Original Article

Near-End of Treatment Panoramic Radiograph in the Assessment of Mesiodistal Root Angulation

Ann Marie Owens[a]; Ama Johal[b]

ABSTRACT

Objectives: To test the hypothesis that there is no difference between the actual mesiodistal root angulation and the mesiodistal root angulation as measured on the panoramic radiograph.

Materials and Methods: A typodont dentition was set up into a Class I occlusion. Wire struts were placed on the buccal surface of each tooth to represent their long axes. The dentition was fixed into a natural skull for imaging. The radiographic and true mesiodistal angulation of each tooth to a horizontal reference plane (the arch wire) was measured using a coordinate measuring machine (CMM). The mesiodistal root positions were then altered to a more mesial and then more distal position and the measurements were repeated.

Results: Only 26.7% of the radiographic root angulations were within the clinically acceptable angular variation range of $\pm 2.5°$. The greatest variation in the upper arch occurred in the canine-premolar area where the roots were projected as being more divergent. The greatest variation in the lower arch occurred in the lateral incisor-canine region where these roots were projected as being more convergent. The extent of radiographic distortion is statistically greater in the lower arch than in the upper arch in the ideal ($P \leq .05$) and distal ($P \leq .01$) root positions.

Conclusions: The hypothesis is rejected. There is a clinically significant variation between the radiographic and the true root angulations recorded. Caution is advised when interpreting mesiodistal root angulation using this radiograph.

KEY WORDS: Panoramic radiograph; Root angulation; Mesiodistal

INTRODUCTION

The panoramic radiograph is an important part of the armamentarium of the orthodontist. Among its uses, this view can be used to: detect the presence or absence of unerupted teeth; act as a preliminary aid to the periodontal state and the presence of any pathology or gross caries; it can be used in the parallax technique to locate the position of unerupted teeth accurately.[1,2] However, the panoramic radiograph is by no means problem-free, being technique sensitive and ultimately designed for the "average" patient. Errors due to insufficient or incorrect trough size and shape will result in distorted images.[3,4] Poor images can also result from incorrect head positioning,[5–7] ghost imaging, summation images, static distortion and processing errors,[8] and patient movement.[9] Even in an ideally positioned panoramic radiograph, errors can occur in root length[10] and morphology.[11]

It is currently considered acceptable practice to take a panoramic radiograph to assess uprighting and paralleling of roots postextraction and postspace closure, prior to debonding of fixed appliances. It is not clear, however, if the panoramic radiograph actually gives an accurate representation of the true mesiodistal root positions of the maxillary and mandibular dentition. Recent changes to ionizing radiation protocols will potentially have a large impact on the number and type of radiographs that a clinician may take during a course of orthodontic treatment. Taking radiographs without any clinical justification is now not acceptable.[12] Cone beam volumetric tomography has recently been suggested in the literature as an alternative option for the assessment of root parallelism. However, this method is not yet routinely available for use for the general practitioner.[13]

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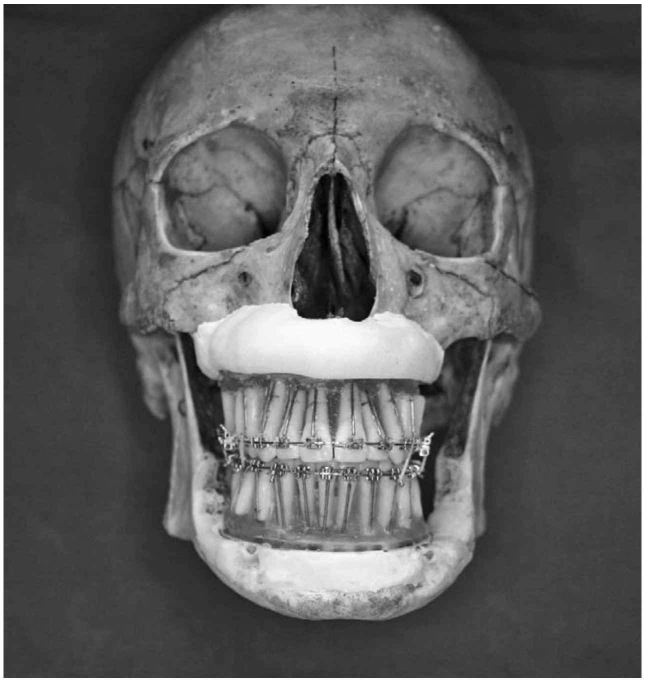

Figure 1. Typodont dentition positioned in natural skull.

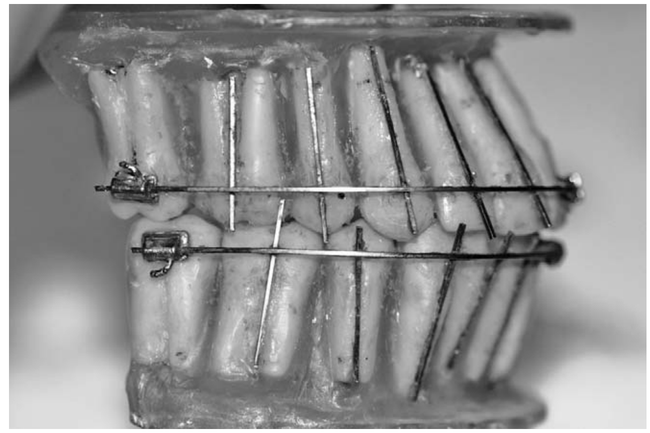

Figure 2. Revised typodont dentition.

Previous studies show notable distortion when comparing true and radiographic root angulation.[14–20] Some studies, however, still advocate the use of panoramic radiography to assess root parallelism provided the clinician was aware of the possible distortions[12] and provided the patient is correctly positioned in the panoramic machine.[21]

MATERIALS AND METHODS

Typodont and Skull Set-up

A typodont dentition was set up to mimic a classic orthodontic extraction pattern (Figure 1). An ideal occlusion was established following placement of fixed appliances and nickel-titanium and stainless steel wires to a 95% arch form. Shallow grooves were cut into the labial root faces along their long axes and steel pins of 0.018-inch diameter were positioned into these grooves to act as radiographic landmarks. The ideal occlusion attained showed relatively parallel root angulations in a mesiodistal dimension (Figure 1).

A natural skull was used for this study. A standardized lateral cephalometric radiograph was taken to confirm that skeletal parameters were within normal ranges. The alveolar processes of the maxilla and mandible were then removed.

The typodont dentition was secured to two thin sheets of Perspex sheets, shaped to the maxillary and mandibular bases of the skull. A female precision attachment was set into each Perspex base. A male attachment was sited on the maxillary and mandibular bases of the natural skull. These attachments would allow easy removal and accurate reattachment of the dentition to the maxillary and mandibular bony bases. Polymethylmetacrylate was used to secure the typodont dentition to the skull bases ensuring the vertical skeletal parameters remained unchanged. A standardized lateral cephalometric radiograph was retaken which confirmed that the anterior-posterior position of the typodont dentition was within the normal range and the functional occlusal plane's relationship to the maxillary and mandibular plane was within normal limits.

The typodont dentition was then altered to allow a direct interface between the archwire and the wire struts for more accurate radiographic and true angular measurements (Figure 2). The fixed appliances were removed with the exception of the brackets and tubes on upper and lower left central incisors and right second molar teeth, respectively, to support the archwire.

Radiographic Angular Measurements of Typodont Model with "Ideal" Root Position

The typodont model was positioned in intercuspal position in the Siemens Orthopantomogram 10E machine using light sources within the machine to allow optimal positioning of the skull. The skull was marked around the semicircular ends of the head support to allow accurate repositioning on different occasions. A panoramic radiograph was taken using Agfa Cronex 10T film type at an exposure of 60 kilowatts and 10 milliamperes (Figure 3). The radiographic angulations were measured using a coordinate measuring machine (CMM).

Assessing True Angulation of the Dentition

The true mesiodistal root angulation of each tooth was measured using a Merlin II CMM (International Metrology Systems, Livingstone, UK). The software used by the CMM to measure tooth angulation was

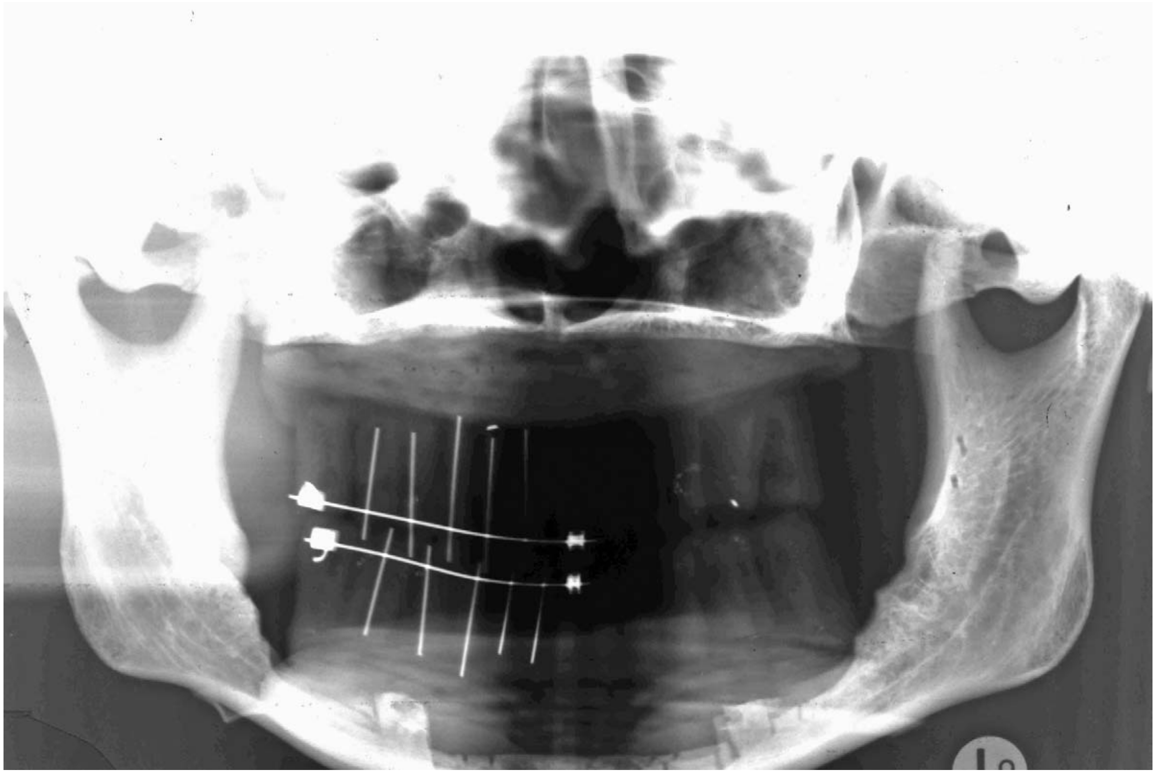

Figure 3. Panoramic radiograph of typodont dentition with ideal occlusion.

Direct Computer Control (DCC337; International Metrology Systems).

A pilot study was undertaken to determine the most accurate measurement strategy appropriate for measuring each root's mesiodistal angulation. The mesiodistal angle of each tooth was determined from the intersection of the long axis and the archwire. Each tooth lies in its own three-dimensional plane. To define the angle of each tooth to the adjacent archwire, the three-dimensional plane of each tooth was converted into a two-dimensional plane. As shown in Figure 4, Line 2a is translated to position 2b which lies in the same two-dimensional plane as Line 1 to allow angle calculation. The angle made by Line 2a to Line 1 (x°) is the same angle as that made by Line 2b to Line 1 (x°). However, Line 2b now lies on the same plane as Line 1 allowing angle determination.

The alignment of each tooth plane used three points:

A Tip of the wire strut on long axis of root
B The "origin" (where the archwire and wire strut on root axis overlap)
C Point on the archwire level with mesial margin of the tooth

Alteration of the Angulation of the Dentition to a More Mesial and Distal Angulation

The angulations of the typodont teeth were then altered in the laboratory to mimic significantly increased mesial and then increased distal angulation of the roots of the upper and lower dentition. Class I molar and incisor relationships were maintained. The true and radiographic angulation of these teeth to the arch wire was again determined using the CMM.

Panoramic radiographs were taken of each root position under standardized conditions. The radiographic tooth angulations also were measured using the CMM. An acceptable angle variation of 2.5° in either direction was utilized in this study as was used by McKee et al.[7] This acceptability level was based on work by Philipp and Hurst,[14] Samawi and Burke,[15] and McDavid et al.[22]

Error Study and Statistical Analysis

A single operator (AMO) performed all measurements, undertook all modifications to the dentition, skull set up, true tooth angle determination using the CMM, positioning of the skull in the radiographic machines, and measurement of radiographic tooth angles. To minimize error, all modifications to the typodont, radiograph positioning, and measurements were performed under the guidance of a senior orthodontic technician, researcher in the use of a CMM and a senior radiographer, respectively.

The true angulations of each root to the archwire at each root position (ideal, mesial, and distal) were measured on 3 successive days to assess repeatability of measurement technique. To assess accuracy of skull

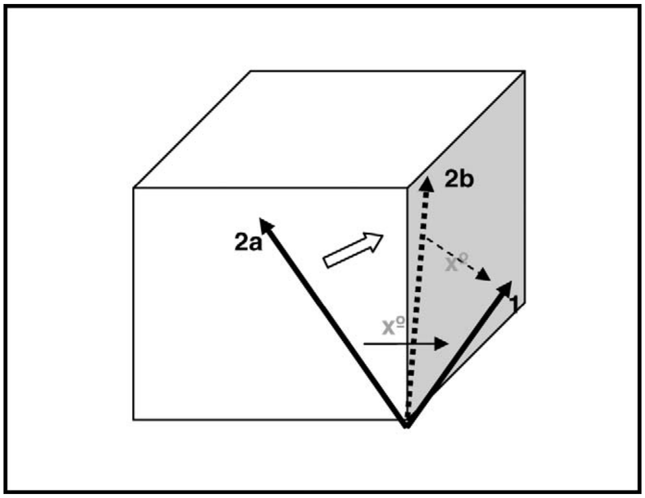

Figure 4. Converting from a three-dimensional plane to a two-dimensional plane.

repositioning in the panoramic radiographic machines, for each root position (ideal, mesial, and distal) was assessed by each radiograph being repeated 1 week later and root angulations digitized on two separate occasions. To assess repeatability error of the true angular measurements and to assess error of digitization and error of repositioning of the skull in the radiographic machines, univariate analysis was applied.

Normal distribution was noted and thus parametric tests were advised. Differences between the mean true and radiographic root angulations at each root position were examined using paired *t*-tests (with statistical significance being recorded at $P \leq .05$). The agreement between the true root angulation and the panoramic radiographic root angulations was also assessed using the Bland-Altman limits of agreement.

The differences between radiographic angulations recorded in the upper and lower arches on panoramic radiographs were measured using two-sample *t*-tests.

RESULTS

There was no statistically significant error detected $P \leq .05$) between each repeat measurement. Therefore, accuracy of repeat measurements with CMM, digitization of radiographs, and repositioning of the skull in the radiographic machine can be considered to be high. Applying an acceptability of variation of 2.5°, only 26.67% of the projected radiographic measurements were within this range of variation (Table 1).

The largest angular difference, in the upper arch, between adjacent teeth occurred between the canine and the premolar (Figure 5). This resulted in the appearance of a more exaggerated root divergence than was actually present. At ideal angulation, the panoramic radiograph tends to underestimate the root angulation of the central incisor, lateral incisor, and canine teeth and overestimate the angulation of the premolar and molar teeth. At a more mesial root angulation, the panoramic radiograph overestimates all root angulations by a clinically significant amount (>2.5°), with all root angulations to the arch wire appearing more obtuse than they actually are. At increased distal root angulation, the radiographic distortion is less apparent clinically throughout the upper arch except in the upper right lateral incisor root.

The largest angular difference in the lower arch between adjacent teeth occurred between the lateral incisor and the canine (Figure 6). This resulted in the appearance of a more exaggerated root convergence than was actually present and was evident at ideal, mesial, and distal root positions. Thus, at all three root positions, the panoramic radiograph overestimates the angulation of lower central and lateral incisor and underestimates the angulation of lower right canine, premolar and molar teeth in the lower arch.

Table 2 shows the Bland-Altman limit of agreement values for panoramic radiographs at ideal, mesial, and distal root positions. These range from −11° to +11°. This suggests that 95% of all differences between the radiographic angle and the true angle lie within this range. These results generally show very poor agreement between the radiographic and true root angulation measurements.

The results of two-sample *t*-tests suggest that there was a statistically significant difference between the upper and lower arches for the panoramic radiograph in the ideal and distal root position (Table 3). The difference between the panoramic radiograph and true angle was significantly smaller for the upper arch than for the lower arch.

DISCUSSION

Every effort was made in setting up the dentition to accurately represent a true clinical situation. In some previous studies, the typodont designs have not been designed to represent a normal dentition, with intercuspating occlusion. This, thereby, creates problems when attempting to extrapolate their findings to the clinical situation.[14–16,18,21] The current study used wire struts, placed along the buccal surfaces, to give a true reflection of the long axes of the teeth, and thus overcame potential error associated with the use of apical metal markers.[19] The current study utilized upper and lower archwires as the horizontal reference planes for the maxillary and mandibular dentition during measurement of the true and radiographic mesiodistal tooth angulation, similar to McKee et al.[19] Other studies have used less clinically representative landmarks to denote the horizontal reference plane.[14–18,21,23]

Table 1. Relationships Between True and Panoramic Radiographic Angulation Measurements of the Teeth in the Upper and Lower Arch at Ideal, Mesial, and Distal Root Positions

Root Position	Tooth	True Angulation, Degrees		Panoramic Radiographic Angulation, Degrees		Mean Difference, Degrees	Statistical Significance
		Mean	SD	Mean	SD		
Ideal	UR1	93.30	0.70	90.79	0.54	+2.51[a]	*
	UR2	93.78	0.70	93.14	0.73	+0.64	NS
	UR3	101.31	0.84	97.03	1.06	+4.28[a]	*
	UR5	95.97	0.44	101.33	1.07	−5.36[a]	**
	UR6	91.23	0.16	94.24	1.29	−3.01[a]	NS
	LR1	90.02	1.09	98.49	0.53	−8.47[a]	**
	LR2	89.30	0.71	95.81	0.67	−6.51[a]	**
	LR3	92.22	0.69	90.40	0.70	+1.82	*
	LR4	87.83	0.41	80.70	0.79	+7.13[a]	**
	LR6	97.75	0.22	89.43	0.73	+8.32[a]	**
Mesial	UR1	84.05	0.25	87.63	1.94	−3.58[a]	*
	UR2	80.14	0.40	87.44	0.45	−7.30[a]	**
	UR3	83.82	0.18	88.00	0.92	−4.18[a]	*
	UR5	81.13	0.34	87.94	0.43	−6.81[a]	**
	UR6	84.55	0.22	88.61	0.85	−4.06[a]	*
	LR1	88.51	0.36	90.94	0.84	−2.43	*
	LR2	84.55	0.16	86.78	0.55	−2.23	**
	LR3	81.81	0.28	77.35	0.65	+4.46[a]	**
	LR4	80.55	0.24	73.59	1.82	+6.96[a]	*
	LR6	84.44	0.43	77.68	0.46	+6.76[a]	**
Distal	UR1	95.53	0.42	96.94	0.81	−1.41	NS
	UR2	94.31	0.53	97.77	2.40	−3.46[a]	NS
	UR3	106.53	0.41	105.89	1.15	0.64	NS
	UR5	110.64	0.51	110.30	0.37	+0.34	NS
	UR6	96.44	0.69	98.60	0.41	−2.16	NS
	LR1	106.26	0.57	115.11	1.25	−8.85[a]	**
	LR2	104.39	0.40	114.36	2.42	−9.97[a]	**
	LR3	108.37	0.46	106.15	0.30	+2.22	*
	LR4	103.09	0.11	96.44	0.33	+6.65[a]	**
	LR6	95.10	0.30	90.56	0.87	+4.54[a]	**

[a] Clinically significant variation (greater than 2.5°).
* $P \leq .05$; ** $P \leq .01$; NS indicates not significant.

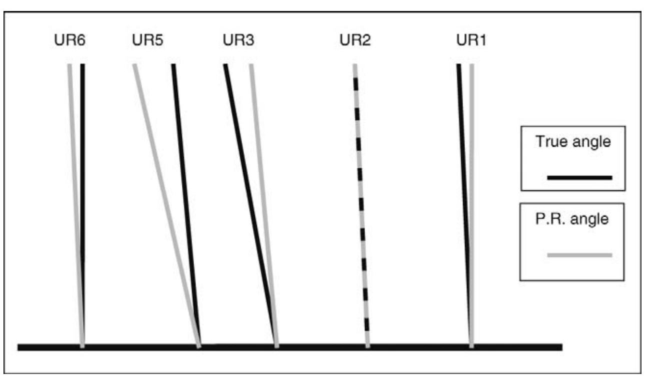

Figure 5. Diagram representing the true and panoramic radiograph root angulation difference at ideal angulation (upper arch) (degrees).

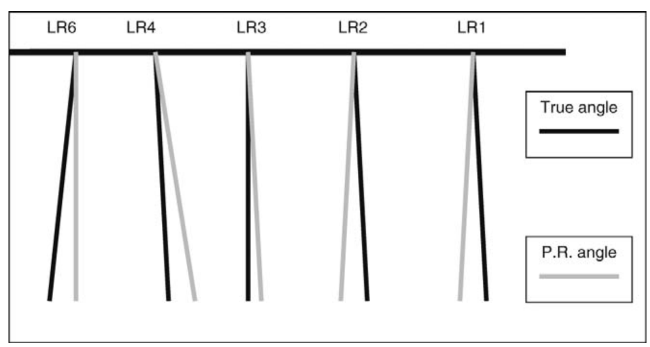

Figure 6. Diagram representing the true and panoramic radiographic root angulation difference at ideal angulation (lower arch) (degrees).

The importance of accurate positioning within the panoramic radiographic machine has previously been highlighted. The use of a natural skull as a casing for the typodont dentition helped ensure an accurate representation of the clinical situation. The use of a CMM allowed very accurate measurement of both the true and radiographic root angulations. This study is the first to have used such a measurement methodology. McKee et al,[19] however, did use a CMM but their measurement methodology was not clear.

The present study showed that there was very poor agreement between the true and radiographic root angulation measurements obtained from a panoramic ra-

Table 2. Bland-Altman Limit of Agreement Values for Panoramic Radiographs

Position	Mean Difference (True-Pan Rad)[a]	Standard Deviation of Difference[b]	95% Bland-Altman Limits of Agreement
Ideal	0.136	5.77	(−11.17; 11.45)
Mesial	−1.24	5.34	(−11.71; 9.23)
Distal	−1.15	5.3	(−11.54; 9.39)

[a] Pan Rad indicates panoramic radiograph.
[b] In degrees.

Table 3. Comparison of Absolute Differences of Upper Dentition to Lower Dentition on Panoramic Radiograph and Lateral Cephalometric Radiograph

Position	Upper Absolute Mean Difference*** (SD)	Lower Absolute Mean Difference*** (SD)	*P* Value
Ideal	3.2 (1.8)	6.4 (2.7)	*
Mesial	5.2 (1.7)	4.6 (2.3)	NS
Distal	1.6 (1.3)	6.5 (3.2)	**

* $P \leq .05$; ** $P \leq .01$; *** in degrees.

diograph. The 95% level of agreement (Table 2) showed a variation of approximately 22°. This degree of variation is not clinically acceptable and could result in an incorrect diagnosis and treatment mechanics being applied to the patient.

The greatest angular difference occurred in the maxillary canine-premolar region. This suggests divergence rather than the actual convergence of the true root angulation. This was similar to the findings of McKee et al,[19] Philipp and Hurst,[14] and Samawi and Burke[15] who also reported the largest distortion of angulation occurred in the maxillary canine-premolar region. This is a critical area, particularly in a patient who has undergone premolar extractions. To base clinical decisions regarding root angulation of these teeth from panoramic radiographic findings may be detrimental. To upright seemingly divergent roots based on the radiographic findings would result in actual increased root convergence and possible root damage, resorption and compromised stability.

The greatest angular difference occurring between adjacent teeth in the mandibular dentition was observed in the lateral incisor-canine region, similar to the findings of McKee et al.[19] This suggests that for all root positions, radiographically an increased root convergence is implied than is clinically present. The greatest variation occurred when the lateral incisor was at ideal angulation and the canine root was more mesially angulated. Therefore, to base a clinical decision, particularly regarding these teeth, on a panoramic radiograph may result in uprighting these roots to reduce the apparent convergence and hence result in overly divergent adjacent roots—a harmful, unwanted effect.

At all root angulations (ideal, mesial, distal), the panoramic radiograph projects the upper premolar and molar roots as more distal than they actually are, confirming the findings of McKee et al.[19] However, ideal root angulation only was assessed in the study by McKee et al.[19] The lower premolar and molar root angulation conversely is underestimated and projects the roots as more mesial than they actually are. This variation may be due to differences in the positioning of the maxillary and mandibular dentition within the focal trough of the panoramic radiographic machine. If this degree of distortion occurs in an ideal occlusion, it suggests that much greater distortion may occur in patients with transverse discrepancies. This finding suggests caution should be applied when interpreting premolar and molar angulation.

The variations in angulation recorded between true and radiographic angulation may be due to aberrant skull positioning within the radiographic machine. However, great care was taken in the standardization and positioning of the skull in the present study and repeat positioning of the skull helped reduce the possibility of error. It is also possible that the skull and dentition is not representative of the general population. Varying face shapes may result in different positioning of the maxillary dentition within the focal trough and, hence, result in more aberrant radiographic angulations for certain face shapes. It is not possible to accurately extrapolate the effects of these different face shapes from this study, but this topic may be worthy of further investigation.

The difference between the true and panoramic radiographic angulation in the lower arch at an ideal root angulation is statistically significant compared to the upper arch. Therefore, greater caution must be taken when interpreting root angulation on a panoramic radiograph, especially in the lower arch.

CONCLUSIONS

- The panoramic radiograph provides a poor representation of true mesiodistal root angulations, and this is more notable in the lower arch.
- Clinicians must exercise caution in relation to panoramic radiographic findings when basing their clinical decisions as to whether teeth require further adjustments in angulation.

REFERENCES

1. Ericson S, Kurol J. Resorption of maxillary lateral incisors caused by ectopic eruption of the canines. A clinical and radiographic analysis of predisposing factors. *Am J Orthod Dentofacial Orthop.* 1988;94:503–513.
2. Jacobs SG. Radiographic localization of unerupted teeth:

further findings about the vertical tube shift and other localization techniques. *Am J Orthod Dentofacial Orthop.* 2000;118:439–447.
3. Lund TM, Manson-Hing LR. Relations between tooth positions and focal troughs of panoramic machines. *Oral Surg Oral Med Oral Pathol.* 1975;40:285–293.
4. Martinez-Cruz S, Manson-Hing LR. Comparison of focal trough dimensions and form by resolution measurements in panoramic radiography. *J Am Dent Assoc.* 1987;114:639–642.
5. Schiff T, D'Ambrosio J, Glass BJ, Langlais RP, McDavid WD. Common positioning and technical errors in panoramic radiography. *J Am Dent Assoc.* 1986;113:422–426.
6. Taylor VE. Improving your radiography. 2. Panoramic technique (i). *Dent Update.* 1987;14:341–350.
7. McKee IW, Glover KE, Williamson PC, Lam EW, Heo G, Major PW. The effect of vertical and horizontal head positioning in panoramic radiography on mesiodistal tooth angulations. *Angle Orthod.* 2001;71:489–497.
8. Taylor VE. Improving your radiography 3. Panoramic technique (ii). *Dent Update.* 1987;14:429–435.
9. Langland OE, Langlais RP, Preece JW. *Principles of Dental Imaging.* 2nd ed. Philadelphia, PA: Lippincott Williams and Wilkins; 2002:219–258.
10. Thanyakarn C, Hansen K, Rohlin M, Akesson L. Measurements of tooth length in panoramic radiographs. 1. The use of indicators. *Dentomaxillofac Radiol.* 1992;21:26–30.
11. Sameshima GT, Asgarifar KO. Assessment of root resorption and root shape: periapical versus panoramic films. *Angle Orthod.* 2001;71:185–189.
12. The Ionising Radiation (Medical Exposure) Regulations (2000); Stationery Instrument 2000 No. 1059; Her Majesty's Stationery Office, London.
13. Peck JL, Sameshima GT, Miller A, Worth P, Hatcher DC. Mesiodistal root angulation using panoramic and cone beam CT. *Angle Orthod.* 2007;77:206–213.
14. Philipp RG, Hurst RV. The cant of the occlusal plane and distortion in the panoramic radiograph. *Angle Orthod.* 1978;48:317–323.
15. Samawi SSB, Burke PH. Angular distortion in the orthopantomogram. *Brit J Orthod.* 1984;11:100–107.
16. Lucchesi MV, Wood RE, Nortje CJ. Suitability of the panoramic radiograph for assessment of mesiodistal angulation of teeth in the buccal segments of the mandible. *Am J Orthod Dentofacial Orthop.* 1988;94:303–310.
17. Ten Bruggenkate CM, Van der Linden LWJ, Oostereek HS. Parallelism of implants visualized on the orthopantomogram. *Int J Oral Maxillofac Surg.* 1989;18:213–215.
18. Wyatt DL, Farman AG, Orbell GM, Silveira AM, Scarfe WC. Accuracy of dimensional and angular measurements from panoramic and lateral oblique radiographs. *Dentomaxillofac Radiol.* 1995;24:225–231.
19. McKee IW, Williamson PC, Lam EW, Heo G, Glover KE, Major PW. The accuracy of 4 panoramic units in the projection of mesiodistal tooth angulations. *Am J Orthod Dentofacial Orthop.* 2002;121:166–175.
20. Lee J. The effects of buccolingual root torque on the appearance of root angulation on panoramic radiographs. *Am J Orthod Dentofacial Orthop.* 2005;127:393.
21. Stramotas S, Geenty JP, Petocz P, Darendelier M. Accuracy of linear and angular measurements on panoramic radiographs taken at various positions in vitro. *Eur J Orthod.* 2002;24:43–52.
22. McDavid WD, Tronje G, Morris CR, Nummikoski P. Imaging characteristics of seven panoramic x-ray units. *Dentomaxillofac Radiol.* 1985;8(suppl):1–68.
23. Ursi WJ, Almeida RR, Tavano O, Henriques JFC. Assessment of mesiodistal axial inclination through panoramic radiography. *J Clin Orthod.* 1990;24:166–173.