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3D CT Cephalometric: A Method to Study Cranio-Maxillofacial Deformities

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Abstract - **The purpose of this study is to present a method of three dimensional computed tomographic (3D CT) cephalometrics and its use to study craniomaxillofacial deformities. Axial images of a patient with hemimandibular hyperplasia were reconstructed into 3D model by using medical image processing software (MIMICS, Materialise N.V.,). Anatomical landmarks were located and stored as template files which can be reproducible in 3D computerized aided design (CAD) system for subsequent analysis. The results indicate that, this method of analysis clearly show the asymmetry of the mandible and the dentition which is very useful for the dentofacial diagnosis. Moreover, the profile of anatomical positions can be created in 3D CAD file for further uses, such as finite element analysis and surgical planning.**

I. INTRODUCTION

CEPHALOMETRIC analysis is a one of essential tools in diagnoses cranio-maxillofacial deformities including facial asymmetry [1-4]. Obtaining cranio-maxillofacial cephalometric data requires the accurately landmarks located on regions of interest. These can be established using various techniques. For example, direct measurements, 2D radiographs and computed tomographic (CT) scanning data [6].

Recently, most clinician identifies landmarks using 2D radiograph is a conventional routine part of the diagnostic evaluation of patients, but this method is not readily comprehensible because of several limitation [5]. The medical imaging is limited in only two dimensions: coronal and axial or sagittal planes. The other limitation is the 2-D imaging always produces image distortion due to the overlapping structures [4], radiographic magnification, and head rotation [6,7]. Since, introduction of 3D surface reconstruction from CT scans. The 3D analysis has been recommended for marking a precisely diagnosis and currently in the area of craniofacial morphology [8-13]. The 3D CT method is widely used and acceptable for many reasons. For example, it can obtained actual measurement and the 3D image can be rotated easily by changing the rotational axis [6,8]. Moreover, 3D CT image can also show asymmetry of the midface and the cranial base; it is difficult to detect in ordinary 2D x-ray film [9,14].

The combination these data with 3D medical imaging, CAD and rapid prototyping (RP) are now an acceptable and essential means for visualization in medical treatment and surgery [15-17]. There are extended to the complex field of surgical reconstruction as these can offer a wide range of desirable features such as accurate preoperative surgical-planning, design and manufacture of custom implants. Moreover, there are accurate assessments of results in longitudinal follow-up of patients undergoing treatment. It were found to be clinically significant to the cranio-maxillofacial deformities treatment [5,18].

This study is aim to introduce a method of 3D cephalometrics of a hemimandibular case based on 3D model reconstructed with 3D CT imaging procedure. The clinical implication is to visualize the diagnosis; treatment planning and outcome evaluation in surgical cases that can be applied in dentofacial deformities.

II. MATERIALS AND METHODS

A case analysis of hemimandibular hyperplasia is presented. The SIEMENS Spiral CT scan (with 512 x 512 matrixes, 120 kV, and 87.75 mAs) was performed 1 mm slice thickness and reconstruction was done with 1 mm interpolated slice thickness. The axial images were reconstructed into a 3D model that developed to extract the boundaries of the bone skeleton from the CT dataset using a threshold and region growing technique by medical image processing software (MIMICS, Materialise N.V.) as shown in Figure 1A. The cephalometric analysis with simulation module of MIMICS was used to measure the 3D models that can be rotated and viewed from any angle as shown in Figure 1B.

The four anatomical areas were studied as following: anterior cranial base, nasomaxillary complex, mandible and the dentition that represented the significant areas for diagnosis and treatment evaluation. All anatomical landmarks were first identified on the 3D model, and their positions were verified in multi-planar reformat mode in directional of axial and sagittal views. The landmarks used in this study are defined in Table I and are shown in Figure 2.

Twenty-one measurements based on thirty-three landmarks in the form of linear and angular measurements are presented in the coronal, axial and sagittal planes both in 2D and 3D images as shown in Table II.

The reference planes of Frankfurt (OrLPoL, OrRPoR), Mandibular (GoL-Me, GoR-Me), Mandibular Occlusal (MoL-Is1u-MoR), Midsagittal (N-S-ANS) and Zygomatic (ZA-AZ) were established on a 3D model, these are for symmetrical analysis as shown in Figure 3.

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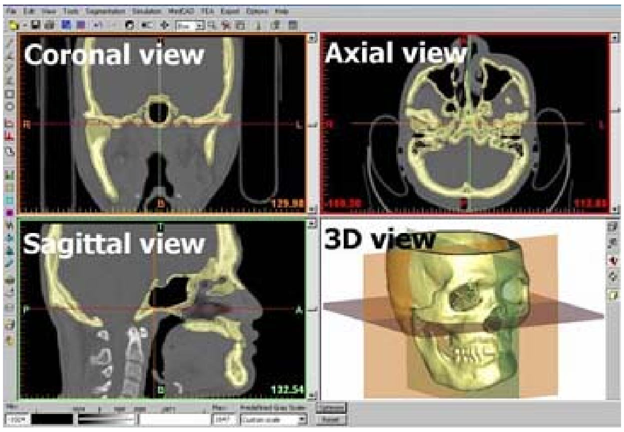
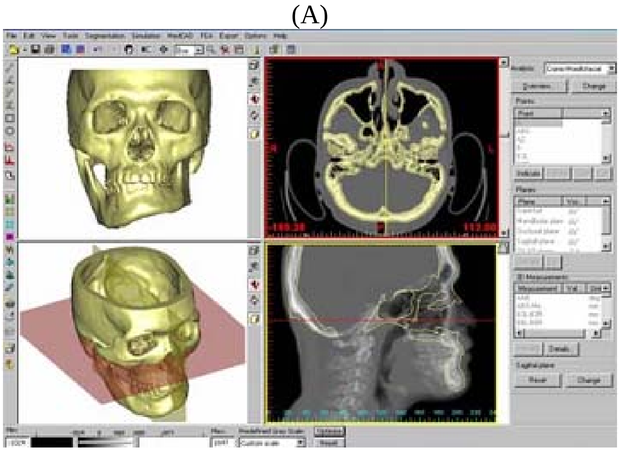
The landmarks and their respective measurements were stored in the segment template's MIMICS file that its can be retrieved for subsequent identification and analysis. The stored coordination of each landmark associated on the template can be transferred and displayed in other CAD system. For further manipulation, its can be significant anatomical area for pre-operation and post-operative treatment planning. Moreover, the profile of anatomical positions can be created as 3D CAD file for further uses such as finite element analysis and surgical planning.



(A)



(B)

Fig 1. A, 3D model made by MIMICS using a threshold and region growing technique that shown in coronal, axial, and sagittal views. B, 3D model used in the anthropometric analysis with simulation module of MIMICS.

TABLE I
LANDMARKS FOR 3D CT USED IN STUDY

Landmark	Landmark definition
Anterior cranial base	
N	Nasion : the inersection of the internasal and frontonasal sutures in the midsagittal plane
S	Sella turcica : geometric center of pituitary fossa
PoL	Porion Left : the most upper point on left bony external auditory meatus
PoR	Porion Right : the most upper point on right bony external auditory meatus
Nasomaxillaery complex	
A	Position of deepest concavity on anterior profile of maxilla
ANS	Tip of Anterior Nasal Spine
ZA	Center of the root of the left zygometic arch
AZ	Center of the root of the right zygometic arch
JL	Jugal Left : intersection of the outline of the tuberosity of the maxilla and zygomatic buttress
JR	Jugal Right : intersection of the outline of the tuberosity of the maxilla and zygomatic buttress
NL	Left Nasal point NR Right Nasal point OrL Orbitale Left : the most a inferior point on left orbit's margin
OrR	Orbitale Right : the most a inferior point on right orbit's margin
ZL	Medial margin of the left zygomaticofrontal suture
ZR	Medial margin of the right zygomaticofrontal suture
Mandible	
B	Position of deepest concavity on anterior profile of mandible
CondL	Condylion Left : the most superior point on left mandibular condile
CondR	Condylion Right : the most superior point on right mandibular condile
Gn	Gnation : in the midline, the lowest point on the lower border of the chin
GoL	Gonion Left : most inferior point on left angle of mandible
GoR	Gonion Right : most inferior point on right angle of mandible
ImL	Antegonial Notch Left
ImR	Antegonial Notch Right
Me	Menton : the most inferior point of the bony mandibular symphysis anteriorly
Pog	Pogoinion : the most anterior point on the bony chin in the midsagittal plane
Landmark	Landmark definition
Dentition	
B3L	Tip of left lower canine
B3R	Tip of right lower canine
B6L	Buccal surface of left 1st molar
B6R	Buccal surface of right 1st molar
Is1u	Inicision superior : most occlusal point of upper incisor
MoL	the overbiting point of the left first molars (if present) or the distal tip of the fist left molar
MoR	the overbiting point of the Right first molars (if present) or the distal tip of the fist right molar

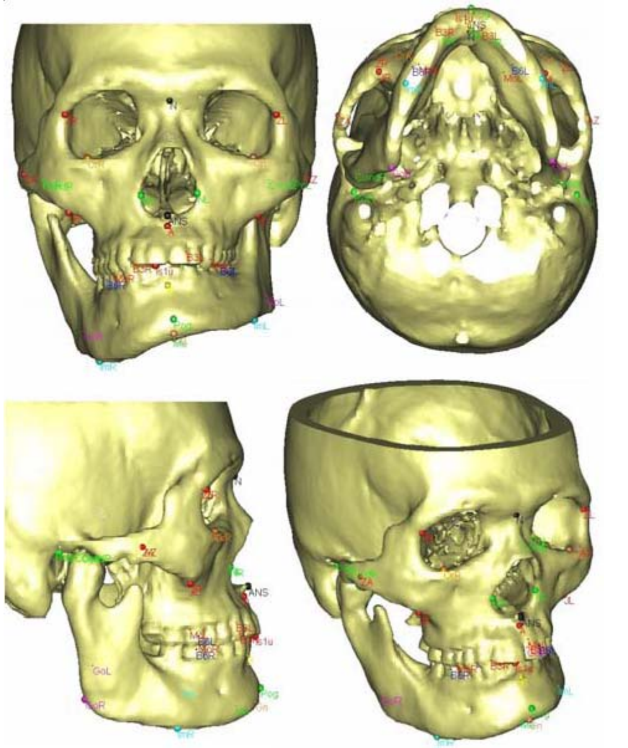


Fig.2. Thirty-three landmarks used in this study

III. RESULT

The results of linear and angular measurements can be displayed in Table II. The most of the 3D measurements are presented in both left and right sides for comparison between the standard norms and symmetrical analysis. The 2D measurements are also

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displayed in the directional of sagittal view for conventional cephalometric analysis as shown in Fig 4. In analysis case, it is impossible to perform just only surgical treatment on the mandible to correct the emimandibular hyperplasia. The malocclusion with the cant occlusal plane and skeletal malrelationship with mandibular hyperplasia need correction as the same time.

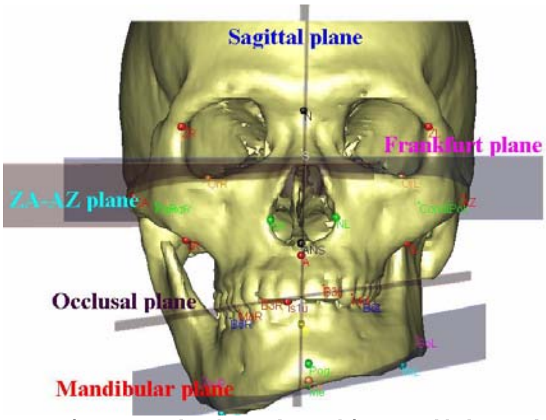

Fig 3. Five references used in this study Frankfurt, Mandibular, Occlusal, Sagittal and ZA-AZ planes

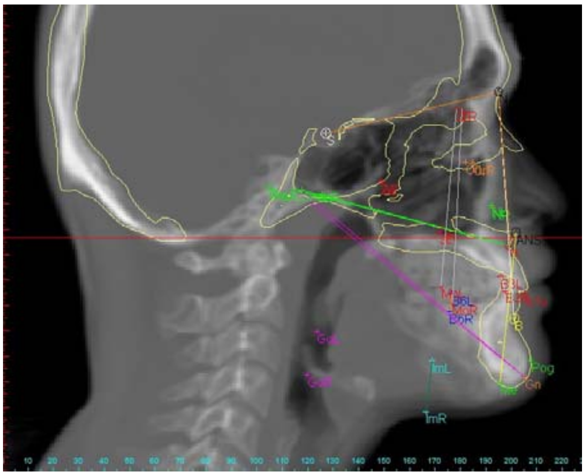

Fig 4. The 3D CT Landmark points displayed on 2D film view mode.

In point of view, the detail will be discussed into two points. First, one is the asymmetry of the structure (mandible) which is the most concern of the patient. And second, the other is the deviation of the skeleton and dentition from standard norms

Normally, both cephalometrics and dental models are common tools to explain skeletal malrelationship and malocclusion of the patient in 2D analysis. In these cases the analysis using 3D scan, not only 3D cephalometric values, but also images in three planes of space are available to move and rotate to show all the structures even the ones those overlapping.

TABLE II
THE RESULTS OF MEASUREMENT DATA

Measurement	Description	unit	3D	2D	
SNA	Sagittal maxillary position	deg	80.6	80.64	
SNB	Sagittal mandibular	deg	80.3	80.31	position
ANB	Sagittal max-mand	deg	0.45	0.33	relationship
OrLPoL-GoLMe	Max-mand vertical relationship-left	deg	27.2	-	
OrRPoR-GoRMe	Max-mand vertical relationship-right	deg	17.07	-	
CondL-A	Maxillary length-	mm	100.84	88.13	left
CondR-A	Maxillary length-	mm	104.21	84.71	right
CondL-Gn	Mandibular length-	mm	126.44	117.78	left
CondR-Gn	Mandibular length-	mm	131.34	114.86	right
Max-Mand L	Left maxillo-mandibular difference	mm	-25.6	-29.64	
Max-Mand R	Right maxillo-mandibular difference	mm	-27.13	-30.16	
ANS-Me	Lower anterior height	mm	59.59	59.52	facial
ZA-AZ	Zygomatic width	mm	136.54	0.67	
NL-NR	Nasal width	mm	27.66	1.12	
ZL-MoL	Upper facial high-	mm	77.24	70.29	left
ZR-MoR	Upper facial high-	mm	80.4	76.74	right
B3L-B3R	Lower intercanine	mm	26.67	5.95	width
B6L-B6R	Lower intermolar	mm	55.57	7.07	width
ImL-ImR	Antigonial notch	mm	77.66	20.15	width

A. Asymmetry of the mandible

It is certain as shown in the Fig 2 that the mandible on the right hand side is much larger compared to the left. The enlargement starts from the mandibular midline and now it is dominant at the condylar head of the effected side. The whole mandible deviates to the right. The Mandibual Occlusal plane and the Mandibular plane tip downward on the same direction and are not parallel with the Frankfurt plane and the Me point is on the left of Midsagittal as shown in Figure 3. The cephalometric values which clearly support the abnormalities are the difference between the left and right Mandibular planes (OrLPoL-GoLMe=27.2o, OrRPoR-GoRMe=17-07.2o), the discrepancy between left and right zygomaticofrontal sutures to the dentition (ZL-MoL=77.24 mm., ZR-MoR=80.4mm.) and to the angle of the mandible (ZL-GoL, ZR-GoR which measurements are not demonstrated) and also the differences between left and right maxillomandibular lengths (Max-Mand Left=-25.6 mm., Max-Mand Right=-27.13 mm, CondL-A=100.84 mm., CondR-A=104.21 mm., CondL-Gn=126.44 mm., CondR-Gn=131.34 mm.).

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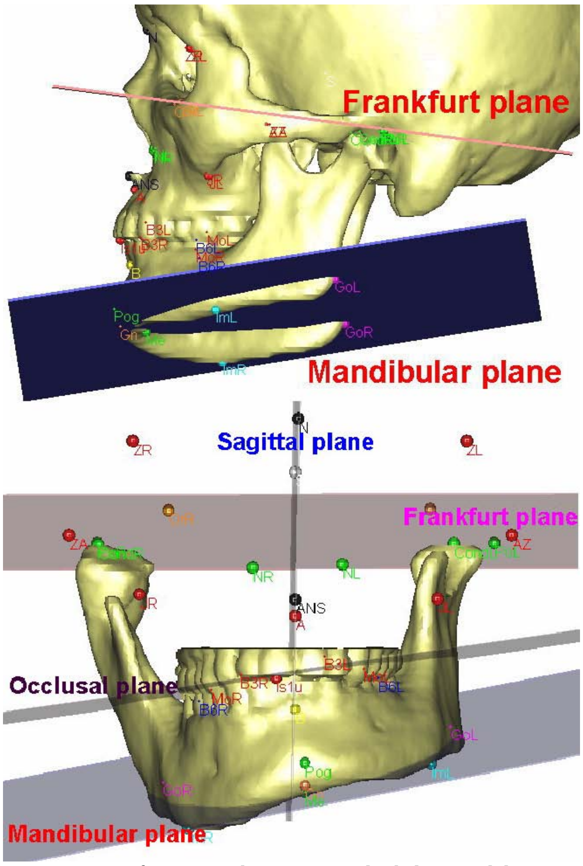

Fig 5. 3D CT of patient with asymmetrical. Skeleton and dentition compared to the standard norms

B. *Skeleton and dentition compared to the standard norms*

It is very difficult to evaluate studies, yet because 3D standard norms have not been reported. Only some measurements in the midsagittal (ANB angle) and the parallel of Mandibular Occlusal plane, Mandibular plane to Frankfurt plane can be discussed as above. Most of the abnormalities are located on the posterior portion of the right mandible. The patient still has normal anterior position of the maxilla and mandible (SNA=80.63, SNB=80.3, ANB=0.45). The others data are the transverse measurements which are available for pre and post treatment comparison.

For the dentition, the mandibular deviation may be causes the lower dentition deviates on the same side. The patient has different Maxilla and Mandibular Occlusal planes, normal lateral overjet on the right but large on the left. The upper left posterior teeth occlude on the buccal surface of the lower instead of to the occlusal surface. There is some crowding. The inclination and position of the upper and lower anterior teeth are not shown here and they are very difficult to assess from the images.

IV. DISSCUSSIONS

1. It can be certainly, there is no significant error that 3D cephalometrics is distinct in advantages. This can evaluate the specific angles that can not be evaluated by a 2D radiographic measurement because of the overlapping. Both the measurement values, the actual images in three planes of space which are available to move and rotate to show all the structures can clearly give good information of the whole picture of the deformities. These make the 3D cephalometrics much more superior to the conventional 2D.

2. The stored coordination of each landmark associated on the template can be transferred and displayed in other 3D CAD system for further manipulation. Moreover, the profile of anatomical positions can be created for further uses. For example, finite element analysis and computer simulation for surgical planning or distraction osteogensis.

3. For the reliability of landmark identification, Kragskov et al [7] reported that 2D cephalograph measures were more reliable than 3D CT, with intraobserver variation less than 1 mm for most points compared to about 2 mm for 3D CT. But for the accuracy, there were studies reported on 3D CT's excellence (Matteson et al [19], Tyndall et al [20], and Adams et al [6]). Marcelo et al [15] studied accuracy of 3D CT comparing to the physical measurement in nine skulls, and they reported that there was no statistically significant differences between two measurement types, with >.05. The mean difference between the image and the real measurements was less than 2 mm. Adams et al [4] did the comparative study between traditional 2D and 3D cephalometry approach on human dry skull in 2004. They have reported that the 2D cephalometry gave great variability compared to the control (direct physical measurement) while the 3D cephalometry was much more precise within approximately 1 mm of the standard and 4 to 5 times more accurate than the 2D approach. The causes of inaccuracy in 2D measurement were difference magnification of the structures on difference distance to the film plate, rotation of the head and also organ overlapping [4,7]. Moreover, Park, et al.,[21] propose that a 3D CT image can also show asymmetry of the midface and the cranial base; this is difficult to detect with ordinary 2D x-ray film. It is concluded that even the 3D CT is more accurate, it is necessary to calibration and practiced before clinical implementation.

4. There is only one study on 3D cephalometric standard norms in Korean adult (Park, et al [8]) appropriate to apply to the Thai population. Further study on Thai samples is required.

5. The 3D CT analysis is very powerful tool for the patients with major deformities. For the general orthodontic use, it depends on logistic and economic consideration. The cost of 3D CT is quite high; relatively the less expensive equipment should be available in the future.

V.CONCLUSION

The development of cranio-maxillofacial cephalometric is a multidisciplinary initiative that provides an important reference in medical application. In this study, the computerized technique was used to evaluate cephalometric of cranio-maxillofacial base on 3D CT landmark system that would give greatly benefit diagnosis, treatment planning and outcome evaluation medical treatment of cranio-maxillofacial deformities.

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