European Journal of Orthodontics 35 (2013) 45–50
doi:10.1093/ejo/cjr045
Advance Access publication 31 March 2011

Evaluation and comparison of postero-anterior cephalograms and cone-beam computed tomography images for the detection of mandibular asymmetry

Janalt Damstra, Zacharias Fourie and Yijin Ren
Department of Orthodontics, University Medical Center Groningen, University of Groningen, The Netherlands

Correspondence to: Janalt Damstra, Department of Orthodontics, University Medical Center Groningen (UMCG), PO Box 30.001, 9700 RB Groningen, The Netherlands. E-mail: j.damstra@dmo.umcg.nl

SUMMARY The aim of this study was to evaluate and compare postero-anterior (PA) cephalograms and cone-beam computed tomography (CBCT) images for the detection of mandibular asymmetry. Six asymmetric anonymous dry human skulls with visible chin deviation were available for this study. Metallic markers were glued on the anatomical landmarks to avoid identification error. PA cephalograms and CBCT scans were made by means of a standardized set-up. Each scan and cephalogram was measured three times by a single observer and the means used for analysis. Asymmetry was defined by the subtraction of the left side and right side measurements. CBCT was reliable [intraclass correlation coefficient (ICC) > 0.957] and very accurate (within 0.5 mm) in detection of all asymmetry. PA cephalograms were not accurate in detection of asymmetry of the mandibular ramus length, the mandibular body length, and the total mandibular length. PA cephalograms were the least reliable in determining the mandibular body length asymmetry (ICC = 0.686). The use of CBCT to detect mandibular asymmetry was validated with this study. CBCT images are very reliable and accurate for the detection of asymmetry and should be considered over conventional PA cephalometry when a chin deviation is present.

Introduction

Radiographic investigation is essential when a visible chin deviation is diagnosed which requires surgery to correct the mandibular asymmetry. The aims of the radiographic examination are to correctly diagnose the cause of the resulting asymmetry and chin deviation and to enable accurate pre-surgical planning. Currently, two imaging modalities e.g. postero-anterior (PA) cephalograms and cone-beam computed tomography (CBCT) imaging can be utilized to determine the cause of chin deviation, plan the surgical correction, and to determine outcome assessment after orthognathic surgery (Reyneke, 2003; Ghafari, 2006; Hwang *et al.*, 2006; Ko *et al.*, 2009; Kokich, 2010).

Since the introduction of conventional PA cephalogram in the 1930s, the PA cephalogram has been used in orthodontic and orthognathic diagnosis and surgery planning for the treatment of asymmetry (Bishara *et al.*, 1994; Athanasiou and Van der Meij, 1995; Reyneke, 2003; Ghafari, 2006). The PA cephalogram provides valuable mediolateral information which is not only useful for facial asymmetric evaluation but is essential for transverse evaluation of the craniofacial skeleton and dentoalveolar structures (Ghafari, 2006). Therefore, PA cephalometric projections and relevant analyses constitute an important adjunct for qualitative and quantitative evaluation of the dentofacial region. However, the PA cephalogram is a projection of a three-dimensional (3-D) object onto a two-dimensional (2-D) surface and is therefore subject to distortion and projection error. This results in differences between actual linear measurements and measurements derived from the PA cephalograms, which have been well documented in the literature (Athanasiou and Van der Meij, 1995; Pirttiniemi *et al.*, 1996; Athanasiou *et al.*, 1999; Yoon *et al.*, 2002; Ghafari, 2006; Van Vlijmen *et al.*, 2009a, b). Furthermore, the PA cephalogram can be used to compare the right and left structures since they are located at relatively the equal distances from the film and X-ray source (Bishara *et al.*, 1994). As a result, the effects of unequal enlargement by diverging rays are minimized and distortion is reduced. This principle allows for valid comparison between two sides of the face in order to evaluate asymmetry (Bishara *et al.*, 1994).

Due to the significant reduction in radiation, CBCT imaging has largely replaced spiral CT in dentistry and has made 3-D imaging routinely accessible to the orthodontist (Halazonetis, 2005). CBCT has been shown to produce very accurate 3-D images of the craniofacial region and produces a 1-to-1 image-to-reality ratio which is necessary for accurate detection of the underlying deformities (Hassan *et al.*, 2008; Lagravere *et al.*, 2008; Brown *et al.*, 2009; Damstra *et al.*, 2010a). In addition, the advantages of CBCT imaging for the evaluation of asymmetry is suggested in the literature (Hwang *et al.*, 2006; Kokich, 2010).

However, it is important to realize that despite the radiation reduction of CBCT compared to spiral CT, CBCT still exposes the patient to more radiation compared to a PA cephalogram (Harrell *et al.*, 2006; SEDENTEXCT, 2009). CBCT imaging is generally also more costly than conventional radiographs. Since the long-term effects of CBCT imaging are unknown, there is a need for evidence-based selection criteria for CBCT imaging to guarantee responsible use of the modality (Farman and Scarfe, 2006; EADMFR, 2008; SEDENTEXCT, 2009). Therefore, since comparison of the left and right sides of the PA cephalogram might be accurate in evaluating asymmetry (Bishara *et al.*, 1994), the added benefits of the 3-D images in evaluating mandibular asymmetry should be carefully weighed against the higher radiation dose before CBCT imaging can be justified. We could not find any studies comparing the accuracy of CBCT images and PA cephalograms for the detection of mandibular asymmetry. Therefore, the aim of this study was to evaluate and compare PA cephalograms and CBCT images for the detection of mandibular asymmetry by comparison of left and right side structures.

Materials and methods

The sample was selected from the collection of anonymous dry skulls from the Department of Orthodontics of the University Medical Center Groningen (UMCG). Before the study sample was selected, the anatomical landmarks described in Table 1 were marked on the skulls with a pencil by means of consensus of two observers (JD and ZF). An inclusion criterion for the selection of skulls was visible chin deviation, defined as at least 4 mm deviation of pogonion (Pog) from the midsagittal line (Haraguschi *et al.*, 2002). The midsagittal line was constructed with a laser level beam which connected nasion (N) and the anterior nasal spine (ANS) of the dry skulls (Figure 1a). This was based on Harvold (1954) who reported that a line through N and ANS represented the midsagittal line in more than 90 per cent of patients. The distance from the laser line to the respective points was measured to Pog by means of a digital caliper. The skulls also had to have a fixed occlusion, with the mandible fixed to the skull by means of two metal springs. Six asymmetric skulls met the selection criteria were included for this study (Figure 1b). Prior to the radiographic examination, metal markers with a diameter of 1.5 mm were glued onto the selected landmarks with cyanoacrylate glue. The metal markers were used to eliminate landmark identification error which is common in frontal 2-D (Major *et al.*, 1994; Pirttiniemi *et al.*, 1996; Athanasiou *et al.*, 1999) and 3-D cephalometry (Lou *et al.*, 2007; De Oliviera *et al.*, 2009; Ludlow *et al.*, 2009).

The 14 linear distances illustrated in Figure 2 were measured directly on the skull by means of a digital caliper by one operator. The centres of the metal markers were used as the reference points for the two imaging techniques. Asymmetry was then calculated as the left side measurement subtracted by the right side measurement (Ghafari, 2006; Hwang *et al.*, 2006). A result of zero indicates perfect symmetry, a negative or positive result indicates a larger measurement on the right or left side. The direct caliper measurements were repeated five times and the mean values were regarded as the reference values.

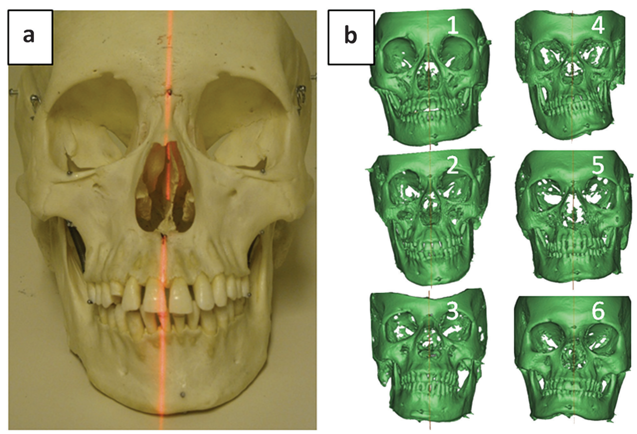

Figure 1 (a) A midsagittal line constructed by a laser beam through nasion (N) and the anterior nasal spine (ANS) used to determine chin deviation. (b) Surface models (with the midsagittal plane) derived from the CBCT scans of the 6 skulls used in this study.

Table 1 Landmarks used in this study.

Landmark	Abbreviation	Definition
Unilateral		
Nasion	N	The most anterior of the frontonasal suture in the median plane
Anterior nasal spine	ANS	The tip of the bony anterior nasal spine in the median plane
Pogonion	Pog	The most anterior point of the bony chin in the median plane
Menton	Me	The most inferior midline point on the mandibular symphysis
Bilateral		
Orbitale	Or	The lowest point in the inferior margin of the orbit
Condylion lateral	CoL	The most lateral point on the condylar head
Jugulare	J	The intersection of the outline of the maxillary tuberosity and the zygomatic buttress
First upper molar	U6	The tip of the mesiobuccal cusp of the maxillary first permanent molar
Gonion	Go	The point on the curvature of the angle of the mandible located by bisecting the angle formed by lines tangent to the posterior ramus and inferior border of the mandible
Antegonion	AG/GA	The lateral inferior margin of the antegonial protuberances

Radiographic examination consisted out of conventional PA cephalograms and CBCT scans. The PA cephalograms were made (ProMax, DiMax2 Digital Cephalometric Unit, Planmeca, Helsinki, Finland) with a resolution quality of 2272 × 2045 pixels at a 24 bit depth. Each skull was carefully placed in the cephalostat with the Frankfort horizontal plane orientated parallel to the floor and the midsagittal plane parallel to the X-ray beam. The orientation of the skull in the cephalostat was checked with laser levels. The PA cephalograms were individually imported into the Viewbox® Version 3.1.1.13 (Halazonetis, Athens, Greece) software. The PA cephalograms were then scaled and the magnification error of 12 per cent corrected using the software. For each PA cephalogram, the centres of the metal markers were identified by a cursor-driven mouse.

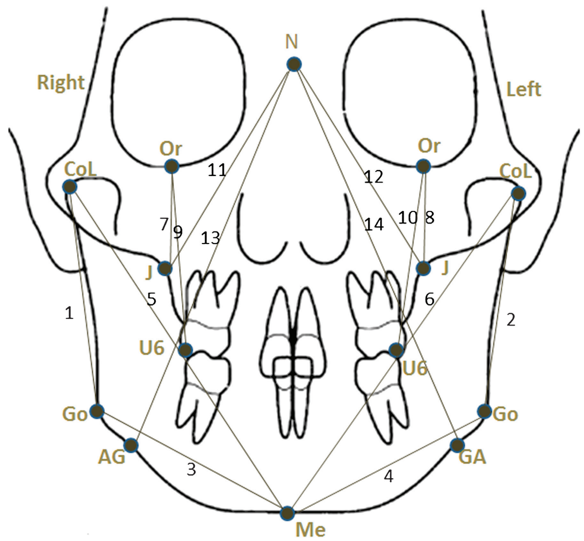

Figure 2 The 14 measurements used in this study. 1, 2: mandibular ramus length (CoL – Go); 3, 4: mandibular body length (Go – Me); 5, 6: total mandibular length (Co – Me); 7, 8: maxillary height (Or – J); 9, 10: maxillary dental height (Or – U6); 11, 12: maxillary height by means of the triangulation approach (N – J); 13, 14: mandibular ramus height by means of the triangulation approach (N – AG).

The CBCT images were acquired with the KaVo 3-D eXam scanner (KaVo Dental GmbH, Biberach/Riß, Germany). The light beams of the CBCT scanner were used to position the skull with the Frankfort horizontal parallel to the floor. The skulls were scanned at a 0.30 voxel size resolution (120 KV, 37.07 mAs and 26.9 s). The CBCT datasets were exported from the eXamVisionQ (Imaging Sciences International LCC, Hatfield, Pennsylvania, USA) software in DICOM multi-file format and imported into SimPlant Ortho Pro 2.00 (Materialise Dental, Leuven, Belgium) software. Importantly, due to scattering in the 3-D reconstruction, the centres of the metal markers were accurately identified by a cursor-driven mouse in the axial, coronal, and sagittal slices and not on the volume renderings and surface models (Figure 3).

Preprogrammed analyses in the Viewbox and SimPlant Ortho Pro 2.00 software calculated the asymmetry for each CBCT scan and PA cephalogram. Each PA cephalogram and CBCT scan was measured three times (each time during a different session, at least 2 weeks apart) and the mean values were regarded as the true values for the respective group.

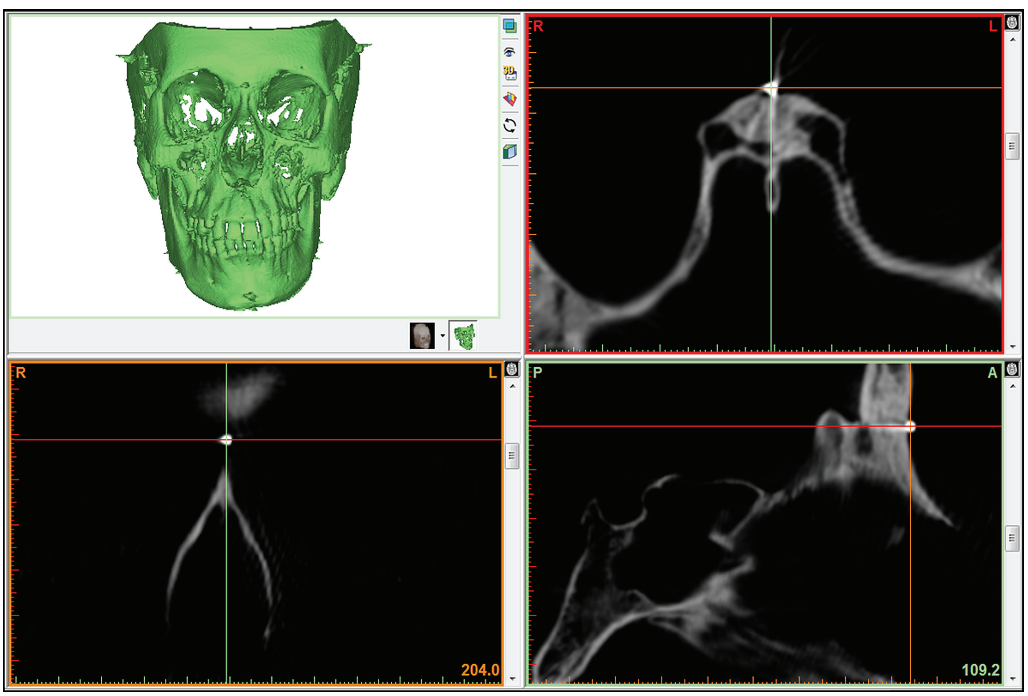

Figure 3 A screen shot of the CBCT images in the 3-D software illustrating accurate identification in the centre of the metal marker of nasion (N) in the axial, coronal, and sagittal slices. The 3-D image was not used for location of the reference points in the middle of the metal markers.

Statistical analysis

The mean and standard deviation of the three measuring techniques (direct caliper, PA cephalogram, and CBCT imaging) were calculated. The accuracy of the asymmetry evaluation was expressed by means of the absolute error (AE). AE was defined as the CBCT or PA cephalogram value subtracted by the reference value.

As a measure of reliability, the intraclass correlation coefficient (ICC) for absolute agreement based on a two-way random effects analysis of variance (ANOVA) was calculated between reference values and the two imaging techniques (e.g. PA cephalogram and CBCT). The smallest detectable difference (SDD) was used to determine the error of the three measurement procedures (Damstra *et al.*, 2010b). The standard error of measurement (SEM) of the three measurement sessions was calculated as the square root of the variance of the random error from two-way random effects ANOVA. The SDD was then calculated as $1.96 \times \sqrt{2} \times$ SEM. The SDD defines the 95 per cent confidence limits of the method error (Damstra *et al.*, 2010b). All statistical analysis was performed with a standard statistical software package (SPSS version 14, Chicago, IL, USA).

Results

The results of this study are summarized in Tables 2 and 3. Table 2 illustrates the mean and standard deviations of the three measuring techniques. There was less than 1 mm difference between all the mean CBCT measurements compared to the reference (direct caliper) measurements. However, major differences (>3 mm) existed between the mean reference and PA cephalogram values for the mandibular ramus length (triangulation approach), the mandibular body length, and the total mandibular length measurements.

Table 3 describes the accuracy of the evaluation of the asymmetry. The CBCT scans were very accurate (<0.50 mm) in the detection of all asymmetry. The PA cephalograms were fairly accurate (0.50–1.00 mm) in detection of the

Table 2 Mean and standard deviations of the caliper (reference), CBCT, and PA cephalogram (PAC) measurements.

Measurement	Reference		CBCT		PAC	
	Mean	SD	Mean	SD	Mean	SD
Right mandibular ramus length	52.77	2.10	52.48	2.10	52.85	2.34
Left mandibular ramus length	51.33	6.92	50.92	6.95	51.09	6.75
Right mandibular body length	80.26	6.25	79.51	6.22	59.13	11.78
Left mandibular body length	78.77	1.59	78.22	1.79	54.13	14.01
Right mandibular length	114.63	8.01	113.74	7.95	101.64	8.89
Left mandibular length	111.43	6.75	110.57	6.81	95.75	13.70
Right maxillary height	23.12	2.07	22.70	2.24	20.64	1.76
Left maxillary height	23.90	2.45	23.72	2.28	21.41	2.68
Right maxillary dental height	46.59	4.06	46.10	3.68	47.60	4.65
Left maxillary dental height	45.09	4.65	44.89	4.60	45.77	4.41
Right maxillary height (TA)	64.97	1.26	64.73	1.17	62.91	2.62
Left maxillary height (TA)	64.06	2.21	63.83	2.41	62.32	3.37
Right mandibular ramus length (TA)	115.43	3.38	114.69	3.27	106.21	6.98
Left mandibular ramus length (TA)	113.99	4.85	113.33	4.57	104.34	8.34

TA, triangulation approach.

Table 3 Accuracy determined by means of the absolute error or AE of the CBCT images and the PA cephalograms (PAC).

Asymmetry measurement	AE − CBCT versus reference			AE − PAC versus Reference			ICC	
	Mean	SD	95% CI	Mean	SD	95% CI	CBCT	PA
Mandibular ramus length difference	0.34	0.28	0.25–0.44	0.67	0.39	0.49−0.85	0.999	0.994
Mandibular body length difference	0.35	0.16	0.23−0.46	5.38	5.96	2.63−8.13	0.998	0.686
Total mandibular length difference	0.32	0.01	0.21−0.43	2.60	2.72	1.34−3.86	0.999	0.934
Maxillary height difference	0.30	0.35	0.21−0.40	0.51	0.29	0.35−0.61	0.980	0.957
Maxillary dental height difference	0.47	0.09	0.32−0.62	0.99	0.58	0.72−1.26	0.979	0.923
Maxillary difference (TA)	0.31	0.04	0.16−0.46	0.63	0.57	0.37−0.90	0.957	0.873
Mandibular ramus difference (TA)	0.29	0.16	0.18−0.41	2.58	1.51	1.89−3.28	0.995	0.819

Reliability (intraclass correlation coefficient, ICC) of the cone-beam computed tomography (CBCT) and PA cephalograms values when compared to the reference values. All measurements = mm; TA, triangulation approach.

asymmetry for the following measurements: the mandibular ramus length, the maxillary height, the maxillary dental height, and the maxillary height (triangulation approach). The PA cephalograms were not accurate (>1.00 mm) in detection of asymmetry of the total mandibular length and the mandibular ramus length (triangulation approach).

The method errors for the direct caliper, CBCT scans, and PA cephalograms were very small (0.05, 0.11, and 0.02 mm, respectively) confirming the absolute accuracy of the methods. The CBCT measurements were very reliable compared to the reference values (ICC > 0.957). The reliability of the PA cephalometric measurements varied when compared to the reference values. The reliability of the total mandibular length difference, maxillary height difference, and maxillary dental height difference was very good (ICC > 0.900). The maxilla height difference and mandibular ramus difference (triangulation approach) was slightly less reliable (ICC = 0.873 and 0.819, respectively). The mandibular body length difference was the least reliable (ICC = 0.686).

Discussion

The aim of this study was to evaluate and compare PA cephalograms and CBCT images for the detection of mandibular asymmetry by comparison of left and right side structures. The results confirmed the absolute accuracy of CBCT images previously reported in the literature (Mischkowski *et al.*, 2007; Hassan *et al.*, 2008; Lagravere *et al.*, 2008; Brown *et al.*, 2009; Damstra *et al.*, 2010a) and validate the use of CBCT imaging to evaluate the cause of mandibular asymmetry. The accuracy of CBCT imaging in determining the characteristics of asymmetry is not only important for diagnosis and evaluating treatment outcomes but it may also enable more precise planning of surgical treatment.

In contrast to the CBCT images, the PA cephalograms were inaccurate in detection of the characteristics of the mandibular asymmetry of this study. This is important because differences of mandibular ramus and body length differences are important factors in detection of chin deviation (Hwang *et al.*, 2006; Baek *et al.*, 2007). The results confirm previous findings that suggest that conventional PA cephalograms might not be reliable for asymmetry analysis (Peck *et al.*, 1991; Hwang *et al.*, 2006). In PA cephalometry, landmarks have their own magnification error since the structures are located at different distances from the film. However, due to the positioning of the head in the cephalostat, the magnification error of bilateral landmarks should be the same since the bilateral structures are located at relatively the equal distances from the film and X-ray source (Bishara *et al.*, 1994). This suggests that the comparison of left and right side structures is possible with PA cephalograms. The results of this study suggest that left and right side measurements cannot be compared when evaluating asymmetry. Simple geometry might offer an explanation. By nature, when mandibular asymmetry is present, point menton (Me) is most likely to deviate across the facial midline. Therefore, in such cases, the structures will not be located at relatively the equal distances making left and right side comparisons unreliable.

It is ethically questionable to expose a patient to radiation from both a conventional PA cephalogram and a CBCT scan for comparative studies. We therefore decided to use dry skulls in combination with metal markers aiming to reduce the measurement error. The absolute accuracy of the methods used in this study was confirmed by the small method error. Although the sample size can be regarded as small, it can be justified because the method error was very small (the SDD means that differences of more than 0.11 mm could be regarded as significant). In addition, it must be noted that the sample is unique and that asymmetric dry skulls are difficult to acquire for comparative study.

The present study investigated the differences between the two imaging modalities by evaluating mandibular asymmetry using dry skulls. It must be kept in mind that this method differs from direct patient care. In the clinical setting, the process of detection of the asymmetry with PA cephalometry or CBCT imaging might be more problematic. The dry skulls used in this study do not move and have fiducial markers for measurement which is not the case with patients. In addition, the lack of soft tissues and peripheral attenuation material may have allowed for increased contrast of the landmarks. Landmark identification error is a major source of PA cephalometric measurement error (Major *et al.*, 1994; Pirttiniemi *et al.*, 1996; Athanasiou *et al.*, 1999). Although we eliminated this problem by using metal markers, in practice the inaccuracy of the asymmetry might be magnified or hidden by the measurement error resulting from identification error. Landmark identification is possibly more accurate on 3-D CBCT images than 2-D cephalograms (De Oliviera *et al.*, 2009; Ludlow *et al.*, 2009). The positioning of the patient is very critical when making a PA cephalogram because rotation of the head results in measurement differences (Yoon *et al.*, 2002; Ghafari, 2006; Van Vlijmen *et al.*, 2009a). We used a standardized set-up, which is difficult to reproduce in practice. Hassan *et al.* (2008) reported that small variation of the head position when making a CBCT does not influence measurement accuracy which makes positioning of the patient in CBCT scanner less critical compared to PA cephalograms.

The measurements we used to detect the contributing factors of the chin deviation were previously described (Bishara *et al.*, 1994; Athanasiou and Van der Meij, 1995; Reyneke, 2003; Hwang *et al.*, 2006; Baek *et al.*, 2007). We used the most lateral point of the condyle (CoL) as reference mark instead of condylion (Co) in order to make direct caliper measurements possible while the teeth are fixed in occlusion. Although the ramus length difference (CoL – Go) was accurate on the PA cephalograms, it is very important to realize that the points of gonion (Go) are not identifiable on PA cephalograms. Instead, the points antegonion (AG/GA) is used in PA cephalometry. We found that determining the ramus length with antegonion was not accurate. This confirms the observation by Hwang *et al*. (2006) that different vertical positions of antegonion are not always evident with conventional PA cephalogram analysis.

It was not the intention to establish CBCT imaging as the routine imaging modality for all mandibular asymmetry cases. However, the results show that the CBCT imaging was more accurate in determining the difference of the mandibular dimensions (ramus length, body length, and total length) than conventional PA cephalometry. Therefore, a CBCT scan should be considered in order to determine the characteristics of the asymmetry of a visible chin requiring surgical correction. In such cases, the risk of misdiagnosis and inappropriate surgical treatment planning using a PA cephalogram possibly outweighs the risk of a higher radiation dose of a CBCT scan.

Conclusion

CBCT imaging provides more accurate information regarding the characteristics of mandibular asymmetry than conventional PA cephalograms. Therefore, a CBCT scan should be considered when a visible chin deviation is present which requires surgical correction.

References

Athanasiou A E, Van der Meij A J W 1995 Posteroanterior (frontal) cephalometry. In: Athanasiou A E (ed). Orthodontic cephalometry. Mosby-Wolfe, London, pp. 125–140

Athanasiou A E, Miethke R R, Van der Meij A J W 1999 Random errors in location of landmarks in postero-anterior cephalograms. British Journal of Orthodontics 26: 273–283

Baek S K, Cho I S, Chang Y I, Kim M J 2007 Skeletodental factors affecting chin point deviation in female patients with class III malocclusion and facial asymmetry: a three dimensional analysis using computed tomography. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics 104: 6286–39

Bishara S E, Burkey P S, Kharouf J G 1994 Dental and facial asymmetries: a review. Angle Orthodontist 64: 89–98

Brown A A, Scarfe W C, Scheetz J P, Silviera J P, Farman A G 2009 Linear accuracy of cone beat CT 3-D images. Angle Orthodontist 79: 150–157

Damstra J, Fourie Z, Huddleston Slater J J R, Ren Y 2010a Accuracy of linear measurements from cone-beam computed tomography-derived surface models of different voxel sizes. American Journal of Orthodontics and Dentofacial Orthopedics 137: 16e1–16.e6

Damstra J, Huddleston Slater J J R, Fourie Z, Ren Y 2010b Reliability and the smallest detectable difference of lateral cephalometric measurements. American Journal of Orthodontics and Dentofacial Orthopedics 138: 546.e1546.–e8

De Oliviera A E F, Cevidanes L H S, Phillips C, Motta A, Burke B, Tyndall D 2009 Observer reliability of three-dimensional cephalometric identification on cone-beam computerized tomography. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics 107: 256–265

EADMFR. 2008 Basic priciples for the use of dental cone beam CT. (www.eadmfr.org/documents) (23 September 2010, date last accessed)

Farman A G, Scarfe W C 2006 Development of imaging selection criteria and procedures should precede cephalometric assessment with cone-beam computed tomography. American Journal of Orthodontics and Dentofacial Orthopedics 130: 257–265

Ghafari G G 2006 Posteroanterior cephalometry: craniofacial frontal analysis. In: Jacobson A, Jacobson R L (eds). Radiographic cephalometry, from basics to 3-D imaging Quintessence Publishing Co, Inc., Hanover Park, pp. 267–292

Halazonetis D J 2005 From 2-dimensional cephalograms to 3-dimensional computed tomography scans. American Journal of Orthodontics and Dentofacial Orthopedics 127: 627–637

Haraguschi S, Takada K, Yasuda Y 2002 Facial asymmetry in patients with skeletal class III deformity. Angle Orthodontist 72: 28–35

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

Harvold E 1954 Cleft lip and palate: morphological studies of the facial skeleton. American Journal of Orthodontics 40: 493–506

Hassan B, Van der Stelt P, Sanderink G 2008 Accuracy of three-dimensional measurements obtained from cone beam computed tomography surface-rendered images for cephalometric analysis: influence of patient scanning position. European Journal of Orthodontics 31: 129–134

Hwang H S, Hwang C H, Lee K H, Kang B C 2006 Maxillofacial 3-dimensional image analysis for the diagnosis of facial asymmetry. American Journal of Orthodontics and Dentofacial Orthopedics 130: 779–785

Ko E W, Huang C S, Chen Y R 2009 Characteristics and corrective outcome of face asymmetry by orthognathic surgery. Journal of Oral and Maxillofacial Surgery 67: 2201–2209

Kokich V G 2010 Cone-beam computed tomography: have we identified the orthodontic benefits? American Journal of Orthodontics and Dentofacial Orthopedics 137: S16

Lagravere M O, Carey J, Toogood R W, Major P W 2008 Three-dimensional accuracy of measurements made with software on cone-beam computed tomography images. American Journal of Orthodontics and Dentofacial Orthopedics 134: 112–116

Lou L, Lagravere M O, Compton S, Major P W, Flores-Mir C 2007 Accuracy of measurements and reliability of landmark identification with computed tomography (CT) techniques in the maxillofacial area: a systematic review. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics 104: 402–411

Ludlow J B, Gubler M, Cevidanes L H S, Mol A 2009 Precision of cephalometric landmark identification: cone-beam tomography vs. conventional cephalometric views. American Journal of Orthodontics and Dentofacial Orthopedics 136: 312e1–312e10 discussion 312–313

Major P W, Johnson D E, Hesse K L, Glover K E 1994 Landmark identification error in posterior anterior cephalometrics. Angle Orthodontist 64: 447–454

Mischkowski R A *et al.* 2007 Geometric accuracy of a newly developed cone-beam device for maxillofacial imaging. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics 104: 551–559

Peck S, Peck L, Kataja M 1991 Skeletal asymmetry in esthetically pleasing faces. Angle Orthodontist 61: 43–46

Pirttiniemi P, Miettinen J, Kantomaa T 1996 Combined effects of errors in frontal-view asymmetry diagnosis. European Journal of Orthodontics 18: 629–636

Reyneke J P 2003 Systematic patient evaluation. In: Reyneke J P (ed.). Essentials of orthognathic surgery. Quintessence Publishing Co, Inc., Hanover Park, pp. 13–68

SEDENTEXCT. 2009 Provisional guidelines on CBCT for dental and maxillofacial radiology. (www.sedentexct.eu/guidelines) (23 September 2010, date last accessed)

Van Vlijmen O J C, Berge S J, Bronkhorst E M, Swennen G R J, Katsaros C, Kuipers-Jagtman A M 2009a A comparison of frontal radiographs obtained from cone-beam CT and conventional frontal radiographs from human skulls. International Journal of Oral and Maxillofacial Surgery 38: 773–778

Van Vlijmen O J, Maal T J J, Berge S J, Bronkhorst E M, Katsaros C, Kuipers-Jagtman A M 2009b A comparison between two-dimensional and three-dimensional cephalometry on frontal radiographs and on cone beam computed tomography scans of human skulls. European Journal of Oral Sciences 117: 300–305

Yoon Y J, Kim D H, Yu P S, Kim H J, Choi E H, Kim K W 2002 Effect of head rotation on posteroanterior cephalometric photographs. Angle Orthodontist 72: 36–42