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Picture archiving and communications systems: a study of reliability of orthodontic cephalometric analysis

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SUMMARY The objectives of this study were to investigate the possibility of using a picture archiving and communications system (PACS) for basic chairside cephalometric analysis and to compare PACS with hand-tracing and on-screen digitization using a commercial program (Dolphin Imaging Plus™ Version 10.0). One hundred digital lateral cephalometric radiographs were selected and analysed using the Eastman analysis. Angular and linear measurements were recorded and a single operator traced each radiograph twice, using each of the following methods: PACS, hand-tracing, and Dolphin™ Imaging. The British Standards Institution Coefficient of Repeatability was used to investigate repeatability within each method and the Bland and Altman method to investigate systematic and random errors between methods.

The PACS was more repeatable than Dolphin™ for measuring the angle between the upper incisors and the maxillary plane but was less repeatable than hand-tracing for measuring percentage lower anterior face height (LAFH). There were statistically significant systematic differences between PACS, hand-tracing, and Dolphin™ for measurement of lower incisor inclination. However, all three methods agreed, on average, and differences between methods were all within clinically acceptable limits.

PACS was found to be clinically acceptable to be used chairside, without the need for hand-tracing or involvement of any orthodontic software. This offers the freedom to analyse digital cephalograms within a clinical area at the same appointment as when the digital radiograph is taken.

Introduction

The picture archiving and communications system (PACS) is a computer network system that is dedicated to support digital radiography. This program allows conversion of digital radiographs into images that can be centrally stored within an electronic database. Apart from data management and storage, PACS also allows the freedom to manipulate and enhance digital images using assistance tools, e.g. adjusting contrast and magnification, and to undertake measurements using the digital protractor for angular measurements and the digital ruler for linear measurements. These measurements can be carried out directly from the digital image displayed on-screen.

Cephalometric studies have found little or no differences between hand-tracing and direct digitization of radiographs, and the facility to enhance digital images does not appear to produce any significant improvements in precision of landmark identification (Richardson, 1981; Sandler, 1988; Oliver, 1991). However, these studies were carried out almost two decades ago and since then, improved versions of orthodontic computer software are now available on the market. This is supported by the results of more recent studies, which found digitizing to be as reliable as hand-tracing (Power *et al.*, 2005; Celik *et al.*, 2009; Polat-Ozsoy *et al.*, 2009). Although there is still no general agreement to suggest a superior method for cephalometric analysis, there has been a shift towards computer digitizing. This is largely a result of advances in technology and the move towards a paperless office, with digital radiography becoming more prevalent and hand-tracing thus being less appealing.

Orthopaedic surgeons first recognized the potential of using PACS for angular and linear measurements of rotated femurs, tibias, and dislocated patellae (Sanfridsson, 2001). They compared measurement techniques using PACS and conventional radiographic films and found that measuring with PACS proved to be reliable. Therefore, with the introduction of PACS, orthodontists may be able to perform a basic cephalometric analysis without the need for hand-tracing or additional computer software. Furthermore, as digital radiographs can be recalled using the PACS program on a computer in the clinical environment, clinicians are able to analyse cephalograms without having to transfer them to a computer in a non-clinical area. The purpose of this study was to investigate the reliability of PACS for chairside cephalometric analysis and to compare PACS with hand-tracing and on-screen digitization (using Dolphin Imaging Plus™ Version 10.0, Chatsworth, California, USA).

Materials and methods

Sample selection

Ethical approval was obtained from the Mid and South Buckinghamshire Ethics Committee prior to commencement of the project. One hundred digital cephalograms of orthodontic patients were selected, all of which were taken using the same machine (Planmeca Proline PM 2002 CC, Planmeca, Helsinki, Finland) and stored on PACS (GE Medical Systems, Little Chalfont, Buckinghamshire, UK) as DICOM files. All selected radiographs fulfilled the following acceptance criteria: in occlusion when the radiograph was taken; no unerupted or partially erupted teeth hindering incisal apex identification; no craniofacial anomalies; no history of any facial surgery; not undergoing fixed appliance treatment at the time the radiograph was taken.

Measurements

The design of the study is shown in Figure 1. Cephalometric analysis was carried out using the Eastman analysis (Mills, 1987). Cephalometric landmarks were first identified and angular measurements and ratios were then calculated (Table 1). A single operator (S.S.W.T.) analysed each radiograph using three methods: on-screen digitization with PACS, hand-tracing, and on-screen digitization with Dolphin Imaging Plus™. All radiographs were digitized twice, 1 month apart with no more than 10 radiographs measured in any one session.

Analysis using PACS

Each radiograph was recalled from the PACS database via a web-based interface (Centricity Enterprise Web V3.0 GE Medical systems; Figure 2). The radiograph was then displayed on a standard computer screen and the Eastman analysis was undertaken using the measuring tools available on PACS. Following landmark identification, the digital protractor calculated the angular measurements and these values were automatically displayed on-screen. The Cobb angle digital protractor was also used in subjects with a low maxillary mandibular plane angle (MMPA) where the intersection between the two lines occurred beyond the edge of the image (Figure 3). Linear measurements were carried out automatically using the digital ruler and this figure was also displayed on-screen (Figure 3). Auxiliary tools were used to allow adjustment of brightness, contrast, and magnification when necessary.

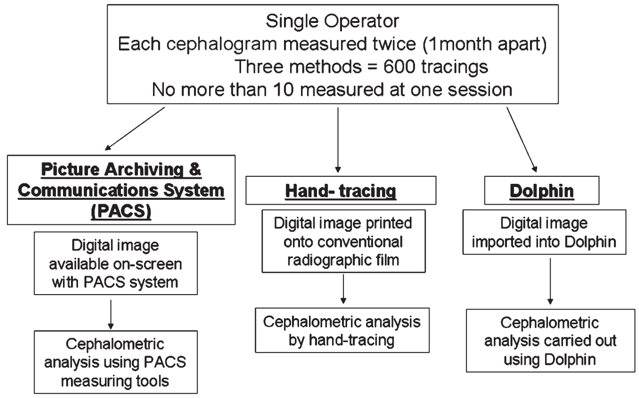

Figure 1 A schematic representation of the study design.

Table 1 The cephalometric measurements used in the study

Cephalometric measurements	Description
Sella–nasion–point A (SNA)	Angle formed between the sella (S)–nasion (N) line and point (A).
Sella–nasion–point B (SNB)	Angle formed between the S–N line and point B (B).
Maxillary mandibular plane angle (MMPA)	Angle formed between the maxillary plane (Mx) and mandibular plane (Md).
Upper incisor to maxillary plane (IMx)	Angle formed between the upper incisor long axis and the Mx.
Lower incisor to mandibular plane (LIMd)	Angle formed between the lower incisor long axis and the Md.
Percentage lower anterior face height (%LAFH)	Ratio of lower anterior face height and total anterior face height.

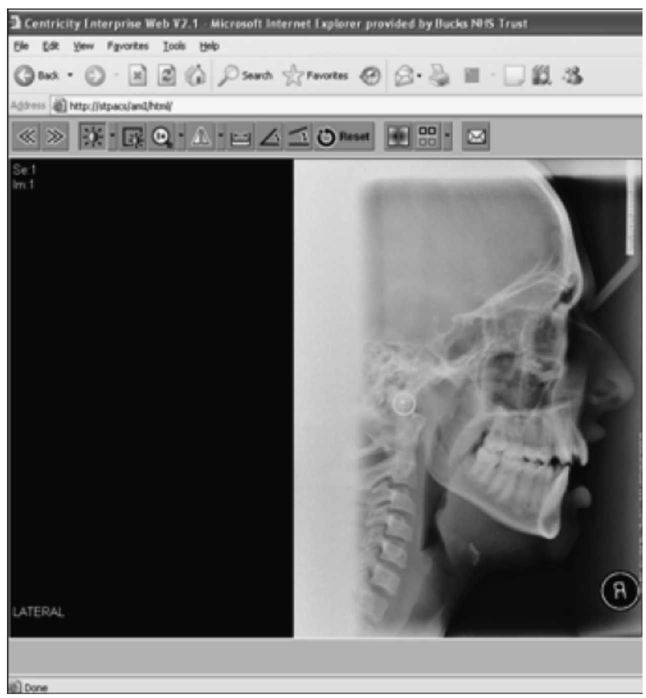

Figure 2 A cephalogram displayed on-screen using the picture archiving and communications system.

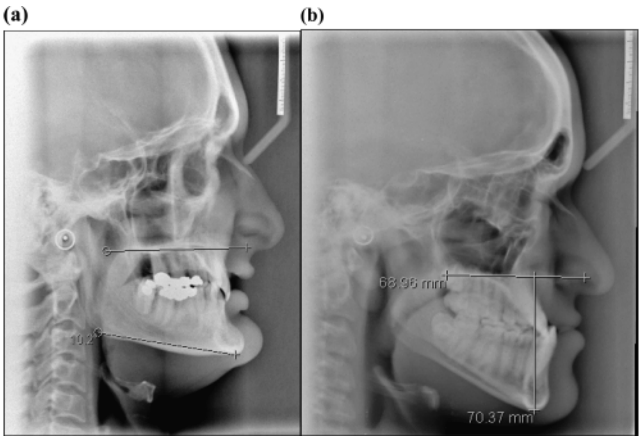

Figure 3 Using the picture archiving and communications system to measure (a) maxillary mandibular plane angle with the Cobb angle protractor and (b) lower anterior face height with the digital ruler.

Hand-tracing

The digital images were extracted from PACS using Kodak Master software and printed on single-sided emulsion Kodak Dryview Laser Imaging film using a Kodak Dryview 8900 printer (Kodak UK, Hemel Hempstead, Hertfordshire, UK). The images were printed in the original quality with no adjustments undertaken to improve diagnostic quality. Hand-tracing was carried out in a darkened room on a well-illuminated viewing box. The radiographs were orientated with the Frankfort plane as a horizontal reference and an acetate sheet was placed over the film; a clear Perspex protractor and ruler were used for landmark identification and measurements.

Analysis using Dolphin™

The digital cephalometric radiographs obtained from PACS were saved as JPEG images in their original quality and form. The radiographs were then imported into Dolphin Imaging Plus™ and digitized on a standard computer screen using the Dolphin cephalometric tracing and analysis program. When necessary, the digital images were enhanced or enlarged to aid landmark location.

Clinically acceptable limits

In order to make this study relevant to clinical practice, clinically acceptable limits (CALs) were set prior to analysis of the data (Table 2). As the Eastman standards are widely used in clinical practice, CAL were set based on these standards and calculated using the British Standards Institution Coefficient of Repeatability (CR) formula (Bland and Altman, 1986):

$$\text{CAL} = \text{Eastman analysis standard deviation} \times 1.96 \text{ (rounded to 2.00)}$$

Table 2 Clinically acceptable limits (CAL) set *a priori* (with respect to Eastman standards)

Parameters	Eastman analysis standard deviation (degrees)	CAL (degrees)
SNA	±3	±6
SNB	±3	±6
MMPA	±4	±8
UIMx	±6	±12
LIMd	±6	±12
%LAFH	±2%	±4%

Statistical methods

Statistical analysis was undertaken using Stata Version 10.0 (StataCorp, College Station, Texas, USA). Initially, a repeatability study was carried out for each method using the standard deviations of the differences between two measurements. The British Standards Institution CR was calculated to indicate the maximum difference likely to occur between two measurements for a single method on 95 per cent of observations. The CR were then compared to investigate the repeatability between methods and tested for statistical significance using the variance ratio test (Petrie and Watson, 1999). Systematic errors were calculated using the paired *t*-test (Petrie and Watson, 1999) and the Bland and Altman method was applied to calculate the 95 per cent limits of agreement (Bland and Altman, 1986).

Results

All three methods showed clinically acceptable repeatability (Table 3). There were statistically significant differences in repeatability for four of the six parameters when comparing hand-tracing and Dolphin™. Hand-tracing was significantly better for upper incisor inclination to maxillary plane (UIMx) and lower anterior face height (%LAFH); Dolphin™ was significantly better for the angle formed between sella, nasion, and point B (SNB) and for the maxillary mandibular planes angle (MMPA); there was no significant difference in repeatability for the angle formed between sella, nasion, and point A (SNA) or for lower incisor inclination to the mandibular plane (LIMd). There were no statistically significant differences between hand-tracing and PACS for any of the angular measurements. However, hand-tracing was found to be more repeatable when calculating %LAFH and this was statistically significant. Dolphin™ was found to be statistically more repeatable than PACS when measuring UIMx.

Table 4 shows the systematic errors between the three different methods. There were no statistically significant systematic errors for any of the angular measurements between hand-tracing and Dolphin™. However, hand-tracing tended to underestimate %LAFH by an average of

Table 3 Comparison of repeatability (CR) between handing-tracing, Dolphin ™, and the picture archiving and communications system (PACS)

Parameters	Hand-tracing versus Dolphin™			Hand-tracing versus PACS			Dolphin™ versus PACS		
	CR		*P* value from variance ratio test	CR		*P* value from variance ratio test	CR		*P* value from variance ratio test
	Hand-tracing	Dolphin™		Hand-tracing	PACS		Dolphin™	PACS	
SNA	3.49	3.70	0.549	3.49	3.15	0.315	3.70	3.15	0.109
SNB	3.08	***2.42***	**0.016**	3.08	2.56	0.038	2.42	2.56	0.559
MMPA	4.93	***3.67***	**0.004**	4.93	4.27	0.154	3.67	4.27	0.135
UIMx	***4.61***	7.84	**<0.001**	4.61	5.51	0.075	7.84	***5.51***	**0.001**
LIMd	7.93	7.27	0.391	7.93	6.83	0.139	7.27	6.83	0.534
%LAFH	***1.69***	2.20	**0.009**	***1.69***	2.34	**0.001**	2.20	2.34	0.546

Statistically significant values and the method with the lowest (i.e. best) CR are italicized and in bold. $P < 0.05$ denotes significance.

Table 4 Systematic errors between handing-tracing, Dolphin ™, and the picture archiving and communications system (PACS)

Parameters	Hand-tracing versus Dolphin™		Hand-Tracing versus PACS		Dolphin™ versus PACS	
	Systematic error		Systematic error		Systematic error	
	Mean difference	*P* value from paired *t*-test	Mean difference	*P* value from paired *t*-test	Mean difference	*P* value from paired *t*-test
SNA	−0.39	0.076	−0.78	**<0.001**	−0.39	0.040
SNB	0.05	0.788	0.19	0.233	0.15	0.184
MMPA	0.18	0.365	0.61	**0.002**	0.43	0.052
UIMx	−0.39	0.198	0.32	0.229	0.70	0.054
LIMd	0.20	0.618	−2.60	**<0.001**	−2.80	**<0.001**
% LAFH	−0.26	**0.025**	−0.01	0.973	0.26	0.033

Statistically significant values are in bold.

0.26 per cent in comparison with Dolphin™. A comparison of hand-tracing and PACS showed more statistically significant systematic errors. Hand-tracing underestimated SNA and overestimated MMPA compared with PACS, although these differences were on average less than 1 degree. When measuring LIMd, hand-tracing underestimated the measurement by almost 2.60 degrees on average compared with PACS. Dolphin™ was found to underestimate LIMd by 2.80 degrees on average compared with PACS.

The limits of agreement calculated using the Bland and Altman method were all within CALs (Table 5).

Discussion

There are many different methods of analysing cephalograms ranging from basic hand-tracing to more complex techniques involving orthodontic computer software. With the increasing use of digital radiography, manual tracing necessitates an extra step to print digital images onto conventional film and this is time-consuming and expensive. Orthodontic computer software has become increasingly popular amongst maxillofacial surgeons and orthodontists and imaging systems such as Dolphin™ are now widely used in many units (Power *et al.*, 2005). However, there is clearly an added cost associated with the purchase and upkeep of the software as well as the additional step of having to transfer digital images from the radiographic database into the computer program itself.

PACS is part of the digital radiography package that supports digital technology, and measuring tools are already incorporated in every computer with PACS. Therefore, there is no need for additional computer software and there is no extra step needed to facilitate the transfer of the digital images. Furthermore, any computer with PACS in a clinical environment can be used to analyse the cephalogram, hence chairside analysis is a viable option.

Table 5 Limits of agreement between handing-tracing, Dolphin ™, and the picture archiving and communications system (PACS)

Parameters	Hand-tracing versus Dolphin™				Hand-tracing versus PACS				Dolphin™ versus PACS			
	Systematic error	Random error	Bland and Altman (systematic + random error)		Systematic error	Random error	Bland and Altman (systematic + random error)		Systematic error	Random error	Bland and Altman (systematic + random error)	
	Mean difference	Standard deviation of differences	Lower limit	Upper limit	Mean difference	Standard deviation of differences	Lower limit	Upper limit	Mean difference	Standard deviation of differences	Lower limit	Upper limit
SNA	−0.39	2.17	−4.65	3.87	−0.78	2.03	−4.75	3.19	−0.39	1.87	−4.06	3.28
SNB	0.05	1.67	−3.23	3.32	0.19	1.58	−2.92	3.30	0.15	1.08	−1.98	2.27
MMPA	0.18	1.98	−3.70	4.06	0.61	1.87	−3.05	4.26	0.43	2.16	−3.82	4.67
UIMx	−0.39	2.99	−6.25	5.48	0.32	2.60	−4.78	5.41	0.70	3.61	−6.37	7.78
LIMd	0.20	4.00	−7.63	8.03	−2.60	3.28	−9.03	3.83	−2.80	3.56	−9.78	4.18
%LAFH	−0.26	1.16	−2.53	2.00	−0.01	1.17	−2.29	2.28	0.26	1.20	−2.09	2.60

Repeatability within methods

The challenge with cephalometric studies is that there is no gold standard for angular and linear measurements; therefore, it is impossible to determine whether a particular method is accurate. Instead, an error study reporting results of replicate measurements should accompany every cephalometric investigation (Houston, 1983).

The file types employed in this study were those routinely used for the computer systems being tested (i.e. a DICOM format for PACS and JPEG images for Dolphin). It does have to be borne in mind when considering the results that DICOM images are of a higher quality than JPEGs, however, it was felt to be appropriate to use the file type most commonly used with the individual systems.

All three methods produced CR that was within the CALs set *a priori*. For SNA and SNB, all three methods produced CR that were below the Eastman analysis standard deviations (±3.0 degrees). PACS had the lowest CR when measuring SNA (3.15 degrees). However, for both hand-tracing and Dolphin™, the values were on average only 0.20–0.40 degrees higher than for PACS and this would not be clinically relevant (Table 3).

For MMPA, Dolphin™ had the lowest CR (3.67 degrees) and hand-tracing the highest (4.93 degrees). This may be due to measurement errors during calculation of MMPA. For example, radiographs of patients with a low MMPA are more difficult to measure by hand due to the necessity to project the planes involved and then measure the angle and this may explain the lower repeatability for MMPA with hand-tracing. In digitized systems such as Dolphin™ and PACS, the MMPA is automatically calculated by the software, thereby reducing measurement errors.

The CRs for all three methods were comparatively higher for LIMd than for the other parameters, although still within the CAL set at the start of the study. The task of identifying lower incisor root apices is difficult because the landmark is often confounded by 'noise' from adjacent structures and the location is said to be uncertain in 75 per cent of cases (Baumrind and Frantz, 1971; Sayinsu *et al.*, 2007). In this study, PACS showed the highest, and manual tracing the lowest, repeatability. This lower repeatability for hand-tracing may be due to the lower incisor apex being more difficult to visualize through the tracing paper (Sandler, 1988).

PACS had the highest CR for %LAFH at 2.34 per cent; however, this was only 0.2 per cent higher than Dolphin™. This may be due to errors that occur during line construction for measurement of face height. When measuring upper anterior face height using PACS, the operator must 'eyeball' the 90 degree angle formed between nasion and the maxillary plane because PACS does not incorporate measuring tools for this function. Similarly, LAFH was determined by eyeballing the 90 degree angle formed between the maxillary plane and menton. In comparison, hand-tracing allows the 90 degree tangents to be placed more reliably using a protractor, and with Dolphin™ the software automatically calculates the %LAFH, hence any operator errors involving line construction or mathematical calculations are reduced. The use of the digital protractor simultaneously with the digital ruler may make this measurement easier.

Comparing repeatability between methods

Hand-tracing versus Dolphin™ There were statistically significant differences in repeatability for four of the six parameters when comparing hand-tracing and Dolphin™. However, there was no clear pattern since hand-tracing was superior for two parameters, Dolphin™ was superior for two, and for the remaining two, there was no evidence of a difference between the methods. This was in contrast with another study which found that measurements using both manual tracing and Dolphin™ highly correlated with each other, but it must be noted that the study by Sayinsu *et al.* (2007) utilized conventional films rather than digital images.

Hand-tracing has often been criticized due to the errors produced during line construction and measurement of distances and angles (Baumrind and Frantz, 1971). However, in the present study, there were only two parameters where hand-tracing was less repeatable than Dolphin™ (SNB and MMPA). Dolphin™ was less repeatable than hand-tracing for %LAFH and UIMx; the difference for UIMx may be due to the relatively large cursor obscuring those peripheral structures that aid landmark identification, thereby making visualization more difficult (Sandler, 1988).

Digitized systems have an added advantage in that line construction and calculations are incorporated within the software, and in this study Dolphin™ was more repeatable when measuring SNB and MMPA. This is in agreement with other research (Oliver, 1991; Power *et al.*, 2005) but their results should be interpreted with caution because neither of the studies tested for statistical significance in their findings.

When calculating %LAFH, hand-tracing produced more statistically repeatable results (CR 2.20 per cent for Dolphin™ and 1.69 per cent for hand-tracing). Interestingly, a similar study found that Dolphin™ had a higher standard deviation of the differences (1.18 per cent) compared with hand-tracing (1.13 per cent); although the differences were very small and as mentioned earlier, their results were not tested for statistical significance (Power *et al.*, 2005). In addition, Power *et al.* (2005) used a different version of the Dolphin™ software that may have influenced the results.

Hand-tracing versus PACS This study found no statistically significant differences between hand-tracing and PACS for any of the angular measurements, suggesting that PACS is as repeatable as hand-tracing for angular measurements. This is in contrast with another study which concluded that monitor displayed images had a lower precision than hand-tracing (Geelen *et al.*, 1998).

The only statistically significant difference between PACS and hand-tracing in the current study was for %LAFH. PACS was found to be less repeatable than hand-tracing, although again by a relatively small amount (CR = 2.34 per cent for PACS and 1.69 per cent for hand-tracing).

Dolphin™ versus PACS Only one of the six parameters showed statistically significant differences between PACS and Dolphin™. Dolphin™ was found to be statistically less repeatable than PACS for measuring UIMx. A previous study suggested that Dolphin™ was less repeatable for UIMx because of the cursor design, which may hinder upper incisor apex location (Power *et al.*, 2005). The cursor design used in PACS is different from that used in Dolphin™ (Figure 4) and this may explain their differences.

Systematic errors

Hand-tracing versus Dolphin™ There were no statistically significant systematic errors between manual tracing and Dolphin™ for any of the angular measurements and these findings were in agreement with a similar study (Power *et al.*, 2005). For %LAFH, there was a statistically significant finding, with hand-tracing underestimating the values relative to Dolphin™, but only by 0.26 per cent.

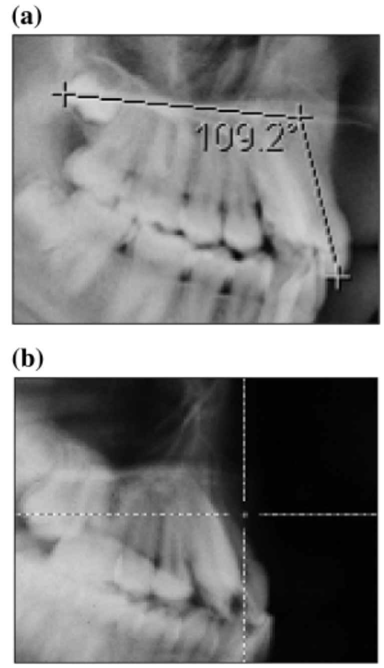

Figure 4 The cursor design for (a) picture archiving and communications system and (b) Dolphin™.

Hand-tracing versus PACS Comparison of hand-tracing and PACS showed statistically significant systematic errors for three parameters. PACS was found to overestimate SNA by 0.78 degrees compared with hand-tracing, but this is unlikely to be clinically relevant. For landmarks that had a smaller range of location, i.e. nasion, the cursor design for PACS was found to be relatively larger compared with the landmark location itself, and this may hinder landmark location. Therefore PACS may have been systematically locating nasion more anteriorly.

A similar situation was found during measurement of LIMd; PACS overestimated this by 2.60 degrees compared with hand-tracing and this may be for the same reasons. Again, it is unlikely to be of clinical relevance, although the values were greater than for SNA.

Dolphin™ versus PACS Of the six parameters measured, only LIMd showed statistically significant systematic differences. As explained previously, it was more difficult to use the cursor design in the PACS system when identifying landmarks with a smaller range of location such as the lower incisal edge. Although these errors were larger (2.80 degrees) compared with other parameters, a discrepancy of this magnitude is unlikely to have major clinical implications.

Assessing agreement

For the Bland and Altman 95 per cent limits of agreement, all three methods were within the CAL set *a priori*. Hence, it may be concluded that all three methods agree on average and any of the three methods is acceptable for clinical use. However, there are advantages and disadvantages to each method and no single method was easier or better to use than the other.

Without taking into account the time needed to develop conventional films, the time taken for hand-tracing was longer and this procedure was more tedious compared with computer-assisted cephalometric analysis. This is in agreement with another study which found that the mean tracing time for Dolphin™ was 2 minutes 41 seconds compared with 6 minutes 51 seconds for manual tracing (Uysal *et al.*, 2009).

Furthermore, accuracy and precision of landmark identification are important because variability in landmark identification is five times greater than variability in measurement (Miller *et al.*, 1966). Both PACS and Dolphin™ can enhance images and magnify cephalometric landmarks which may reduce errors in landmark identification, although earlier research cast doubt on whether enhancement of digital images significantly improved the precision of landmark identification (Richardson, 1981; Sandler, 1988; Oliver, 1991). However, the cursor designs for both digitized systems are not yet ideal and some landmarks were harder to identify with the digitized systems compared with hand-tracing.

The added advantage of digitized systems is the ability to store all information electronically and Dolphin™ permits the operator to review identified landmarks at a later date and edit their positions (Forsyth *et al.*, 1996).

Conclusion

1. All three methods were clinically acceptable for undertaking chairside analysis. However, care must be taken when measuring LIMd using any of the methods as LIMd was found to be less repeatable compared with other parameters.
2. For the majority of measurements, this study found no significant differences in the repeatability of PACS, hand-tracing, and Dolphin™. PACS was less repeatable than hand-tracing for %LAFH but more repeatable when measuring UIMx compared with Dolphin™.
3. There were some statistically significant systematic errors, although these were relatively small. It may be that these systematic errors are due to the cursor design in the PACS measuring tools.
4. PACS offers the freedom and ease of use for clinicians to analyse the digital image chairside at the same appointment as when the digital radiograph is captured. This may potentially combine the diagnostic and treatment planning appointments into one visit and could save time, money, and improve patient experience.

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