European Journal of Orthodontics 34 (2012) 164–169
doi:10.1093/ejo/cjq175
Advance Access Publication 5 April 2011

Panoramic radiography: effects of head alignment on the vertical dimension of the mandibular ramus and condyle region

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SUMMARY The aim of this study was to assess whether it is possible to derive accurate vertical measurements of the mandibular ramus and condyle from panoramic radiographs.

A human dry skull was positioned in a panoramic machine. The skull was displaced along the sagittal and transverse plane and rotated around the vertical and transverse axes. A set of 252 digital radiographs with defined positioning errors was compared with a set of 42 radiographs in the 'ideal' position. The distances between the metal markers that had been attached at the angle of the mandible at a distance of 60 mm in the condyle region to produce fixed reference points on the radiographs were measured. Statistical differences were investigated using Friedman repeated measures analysis of variance on ranks followed by the Dunnett's test for the comparison against the control group in the ideal position ($\alpha = 0.05$).

Vertical measurements were significantly affected when the skull was rotated around the vertical ($P < 0.001$) or shifted along the transverse axis ($P < 0.001$). Misalignment of the head affected the vertical measurement of the mandibular ramus and condyle. However, asymmetries of more than 6 per cent are probably not due to patient positioning in the panoramic machine.

Introduction

Condylar asymmetries between the left and right sides of the mandible are often associated with temporomandibular disorders. Several studies have attributed asymmetries in the ramus and condyle in children and adolescents to the growth deficit on the side exhibiting dysfunctions of the temporomandibular joint (TMJ; Stabrun, 1985; Legrell and Isberg, 1999; Trpkova *et al.*, 2000). In adults, however, reduction in the vertical height of the ramus and condyle has been linked to adaptive and degenerative processes as a result of increased strain (Bezuur *et al.*, 1989a,b; Mongini, 1989; Schellhas *et al.*, 1990; Westesson *et al.*, 1994; Hatcher *et al.*, 1997).

Radiography has been advocated by some clinicians as an appropriate screening tool for early TMJ diagnosis. Because a dental pantomograph (DPT) provides bilateral information, this type of image permits evaluation not only of the morphology of the condyles (Kononen and Kilpinen, 1990; Peltola, *et al.*, 1995; Epstein, *et al.*, 2001; Kononen, *et al.*, 2002) but also of comparative symmetry of the height of the ramus and condyle, as a diagnostic criterion for assessing functional and developmental status (Bezuur *et al.*, 1988, 1989a; Habets *et al.*, 1988, 1989; Athanasiou *et al.*, 1989; Schokker *et al.*, 1990; Kjellberg *et al.*, 1994; Miller *et al.*, 1994, 1998; Inui *et al.*, 1999; Saglam, 2002).

Habets *et al.* (1988) and Kjellberg *et al.* (1994) proposed indices to determine condylar asymmetries by measuring vertical distances on panoramic radiographs. However, there are controversial reports concerning the validity of panoramic radiography concerning the detection of condylar and total ramal height asymmetries. Türp *et al.* (1996) evaluated asymmetry of the condylar and rami comparing panoramic images with the results obtained by direct measurements of macerated skulls. They found a very low correlation between the two measurements. They concluded that this approach has a low validity for detecting vertical asymmetries. However, a recent study by Kambylafkas *et al.* (2006) revealed a high correlation for this method. They concluded that panoramic images are appropriate for diagnosing vertical mandibular asymmetries.

The objective of this study was to determine the effects of patient misalignment on the vertical distortions of the ramus and condyle region on panoramic radiographs. The hypothesis tested is whether panoramic imaging is an appropriate approach for the assessment of asymmetries in the temporomandibular region.

Materials and methods

Experimental set-up

An average formed macerated skull (Figure 1) was selected for the present *in vitro* study. Ten metal spheres, each 2 mm in diameter, were fixed to the skull and lower jaw, to serve

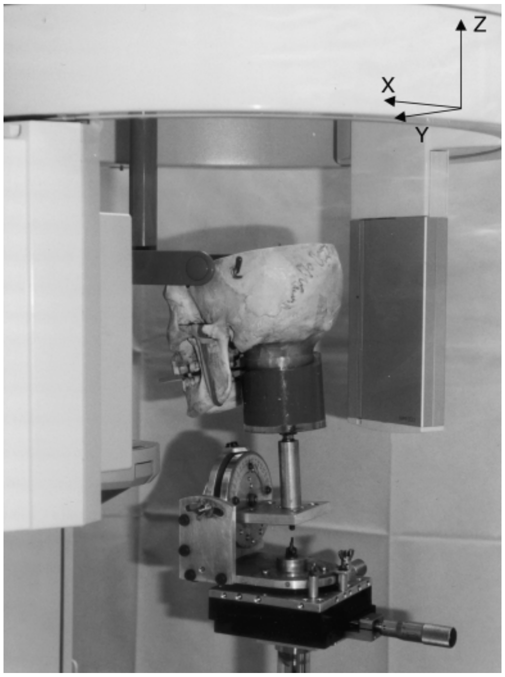

Figure 1 Macerated skull in the panoramic machine.

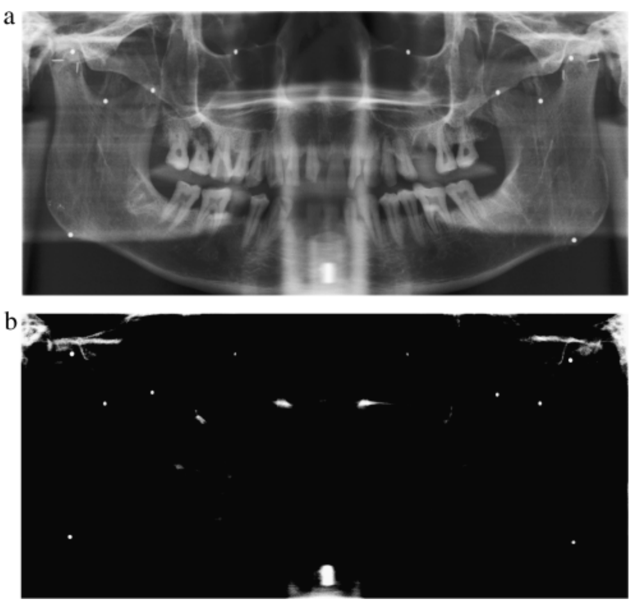

Figure 2 Panoramic radiograph before (a) and after (b) processing.

as points of reference for measuring the DPTs. The spheres were fixed on both sides of the skull, in the lower margin of the orbit. In the lower jaw, the markers were fixed at the angle of the mandible, and at a distance of 60 mm in the condyle region, on each side.

All radiographs were taken using a digital charge-coupled device sensor (Orthophos DS; Sirona, Bensheim, Germany). The exposures were made in each position at 68 kV and 8 mA. The radiographs were saved to a personal computer using the manufacturer's software (Sidexis 5.3; Sirona).

All skulls were positioned out by the same author (LB). To exclude errors caused by individual factors, all radiographs were subjected to a standardized process as follows: to measure the individual distances, the images (Figure 2a) were imported to the SigmaScan Pro 5.0 application (SPSS Inc., Chicago, Illinois, USA), where their brightness was reduced by 25 per cent. Grey scales smaller than 95 were assigned a value 0 and larger than 195 a value 255. The image contrast was then increased to maximum (100 per cent). Processing the images in this way allowed for demarcation of the markers from their environment (Figure 2b). Due to the distortion effects, the markers took on an oval shape. The programme was then used to determine the coordinates of the centre of mass of the markers. Using these coordinates, the distances between the markers were calculated for the ramus and condyle regions. Finally, the measured radiographic distances and the actual lengths measured on the skull were used to calculate the magnification factor of the ramus and condyle regions. The asymmetry between the right (R) and left (L) vertical measurements was calculated using the formula: % asymmetry = $[(R - L)/(R + L)] \times 2 \times 100\%$.

Positioning of skull in the panoramic unit

The skull was fixed on a moveable sheet, which was equipped with a micrometre screw for controlling linear movements in the sagittal and transverse planes. In addition, it was possible to rotate the skull around a cranio-caudal axis through the foramen magnum. The skull could also be tilted cranially or caudally around the transverse axis. Tilts and rotations could be set to an accuracy of up to 1 degree (Figure 1).

Following the manufacturer's instructions, the skull was positioned with the aid of horizontal and vertical positioning light guides, to simulate the ideal position of the patient's head in the panoramic machine. The ideal positioning of the phantom served as the starting point for the positioning errors as follows:

1. Axial shifts:

(a) Dorsoventral axis (*X*-axis): the skull was shifted to anteriorly and/or posteriorly along the median sagittal plane, in 2 mm increments up to 12 mm.
(b) Transverse axis (*Y*-axis): after setting the ideal position, the skull was shifted in 2 mm increments to the left, up to 14 mm.

2. Axial rotation:

(a) Cranio-caudal axis (*Z*-axis): the skull was rotated to the left around the cranio-caudal axis, in 2 degree increments up to 14 degrees.

(b) Transverse axis (*Y*-axis): the skull was rotated around the transverse axis, in 2 degree increments up to 4 degrees towards the cranial and to 6 degrees towards the caudal.

The risk of an involuntary minor misalignment of the patients is usually larger than that of an isolated extreme incorrect positioning. Therefore, the research went beyond the described positions to investigate a 'combined incorrect positioning' of the skull. For this, two relatively minor misalignments were combined with each other in order to determine whether and to what extent there is a summative effect.

The following misalignments were combined:

1. A 2 mm anterior shift of the skull along the dorsoventral axis (*X*-axis), in combination with:

   (A) a 2 degree rotation of the skull to the left around the cranio-caudal (*Z*-axis), (B) a 2 degree tilt to the cranial, or (C) caudal around the transversal axis (*Y*-axis).
2. A 2 mm posterior shift of the skull along the dorsoventral axis (*X*-axis), in combination with:

   (D) a 2 degree rotation of the skull to the left around the cranio-caudal axis (*Z*-axis), (E) a 2 degree tilt to the cranial, or (F) caudal around the transversal axis (*Y*-axis).
3. A 2 mm shift of the skull to the left along the transverse axis (*Y*-axis) in combination with:

   (G) a 2 degree rotation of the skull to the left around the cranio-caudal axis (*Z*-axis), (H) a 2 degree rotation to cranial, or (I) caudal around the transverse axis (*Y*-axis).
4. A 2 degree rotation of the skull to the left around the cranio-caudal axis (*Z*-axis) in combination with:

   (J) a 2 degree rotation of the skull to cranial or (K) to caudal around the transverse axis (*Y*-axis).

The series of panoramic radiographs taken in these misaligned positions were repeated six times each; a total of 252 radiographs were taken in the misaligned positions. Before each of the 42 series with misalignment of the skull, one radiograph was taken in the 'ideal' position. This resulted in 42 images of the ideal position.

Statistical analysis

The null hypothesis assumed that there were no statistically significant differences between the values measured for different skull positions. The data were tested for normality and as they were not normally distributed, Friedman repeated measures analysis of variance on ranks was used to compare the samples. Where a significant difference existed between several samples, Dunnett's test was used to compare them against the control group in the ideal position. All tests were conducted at a level of significance of $\alpha = 5$ per cent. The SigmaStat 3.0 software (SPSS Inc.) was used for statistical evaluation.

Measurement errors

A drawing created with Photoshop 6.0 (Adobe Systems Inc., San Jose, California, USA) and saved in TIF format at a resolution of 300 dpi was used to check the accuracy of measurements. Six circles, each with a diameter of 2 mm, were arranged at defined intervals (30.00, 50.00, and 70.00 mm) to each other. The distance between the circles was then determined using SigmaScan Pro software. It was found that measuring errors depended on the length of the distance measured and ranged between 0.04 and 0.11 mm.

To assess the error of method, the skull was radiographed in the ideal position by the same author (LB) on 12 consecutive days. The distance between the markers in the ramus and condyle regions on the panoramic radiographs was then measured. The magnitude of the method error *s(i)* was calculated using the formula (Dahlberg, 1940):

$$s(i) = \sqrt{\frac{\sum d^2}{2n}},$$

where *d* is the difference between two measurements and *n* is the number of double determinations. A 0.14 mm magnitude of the method error was found for the above-described experimental set-up.

Results

When the skull was shifted to the anterior and posterior in the sagittal plane, the changes in magnification factors did not exceed 0.01 (Table 1). Tilting the skull cranially and caudally around the transverse axis (*Y*-axis) had a negligible effect on the distortion of the vertical distances in the ramus and condyle region (Table 2). Compared with the ideal position, the changes in the magnification factor did not exceed 0.015 at maximum incorrect positioning.

Both the lateral shift of the skull (Figure 3a) and rotating the skull around the cranio-caudal axis (*Z*-axis; Figure 3b) had a significant influence ($P < 0.001$) on the magnification factors. When the skull was rotated 14 degrees to the left, the distances between the markers increased by 3.1 mm/decreased by 2.1 mm. On average, asymmetry of 6.7 per cent was determined between the two sides.

Of the combined positioning errors, the combination of rotating the skull by 2 degrees around the cranio-caudal axis and shifting the skull along the transverse axis to the same side resulted in the largest deviations from the ideal position. On average, the magnification factor increased by 0.013 on the right and decreased by 0.011 on the left. The asymmetry between the two sides was 1.3 per cent. Changes in the magnification factors of all other combined positioning errors resulted in asymmetries between −1.1 and 0.5 per cent (Table 3).

Table 1 Mean magnification factors and standard deviations (SD) when skull is shifted along the *X*-axis (medial–sagittal plane).

Shift along the X-axis			Ideal	2 mm	4 mm	6 mm	8 mm	10 mm	12 mm
Anterior	Right	Mean	1.167	1.168	1.167	1.167	1.168	1.168	1.167
		SD	0.001	0.003	0.002	0.001	0.002	0.002	0.002
	Left	Mean	1.173	1.175	1.175	1.176	1.176	1.177	1.177*
		SD	0.002	0.001	0.001	0.002	0.002	0.002	0.001
Posterior	Right	Mean	1.168	1.167	1.166	1.168	1.167	1.165	1.163*
		SD	0.002	0.002	0.003	0.001	0.002	0.002	0.003
	Left	Mean	1.174	1.174	1.172	1.176	1.170	1.168	1.167*
		SD	0.002	0.002	0.001	0.002	0.003	0.003	0.002

*$P < 0.05$.

Table 2 Mean magnification factors and standard deviations (SD) when skull is rotated around the *Y*-axis (transversal axis).

Rotation around the Y-axis			Ideal	2°	4°	6°
Caudal	Right	Mean	1.168	1.168	1.166	1.160
		SD	0.002	0.001	0.002	0.002
	Left	Mean	1.173	1.177	1.178	1.176
		SD	0.001	0.002	0.002	0.001
Cranial	Right	Mean	1.166	1.164	1.156*	
		SD	0.002	0.002	0.003	
	Left	Mean	1.174	1.168*	1.159*	
		SD	0.002	0.002	0.002	

*$P < 0.05$.

Discussion

Panoramic radiography is the diagnostic radiograph used for gaining a comprehensive overview of the dentomaxillofacial complex (Langland, *et al.*, 1989). However, this procedure has the disadvantage that anatomical structures outside the central plane are distorted (Tronje *et al.*, 1981a,b; McDavid *et al.*, 1989, 1993). In particular, the horizontal magnification factors vary considerably with the distance between the object and the sensor. Vertical measurements may be used if patient positioning is accurate and their jaws have an average anatomical shape (Tronje *et al.*, 1981a; Larheim and Svanaes, 1986).

In most studies, vertical measurements are confined to the tooth-bearing sections of the jaw (Larheim and Svanaes, 1986; Wyatt *et al.*, 1995; Xie *et al.*, 1996; Gomez-Roman *et al.*, 1999; Akdeniz *et al.*, 2000; Stramotas *et al.*, 2002). These measurements cannot necessarily be transferred to other areas of the jaw as the width of the central layer differs in different areas of the jaw. Few studies have dealt with the distortion of the vertical dimension in the ramus and condyle region (Habets *et al.*, 1987; Kjellberg *et al.*, 1994; Türp *et al.*, 1996; Kambylafkas *et al.*, 2006). Habets *et al.* (1987) used two spheres positioned in the panoramic machine in place of the condyles to study the effect of incorrect positioning of the patient in the vertical dimension on the radiographs.

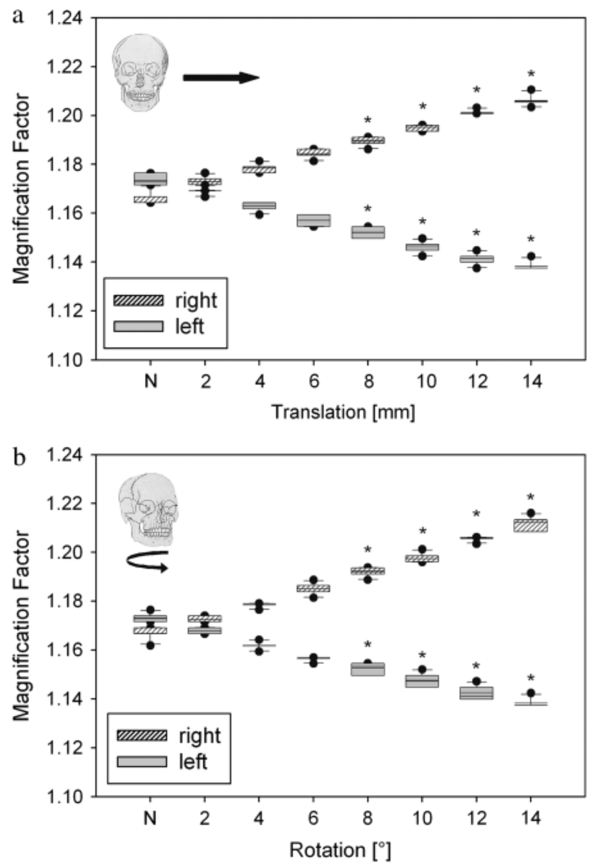

Figure 3 Change in magnification factors when the skull is shifted to the left along the *Y*-axis (a) and when the skull is rotated to the left around the *Z*-axis (b). *$P < 0.05$.

That research was based on a total of nine radiographs. Similar to the present study, they registered the greatest distortions in the model's shift along the transverse axis. Those authors concluded that, even in the worst case scenario, the asymmetry caused by incorrect positioning was not larger than 6 per cent. The study did not take into account any rotational movement of the stylized model around the various axes.

Kjellberg *et al.* (1994) calculated the magnification factor in the ramus and condyle region of the lower jaw both in an

Table 3 Mean magnification factors and standard deviations (SD) when two positioning errors are combined.

Combined misalignments		A	B	C	D	E	F	G	H	I	J	K	Ideal
Right	Mean	1.174	1.161	1.166	1.172	1.159	1.167	1.179*	1.166	1.172	1.168	1.176*	1.166
	SD	0.004	0.003	0.001	0.004	0.004	0.004	0.004	0.002	0.003	0.003	0.003	0.001
Left	Mean	1.170	1.171	1.179	1.167	1.168	1.178	1.163*	1.164*	1.174	1.162*	1.170	1.174
	SD	0.003	0.002	0.001	0.003	0.002	0.003	0.003	0.002	0.003	0.002	0.003	0.002

1. An anterior shift along the *X*-axis in combination with: (A) a rotation to the left around the *Z*-axis, (B) a tilt to cranial, or (C) caudal around the *Y*-axis
2. A posterior shift along the *X*-axis, in combination with: (D) a rotation to the left around the *Z*-axis, (E) a tilt to cranial, or (F) caudal around the *Y*-axis
3. A lateral shift to the left along the *Y*-axis in combination with: (G) a rotation to the left around the *Z*-axis, (H) a rotation to cranial, or (I) caudal around the *Y*-axis.4. A rotation to the left around the *Z*-axis in combination with: (J) a rotation to cranial or (K) to caudal around the *Y*-axis.
*$P < 0.05$.

ideal position and following positioning errors. In their study, the magnification factors were always shown as an average of the right and left sides. It was probably for this reason that they were unable to register any change in magnification factors versus the ideal position even when there were major asymmetrical positioning errors of the skull.

The results of the present investigation showed that incorrectly positioning the skull along the medial–sagittal plane (X-axis) had only a slight effect on the magnification factors in the ramus and condyle region. Any variation in the position of the skull of between +12 mm and −12 mm from the ideal caused a maximum change in distance of only 0.6 mm. Likewise, a rotation of the skull around the transverse axis had no clinically relevant effect on the linear measurements in the ramus and condyle region. A change in the tilt of the skull to the cranial and caudal by a total of 10 degrees resulted in a maximum 1.1 mm variation in the vertical distances. In all these misalignments, the ramus and condyle probably remained largely within the central layer despite the larger changes in position so that the magnification factors remained relatively constant.

However, if an object lies between the centre of the sharply depicted plane and the sensor, the magnification factor becomes smaller. The opposite applies for objects located between the centre of the sharply depicted plane and the effective rotation centre: here, the magnification factor increases. In the present study, the lateral displacement/rotation of the skull around the cranio-caudal axis caused an asymmetric change in the right and left object–sensor distances, resulting in opposite changes in the magnification factors on the two sides. Such asymmetrical positioning of the skull placed the left ramus and condyle closer to the sensor. As expected, reduction of the object–sensor distance resulted in a decrease in the magnification factor, while, on the contralateral side, the right ramus and condyle were shifted towards the medial–sagittal plane so that this increase in the object–sensor distance was coupled with an increase in the magnification factor. In the worst case scenario, asymmetry of 6.7 per cent was observed between the two sides. For this reason, asymmetrical conditions exceeding 6 per cent in the ramus and condyle region are probably not caused by incorrect positioning of the patient in the panoramic machine. These results are in accordance with the findings of Kambylafkas *et al.* (2006), who concluded that the use of the panoramic radiograph for evaluation of total ramal height is reliable and an asymmetry of more than 6 per cent is an indication of a true asymmetry.

In practice, the risk of extreme incorrect positioning tends to be slight. It is more likely that several smaller errors in different directions occur in positioning the patient. The series of combined misalignments showed summative effects. The vertical distortions were either intensified or diminished by two positioning errors. The least favourable combination was the simultaneous rotation of the skull around the cranio-caudal axis and the shift along the *Y*-axis (to the same side in each case). Each of these two positioning errors resulted in asymmetric distances between the sensor, the ramus and the condyle, so that the greatest asymmetry between the two sides of the lower jaw was with this combination. In practice, even this combination of positioning errors will probably not result in asymmetry of more than 2 per cent.

Conclusions

Differing distances between the object and the sensor for the two sides of the lower jaw cause an asymmetric depiction of the ramus and condyle on panoramic radiographs. Symmetric positioning of the patient in the panoramic machine is essential for linear measurements in the vertical direction. However, asymmetry of more than 6 per cent in the ramus and condyle region should not be interpreted as incorrect positioning of the patient.

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