Scholars Journal of Dental Sciences (SJDS)
Abbreviated Key Title: Sch. J. Dent. Sci.
©Scholars Academic and Scientific Publisher
A Unit of Scholars Academic and Scientific Society, India
www.saspublishers.com

ISSN 2394-4951 (Print)
ISSN 2394-496X (Online)
DOI:10.36347/sjds.2017.v04i12.004

CBCT in Orthognathic Surgery

Dr. Sharath Kumar Shetty[1], Dr. Neeraja U[2]*, Dr. Mahesh Kumar Y[3], Dr. Vivek V[4]
[1]Professor and Head of the Dept, Dept of Orthodontics and Dentofacial Orthopedics K.V.G Dental College and Hospitals Sullia D.K, India
[2]Final year PG student, Dept of Orthodontics and Dentofacial Orthopedics K.V.G Dental College and Hospitals Sullia D.K, India
[3]Professor, Dept of Orthodontics and Dentofacial Orthopedics K.V.G Dental College and Hospitals Sullia D.K, India
[4]Final year PG student, Dept of Oral and Maxillofacial Surgery Govt. Dental College Trivandrum, India

Review Article

***Corresponding author**
Dr. Neeraja U

Article History
Received: 07.12.2017
Accepted: 12.12.2017
Published: 30.12.2017

DOI:
10.21276/sjds.2017.4.12.4

Abstract: The advent of Cone beam computed tomography has brought about a giant leap in the field of Orthognathic surgical treatment. The CBCT imaging has wide range of uses in diagnosis, treatment planning, mock surgery and assessment of post treatment changes in patients planned for orthognathic surgery. This review article collaborates literature on uses of CBCT in Orthognathic surgery.

Keywords: CBCT, Orthognathic surgery, 3D virtual Imaging

INTRODUCTION

Over the past 25 years, tremendous advances in the area of orthognathic surgery have occurred. Rapid changes in surgical technology have made it possible to successfully treat patients for whom orthodontic camouflage was once the only method of treating a dentofacial deformity, which often resulted in esthetically unacceptable and, quite often, unstable results. When a jaw discrepancy accompanies a severe malocclusion, there are three broad possibilities for correction: (1) growth modification, (2) camouflage (orthodontic positioning of the teeth to compensate for the jaw discrepancy), or (3) orthognathic surgery in conjunction with orthodontics to reposition the jaws and/or dentoalveolar segments.

Once growth has ceased, surgery becomes the only means of correcting a severe jaw discrepancy. Although surgery may allow greater changes, there are still limitations to the surgical options, depending on the type of problem and direction of desired jaw movement, and certain problems are more receptive to surgical correction than others. Therefore diagnosing a case which requires surgical treatment and proper planning of treatment is very essential in this regard.

Recent advances in 3-dimensional (3D) image computing have enabled a major breakthrough and allowed unmatched However, to enable the clinician to make this major paradigm shift in routine planning of orthognathic surgery, both image acquisition systems and 3D virtual planning software must become user-friendly, easily accessible, and available at a relatively low cost. The basis for three-dimensional (3D) virtual planning in orthognathic surgery is to obtain a virtual anatomic model of the patient that includes the facial soft tissue mask, underlying bone, and teeth [1].

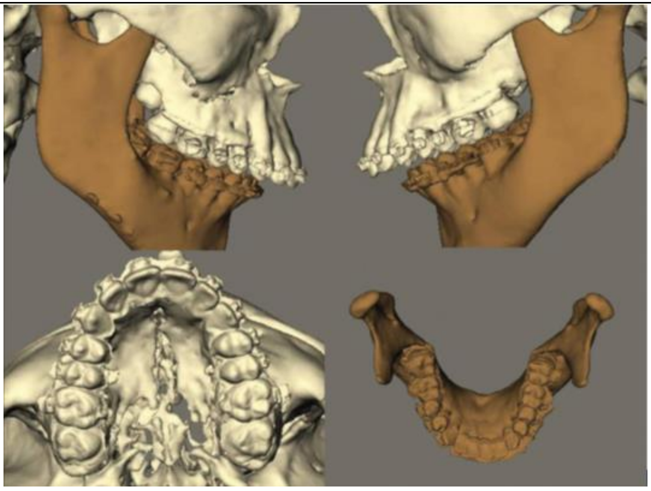

Fig-1: Hard tissue representation of the augmented bony patient model with detailed occlusion virtual diagnosis, treatment planning, and evaluation of treatment outcomes for patients treated by orthognathic surgery.

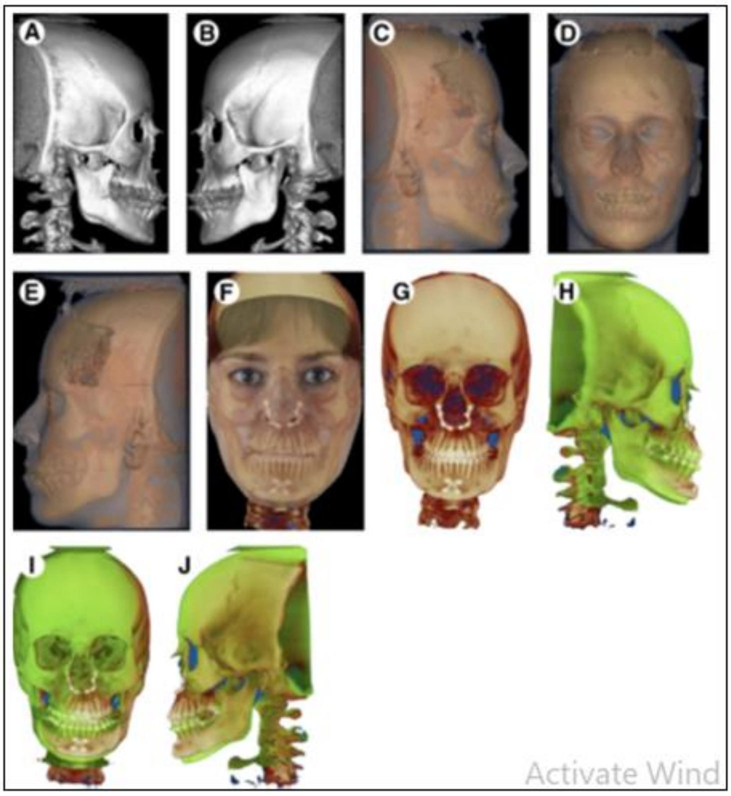

Fig-2: Current imaging study of an orthognathic case, using CBCT and 3D software technology. A, B, Preoperative 3D reconstruction. C, D, E, Preoperative soft/hard tissue composite. F, Postoperative soft/hard tissue composite. G, Postoperative 3D reconstruction. H, I, J, Preoperative and postoperative superimposed 3D reconstructive imaging

IMAGE ACQUISITION FOR 3D VIRTUAL ORTHOGNATHIC SURGERY

To enable proper planning of orthognathic surgery, the patient should undergo imaging in the NHP with relaxed facial soft tissues. The conebeam computed tomography (CBCT) scanners have the potential advantage of scanning the patient with a low radiation [2]. CBCT is a volumetric image acquisition technique that offers unique accessibility because of its low costs compared with multislice CT (MSCT) and the potential for in-office imaging. A number of problems will be encountered in the routine clinical situation. But the scanned volume of CBCT scanners is currently too small to capture all types of maxillofacial deformities. Owing to the relatively small detector size of the available CBCT apparatus, the scanned volume is limited. With the fast evolution in detector technology, it is expected that CBCT with larger detectors will become available and eliminate this limitation in the near future. Due to the limits in the scanned volume, accurate positioning of the patient in the NHP in the CBCT apparatus is sometimes difficult or not feasible.

To identify the extension of the orientation of the assistance of the patient's own NHP, especially when we have a difficult case (a severely asymmetric face or a patient reluctant to repeat a given position), we use a spirit-level guide placed on the face bow [3, 4]. This positioning allows us to assess our patients with respect to a true horizontal/vertical reference, which is a permanent common requirement for all of our records. Improvements in CBCT hardware and software to allow larger scanned volumes and decreased scan times are expected to solve these problems in the near future. Parallel to the volumetric data acquisition by CBCT, 3D surface information can be acquired for a more natural and realistic visualization of the patient by obtaining the color and texture of the facial soft tissues. The major advantage of 3D photography is the short acquisition time compared with laser surface scanning of the face. The latter, however, is more accurate if the scanned patient is not moving.

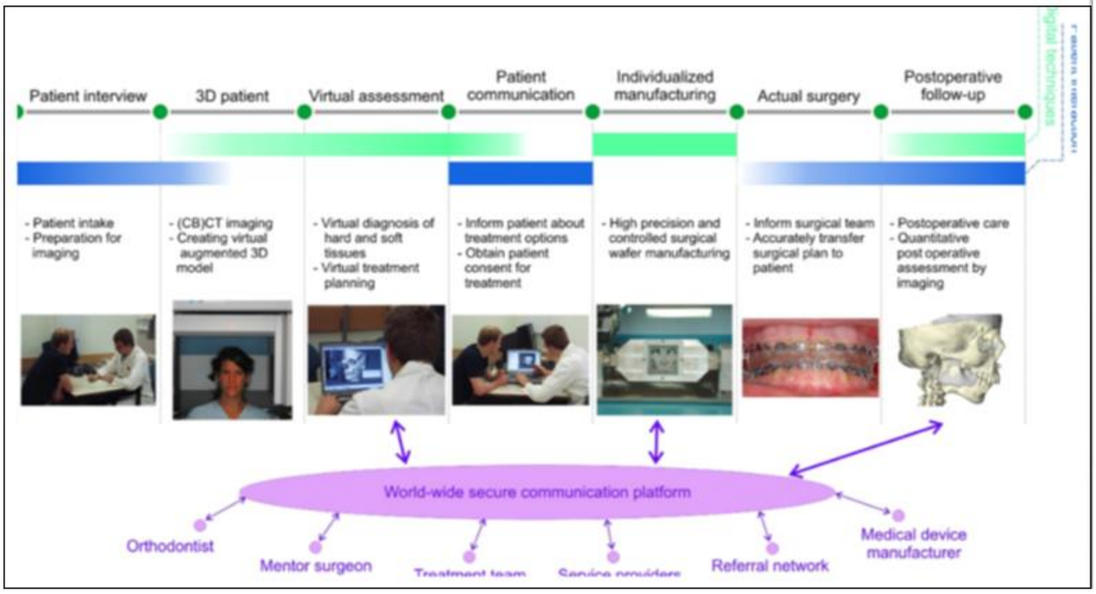

Fig-3: Workflow process for 3D virtual treatment planning of orthognathic surgery

DATA PROCESSING FOR CONSTRUCTION OF VIRTUAL 3D MODEL OF HEAD

The aim of 3D virtual imaging for orthognathic surgery is to create one virtual anatomic model of the patient, including the triad of the facial soft mask, underlying bony structures, and teeth. To enable 3D virtual treatment planning of orthognathic surgery, the acquired volumetric CBCT image data are segmented by semiautomated thresholding. The resulting surface representations of the patient's anatomy are then drawn (rendered) on the computer screen, given a viewing direction of the virtual camera, called "surface rendering." A tetrahedral soft-tissue mesh can subsequently be built to enable fast soft-tissue simulation using a biomechanical model [5-7]. Gateno *et al.*, [8] should be credited for developing the first method applicable to the clinical routine of orthognathic surgery to integrate accurate dental information into the patient's skull. Later, a "triple" CBCT scan procedure with "triple" voxelbased rigid registration [9] has been introduced. The protocol [9] consists of 1) a first CBCT scan of the patient in the NHP with central occlusion and relaxed lips; 2) a second low-resolution and low-dose CBCT scan of the patient with a double impression tray in the mouth; and 3) a high-resolution CBCT scan of the impression tray. After the "triple" CBCT scan procedure, a 3D virtual model of the patient with accurate occlusal and intercuspidation data is made using a semiautomated procedure and the 3 consecutive "voxel-based" registrations [9].

DIAGNOSIS USING 3 D VIRTUAL IMAGE

The combination of a good clinical examination and 3D inspection of the virtual model of the patient's head has an unprecedented potential toward the diagnosis of the patient with a maxillofacial deformity. Both "volume rendering" and "surface rendering" offer a thorough in-depth 3D virtual inspection of the patient's anatomy in the 3D virtual scene. Both viewing methods also incorporate the original axial CBCT slices and coronal and sagittal reconstructions, which allow 2-dimensional inspection of the patient's anatomy in the 3 standard planes (axial, sagittal, coronal) and multiplanar planes. A large amount of relevant clinical information with regard to the patient with a maxillofacial deformity can be gleaned from these slices which helps in diagnosis of even mild skeletal defects.

Volume rendering is currently the most appropriate for 3D virtual assessment of the roots of the teeth, the temporomandibular joints, and the airway.

The "triple CBCT scan protocol" was developed and validated and allows one to augment the virtual model of the patient's head to be appropriate for orthognathic surgery planning without the use of markers and plaster dental models [9-14]. Dynamic diagnosis of dentofacial deformity is now possible with the help of a Hinge Axis Locator. This procedure takes approximately 25 minutes to perform and is incorporated as part of a whole presurgical records session appointment, which includes clinical photos, determination of the HOLTA fiducial marking for clinical photos and radiography/CBCT imaging. With this procedure, we strive to develop a skull-dental composite 3D model (virtual articulator), allowing us to study dental and skeletal relations more precisely [15].

NEW 3-DIMENSIONAL CEPHALOMETRIC ANALYSIS FOR ORTHOGNATHIC SURGERY

The current standard in cephalometry is to use 2-dimensional (2D) cephalometric analyses of plain lateral and frontal cephalograms. However, the current methods have 2 basic problems. First, many important parameters cannot be measured on plain cephalograms; and second, most 2D cephalometric measurements are distorted in the presence of facial asymmetry [16]. To solve these problems, Grayson *et al.*, [17, 18] and other investigators [19, 20] pioneered the transition from 2D to 3D cephalometry. They combined lateral and frontal 2D cephalograms into a single coordinate system and calculated the 3D coordinates for the cephalometric landmarks.

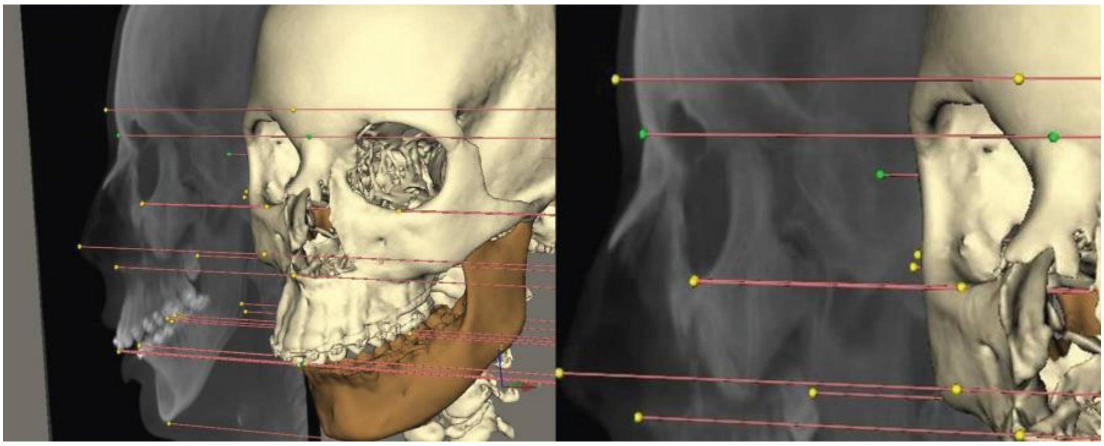

Fig-4: Virtual 2D lateral cephalogram created from CBCT data with landmarks identified and extrapolated onto the 3D patient model

The images obtained by traditional (fan-beam) computed tomography and cone-beam computed tomography scanners can be used to create 3D models of the craniofacial skeleton, teeth, and soft tissues [1, 14, 21-24]. By placing these models into the neutral head posture, [25-29] we can now convert them into "3D cephalograms" similar to how a lateral head film is considered a cephalogram if taken at a fixed distance from the subject with the subject's head in a cephalostat. The goal of our new 3D cephalometric analysis was to maintain all the positive aspects of conventional 2D analysis and to address its negative aspects. This has been accomplished by incorporating different strategies to solve the problems of direct 3D measurements. All cephalometric measurements were classified into 4 groups (size, shape, position, and orientation) according to the parameter they measure. In our new analysis, size was measured as a linear distance in 3D space.

Shape was measured by projecting the involved landmarks onto the midsagittal plane of the local coordinate system for each facial unit. Position was measured differently depending on the direction of the measurements. The transverse position was measured as a linear distance between the involved landmark and the midsagittal plane of the world coordinate system. The anteroposterior and vertical positions were measured after all the involved landmarks had been projected onto the midsagittal plane of the world coordinate system. Finally, orientation was measured as the separate pitch, roll, and yaw for each facial unit.

VIRTUAL SURGICAL PLANNING IN ORTHOGNATHIC SURGERY

After segmentation of the anatomic structures of interest, 2 technological options are available to visualize these structures 3 dimensionally. The first are surfacebased methods, which require the generation of an intermediate surface representation (triangular mesh) of the object to be displayed. The second are volume-based methods, which create a 3D view directly from the volume data [30]. After establishment of the diagnosis, the next step is to use the 3D representations of the anatomy to plan and simulate the surgical intervention. In orthognathic surgery, a distinction should be made between the tasks involved in corrective and reconstructive interventions. Corrective intervention designates procedures that do not require an extrinsic graft, and reconstructive interventions are designated for situations when a graft is used.

In corrective procedures, it is important to determine the location of the surgical cuts, to plan the movements of the bony segments relative to one another, and to achieve the desired realignment intraoperatively. In reconstructive procedures, problems include determining the desired implant or graft shape. Reconstructive procedures will be assessed in a future article. In the case of an implant, the problems are to select the proper device and shape it, or to fabricate an individual device from a suitable biocompatible material. With a graft, the difficulties lie in choosing the harvesting site, shaping the graft, and placing the implant or graft in the appropriate location [31]. In a virtual osteotomy, the resulting mesh from a segment is complex for several reasons: (1) cranial anatomy is intrinsically complex; (2) regions of thin (or absent) bone, such as the orbital floor, create sudden discontinuities in the mesh; and (3) inner structures (eg, the mandibular nerve canal) are often included in the surface model. For this reason, a virtual osteotomy with the CMFApp software uses a robust cutting algorithm, able to cope with triangular meshes of any complexity [32-36].

Osteotomies are simulated in the CMFApp software with combinations of planar cuts into the skeletal model. The aim of the osteotomy simulation is a set of realistically separated bone segments for relocation planning. This step is an individually based plan of the anatomic cuts before the surgical procedure. This allows for planning of the position and the size of the fixation screws and plates. The osteotomy tool in CMFApp supports any type of cut with reliable detection and separation of the resulting segments. Cutting planes are defined with 3 or more landmarks selected on the surface. After the virtual osteotomy, the virtual surgery with relocation of the bony segments can be performed with quantification of the planned surgical movements. Relocation of the anatomic segments with 6 df is tracked for each bone fragment. This allows for the correction of the skeletal discrepancy for a patient and simultaneous tracking of measurements of the x, y, and z rotational axes and the rotation about each axis [37].

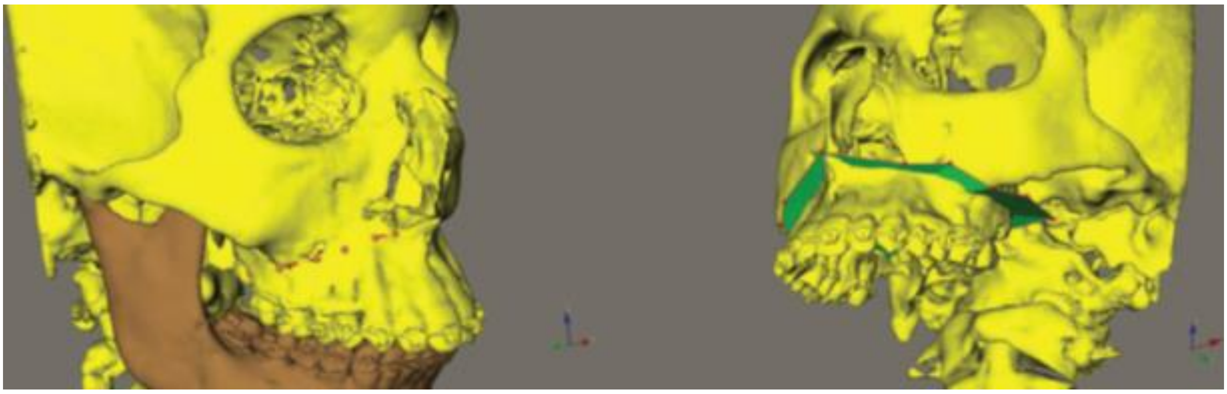

Fig-5: Le Fort 1 virtual osteotomy being outlined to allow segmentation of the maxilla

MANUFACTURING SPLINTS FOR ORTHOGNATHIC SURGERY USING A THREE-DIMENSIONAL PRINTER

FIRST SPLINT: To produce the first splint, the repositioned upper jaw and the original lower jaw with their aligned STL files were used to transform the necessary information into a virtual splint. This was selected from a database including several different sizes of virtual “blank splints”. A correctly sized splint was selected and placed between the tooth rows.

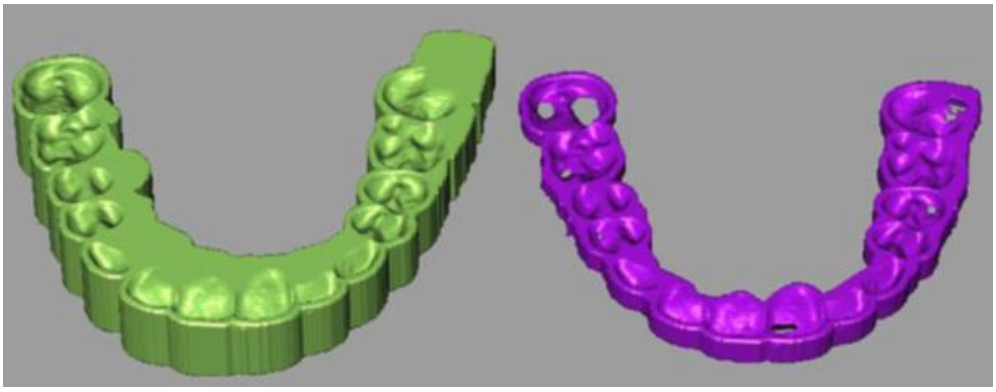

Fig-6: 3D virtual intermediate and final surgical splint (Maxilim, version 2.2.2, Medicim NV, Mechelen, Belgium).

SECOND SPLINT: To produce the second splint, the repositioned upper and lower jaws with their aligned STL files were used. A second virtual splint was selected and also placed between the tooth rows. After performing the splint placement, the software performs a boolean operation by subtracting the impressions of the virtual models from the virtual "blank splint," resulting in final splints. After these steps, it is possible to export the virtual splints (STL files) to a 3D printer or a drilling device to produce the final splints [38].

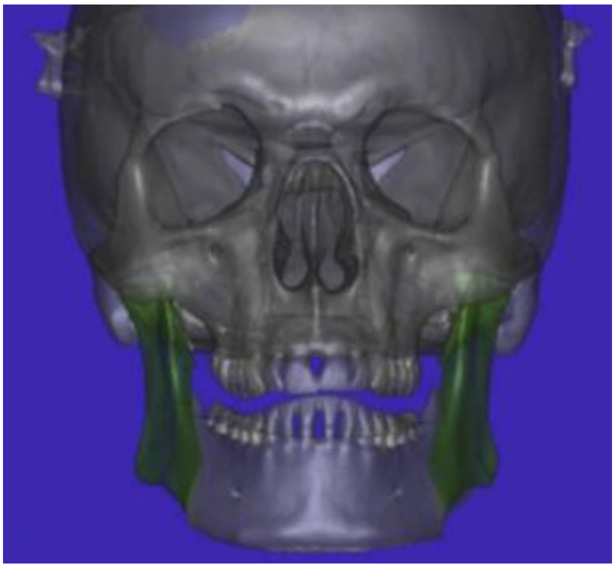

Fig-7: Mandibular repositioning after bilateral sagittal split osteotomy. The STL file allowed for the generation of a CAD/CAM intermediate splint.

Fig-8: Mandibular repositioning with the CAD/CAM generated splint

ANALYSIS OF 3D CHANGES AFTER ORTHOGNATHIC SURGERY SUPERIMPOSITION OF 3D CONE-BEAM CT

Segmentation of the cranial base and mandible was done with the Insight SNAP software, an interactive image segmentation program. Image segmentation refers to a process of examining cross-sections of a volumetric data set and outlining the shape of structures visible in these cross-sections. A key feature of SNAP is the ability to segment and navigate through the volumetric data set in any of the orthogonal slice windows (sagittal, coronal and axial views) with a linked cursor system that allows tracking of a single voxel. SNAP allows regional semiautomatic segmentation employing user-initialized deformable implicit surfaces that evolve to the most appropriate border between neighbouring structures. After the segmentation, a 3D graphical rendering of the volumetric object allows navigation between voxels in the volumetric image and the 3D graphics with zooming, rotating and panning. The pre- and post-surgery models were registered based on the cranial base surface, as the cranial base structures are not altered by the surgery, unlike the maxilla and/or mandible. The fully automated registration was computed by the MIRIT software.18 MIRIT computed the rigid registration (translation and rotation) that optimally aligns the pre- and post-operative dataset with subvoxel accuracy at the cranial base. VALMET a new tool for comparison of 3D models, was used for studying intraobserver and interobserver variability of segmentations.

VALMET allowed both visual and quantitative assessment of the location and magnitude of segmentation differences via graphical overlays and 3D displays. Inputs to VALMET are the registered pre- and post-surgery segmented models of the mandibular rami. Quantitative evaluation includes intraclass correlation of the resulting volumes and shape distance metrics such as the mean absolute distance between the segmentations. These volumetric and shape measures are calculated for the full 3D segmentations. The resulting 3D graphical display of the structure is colour-coded with the regional magnitude of the displacement between the pre- and post-surgery segmentations. The pre- or post-operative segmentation results are overlaid on the CBCT image data for visual comparison. VALMET computes several cumulative measures of the surface distances between pre- and post-surgery models [39]. Semitransparency tools can be used for visualization of the 3D overlays.

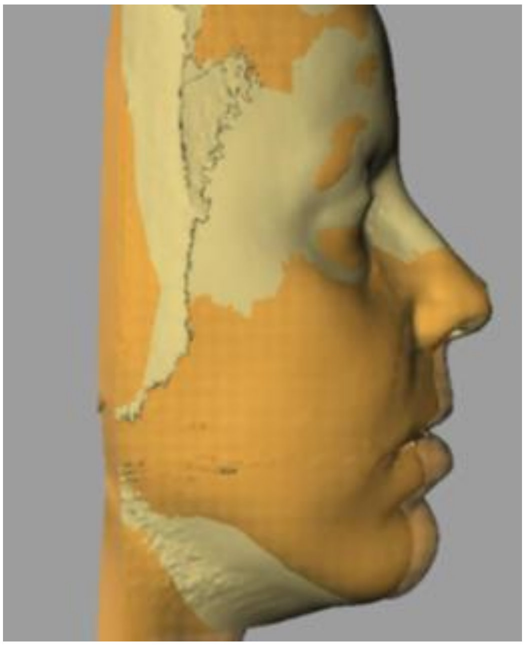

Fig-9: Surface-rendered right profile soft-tissue representations after voxel-based superimpositioning on cranial base before and 6 months after bimaxillary surgery (Maxilim, version 2.2.2, Medicim NV, Mechelen, Belgium)

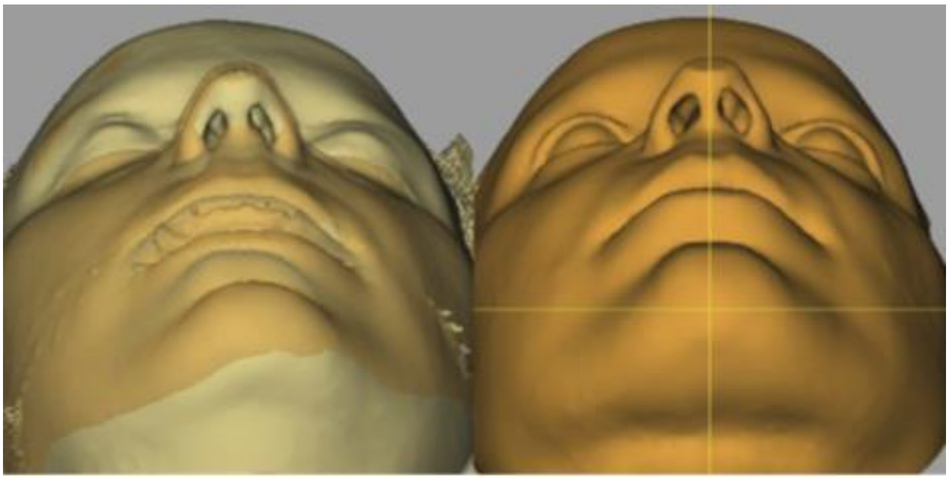

Fig-10: Surface-rendered base view of soft-tissue representations after voxel-based superimpositioning on the cranial base before and 6 months after bimaxillary surgery (Maxilim, version 2.2.2, Medicim NV, Mechelen, Belgium)

CONCLUSION

The three important tissue groups in orthognathic surgery (facial soft tissues, facial skeleton and dentition) can be referred to as a triad. This triad plays a decisive role in planning orthognathic surgery. Technological developments have led to the development of different three-dimensional (3D) technologies such as multiplanar CT and MRI scanning, 3D photography modalities and surface scanning. An objective method to predict surgical and orthodontic outcome should be established based on the integration of structural (soft tissue envelope, facial skeleton and dentition) and photographic 3D images. From these articles it is concluded, that image fusion and especially the 3D virtual head are accurate and realistic tools for documentation, analysis, treatment planning and long term follow up. This may provide an accurate and realistic prediction model.

REFERENCES

1. Swennen GR, Mollemans W, Schutyser F. Three-dimensional treatment planning of orthognathic surgery in the era of virtual imaging. J Oral Maxillofac Surg. 2009;67: 2080–92.
2. De Vos W, Casselman J, Swennen G. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillo-facial region: A systematic review of the literature. Int J Oral Maxillofac Surg. 2009; 38:609.
3. Quevedo L, Jedes G. Análisis cefalométricos y estéticos más utilizados. Facultad de Odontología Universidad de Chile, Santiago, Chile, 2004, pp 117-123.
4. Quevedo L. Predicciones cefalométricas para cirugía ortognática. Facultad de Odontología Universidad de Chile, Santiago, Chile, 2004, pp 16-23.
5. Mollemans W, Schutyser F, Nadjmi N, Maes F, Suetens P. Predicting soft tissue deformations for a maxillofacial surgery planning system: from computational strategies to a complete clinical validation. Medical image analysis. 2007 Jun 30;11(3):282-301.
6. Marchetti C, Bianchi A, Bassi M, Gori R, Lamberti C, Sarti A. Mathematical modeling and numerical simulation in maxillo-facial virtual surgery (VISU). Journal of Craniofacial Surgery. 2006 Jul 1;17(4):661-7.
7. Marchetti C, Bianchi A, Bassi M, Gori R, Lamberti C, Sarti A. Mathematical modeling and numerical simulation in maxillo-facial virtual surgery (VISU). Journal of Craniofacial Surgery. 2007.
8. Gateno J, Xia J, Teichgraeber JF, Rosen A. A new technique for the creation of a computerized composite skull model. Journal of oral and maxillofacial surgery. 2003 Feb 28;61(2):222-7.
9. Swennen GR, Mollemans W, De Clercq C, Abeloos J, Lamoral P, Lippens F, Neyt N, Casselman J, Schutyser F. 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. 2009 Mar 1;20(2):297-307.
10. Schutyser F, Swennen G, Suetens P. Robust visualization of the dental occlusion by a double scan procedure: Lecture notes in computer science. Med Imag Comput Comput Assist Interven. 2005; 3749:368.
11. Swennen GR, Barth EL, Eulzer C, Schutyser F. 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. 2007 Feb 28;36(2):146-52.
12. Swennen GR, Mollemans W, De Clercq C, Abeloos J, Lamoral P, Lippens F, Neyt N, Casselman J, Schutyser F. 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. 2009 Mar 1;20(2):297-307.
13. Swennen GR, Mollemans W, De Clercq C, Abeloos J, Lamoral P, Lippens F, Neyt N, Casselman J, Schutyser F. 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. 2009 Mar 1;20(2):297-307.
14. Swennen GR, Mollemans W, Schutyser F. Three-dimensional treatment planning of orthognathic surgery in the era of virtual imaging. Journal of oral and maxillofacial surgery. 2009 Oct 31;67(10):2080-92.
15. Quevedo LA, Ruiz JV, Quevedo CA. Using a clinical protocol for orthognathic surgery and assessing a 3-dimensional virtual approach: current therapy. Journal of Oral and Maxillofacial Surgery. 2011 Mar 31;69(3):623-37.
16. Xia JJ, Gateno J, Teichgraeber JF. New clinical protocol to evaluate craniomaxillofacial deformity and plan surgical correction. J Oral Maxillofac Surg. 2009; 67:2093.
17. Grayson B, Cutting C, Bookstein FL, Kim H, McCarthy JG. The three-dimensional cephalogram: theory, techniques, and clinical application. American Journal of Orthodontics and Dentofacial Orthopedics. 1988 Oct 1;94(4):327-37.
18. Grayson BH, McCarthy JG, Bookstein F. Analysis of craniofacial asymmetry by multiplane cephalometry. Am J Orthod. 1983; 84:217.
19. Bookstein FL, Grayson B, Fellingham L, McCarthy JG. Three-dimensional computer-assisted design of craniofacial surgical procedures: optimization and interaction with cephalometric and CT-based

models. Plastic and reconstructive surgery. 1986 Jun 1;77(6):877-85.

20. Zhu M, Cai Z, Zhang LY. Establishment of 3D analysis system of craniomaxillofacial skeleton. [Chinese]. J Oral Maxillofac Surg. 1998; 8:15.
21. Gateno J, Xia J, Teichgraeber JF, Rosen A. A new technique for the creation of a computerized composite skull model. Journal of oral and maxillofacial surgery. 2003 Feb 28;61(2):222-7.
22. Xia J, Ip HH, Samman N, Wong HT, Gateno J, Wang D, Yeung RW, Kot CS, Tideman H. Three-dimensional virtual-reality surgical planning and soft-tissue prediction for orthognathic surgery. IEEE transactions on information technology in biomedicine. 2001 Jun;5(2):97-107.
23. Xia J, Samman N, Yeung RW, Wang D, Shen SG, Ip HH, Tideman H. Computer-assisted three-dimensional surgical planning and simulation: 3D soft tissue planning and prediction. International journal of oral and maxillofacial surgery. 2000 Aug 1;29(4):250-8.
24. Farman AG, Scarfe WC. Development of imaging selection criteria and procedures should precede cephalometric assessment with cone-beam computed tomography. Am J Orthod Dentofac Orthop 130:257, 2006.
25. Schatz EC. *A new technique for recording natural head position in three dimensions* (Doctoral dissertation, MS Thesis in Orthodontics. Houston, University of Texas Health Science Center).2006.
26. Schatz EC, Xia JJ, Gateno J, English JD, Teichgraeber JF, Garrett FA. Development of a technique for recording and transferring natural head position in 3 dimensions. Journal of Craniofacial Surgery. 2010 Sep 1;21(5):1452-5.
27. Weiskircher MN. Accuracy of a new technique for recording natural head position in three dimensions. Orthodontics. The University of Texas Health Science Center at Houston. 2007.
28. Xia JJ, McGrory JK, Gateno J, Teichgraeber JF, Dawson BC, Kennedy KA, Lasky RE, English JD, Kau CH, McGrory KR. A new method to orient 3-dimensional computed tomography models to the natural head position: a clinical feasibility study. Journal of Oral and Maxillofacial Surgery. 2011 Mar 31;69(3):584-91.
29. Gateno J, Xia JJ, Teichgraeber JF. New 3-dimensional cephalometric analysis for orthognathic surgery. Journal of Oral and Maxillofacial Surgery. 2011 Mar 31;69(3):606-22.
30. Pommert A, Riemer M, Schiemann T, Schubert R, Tiede U, Hohne KH. Three-dimensional imaging in medicine: methods and applications. In: Taylor R, Lavallee S, Burdea G, Mosges R, editors. Computer integrated surgery. Cambridge, Mass: MIT Press; 1996. p. 155-74.
31. Chapuis J. Computer-aided cranio-maxillofacial surgery [thesis]. Bern, Switzerland: University of Bern; 2006.
32. De Momi E, Chapuis J, Pappas I, Ferrigno G, Hallermann W,Schramm A. Automatic extraction of the mid-facial plane for cranio-maxillofacial surgery planning. Int J Oral Maxillofac Surg. 2006;35:636-42.
33. Krol Z, Chapuis J, Schwenzer-Zimmerer K, Langlotz F,Zeilhofer HF. Preoperative planning and intraoperative navigation in the reconstructive craniofacial surgery. J Med Inform Tech. 2005;9:83-9.
34. Chapuis J, Langlotz F, Blaeuer M, Hallermann W, Schramm A, Caversaccio M. A novel approach for computer-aided corrective jaw surgery. Proceedings of the 3rd International Conference on Computer-Aided Surgery around the Head; 2005 Aug 25-27; Berlin, Germany. Berlin: Pro Business Verlag; 2005.
35. Chapuis J, Ryan P, Blaeuer M, Langlotz F, Hallermann W, Schramm A, Caversaccio M. A new approach for 3D computer-assisted orthognathic surgery—first clinical case. InInternational Congress Series. 2005 May 31 (Vol. 1281, pp. 1217-1222). Elsevier.
36. Chapuis J, Rudolph T, Borgesson B, De Momi E, Pappas IP, Hallermann W, Schramm A, Caversaccio M. 3 D surgical planning and navigation for CMF surgery. In Proceedings of SPIE. 2004 Feb (Vol. 5367, pp. 403-410).
37. Cevidanes LH, Tucker S, Styner M, Kim H, Chapuis J, Reyes M, Proffit W, Turvey T, Jaskolka M. Three-dimensional surgical simulation. American journal of orthodontics and dentofacial orthopedics. 2010 Sep 30;138(3):361-71.
38. Metzger MC, Hohlweg-Majert B, Schwarz U, Teschner M, Hammer B, Schmelzeisen R. Manufacturing splints for orthognathic surgery using a three-dimensional printer. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2008 Feb 29;105(2):e1-7.
39. Cevidanes LH, Bailey LJ, Tucker Jr GR, Styner MA, Mol A, Phillips CL, Proffit WR, Turvey T. Superimposition of 3D cone-beam CT models of orthognathic surgery patients. Dentomaxillofacial Radiology. 2005 Nov;34(6):369-75.