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Precision of measurements on conventional negative 'bones white' and inverted greyscale 'bones black' digital lateral cephalograms

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SUMMARY The objective of this study was to determine whether the accuracy of measurement data from inverted greyscale digital cephalometric radiographs equals that obtained from conventional negative digital cephalometric radiographs. Fifty-five consecutively lateral cephalometric radiographs from a university orthodontic clinic obtained for treatment planning were used for this study. A 5 MB conventional negative 'bones white' and inverted greyscale 'bones black' TIFF digital image of each radiograph was produced. These were allocated a unique identifier and were analysed in random order by one clinician. Eighteen cephalometric landmarks were digitized using the Opal 2.1 package and the angles were calculated. The angular measurements were compared using two-sample *t*-tests ($P < 0.05$).

The angular measurements from the conventional negative bones white and inverted greyscale bones black lateral cephalometric radiographs were neither statistically significantly different nor clinically different from each other. Therefore, measurements derived from conventional negative bones white and inverted greyscale bones black lateral cephalometric radiographs have a similar level of precision.

Introduction

Cephalometrric radiography is a standardized and reproducible form of skull radiography to assess the relationships of the teeth to the jaws and the jaws to the rest of the facial skeleton (Whaites, 2002). In routine clinical practice, lateral cephalometric radiographs are recorded during orthodontic treatment to assess malocclusions and aid both non-surgical and surgical treatment planning, as well as monitoring the progress of treatment. In addition, there are many other indications for the recording of lateral cephalometric radiographs including the localisation of unerupted teeth and in planning the locations of dental implants in edentulous subjects.

There are many potential sources of error in cephalometrics including radiographic technique, patient positioning, landmark identification, and measurements. These have been widely investigated (Baumrind and Frantz, 1971a,b; Gravely and Benzies, 1974; Cohen, 1984; Houston *et al.*, 1986; Battagel, 1993; Turner and Weerakone, 1993; Chen *et al.*, 2000, 2004) with landmark identification being determined to be the main source of error in the measurement of the craniofacial complex when using cephalometry (Richardson, 1966; Baumrind and Frantz, 1971a,b; Gravely and Benzies, 1974). The difficulty in identifying cephalometric landmarks is mainly due to the superimposition of the right and left paired anatomical structures resulting from craniofacial asymmetries and positioning errors within the cephalostat. This leads to landmarks appearing as double or blurred images on lateral cephalograms (Richardson, 1966; Baumrind and Frantz, 1971a,b; Gravely and Benzies, 1974; Silveira and Silveira, 2006) and by convention, the midpoint of the two is recorded. Furthermore, the error of the method should be minimal otherwise it is doubtful whether any differences between images are attributable to growth and treatment effects, among other variables (Kamoen *et al.*, 2001).

The use of 'on-screen' facilities for landmark identification was first used by Jackson *et al.* (1985) who found the errors associated with their digital image system comparable with those from conventional cephalometry. Subsequently, studies investigating landmark and measurement reproducibility using direct digital cephalograms have not been conclusive. Chen *et al.* (2000) found landmark reproducibility to be inferior, whereas Lim and Foong (1997) found digital cephalometry to be associated with an indifferent level of landmark reproducibility in comparison with that associated with conventional cephalometry. In contrast, Hagemann *et al.* (2000) found direct digital cephalograms to be associated with greater landmark reproducibility than conventional cephalograms. In a more recent study, it was noted that the errors associated with cephalometric measurements were comparable when derived from either analogue films or from those scanned at 300 dots per inch (Ongkosuwito *et al.*, 2002). With direct digital cephalograms captured and stored using a picture archiving and communication system, image quality can be altered by enhancing the contrast and therefore discrete anatomical edges may be more easily delineated.

One method of altering the image format is to invert the greyscale properties to 'bones black' in comparison with the conventionally accepted 'bones white' cephalograms (Figure 1). Although Haak and Wicht (2005) found that this procedure did not enhance the detection of approximal caries and Kheddache *et al.* (1991) did not find any significant difference in the detectability of the test structures when comparing positive (bones black) and negative (bones white) chest radiographs using a true greyscale reversal. No evidence is available to determine if inverted greyscale lateral cephalograms are associated with a different level of landmark reproducibility than conventional bones white cephalograms.

The aim of the present study was to determine whether the precision of measurement data associated with inverted greyscale digital cephalometric radiographs is different to that associated with conventional negative bones white digital cephalometric radiographs. The null hypothesis tested was that there are no statistically significant differences in the precision of cephalometric measurements between conventional negative and inverted greyscale lateral cephalograms.

Materials and Methods

Caldicott Guardian approval was obtained for the use of 55 consecutive lateral cephalometric radiographs recorded from 1 January 2006 at a university orthodontic clinic to investigate the precision of cephalometric measurements using different cephalometric image formats. Caldicott Guardian approval was necessary as the images were patient-identifiable and the patients had not given consent for use of their radiographs in research when they were recorded for clinical purposes. The original cephalometric images were identified from the Sidexis radiography server (www.sidexis.com). The patients when all at the commencement of orthodontic treatment where the lateral cephalometric radiographs had been recorded for diagnostic and treatment planning purposes. As a result, medical ethics committee approval was not required. Images were only selected with optimal cephalogram quality to facilitate landmark identification, where all incisor teeth were fully erupted and where the soft tissue nasal tip and chin were visible on the image. The sample size was calculated using a clinically significant difference in angular measurements of 2 degrees as determined by McIntyre and Mossey (2002) at 80 per cent power. The cephalometric radiographs were acquired using an OrthoPlus DS digital cephalometer (Siemens, Munich, Germany), where the subjects were positioned with the Frankfort plane parallel to the floor.

A 5 MB conventional negative bones white (Figure 1a) and inverted greyscale bones black (Figure 1b) TIFF digital image of each radiograph was produced. These were anonymized and allocated a unique identifier by one author (GM). The images were then analysed in random order using a random number table by one investigator (FB). Eighteen cephalometric landmarks (Table 1) were digitized using the Opal 2.1 package [British Orthodontic Society, 2006 (http://www.opalimage.co.uk)]. This was installed on a Dell Optiplex 755 PC attached to a Dell 2-button USB optical mouse and 17-inch UltraSharp 1707FPV TFT LCD monitor with 1280 × 1024 resolution, aspect ratio 4:3, pixel pitch 0.297 × 0.297, and contrast ratio 500:1 (www.dell.com). When bilateral structures led to double images the midpoint of the right and left structures was used. Opal automatically calculated the magnitude of the

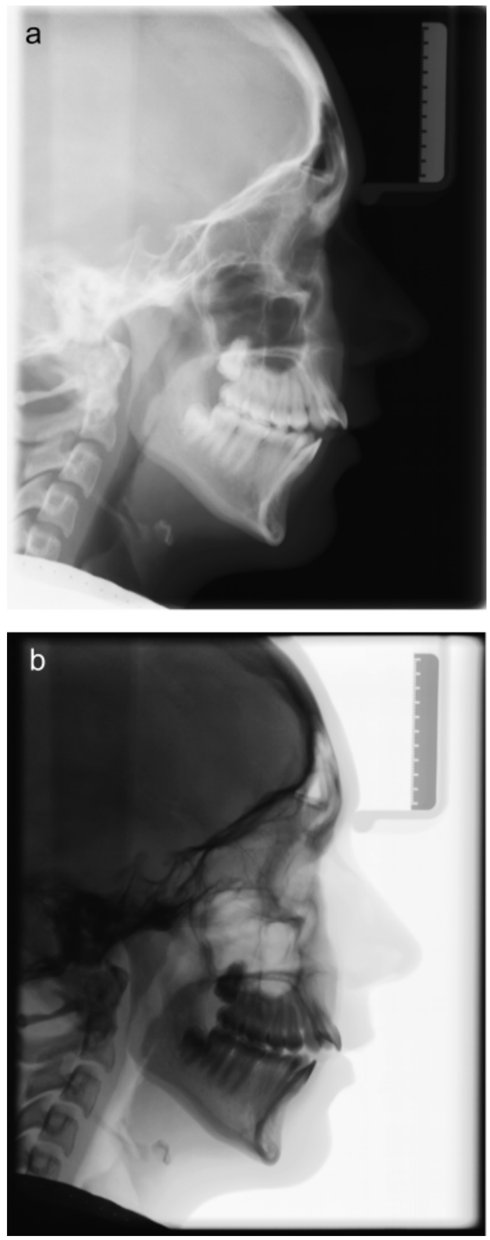

Figure 1 (a) Conventional negative bones white and (b) inverted greyscale bones black lateral cephalograms of one subject.

angles (Table 2). The Opal data were exported into an Excel spreadsheet (Microsoft Inc, Redmond, California, USA) and the values rounded up or down to the nearest 0.1 degree in relation to the pixel pitch value of the monitor.

Statistical analysis

The angular measurements for each parameter were compared using two-sample *t*-tests to determine statistical significance. In order to evaluate individual landmark intra-operator repeatability, 25 of the images were re-measured 1 month later (Houston, 1983). Random and systematic errors were calculated using the formula of Dahlberg (1940) and a two-sample *t*-test (Houston, 1983), respectively. The level of significance was set at $P < 0.05$ for the systematic error.

Results

The random error did not exceed 0.5 degrees and the systematic errors did not exceed the level of significance set at $P < 0.05$. The angular measurements for the inverted greyscale bones black lateral cephalometric radiographs were neither statistically nor clinically significantly different to those of the conventional negative bones white lateral cephalometric radiographs ($P > 0.05$). However, the variability of seven of the parameters (SNA, SNB, MMPA, angle between the maxillary incisor and maxillary plane, inter-incisal angle, nasolabial angle, and Holdaway angle) were lower in the inverted greyscale bones black images in contrast to the conventional negative bones white images (Table 3).

Discussion

In this study, it was found that measurements using inverted greyscale bones black lateral cephalometric radiographs were neither statistically nor clinically significantly different to those from conventional negative bones white lateral cephalometric radiographs. The null hypothesis was therefore supported. However, it was interesting to note that the variability of the measurements was lower for seven of the 10 parameters in the inverted greyscale bones black group. As the

Table 1 Cephalometric landmarks.

Sella	Central point by eye estimation of the pituitary fossa
Nasion	Most anterior point of the fronto-nasal suture
Upper incisor apex	Root apex of the most anterior maxillary central incisor
Upper incisor tip	Incisal edge of the most prominent maxillary central incisor
Lower incisor tip	Incisal edge of the most prominent mandibular central incisor
Lower incisor apex	Root apex of the most anterior mandibular central incisor
Point B	The point on the anterior surface of the mandibular symphysis between infradentale and pogonion which is furthest from a line joining these points
Point A	The point on the anterior surface of the maxilla which is furthest from a line joining anterior nasal spine and prosthion
Pogonion	Most anterior point of the bony chin in the median plane
Menton	Most inferior point on the mandibular symphysis
Gonion	Constructed point at the intersection of the posterior and lower borders of the mandible
Anterior nasal spine	Tip of the anterior bony spine of the maxilla
Posterior nasal spine	Most posterior point on the outline of the hard palate
Soft tissue nasion	Point of deepest concavity of the soft tissue contour of the root of the nose
Columella	Point at the junction of the nasal base and the superior labial sulcus
Labrale superius	Median point in the upper margin of the upper membranous lip
Labrale inferius	Median point in the lower margin of the lower membranous lip
Soft tissue pogonion	Most prominent point on the soft tissue contour of the chin

Table 2 Cephalometric measurements.

Variable	
SNA	Angle between sella–nasion and nasion–point A
SNB	Angle between sella–nasion and nasion–point B
ANB	SNA minus SNB
S–N/maxillary plane angle	Angle between sella–nasion and the maxillary plane (ANS-PNS)
MMPA	Angle between the maxillary plane (ANS-PNS) and the mandibular plane (gonion–menton)
Maxillary incisor/maxillary plane	Postero-inferior angle between the upper incisor long axis and the maxillary plane
Mandibular incisor/mandibular plane	Postero-superior angle between the mandibular plane and the long axis of the lower incisor
Inter-incisal angle	Angle formed by the intersection of the long axes of the upper and lower incisors
Nasolabial angle	Angle between columella–subnasale and subnasale–labrale superius
Holdaway angle	Angle between soft tissue nasion/soft tissue pogonion/labrale superiu

Table 3 Means, standard deviations (SD), and statistical significance of the differences between the angular measurements from conventional negative cephalograms and inverted greyscale cephalograms.

Variable	Mean and SD for conventional negative cephalograms	Mean and SD for inverted greyscale cephalograms	*P*
SNA	79.9 (4.3)	79.5 (4.2)	0.052
SNB	77.0 (5.5)	76.7 (5.3)	0.139
ANB	2.9 (4.2)	2.8 (4.2)	0.498
SN-MxP	9.4 (3.8)	9.5 (3.8)	0.432
MMPA	25.6 (6.4)	25.0 (6.0)	0.054
Angle between the maxillary incisor and maxillary plane	114.1 (7.9)	114.4 (7.8)	0.517
Angle between the mandibular incisor and mandibular plane	90.7 (8.9)	90.9 (8.9)	0.585
Inter-incisal angle	129.2 (11.5)	129.6 (11.2)	0.472
Nasolabial angle	144.6 (16.0)	146.7 (14.6)	0.061
Holdaway angle	15.3 (4.9)	15.1 (4.8)	0.080

radiographs originated from the same patient cohort, there would be no bias resulting from subject selection and therefore the reduced variability in the inverted-grey scale bones black group indicates that cephalometric measurements using this image format are likely to be marginally more precise.

It is interesting that despite many digital radiography packages having the facility to produce inverted greyscale images, the clinical utility of this image format has not been investigated. However, it is reassuring to note that the finding of no statistically or clinically significant differences between the measurements made on inverted greyscale bones black and conventional negative bones white lateral cephalometric radiographs is in line with the results of Haak and Wicht (2005) and Kheddache *et al.* (1991) who found there to be no improvement in the detection of approximal caries and detectability of their test structures using chest radiographs, respectively.

Nevertheless, the reduced variability in the measurement data for the inverted greyscale bones black lateral cephalometric radiograph group could indicate that certain landmarks are more reproducible when using this image format. This may be due to the improvement in contrast that occurs when inverting the greyscale or perhaps rendering the anatomical structures as 'positive' which may be easier to identify by the human eye.

Cephalometetric imaging formats have been investigated widely and it has been noted that only minor differences exist in the reproducibility of landmarks and measurement data when comparing analogue film, monitor-displayed digital images, and laser printer images of cephalograms (Geelen *et al.*, 1998). It would be interesting to determine if laser printer images of inverted greyscale cephalometric radiographs were also associated with a similar level of precision in relation to the eventual measurement data that is produced in cephalometric analysis.

All studies are associated with bias that can influence the results. In this study, bias may have contributed to the results from the original cohort of subjects and the cephalometric analysis that was selected. Although the cohort of subjects were a consecutive series of referred patients, because they were referred to a university orthodontic clinic, it is likely that they represented the extremes of malocclusion and therefore were relatively heterogeneous. This explains the level of variability in the measurements which was higher than desirable. The cephalometric analysis selected comprised exclusively angles and no linear distance measurements or ratios were included because linear distance measurements are influenced by magnification of individual cephalograms (McIntyre and Mossey, 2003). Nevertheless, it is unlikely that including these would have any effect on the final results of this study.

Conclusion

Measurements made using conventional negative bones white and inverted greyscale bones black lateral cephalometric radiographs have a similar level of precision.

References

Battagel J M 1993 A comparative assessment of cephalometric errors. European Journal of Orthodontics 15: 305–314

Baumrind S, Frantz R 1971a The reliability of head film measurements. 1. Landmark identification. American Journal of Orthodontics 60: 111–117

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

Chen S K, Chen Y J, Yao C C, Chang H F 2004 Enhanced speed and precision of measurement in a computer-assisted digital cephalometric analysis system. Angle Orthodontist 74: 501–507

Chen Y J, Chen S K, Chang H F, Chen K C 2000 Comparison of landmark identification in traditional versus computer-aided digital cephalometry. Angle Orthodontist 70: 387–392

Cohen A M 1984 Uncertainty in cephalometrics. British Journal of Orthodontics 11: 44–48

Dahlberg A G 1940 Statistical methods for medical and biological students. Bradford and Dickens, London

Geelen W, Wenzel A, Gotfredsen E, Kruger M, Hansson L G 1998 Reproducibility of cephalometric landmarks on conventional film, hardcopy, and monitor-displayed images obtained by the storage phosphor technique. European Journal of Orthodontics 20: 331–340

Gravely J F, Benzies P M 1974 The clinical significance of tracing error in cephalometry. British Journal of Orthodontics 1: 95–101

Haak R, Wicht M J 2005 Grey-scale reversed radiographic display in the detection of approximal caries. Journal of Dentistry 33: 65–71

Hagemann K, Vollmer D, Niegel T, Ehmer U, Reuter I 2000 Prospective study on the reproducibility of cephalometric landmarks on conventional and digital lateral headfilms. Journal of Orofacial Orthopedics 61: 91–99

Houston W J B 1983 The analysis of errors in orthodontic measurements. American Journal of Orthodontics 83: 382–390

Houston W J B, Maher R E, McElroy D, Sherriff M 1986 Sources of error in measurements from cephalometric radiographs. European Journal of Orthodontics 8: 149–151

Jackson P H, Dickson G C, Birnie D J 1985 Digital image processing of cephalometric radiographs: A preliminary report. British Journal of Orthodontics 12: 122–132

Kamoen A, Dermaut L, Verbeeck R 2001 The clinical significance of error measurement in the interpretation of treatment results. European Journal of Orthodontics 23: 569–578

Kheddache S, Månsson L G, Angelhed J E, Denbratt L, Gottfridson B, Schlossman D 1991 Digital chest radiography: should images be presented in negative or positive mode? European Journal of Radiology 13: 151–155

Lim K F, Foong K W 1997 Phosphor-stimulated computed cephalometry: reliability of landmark identification. British Journal of Orthodontics 24: 301–308

McIntyre G T, Mossey P A 2002 The craniofacial morphology of the parents of children with orofacial clefting: a systematic review of cephalometric studies. Journal of Orthodontics 29: 23–29

McIntyre G T, Mossey P A 2003 Size and shape measurement in contemporary cephalometrics. European Journal of Orthodontics 25: 231–242

Ongkosuwito E M, Katsaros C, van 't Hof M A, Bodegom J C, Kuijpers-Jagtman A M 2002 The reproducibility of cephalometric measurements: a comparison of analogue and digital methods. European Journal of Orthodontics 24: 655–665

Richardson A 1966 An investigation into the reproducibility of some points, planes and lines used in cephalometric analysis. American Journal of Orthodontics 52: 637–651

Silveira H, Silveira H 2006 Reproducibility of cephalometric measurements made by three radiology clinics. Angle Orthodontist 76: 394–399

Turner P J, Weerakone S 1993 An evaluation of a hypertext system for computer-assisted learning in orthodontics. British Journal of Orthodontics 20: 145–148

Whaites E 2002 Essentials of dental radiography and radiology. Churchill-Livingstone, London