm to rectify Class III malocclusion.

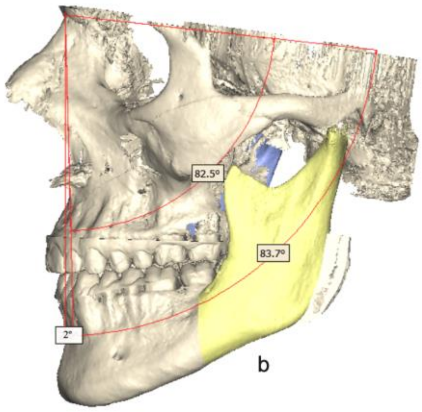


Figure (9): Three-dimensional cephalometric analysis: planned SNA= 82.5°, SNB= 83.7°, ANB= 2°

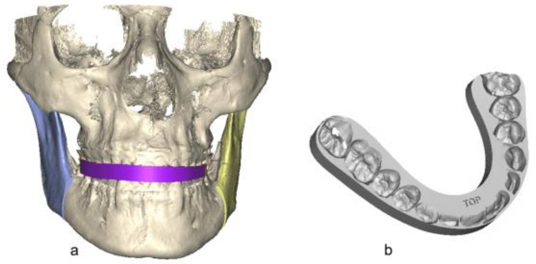


Figure (10): Splint design (a) digital impressions of the patient's teeth, and (b) three-dimensional digital model of the splint

4. Discussion

Special computer software was used to construct and manipulate the digital three-dimensional models of the patient's anatomical structures and simulate the orthognathic surgery.

CBCT scans are medical imaging techniques used to scan the patient's head. The presence of noise affects the quality of the CBCT images due to the distortion and artifact in the dental region. The image quality is essential for accurate measurements, planning, and assessments. An intelligent approach to removing noise is utilizing the superimposition process to create a composite model by merging the digital dental model and CBCT model. Use this three-dimensional composite model for planning and simulating surgical procedures before the actual surgery. The dental region of the CBCT model is replaced with the dental region of the digital dental model, creating a virtual dentoskeletal model. The purpose of creating the virtual dentoskeletal model is to accurately illustrate the patient's craniofacial anatomy and optimizing dental precision. This helps improve the resolution of dental structures and occlusion by eliminating the noise in the dental region that affects the diagnosis and treatment planning phase during the virtual planning of orthognathic surgery. The accuracy of the virtual dentoskeletal model evaluated before the virtual surgical planning. The superimposition results (virtual dentoskeletal model) accuracy is evaluated using qualitative and quantitative measures to avoid misalignment or errors [11]، a visual inspection of the registration process results can provide valuable insight into accuracy and quality, the quantitative measures show that the mean distance between the virtual dentoskeletal model and the CBCT model is 0.236 mm [11] (clinically accepted value must by <0.5 mm [43, 44]). Another test applied to evaluate the accuracy of the virtual dentoskeletal model compare with the CBCT model using 3D cephalometric analysis, the mean differences of this test ranging from 0.057 mm to 0.329 mm, these differences fall within an acceptable boundary (clinically insignificant) [11].

The digital dental model can be created using SfM photogrammetry, which involves capturing multiple photographs of the patient's dental cast (maxillary and mandibular casts) from various angles and utilizing computer software (Agisoft Metashape Professional) to construct a three-dimensional model from the two-dimensional images.

This study uses the Materialise Mimics software (medical software) to read and interpret the CBCT scan data and segmentation process. In the segmentation process, three-dimensional models are generated by separating anatomical structures (such as bones) from medical imaging data (such as CBCT scans). The software can semi-automatically segment anatomical structures from the CBCT image based on the assigned range of pixel intensities by utilizing thresholding techniques as a segmentation process. Achieved by setting intensity limits for each anatomical structure. Accurate segmentation depends on the user's knowledge and skill, advanced tools and algorithms, and the quality of the CBCT scan images.

After creating the composite (virtual dentoskeletal model), the diagnosis phase begins with identifying landmarks and conducting three-dimensional cephalometric analysis, including linear and angular measurements. All landmarks were identified manually. The accuracy of manual identification depends on various factors, such as the skill level of the observer, variations in anatomical structure, the presence of noise, and the quality of the three-dimensional model. The accuracy of a landmark's location depends on the observer's experience and knowledge. The observer was adequately trained to use a standardized measurement tool and protocol, ensuring the reliability of the measurements. The linear and angular measurements of three-dimensional cephalometric analysis are automatically calculated.

The treatment planning phase involves planning osteotomy and bone repositioning, which primarily depends on the diagnosis phase. The splint can be designed after the virtual treatment plan is completed. Transferring the planned bone movements guides the teeth to their correct positions. The splint can be essential in achieving the desired treatment outcome. Ensures the movement and stabilization of the teeth in their intended positions. The virtual dentoskeletal model significantly influences the splint design. Improve the alignment of the maxilla and mandible, enhance the planning for the final occlusion, evaluate the bite relationship more effectively, and reduce errors or inaccuracies in the splint design. Improving the overall accuracy of the virtual surgery planning.

The results illustrate that the essential steps of virtual planning of orthognathic surgery were applied to the patient with skeletal malocclusion. The diagnosis, treatment phase, and splint design demonstrate the role of the virtual dentoskeletal model in improving the clarity and accuracy of dental structures.

Various studies use the swennen approach for virtual treatment planning of orthognathic surgery, with different in time consumption, computational costs and data acquisition. The aims of all these studies are using virtual environment in enhancing precision of analysis and planning, reduced surgery time, improved outcomes and optimizing the performance of complicated surgeries. In the virtual surgical

planning, the time consumption is different for each case depending on several factors like: procedure complexity, team expertise, software used, patient data (data acquisition and processing) also affect the overall planning time, surgical team cooperation and its communication, the design of patient-specific dental splint or implants. Other factors can affect the computational costs like: the complexity of surgical procedure and anatomical structures which required more computational power, the medical imaging techniques and the resolution of patient data, efficiency of computer system which require for large dataset processing, the integration with various medical imaging techniques, the creation of patient-specific dental splint or implants.
The abbreviations list is shown in *Appendix I.*

5. Conclusion

This practical guide gives step-by-step manual for optimizing dental precision in the patient data by virtual dentoskeletal model, planning virtually of the orthognathic surgery and surgical dental splint design with virtual dentoskeletal model. this virtual dentoskeletal model created from digital files gives dentists more precise information about the dental anatomical structure. The accuracy of 3d cephalometric analysis can be improved, enhancing the clarity of dental region and occlusion enable more accurate and specific diagnosis, treatment, making it a valuable tool for dentists, virtual surgical planning, and splint design. it also benefits both clinical practice and research. Suggests for future research, study the digital transformation in orthodontics using the virtual dentoskeletal model.

6. References

[1] G. R. Swennen, "3D virtual treatment planning of orthognathic surgery," 3D virtual treatment planning of orthognathic surgery: a step-by-step approach for orthodontists and surgeons, pp. 217-277, 2017.

[2] J. Xia, H. H. Ip, N. Samman, D. Wang, C. S. Kot, R. W. Yeung, and H. Tideman, "Computer-assisted three-dimensional surgical planning and simulation: 3D virtual osteotomy," International journal of oral and maxillofacial surgery, vol. 29, no. 1, pp. 11-17, 2000.

[3] G. R. Swennen, W. Mollemans, and F. Schutyser, "Three-dimensional treatment planning of orthognathic surgery in the era of virtual imaging," Journal of oral and maxillofacial surgery, vol. 67, no. 10, pp. 2080-2092, 2009.

[4] S.-J. Lee, J.-Y. Yoo, S.-Y. Woo, H. J. Yang, J.-e. Kim, K.-H. Huh, S.-S. Lee, M.-S. Heo, S. J. Hwang, and W.-J. Yi, "A complete digital workflow for planning, simulation, and evaluation in orthognathic surgery," Journal of Clinical Medicine, vol. 10, no. 17, pp. 4000, 2021.

[5] B. F. Gribel, M. N. Gribel, D. C. Frazão, J. A. McNamara Jr, and F. R. Manzi, "Accuracy and reliability of craniometric measurements on lateral cephalometry and 3D measurements on CBCT scans," The Angle Orthodontist, vol. 81, no. 1, pp. 26-35, 2011.

[6] S. A. Khazal, and M. H. Ali, "An Accelerated Iterative Cone Beam Computed Tomography Image Reconstruction Approach," Al-Nahrain Journal for Engineering Sciences, vol. 22, no. 4, pp. 307-314, 2019.

[7] R. Jacobs, B. Salmon, M. Codari, B. Hassan, and M. M. Bornstein, "Cone beam computed tomography in implant dentistry: recommendations for clinical use," BMC Oral Health, vol. 18, no. 1, pp. 1-16, 2018.

[8] E. Nkenke, S. Zachow, M. Benz, T. Maier, K. Veit, M. Kramer, S. Benz, G. Hausler, F. W. Neukam, and M. Lell, "Fusion of computed tomography data and optical 3D images of the dentition for streak artefact correction in the simulation of orthognathic surgery," Dentomaxillofacial Radiology, vol. 33, no. 4, pp. 226-232, 2004.

[9] B. Zou, J.-H. Kim, S.-H. Kim, T.-H. Choi, Y. Shin, Y.-A. Kook, and N.-K. Lee, "Accuracy of a surface-based fusion method when integrating digital models and the cone beam computed tomography scans with metal artifacts," Scientific Reports, vol. 12, no. 1, pp. 8034, 2022.

[10] R. S. Mahmood, S. J. Hamandi, and A. H. Al-Mahdi, "Three-Dimensional Cephalometric Analysis of Virtual Dentoskeletal Model (in press)," International Journal of Advanced Technology and Engineering Exploration.

[11] R. S. Mahmood, S. J. Hamandi, and A. H. Al-Mahdi, "Create Virtual Dentoskeletal Model by Superimposing Digital Dental Cast into Cone-Beam Computed Tomography Scan, (in press)," International Journal for Computer Assisted Radiology and Surgery

[12] G. Swennen, M. Mommaerts, J. Abeloos, C. De Clercq, P. Lamoral, N. Neyt, J. Casselman, and F. Schutyser, "A cone-beam CT based technique to augment the 3D virtual skull model with a detailed dental surface," International journal of oral and maxillofacial surgery, vol. 38, no. 1, pp. 48-57, 2009.

[13] G. R. Swennen, W. Mollemans, C. De Clercq, J. Abeloos, P. Lamoral, F. Lippens, N. Neyt, J. Casselman, and F. Schutyser, "A cone-beam computed tomography triple scan procedure to obtain a three-dimensional augmented virtual skull model appropriate for orthognathic surgery planning," Journal of Craniofacial Surgery, vol. 20, no. 2, pp. 297-307, 2009.

[14] F. Baan, R. Bruggink, J. Nijsink, T. Maal, and E. Ongkosuwito, "Fusion of intra-oral scans in cone-beam computed tomography scans," Clinical oral investigations, vol. 25, pp. 77-85, 2021.

[15] J. Gateno, J. Xia, J. F. Teichgraeber, and A. Rosen, "A new technique for the creation of a computerized composite skull model," Journal of oral and maxillofacial surgery, vol. 61, no. 2, pp. 222-227, 2003.

[16] R. S. Mahmood, S. J. Hamandi, and A. H. Al-Mahdi, "Creating a Digital 3D Model of the Dental Cast Using Structure-from-Motion Photogrammetry

Technique," International Journal of Online and Biomedical Engineering (iJOE), vol. 19, no. 03, pp. 4-17, 2023.

[17] G. K. Sason, G. Mistry, R. Tabassum, and O. Shetty, "A comparative evaluation of intraoral and extraoral digital impressions: An in vivo study," The Journal of the Indian Prosthodontic Society, vol. 18, no. 2, pp. 108, 2018.

[18] O. de Waard, F. Baan, L. Verhamme, H. Breuning, A. M. Kuijpers-Jagtman, and T. Maal, "A novel method for fusion of intra-oral scans and cone-beam computed tomography scans for orthognathic surgery planning," Journal of Cranio-Maxillofacial Surgery, vol. 44, no. 2, pp. 160-166, 2016.

[19] H. Rudolph, H. Salmen, M. Moldan, K. Kuhn, V. Sichwardt, B. Wöstmann, and R. G. Luthardt, "Accuracy of intraoral and extraoral digital data acquisition for dental restorations," Journal of Applied Oral Science, vol. 24, pp. 85-94, 2016.

[20] J. Xia, J. Gateno, J. Teichgraeber, P. Yuan, K.-C. Chen, J. Li, X. Zhang, Z. Tang, and D. Alfi, "Algorithm for planning a double-jaw orthognathic surgery using a computer-aided surgical simulation (CASS) protocol. Part 1: planning sequence," International journal of oral and maxillofacial surgery, vol. 44, no. 12, pp. 1431-1440, 2015.

[21] J. Xia, J. Gateno, J. Teichgraeber, P. Yuan, J. Li, K.-C. Chen, A. Jajoo, M. Nicol, and D. Alfi, "Algorithm for planning a double-jaw orthognathic surgery using a computer-aided surgical simulation (CASS) protocol. Part 2: three-dimensional cephalometry," International journal of oral and maxillofacial surgery, vol. 44, no. 12, pp. 1441-1450, 2015.

[22] J. J. Xia, J. Gateno, and J. F. Teichgraeber, "New clinical protocol to evaluate craniomaxillofacial deformity and plan surgical correction," Journal of Oral and Maxillofacial Surgery, vol. 67, no. 10, pp. 2093-2106, 2009.

[23] H. Popat, and S. Richmond, "New developments in: three-dimensional planning for orthognathic surgery," Journal of orthodontics, vol. 37, no. 1, pp. 62-71, 2010.

[24] G. R. Swennen, F. A. Schutyser, and J.-E. Hausamen, Three-dimensional cephalometry: a color atlas and manual: Springer Science & Business Media, 2005.

[25] C. D. Donaldson, M. Manisali, and F. B. Naini, "Three-dimensional virtual surgical planning (3D-VSP) in orthognathic surgery: Advantages, disadvantages and pitfalls," Journal of Orthodontics, vol. 48, no. 1, pp. 52-63, 2021.

[26] F. Hernández-Alfaro, and R. Guijarro-Martinez, "New protocol for three-dimensional surgical planning and CAD/CAM splint generation in orthognathic surgery: an in vitro and in vivo study," International journal of oral and maxillofacial surgery, vol. 42, no. 12, pp. 1547-1556, 2013.

[27] S. Bobek, B. Farrell, C. Choi, B. Farrell, K. Weimer, and M. Tucker, "Virtual surgical planning for orthognathic surgery using digital data transfer and an intraoral fiducial marker: the charlotte method," Journal of Oral and Maxillofacial Surgery, vol. 73, no. 6, pp. 1143-1158, 2015.

[28] B. B. Farrell, P. B. Franco, and M. R. Tucker, "Virtual surgical planning in orthognathic surgery," Oral and Maxillofacial Surgery Clinics, vol. 26, no. 4, pp. 459-473, 2014.

[29] E. Shaheen, S. Shujaat, T. Saeed, R. Jacobs, and C. Politis, "Three-dimensional planning accuracy and follow-up protocol in orthognathic surgery: a validation study," International journal of oral and maxillofacial surgery, vol. 48, no. 1, pp. 71-76, 2019.

[30] M. H. Elnagar, S. Aronovich, and B. Kusnoto, "Digital workflow for combined orthodontics and orthognathic surgery," Oral and Maxillofacial Surgery Clinics, vol. 32, no. 1, pp. 1-14, 2020.

[31] G. Lauria, L. Sineo, and S. Ficarra, "A detailed method for creating digital 3D models of human crania: an example of close-range photogrammetry based on the use of structure-from-motion (SfM) in virtual anthropology," Archaeological and Anthropological Sciences, vol. 14, no. 3, pp. 42, 2022.

[32] R. S. Mahmood, S. J. Hamandi, and A. H. Al-Mahdi, "Create a virtual dentoskeletal model by superimposing digital dental cast into CBCT scan, (in press)," Bulletin of the Polish Academy of Sciences: Technical Sciences, 2023.

[33] U. Mangal, J. J. Hwang, H. Jo, S. M. Lee, Y.-H. Jung, B.-H. Cho, J.-Y. Cha, and S.-H. Choi, "Effects of changes in the Frankfort horizontal plane definition on the three-dimensional cephalometric evaluation of symmetry," Applied Sciences, vol. 10, no. 22, pp. 7956, 2020.

[34] D. Zhang, S. Wang, J. Li, and Y. Zhou, "Novel method of constructing a stable reference frame for 3-dimensional cephalometric analysis," American Journal of Orthodontics and Dentofacial Orthopedics, vol. 154, no. 3, pp. 397-404, 2018.

[35] P. Pittayapat, R. Jacobs, M. M. Bornstein, G. A. Odri, I. Lambrichts, G. Willems, C. Politis, and R. Olszewski, "Three-dimensional Frankfort horizontal plane for 3D cephalometry: a comparative assessment of conventional versus novel landmarks and horizontal planes," European journal of orthodontics, vol. 40, no. 3, pp. 239-248, 2018.

[36] G. R. Swennen, F. Schutyser, E.-L. Barth, P. De Groeve, and A. De Mey, "A new method of 3-D cephalometry Part I: the anatomic Cartesian 3-D reference system," Journal of craniofacial surgery, vol. 17, no. 2, pp. 314-325, 2006.

[37] C. C. Steiner, "The use of cephalometrics as an aid to planning and assessing orthodontic treatment: report of a case," American journal of orthodontics, vol. 46, no. 10, pp. 721-735, 1960.

[38] A. E. F. de Oliveira, L. H. S. Cevidanes, C. Phillips, A. Motta, B. Burke, and D. Tyndall, "Observer reliability of three-dimensional cephalometric landmark identification on cone-beam computerized tomography," Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology, vol. 107, no. 2, pp. 256-265, 2009.

[39] C. C. Steiner, "Cephalometrics for you and me," American journal of orthodontics, vol. 39, no. 10, pp. 729-755, 1953.
[40] G. R. Swennen, and F. Schutyser, "Three-dimensional cephalometry: spiral multi-slice vs cone-beam computed tomography," American Journal of Orthodontics and Dentofacial Orthopedics, vol. 130, no. 3, pp. 410-416, 2006.
[41] G. Swennen, E.-L. Barth, C. Eulzer, and F. Schutyser, "The use of a new 3D splint and double CT scan procedure to obtain an accurate anatomic virtual augmented model of the skull," International journal of oral and maxillofacial surgery, vol. 36, no. 2, pp. 146-152, 2007.
[42] U. Oz, K. Orhan, and N. Abe, "Comparison of linear and angular measurements using two-dimensional conventional methods and three-dimensional cone beam CT images reconstructed from a volumetric rendering program in vivo," Dentomaxillofacial Radiology, vol. 40, no. 8, pp. 492-500, 2011.
[43] L. Schieffer, L. Latzko, H. Ulmer, N. Schenz-Spisic, U. Lepperdinger, M. Paulus, and A. G. Crismani, "Comparison between stone and digital cast measurements in mixed dentition: Validity, reliability, reproducibility, and objectivity," Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie, vol. 83, no. Suppl 1, pp. 75-84, 2022.
[44] J. Asquith, T. Gillgrass, and P. Mossey, "Three-dimensional imaging of orthodontic models: a pilot study," The European Journal of Orthodontics, vol. 29, no. 5, pp. 517-522, 2007.

Appendix I

List of abbreviations

No.	*Symbol*	*Description*
1	*BSSO*	*Bilateral sagittal split osteotomy*
2	*CBCT*	*cone-beam computed tomography*
3	*CAD/CAM*	*computer-aided design and computer-aided manufacturing*
4	*DICOM*	*digital imaging and communication in medicine*
5	*NHP*	*Natural head position*
6	*SfM*	*Structure-from-Motion*
7	*STL*	*Stereolithography*