*European Journal of Orthodontics* 32 (2010) 627–632
*doi:10.1093/ejo/cjq026*
*Advance Access Publication 21 July 2010*



# Three-dimensional analysis of biplanar cephalograms

Min-Ching Wu*, Kuo-Sheng Cheng**, Yen-Ting Chen***, Jia-Kuang Liu* and Wen-Hung Ting**

Institutes of *Oral Medicine and **Biomedical Engineering, National Cheng Kung University and ***Department of Electrical Engineering, Southern Taiwan University of Technology, Tainan, Taiwan, Republic of China

*Correspondence to:* Jia-Kuang Liu, Department of Stomatology, National Cheng Kung University Hospital, #138 Sheng-Li Road, Tainan 704, Taiwan, Republic of China. E-mail: jkliu@mail.ncku.edu.tw

SUMMARY The aims of this study were to reconstruct a three-dimensional (3D) model, to provide a 3D analysis using biplanar cephalograms [postero-anterior (PA) and lateral] with orthogonal projection, and to compare the differences between the 3D and two-dimensional (2D) analyses. The procedures were as follows: (1) to identify landmarks from a dry skull and to construct the norms for the spatial information of the skull from the 3D reconstruction using computerized tomography (CT); (2) to reconstruct a 3D model using biplanar cephalograms (PA and lateral); and (3) to compare the differences between the 2D and 3D analyses. Fifteen clearly visible landmarks identified on both films were used in this study.

By comparing the data from the CT and the biplanar cephalograms, it was found that the accuracy for the 3D linear measurements from biplanar cephalograms was 98.9 per cent. However, the accuracy for the linear measurements from 2D and CT data was only 89.2 per cent. If the measurement of gonion (Go) to menton (Me) was excluded, the accuracy for the linear measurements from 2D and CT data was 95.1 per cent. When using a *t*-test to compare the linear distances of 2D-CT and 3D-CT data (Go to Me excluded), the difference was statistically significant ($P < 0.05$). The findings indicate that biplanar cephalograms with orthogonal projection are able to provide a 3D analysis that is more accurate than 2D analysis.

## Introduction

Cephalometry, which is a method used for measurement of a standardized head radiograph, was introduced by Broadbent (1931). The most commonly used cephalograms are those taken in the postero-anterior (PA) and lateral views. These two cephalograms can provide information in two dimensions, but they cannot accurately explain the relationships of the various anatomical structures in three dimensions and, as a result, may introduce measurement errors due to distortions (Baumrind and Frantz, 1971). To minimize errors and achieve accurate three-dimensional (3D) representation of the craniofacial structures, laser scanning, stereophotogrammetry, and computerized tomography (CT) were developed. Although these 3D imaging techniques can provide accurate information concerning craniofacial structures and measurements in three dimensions, the disadvantage of laser scanning and stereophotogrammetry is that they only estimate the external surface of the soft tissues. The disadvantages of CT are the radiation hazard, high cost, and time required (Harrell *et al.*, 2006).

To avoid the above-mentioned disadvantages when producing 3D information, attempts have been made to develop 3D analysis using a pair of PA and lateral cephalograms (Grayson *et al.*, 1988). To obtain biplanar cephalograms with orthogonal projection of the two films, images are captured of the same head orientated in two planes at right angles to each other. The 3D cephalometric landmarks are then located from these two-dimensional (2D) biplanar cephalograms aided by a computer program, and 3D co-ordinates based on the cephalometric landmarks are calculated. The 3D reconstruction can then be used to display wire-frame models based on landmarks. This type of 3D cephalometry reconstruction from 2D biplanar cephalograms is available for clinical applications (Grayson *et al.*, 1988; Brown and Abbott, 1989). However, in these previous studies, no linear or angular measurements were provided by the 3D analysis as is the case with conventional 2D analysis, and the accuracy of the 3D cephalometry created from biplanar cephalograms with orthogonal projection is still unclear. The aims of this study were to reconstruct a 3D model, to provide a 3D analysis using biplanar cephalograms with orthogonal projection, and then to compare the differences between 3D and 2D analyses.

## Materials and methods

### *Landmarks selection for 3D reconstruction*

The 15 landmarks that could be located on both the lateral and PA films are defined in Figure 1. Metallic markers, 1 mm in diameter, were attached to each landmark location on a dry skull. The skull was then captured as a pair of lateral and PA cephalograms precisely in the Frankfort horizontal plane and then again after 90 degrees rotation along the vertical axis using an Ortho Stage machine (Auto

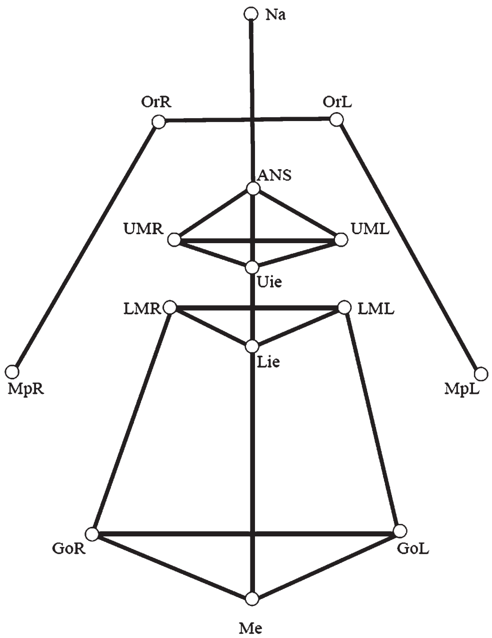


**Figure 1** Three-dimensional wire frame of the skull. Midline landmarks: Na, the anterior point of the intersection between the nasal and frontal bones; ANS, the tip of anterior nasal spine; Uie and Lie, upper and lower incisal edge; and Me, the most inferior point on the mandibular symphysis. Bilateral landmarks: OrR and OrL, the lowest point on the inferior margin of the orbital rim; MpR and MpL, the lowest point of the mastoid process; UMR and UML, upper first molar mesio-buccal cusp tip; LMR and LML, lower first molar disto-lingual cusp tip; and GoR and GoL, the midpoint of the contour connecting the ramus and body of the mandible.

III NCM, Asahi Roentgen, Kyoto, Japan). The X-ray source was set at 60 kVp and 12 mAs. A second lateral cephalogram was obtained at a lower dose of 60 kVp and 2 mAs in order to accentuate some of landmarks. The source–object distance was 150 cm and the source–film distance 165 cm. A line connecting the centre of right and left machine ear rods (CER and CEL) was used as the $z$ axis. The centre of the bilateral machine ear rods in the cephalograms was defined as the CE point. The $x$ axis was a horizontal line through CE perpendicular to the CER–CEL line and $y$ axis a vertical line through CE perpendicular to the CER–CEL line. Based on this, the 3D co-ordinates for landmarks could then be identified accurately and were calculated from the 2D data by the 'Landmarker' computer program (Imagelab, Biomedical Engineering, National Cheng Kung University, Tainan, Taiwan).

In order to evaluate the accuracy of the landmarks resulting from the 3D reconstruction using two orthogonal views, the norms of the spatial locations of the metallic markers on the skull were calculated using CT. Scanning of the skull from the top to the bottom was carried out at an interval of 1 mm and 222 CT slices were acquired. The skull was reconstructed in 3D from the 222 slices using CT reconstruction software (Imagelab). The centre of each metal marker was manually located 10 times and the means of the 3D co-ordinates for each metal marker were calculated. These were recorded for the CT scan as well as the biplanar cephalogram 3D reconstruction using the same skull. The positions of the landmark co-ordinates were compared between the CT and biplanar cephalogram 3D reconstructions.

To determine the accuracy of landmark identification without the aid of metallic markers, a second pair of cephalograms was obtained under the same exposure condition after removing all markers. Three 2-year experienced orthodontists at National Cheng Kung University Hospital were asked to locate each landmark 10 times on the biplanar cephalograms without markers in the software Landmarker once per day to compare the data obtained with and without markers.

### *3D analysis from 3D reconstruction*

From the 3D co-ordinates of these landmarks, a wire frame based on 15 landmarks from the skull was plotted using the CT reconstruction system for visualization (Figure 1). The wire frame could be manipulated by the mouse and observed in the frontal, lateral, or axial directions.

Quantification based on the 3D cephalograms, including linear and angular measurement, was performed. There were seven transverse, six sagittal, and eight vertical linear measurements as well as eight angular measurements. Most of the linear measurements were distances between two points. Otherwise, the measurement was from a point to a line. For sagittal measurements, the horizontal reference line was a line connecting the CE and a midpoint between OrR and OrL. Similarly, for the vertical reference line, this was a line through the CE point perpendicular to the horizontal reference line. The shortest distance from ANS, Uie, Lie, and menton (Me) to the vertical reference line was then measured. For vertical measurements, the horizontal maxillary reference was a line connecting ANS and a midpoint between MpR and MpL. The shortest distance from upper molar cusp tip (UMR or UML) to the maxillary horizontal reference line was measured. The horizontal mandibular reference line was the plane connecting Me and a midpoint between GoR and GoL, the shortest distance from the lower molar cusp tip (LMR or LML) to the mandibular horizontal reference line was measured (Figure 2).

The angular measurements comprised the angle between two planes during 3D analysis, which was analogous to conventional 2D analysis. With this system, CE, ANS, and Mp could be used instead of porion, point A, and PNS, respectively. The CE OrR OrL plane was used as the horizontal reference plane and the line through the CE perpendicular to the horizontal reference plane as the vertical reference plane. The planes MpR MpL ANS, UMR UML Uie, LMR LML Lie, and GoR GoL Me represented the palatal, upper occlusal, lower occlusal, and mandibular planes, respectively. It was possible to measure the angles between two planes in order to obtain their relative relationship.

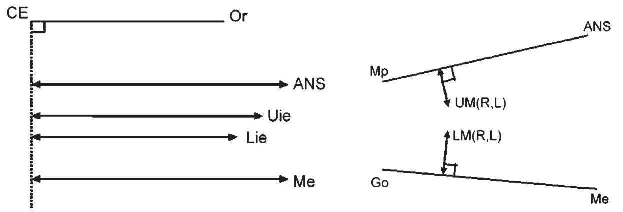


**Figure 2** The distance from each landmark to the reference line in the sagittal (left) and vertical (right) linear measurements. Left: horizontal reference line—the line connecting the CE (the centre point of the bilateral machine ear rods) and a midpoint between OrR and OrL; vertical reference line—a line through the CE point perpendicular to horizontal reference line. Right: horizontal reference line in the maxilla—a line connecting ANS and a midpoint between MpR and MpL; horizontal reference line in the mandible—a line connecting Me and a midpoint between GoR and GoL.

*Comparison of 2D and 3D analyses*

The differences between the linear measurements of 2D and 3D analyses based on biplanar cephalograms and the data from the CT were compared. A paired *t*-test was used to compare the linear distances of 2D CT and 3D CT, excluding gonion (Go) to Me data. The angular measurements were taken as the angle between two lines from the 2D analysis and the differences between the angular measurements for the 2D and 3D analyses from biplanar cephalograms were also compared.

## Results

After 3D reconstruction, the co-ordinates of the 15 landmarks and the differences between them from the two different systems were obtained (Table 1). The wire frames of the skull from the CT data and from the biplanar radiographs are shown in Figure 3a. The differences between the two wire frames were compared by superimposing the two graphs through registration procedures (Figure 3b). The errors in the differences ranged from 0.14 to 1.34 mm all of the errors in the 3D co-ordinates were below 2 mm, with most below 1 mm. The smallest error was found for ANS and the largest for Lie. The mean error for the differences of all landmarks was 0.85 mm. When the differences in landmark identification between 3D co-ordinates with and without metallic markers from a pair of cephalograms were compared, errors larger than 1 mm were found for OrL and GoL for the first, OrR, MpR, and MpL for the second, and N, ANS, Lie, Me, OrR, MpL, LMR, and GoL for the third assessor.

The differences among the distances between the 2D and 3D measurement from the biplanar cephalograms and data from the CT of the skull are summarized in Table 2. There was a lack of data from CT for the differences in measurements from ANS, Uie, Lie, and Me to the vertical reference line and therefore these are shown only between the 2D and 3D analyses. The differences in the 3D measurements from the biplanar cephalograms and CT ranged from 0.02 to 1.47 mm. The smallest was the distance from UML to the ANS–Mp line and the largest the distance between UMR and UML. The mean difference was 0.53 mm and the overall accuracy was 98.9 per cent. However, the range of differences between measurements from 2D and CT distances was significantly larger and was between 0.5 and 4.27 mm for most measurements except GoR–Me and GoL–Me. The values shown for the 2D measurements had already been adjusted to take into account the 10 per cent enlargement rate. Overall, the range was much larger than that between measurements from 3D co-ordinates and CT distances. Particularly, the range of differences for the GoR(L)–Me measurements from the 2D and CT distances was between 15.39 and 32.88 mm, which is significantly larger than for the other measurements. The overall mean

**Table 1** The three-dimensional (3D) co-ordinates and errors in differences from biplanar cephalograms and from computerized tomography (CT) data.

| Landmark | 3D co-ordinates, *x*, *y*, *z* (biplanar radiograph) | 3D co-ordinates, *x*, *y*, *z* (CT data) | Error difference (mm) |
|---|---|---|---|
| Na | −1.92, 46.95, 80.81 | 4.53, 25, 81.19 | 0.86 |
| ANS | 0.00, −5.80, 95.45 | 4.95, −28, 91.50 | 0.14 |
| Uie | −0.97, −38.80, 100.84 | 2.47, −61, 94.79 | 0.59 |
| Lie | 0.00, −35.57, 86.36 | 3.71, −56, 80.78 | 1.34 |
| Me | 3.84, −77.84, 85.67 | 5.36, −99, 76.25 | 0.69 |
| OrR | −46.74, 14.31, 73.98 | −42.45, −5, 75.42 | 0.96 |
| OrL | 45.79, 17.17, 74.01 | 49.87, −5, 69.65 | 0.61 |
| MpR | −52.39, −26.19, −9.65 | −55.23, −37, −12.36 | 1.30 |
| MpL | 51.49, −23.49, −9.40 | 48.63, −39, −18.37 | 1.03 |
| UMR | −28.59, −40.02, 72.23 | −27.61, −59, 67.59 | 1.01 |
| UML | 26.71, −36.25, 74.02 | 29.26, −57, 66.35 | 0.78 |
| LMR | −28.25, −39.54, 53.52 | −26.79, −57, 49.04 | 0.59 |
| LML | 23.54, −34.84, 53.55 | 25.14, −55, 45.75 | 0.98 |
| GoR | −50.67, −60.81, 20.20 | −52.75, −74, 14.42 | 1.17 |
| GoL | 53.49, −53.49, 21.65 | 51.34, −72, 11.30 | 0.73 |

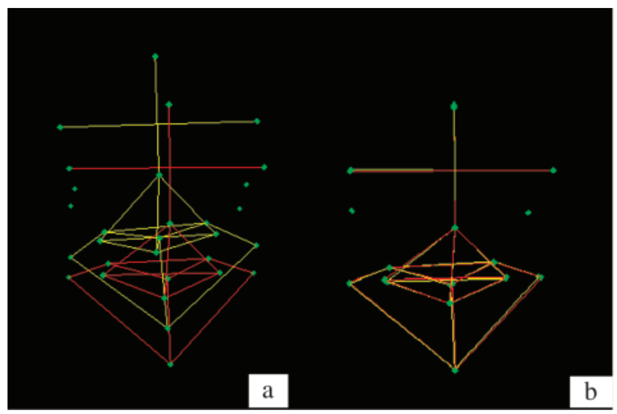


**Figure 3** a) The wire frames of the skull from the computerized tomography (CT) data and from the biplanar radiographs are shown in red and yellow respectively. (b) Superimposition on the two wire frames from CT data and biplanar radiographs through registration procedures.

**Table 2** Comparison of the distances (mm) among two-dimensional (2D), three-dimensional (3D), and computerized tomography (CT) data.

| Skull | 2D data | 3D data | CT data | Difference |
|---|---|---|---|---|
| | | | | 2D CT/3D CT |
| Transverse distance (2D postero-anterior film) | | | | |
| GoR–GoL | 101.85 | 103.49 | 104.16 | 2.31/0.67 |
| OrR–OrL | 88.23 | 92.53 | 92.5 | 4.27/0.03 |
| MpR–MpL | 104.55 | 103.89 | 104.05 | 0.50/0.16 |
| UMR–UML | 52.8 | 55.45 | 56.92 | 4.12/1.47 |
| LMR–LML | 51.04 | 52.94 | 52.07 | 1.03/0.87 |
| GoR–Me | 55.57 | 87.73 | 88.45 | 32.88/0.72 |
| GoL–Me | 51.18 | 84.35 | 84.03 | 32.85/0.32 |
| Vertical distance (2D lateral film) | | | | |
| Na–ANS | 52.7 | 54.74 | 53.99 | 1.29/0.75 |
| ANS–Me | 68.78 | 72.68 | 72.62 | 3.84/0.06 |
| ANS–Uie | 30.66 | 32.67 | 33.26 | 2.60/0.59 |
| Lie–Me | 40.92 | 43.41 | 43.27 | 2.35/0.14 |
| UMR–Mxref | 27.64 | 28.29 | 29.05 | 1.41/0.76 |
| UML–Mxref | 23.91 | 26.19 | 26.17 | 2.26/0.02 |
| LMR–Mdref | 26.69 | 29.27 | 28.72 | 1.63/0.55 |
| LML–Mdref | 30.58 | 29.85 | 28.98 | 2.60/0.87 |
| Sagittal distance (2D lateral film) | | | | |
| GoR–Me | 67.05 | 87.73 | 88.45 | 21.40/0.72 |
| GoL–Me | 68.14 | 84.35 | 84.03 | 15.89/0.32 |
| ANS–Vref | 91.52 | 90.91 | — | 0.61[#] |
| Uie–Vref | 91.95 | 90.20 | — | 1.75[#] |
| Lie–Vref | 78.2 | 76.75 | — | 1.45[#] |
| Me–Vref | 69.39 | 66.82 | — | 2.57[#] |

[#]Difference between 2D & 3D data.

difference was 7.8 mm and the overall accuracy was 89.2 per cent. The mean difference excluding GoR–Me and GoL–Me was 2.28 mm and the accuracy was 95.1 per cent. The difference of linear distances of 2D CT and 3D CT data was statistically significant ($P < 0.05$).

The differences between the 2D and 3D measurement angles from the skulls are summarized in Table 3. The range of differences between the angles calculated from 2D and 3D co-ordinates were between 0.79 and 3.62 degrees. The overall mean difference was 1.88 degrees. The differences between the angles CE–Or–Me in 2D and the CE–OrR–OrL/OrR–OrL–Me plane in 3D and between the angles CE–Or/Mp–ANS in 2D and the CE–OrR–OrL/MpR–MpL–ANS plane in 3D were smaller than 1 degree. The difference between the angle CE–Or/Go–Me in 2D and CE–OrR–OrL/GoR–GoL–Me plane in 3D was larger than 3 degrees.

*Application to a single case*

The method was used to construct the skeletal structures of an 18-year-old female patient with facial asymmetry. Table 4 lists the 3D co-ordinates of the 15 landmarks and Figure 4a–c show the wire frames of this patient before treatment in the frontal, lateral, and axial directions. The mandible was shifted to the right and the upper occlusal plane canting with the left portion growing down (Figure 4a). Right Go was found be superior to left Go (Figure 4b and 4c). Shifting of Me to the right side is shown in Figure 4c. In order to realize the 3D motion of mandibular structures during orthognathic surgery, a calculation function was added to the CT reconstruction software. After inputting the new co-ordinates of the landmarks, the predicted positions of the landmarks were calculated by the software and new wire frames were drawn. Figure 5a and 5b demonstrates the wire frames plotted from the predicted data and the real data post surgery.

## Discussion

The 2D geometric errors of projection, magnification, and head positioning can be avoided in the 3D environment. CTs can provide more accurate information concerning craniofacial structures and measurements in three dimensions, but the radiation exposure dose is high. Cone-beam CT (CBCT) delivers only one-tenth of the exposure dose compared with conventional CT, hence, its growing popularity. The effective absorbed radiation dose for two cephalograms is between 10 and 14 μSv, which is much less than even for CBCT at between 40 and 135 μSv (Harrell *et al.*, 2006). Thus, traditional cephalograms only give 1/10 to 1/4 of the exposure dose of CBCT and they have the additional

**Table 3** Differences in the angles (degree) between two-dimensional (2D) and three-dimensional (3D) data.

| Angle | | 2D data | 3D data | Difference |
|---|---|---|---|---|
| 2D | 3D | | | |
| ∠CE Or ANS | ∠CE OrR OrL/OrR OrL ANS | 123.83 | 121.89 | 1.94 |
| ∠CE Or Me | ∠CE OrR OrL/OrR OrL Me | 86.38 | 85.60 | 0.79 |
| ∠ANS Or Me | ∠OrR OrL ANS/OrR OrL Me | 37.44 | 36.29 | 1.51 |
| ∠CE Or/Mp ANS | ∠CE OrR OrL/MpR MpL ANS | 1.07 | 1.94 | 0.87 |
| ∠CE Or/UM Uie | ∠CE OrR OrL/UMR UML Uie | 11.17 | 13.41 | 2.24 |
| ∠CE Or/LM Lie | ∠CE OrR OrL/LMR LML Lie | 7.20 | 10.03 | 2.83 |
| ∠CE Or/Go Me | ∠CE OrR OrL/GoR GoL Me | 26.80 | 30.42 | 3.62 |
| ∠ANS CE Me | ∠CER CEL ANS/CER CEL Me | 37.25 | 38.52 | 1.27 |

**Table 4** The three-dimensional (3D) co-ordinates of pre-surgery and those predicted post-surgery for 15 landmarks calculated using the computed tomographic reconstruction system software.

| Landmark | 3D co-ordinates, *x*, *y*, *z* (pre-surgery) | 3D co-ordinates, *x*, *y*, *z* (post-surgery) |
|---|---|---|
| Na | −0.96, 41.22, 81.77 | −0.96, 41.22, 81.77 |
| ANS | 0, −11.53, 86.36 | 0, −11.53, 86.36 |
| Uie | −2.89, −43.36, 89.83 | 0.11, −40.86, 86.83 |
| Lie | −3.85, −49.11, 88.86 | 0.79, −46.61, 83.36 |
| Me | −9.51, −89.37, 68.65 | −1.12, −85.87, 62.38 |
| OrR | −33.33, 10.47, 71.11 | −33.33, 10.47, 71.11 |
| OrL | 36.26, 12.41, 74.49 | 36.26, 12.41, 74.49 |
| MpR | −51.76, −14.53, −1.76 | −51.76, −14.53, −1.76 |
| MpL | 49.06, −11.81, −0.94 | 49.06, −11.81, −0.94 |
| UMR | −29.34, −36.91, 61.50 | −26.51, −34.91, 66.0 |
| UML | 23.68, −41.68, 62.79 | 26.51, −34.68, 67.09 |
| LMR | −22.66, −38.72, 58.20 | −18.41, −36.82, 52.2 |
| LML | 14.15, −41.52, 56.90 | 18.41, −36.07, 51.90 |
| GoR | −51.45, −42.26, 15.80 | −46.82, −38.34, 13.15 |
| GoL | 39.43, −46.77, 13.06 | 44.08, −33.69, 12.04 |

advantages of being low cost and time saving. Based on the above, the use of 3D cephalograms produced by orthogonal projection is supported in order to provide 3D information.

Although 3D cephalograms produced by the orthogonal projection have been introduced in previous studies (Grayson *et al.*, 1988; Brown and Abbott, 1989), this type of 3D reconstruction has several inherent errors and limitations. One basic difficulty is associated with the corresponding landmarks on the PA and lateral films that actually pertain to the same 3D point on the skull; as a result, only a few landmarks are identified. In one previous study, 12 landmarks, which included nasion, upper and lower incisal edges, Me and right and left orbital, porion, condylion, and Go, were located (Grayson *et al.*, 1988). In the present study, 15 landmarks were defined. Landmarks for anterior nasal spine and right and left mastoid process and upper and lower molar cusp tip were added and those of bilateral porion and condylion were discarded.

Landmarks can be located after 3D reconstruction from orthogonal projection, but their accuracy remains unclear (Grayson *et al.*, 1988; Brown and Abbott, 1989). In one study, when the 3D co-ordinate measurement errors were checked using metal markers on an acrylic object, the errors averaged 0.16 mm (Brown and Abbott, 1989). When determining the accuracy of 3D cephalometry of a skull, CT data were used as the gold standard data in the present study. The mean error in differences for the 15 landmarks was 0.85 mm. The mean difference in landmark location was thus larger than in the previous study that was probably because a real skull is a more complicated object than the acrylic object used as a standard in the previous study. Osseous landmarks are more difficult to locate, and observer accuracy is highly individual. When the differences in landmark identification between the 3D co-ordinates with and without metallic markers were compared, the differences between the two methods larger than 1 mm were 2, 3, and 8, respectively, for the three assessors.

For the 3D cephalogram, the simplified wire-frame models were able to display the skull of a patient before and after treatment. This is especially applicable when used on an orthognathic surgery patient (Grayson *et al.*, 1988; Brown and Abbott, 1989). In the current study, the 3D wire-frame models were able to demonstrate the jaw bones and dentition and it could be rotated along *x*, *y*, and *z* axes. The 3D wire-frame models were able to depict changes in the co-ordinates after treatment and pairs of wire-frame models could be easily used to recognize the variance before and after treatment.

For 2D analysis, linear and angular measurements are commonly used. Due to 2D image distortions, measurement errors frequently occur (Grayson *et al.*, 1988). It was found that magnification changed the distances between two points for the 2D measurements. In the present study, the overall mean difference compared with the CT data was 7.8 mm for the 2D linear measurements, but only 0.53 mm for the 3D

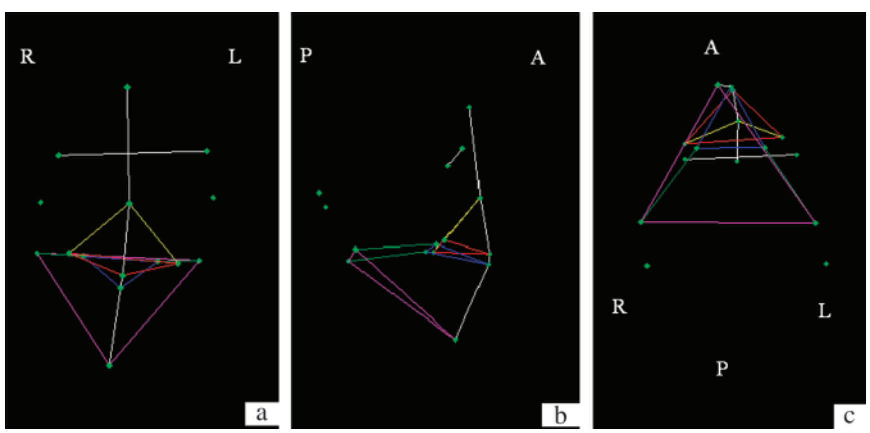


**Figure 4** The wire frame: (a) frontal direction, (b) lateral direction, and (c) axial direction. The red, blue, and purple triangles represent the upper occlusal, lower occlusal, and mandibular planes, respectively. R: right, L: left, P: posterior, and A: anterior.

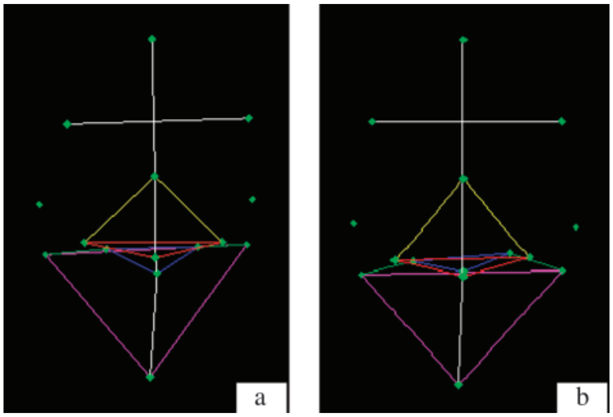


**Figure 5** The wire frames plotted from the predicted data (a) and the real data (b) post-surgery of an 18-year-old female patient.

linear measurements. Thus, the overall accuracy was 98.9 per cent using the 3D linear measurements, but only 89.2 per cent using the 2D linear measurements. The reported accuracy of the 2D linear measurements was significantly skewed by the GoR–Me and GoL–Me distances. This is to be expected, since these distances are at an angle with both the sagittal and transverse planes. The accuracy of 2D linear measurements was 95.1 per cent if GoR–Me and GoL–Me distances were not included in the calculations, but this was still larger than measurements for 3D co-ordinates and CT distances. Although the original mean difference in landmark location was 0.85 mm, the mean difference was only 0.53 mm for the 3D linear measurement. It seems that the differences in 3D landmark location did not significantly influence the 3D linear measurements and therefore the 3D linear measurements obtained from biplanar cephalograms with orthogonal projection are highly applicable to orthodontics. This combined 2D and 3D approach is able to provide both reliable and repeatable 3D analysis of the head. In 3D CT imaging, many reference planes and any angle between two planes can be defined easily (Harrell *et al.*, 2006; Swennen *et al.*, 2006). As a result, a system of 3D angular analysis based on the biplanar cephalograms was designed, which is analogous to conventional 2D cephalometrics. The angles between two planes could be measured in order to obtain their relationship, such as that between the horizontal reference plane and the OrR OrL ANS plane, which gives the relationship between the cranium and the maxilla. Similarly, the angle of OrR OrL ANS and OrR OrL Me planes was analysed to obtain the antero-posterior relationship of the maxilla and mandible, and the angle of CE OrR OrL and GoR GoL Me planes to determine the mandibular plane angle.

It is possible to identify any anatomical landmark of interest using the 3D co-ordinates obtained from 3D cephalometry generated by CT imaging. In contrast, the major limitation when using biplanar cephalometry is landmark identification. It is difficult to recognize the more conventional 2D landmarks on both films together. Further efforts are required to overcome these problems. Only 15 landmarks could be defined from a pair of cephalograms with orthogonal projection, so 3D analysis using this method is not as complete as conventional 2D analysis. Although there were some shortcomings in 3D cephalometry by orthogonal projection, 3D linear measurements can be made with greater accuracy. The wire-frame models could easily display the pre- and post-treatment changes and 3D angular analysis was also possible.

## Conclusions

The 3D reconstruction using a pair of cephalograms by orthogonal projection was demonstrated in this study. Fifteen landmarks were explored on both films, and wire-frame models constructed to display the jaws and dentition. By comparing the accuracy in linear measurements between CT and biplanar cephalogram analyses, it was found that the accuracy with this 3D reconstruction method from biplanar cephalograms was 98.9 per cent. By comparing the accuracy in linear measurements from 2D co-ordinates and real data, the accuracy for 2D linear measurements was only 89.2 per cent. Comparison of the linear distances of 2D CT and 3D CT, except for Go to Me data, showed the difference was statistically significant ($P < 0.05$). An approach to 3D angular analysis was also developed in the research.

## Funding

Minister of Economic Affairs, Taiwan, Republic of China (96-EC-17-A-19-S1-053, 97-EC-17-A-19-S1-053).

## References

Baumrind S, Frantz R C 1971 The reliability of head film measurements. 2. Conventional angular and linear measures. American Journal of Orthodontics 60: 505–517

Broadbent B H 1931 A new X-ray technique and its application to orthodontia. Angle Orthodontist 1: 45–66

Brown T, Abbott A H 1989 Computer-assisted location of reference points in three dimensions for radiographic cephalometry. American Journal of Orthodontics and Dentofacial Orthopedics 95: 490–498

Grayson B, Cutting C, Bookstein F L, Kim H, McCarthy J G 1988 The three-dimensional cephalogram: theory, technique, and clinical application. American Journal of Orthodontics and Dentofacial Orthopedics 94: 327–337

Harrell W E, Jacobson R L, Hatcher D C, Mah J 2006 Cephalometric imaging in 3D. In: Jacobson A, Jacobson R L (eds). Radiographic cephalometry—from basics to 3D imaging, Quintessence Publishing, Chicago, pp. 233–247

Swennen G R J, Schutyser F, Hausamen J E 2006 Three-dimensional cephalometry—a color atlas and manual. Springer, New York