*European Journal of Orthodontics* 31 (2009) 523–528
*doi:10.1093/ejo/cjp022*
*Advance Access Publication 14 May 2009*


# Evaluation of speed, repeatability, and reproducibility of digital radiography with manual versus computer-assisted cephalometric analyses

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SUMMARY The aims of this study were to evaluate intra-examiner repeatability and inter-examiner reproducibility of landmarks using two cephalometric analysing techniques, manual and computerized, and to compare these for speed. One hundred lateral cephalometric radiographs were randomly selected and 11 angular and six linear parameters were traced and measured by two examiners using the manual method and Dolphin Image Software 9.0 on each radiograph. A Student's *t*-test for paired and independent samples was used to compare the mean values of intra- and inter-examiner differences. Intraclass correlation coefficients (ICC) were calculated to determine intra- and inter-examiner correlation (*r* value).

Both operators were generally consistent in the repeated measurements; however, for one examiner, the differences for Na⊥A ($P < 0.001$), Na⊥Pog, and U1–NA ($P < 0.01$) distance measurements were found to be statistically significant. Intra-examiner repeatability of landmarks both with the manual and Dolphin techniques showed high correlation coefficients. While inter-examiner reproducibility of landmarks was unacceptable, measurement errors with the manual technique were generally comparable with the Dolphin technique. The mean tracing times of the two operators for a single tracing was 2 minutes 41 seconds for Dolphin and 6 minutes 51 seconds for manual tracings. Computer-assisted cephalometric analysis does not increase intra- and inter-examiner reliability but can result in time saving.

## Introduction

For interpretation of the changes in hard and soft tissues due to growth or treatment, patients' records at different time periods must be taken. Recently, three-dimensional (3D) images or computerized analysis has become popular in orthodontics. Although 3D images seem to provide more realistic/accurate data, these systems are expensive and cannot yet be used widely in orthodontics. Since the introduction of cephalometry (Broadbent, 1931), lateral cephalograms are normally taken for all orthodontic patients, and diagnosis, treatment plans, and treatment outcomes have been undertaken based on these radiographs.

The most common technique for cephalometric analysis is the manual technique. An acetate sheet is placed over the cephalometric radiograph and measurements are recorded of the distances and angles between cephalometric landmarks with a ruler and protractor. However, this technique is time consuming (Liu *et al.*, 2000) and cephalometric errors are not uncommon (Chen *et al.*, 2004a).

Landmark identification is the main source of error in the manual technique (Baumrind and Frantz, 1971a; Mitgård *et al.*, 1974; Houston, 1983; Houston *et al.*, 1986). It can depend on visual performance, training, and experience of the clinician, and the density and sharpness of the image (Björk and Solow, 1961). Other reproducibility errors are caused by image acquisition and measurement errors. Acquisition errors are dependent on the errors during exposure or computer processing of cephalometric radiographs (Onkosuwito *et al.*, 2002), while measurement errors are due to faulty measuring devices or the technique itself (Onkosuwito *et al.*, 2002).

Another technique is computer aided; the landmarks are located manually and the computer system completes the analysis. Computer-aided cephalometric analysis can eliminate errors such as those during drawing the lines with a ruler and measuring the angles with a protractor (Liu *et al.*, 2000). In computerized cephalometric analysis if landmarks are determined by hand, measurement errors are similar to the manual technique (Gravely and Benzies, 1974). Chen *et al.* (2000) demonstrated the statistical difference in landmark identification between original cephalometric films and their digitized counterparts.

The aims of this study were to evaluate intra-examiner repeatability and inter-examiner reproducibility of landmarks between two cephalometric analysing techniques, manual and computerized, and to compare the techniques for speed.

## Materials and Methods

One hundred lateral cephalometric radiographs taken with an Orthopantomograph® (OP100, Instrumentarium, Tuusula, Finland), were randomly obtained from the active orthodontic patient files at the Department of Orthodontics, Erciyes University. All subjects had been positioned in the cephalostat with the sagittal plane at right angles to the path of the X-rays, the Frankfort plane parallel to the floor, the teeth in centric occlusion, and the lips lightly together. Exclusion criteria were unerupted or missing teeth, periapical pathology, including incisor apices, and poor quality films.

The selected radiographs were traced manually on acetate sheets by two operators (AB and AY) with a 0.35 mm drawing pen and a tracing kit (No.075-400-01 Dentaurum, Ispringen, Germany) on a standard light box in a darkened room. Bilateral structures were averaged to make a single structure or landmark. All measurements were carried out manually and entered into an Excel (Microsoft, Seattle, Washington, USA) spread sheet for statistical evaluation.

The radiographs were then scanned into digital format at 300 dpi, 24 bit, using an Epson 1680 Pro scanner. The digital radiographs were traced by the same two operators (AB and AY) using Dolphin Image Software 9.0 (Dolphin Imaging and Management Solutions, Los Angeles, California, USA). Landmark identification was carried out manually on digital images using a mouse-driven cursor. Twenty-eight hard and 15 soft tissue landmarks were digitized. Four fiducial points were also digitized using the Dolphin Imaging's custom cephalometric landmark function. Image enhancements, including brightness, contrast, and magnification, were used as required to identify individual landmarks as precisely as possible. All measurements were carried out automatically by the software.

Eleven angular and six linear parameters were measured on each radiograph (Figure 1).

To determine intra-examiner repeatability, 30 radiographs from the original 100 were randomly selected and retraced and remeasured by the same authors, using both the manual and digital tracing techniques, 2 weeks after the first tracings.

To determine the time taken using both techniques, the tracing time was determined with a digital chronometer and recorded. The mean tracing time for each method was calculated by dividing the total time by the total number of tracings.

### *Statistical analysis*

All statistical analyses were performed using the Statistical Package for Social Sciences Windows, version 10.1 (SPSS Inc., Chicago, Illinois, USA). Statistical significance was set at $P < 0.05$. Means and standard deviations were calculated for all data. Paired Student's *t*-tests were used to compare the mean values between the first and second measurements. A Student's *t*-test for independent samples was used to compare the mean values of intra- and inter-examiner differences. Intraclass correlation coefficients (ICC) were calculated to determine intra- and inter-examiner correlation (*r* value).

## Results

The mean differences and standard deviations for each of the 17 measurements of the two examiners with the manual technique and Dolphin software program are shown in Table 1. When the two techniques were compared with respect to differences in the means, no statistically significant differences were found for the first examiner's measurements. For the second examiner, the differences for Na⊥A ($P < 0.001$), Na⊥Pog, and U1–NA ($P < 0.01$) distance measurements were statistically significant.

ICC (*r*) calculated to determine intra-examiner repeatability and inter-examiner reproducibility are shown in Tables 2 and 3. Parameters with the highest and lowest correlation for repeated measurements for the first examiner ranged from 0.518 to

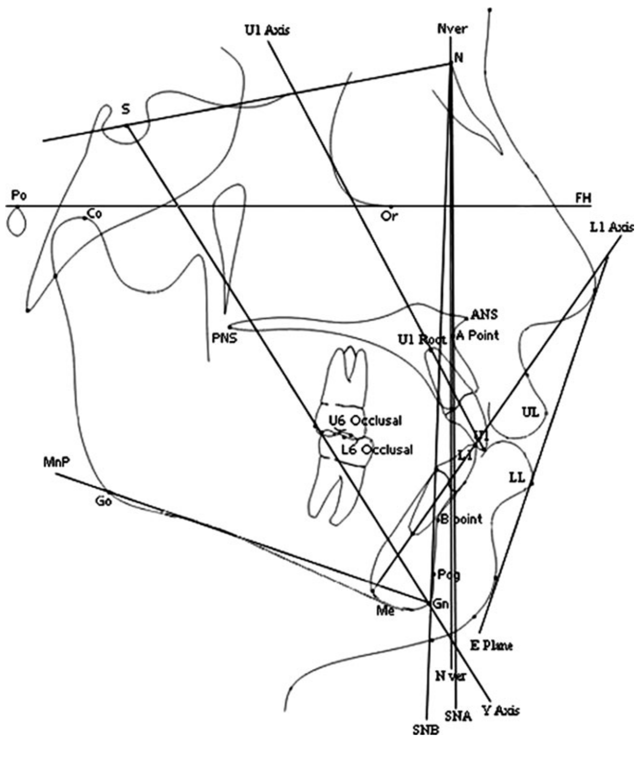


**Figure 1** Description of the measurements used in the study. SNA: angle formed between points S, N, and A; SNB: angle formed between points S, N, and B; ANB: angle formed between points A, N, and B; Na⊥A: perpendicular distance from point A to nasion perpendicular to Frankfort horizontal (FH) plane; Na⊥Pog: perpendicular distance from Pog to nasion perpendicular to FH plane; FMA: angle formed between the FH plane and the mandibular plane; FMIA: angle formed between the FH plane and the long axis of the lower incisor; SN–GoGn: angle formed between SN and GoGn planes; U1–NA (mm): perpendicular distance from the tip of the maxillary incisor to NA plane; U1–NA (º): angle formed by the intersection of the maxillary incisor axis to NA plane; IMPA: angle formed by the intersection of the mandibular incisor axis to mandibular plane; L1–NB (mm): perpendicular distance from the tip of the mandibular incisor to NB plane; L1–NB (º): angle formed by the intersection of the mandibular incisor axis to NB plane; interincisal angle: angle between the maxillary and mandibular incisor axis; nasolabial angle: angle formed between columella, subnasale, and the upper lip; E/LL: perpendicular distance from the lower lip to E plane; and E/UL: perpendicular distance from the upper lip to E plane.

**Table 1** Differences in cephalometric measurements ($n$ = 30) generated by manual and Dolphin cephalometric analysing methods by two examiners.

| Parameters | Examiner 1 | | | | | Examiner 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Conventional | | Dolphin | | Independent samples | Conventional | | Dolphin | | Independent samples |
| | Mean | SD | Mean | SD | *t*-test | Mean | SD | Mean | SD | *t*-test |
| SNA (degree) | 1.85 | 2.60 | 1.59 | 1.30 | ns | 0.98 | 0.80 | 0.99 | 0.70 | ns |
| SNB (degree) | 1.30 | 1.90 | 1.17 | 0.90 | ns | 0.73 | 0.50 | 0.67 | 0.65 | ns |
| ANB (degree) | 0.94 | 1.30 | 0.81 | 0.80 | ns | 0.60 | 0.80 | 0.89 | 0.70 | ns |
| Na⊥A (mm) | 2.35 | 3.50 | 1.10 | 1.10 | ns | 1.20 | 1.00 | 2.79 | 1.90 | *** |
| Na⊥Pog (mm) | 6.09 | 7.00 | 2.37 | 2.30 | ns | 1.64 | 1.90 | 3.88 | 3.40 | ** |
| FMA (degree) | 2.37 | 3.40 | 1.49 | 1.00 | ns | 3.15 | 2.50 | 2.62 | 2.30 | ns |
| FMIA (degree) | 4.60 | 8.90 | 2.28 | 2.00 | ns | 2.61 | 2.50 | 3.21 | 3.00 | ns |
| SN–GoGn (degree) | 2.00 | 2.60 | 1.47 | 0.90 | ns | 1.43 | 1.30 | 1.23 | 1.00 | ns |
| U1–NA (mm) | 1.78 | 2.60 | 1.20 | 1.20 | ns | 0.69 | 0.80 | 1.44 | 1.10 | ** |
| U1–NA (degree) | 2.71 | 2.90 | 2.71 | 1.70 | ns | 2.90 | 2.70 | 2.69 | 2.10 | ns |
| IMPA (degree) | 2.80 | 3.30 | 2.52 | 1.80 | ns | 2.75 | 2.00 | 1.94 | 1.80 | ns |
| L1–NB (mm) | 0.92 | 1.00 | 0.51 | 0.60 | ns | 0.79 | 0.80 | 0.52 | 0.50 | ns |
| L1–NB (degree) | 2.40 | 2.80 | 2.16 | 2.20 | ns | 2.16 | 2.20 | 2.01 | 1.70 | ns |
| Interincisal angle | 3.03 | 2.70 | 3.47 | 2.80 | ns | 3.46 | 3.30 | 3.36 | 2.20 | ns |
| Nasolabial angle | 7.70 | 9.30 | 3.18 | 3.70 | ns | 4.56 | 4.00 | 4.65 | 3.60 | ns |
| E/LL (mm) | 1.15 | 2.20 | 0.45 | 0.30 | ns | 0.49 | 0.40 | 0.46 | 0.40 | ns |
| E/UL (mm) | 1.43 | 3.30 | 0.62 | 0.50 | ns | 0.77 | 0.80 | 0.56 | 0.40 | ns |

ns, not significant; $^{**}P < 0.01$; $^{***}P < 0.001$.

**Table 2** Intraclass correlation coefficients calculated for intra-examiner repeatability.

| Parameters | Examiner 1 | | | Examiner 2 | | |
|---|---|---|---|---|---|---|
| | Manual first and second measurement ($n$ = 30) | Dolphin first and second measurement ($n$ = 30) | Manual/Dolphin ($n$ = 100) | Manual first and second measurement ($n$ = 30) | Dolphin first and second measurement ($n$ = 30) | Manual/Dolphin ($n$ = 100) |
| SNA (degree) | 0.657 | 0.816 | 0.705 | 0.942 | 0.940 | 0.632 |
| SNB (degree) | 0.792 | 0.901 | 0.766 | 0.967 | 0.970 | 0.681 |
| ANB (degree) | 0.745 | 0.879 | 0.797 | 0.899 | 0.899 | 0.803 |
| Na⊥A (mm) | 0.872 | 0.893 | 0.598 | 0.877 | 0.720 | 0.728 |
| Na⊥Pog (mm) | 0.880 | 0.821 | 0.483 | 0.861 | 0.600 | 0.596 |
| FMA (degree) | 0.712 | 0.946 | 0.784 | 0.663 | 0.855 | 0.648 |
| FMIA (degree) | 0.788 | 0.900 | 0.672 | 0.828 | 0.867 | 0.788 |
| SN–GoGn (degree) | 0.887 | 0.961 | 0.939 | 0.959 | 0.971 | 0.759 |
| U1–NA (mm) | 0.813 | 0.821 | 0.770 | 0.842 | 0.794 | 0.708 |
| U1–NA (degree) | 0.811 | 0.893 | 0.802 | 0.870 | 0.892 | 0.875 |
| IMPA (degree) | 0.787 | 0.896 | 0.873 | 0.885 | 0.946 | 0.849 |
| L1–NB (mm) | 0.822 | 0.924 | 0.947 | 0.831 | 0.950 | 0.821 |
| L1–NB (degree) | 0.758 | 0.873 | 0.582 | 0.886 | 0.926 | 0.857 |
| Interincisal angle | 0.876 | 0.882 | 0.897 | 0.869 | 0.914 | 0.898 |
| Nasolabial angle | 0.518 | 0.842 | 0.576 | 0.747 | 0.578 | 0.847 |
| E/LL (mm) | 0.917 | 0.979 | 0.786 | 0.971 | 0.974 | 0.890 |
| E/UL (mm) | 0.877 | 0.947 | 0.773 | 0.938 | 0.971 | 0.922 |

0.917 for conventional and 0.816 to 0.979 for Dolphin tracings and for the second examiner from 0.663 to 0.971 and 0.578 to 0.974, respectively. Inter-examiner correlation coefficients for the manual technique showed the highest value for interincisal angle ($r$ = 0.770) and the lowest value for Na⊥Pog (mm; $r$ = 0.365). For Dolphin tracings, the highest and lowest correlation coefficients were for L1–NB distance ($r$ = 0.727) and Na⊥Pog (mm; $r$ = 0.449) measurements, respectively.

To evaluate the consistency of the two techniques, manual tracing values were compared with digital tracings for both examiners (Table 3). The lowest and highest correlation coefficients ranged between 0.483 and 0.939 for the first and 0.596 and 0.922 for the second examiner.

Total and mean tracing times for each procedure of the manual and Dolphin cephalometric analyses for the two examiners are shown in Table 4.

## Discussion

Until recently, manual tracings have been considered to be the best method for accurate cephalometric analysis but advances in computer-assisted cephalometric analysing systems have resulted in their widespread use in orthodontic practice. According to Richardson (1981) and Sandler (1988), the manual tracing technique compares favourably with the results of digitized radiographs, and studies using manual methods could be considered perfectly valid. Generally with computerized cephalometric analyses, landmark identification can be carried out manually but with automatic landmark identification. In computerized cephalometric analysis, if the landmarks are determined by hand, measurement errors are no different from the manual technique (Gravely and Benzies, 1974). In the present study, landmark identification was carried out manually on digital images using a mouse-driven cursor and the measurements were determined automatically by the software.

**Table 3** Intraclass correlation coefficients (*r*) calculated for inter-examiner reproducibility.

| Parameters | Manual | Dolphin |
|---|---|---|
| SNA (degree) | 0.758 | 0.484 |
| SNB (degree) | 0.702 | 0.544 |
| ANB (degree) | 0.747 | 0.511 |
| Na⊥A (mm) | 0.458 | 0.498 |
| Na⊥Pog (mm) | 0.365 | 0.449 |
| FMA (degree) | 0.575 | 0.481 |
| FMIA (degree) | 0.534 | 0.661 |
| SN–GoGn (degree) | 0.723 | 0.545 |
| U1–NA (mm) | 0.625 | 0.548 |
| U1–NA (degree) | 0.645 | 0.599 |
| IMPA (degree) | 0.648 | 0.655 |
| L1–NB (mm) | 0.764 | 0.727 |
| L1–NB (degree) | 0.510 | 0.699 |
| Interincisal angle | 0.770 | 0.715 |
| Nasolabial angle | 0.473 | 0.464 |
| E/LL (mm) | 0.615 | 0.638 |
| E/UL (mm) | 0.432 | 0.539 |

If the films are scanned and transferred to digital format, as in this study, the quality of the original film is one of the most important criteria in the validity of the result (Sayinsu *et al.*, 2007). For scanning lateral cephalograms, it is suggested that 75 dpi is sufficient (Rogers, 2002; Held *et al.*, 2001). Chen *et al.* (2000) stated that digital cephalometrics could produce better results if digital images of 150 dpi, 8 bits were used; whereas in another study, 300 dpi resolutions was reported to be sufficient for clinical purposes and comparable with analogue cephalograms (Onkosuwito *et al.*, 2002). Macrì and Wenzel (1993) found a statistical difference in low-quality digital and low-quality original cephalograms and concluded that digital processing did not improve the overall reliability of landmark identification when poorer quality radiographs were used. In current study, high-quality films at a resolution of 300 dpi were used even though a lower resolution of 150 dpi is recommended by the software manufacturers because the landmarks are easier to identify. Magnification leads to a lack of clarity of the image and selecting a higher scanning dpi prevented this problem. However, high-resolution radiographs are disadvantageous in terms of larger file sizes.

When the two techniques were compared to determine differences between the first and second measurements, no statistically significant differences were found for the first examiner whereas for the second examiner, Na⊥A ($P < 0.001$), Na⊥Pog, and U1–NA ($P < 0.01$) distance measurements were statistically significant. All these measurements were based on nasion localization and the differences may be due to difficulty in identification at this point. Several studies have shown that inconsistency in landmark identification is an inherent cause of errors in conventional cephalometry (Broadbent, 1931; Baumrind and Frantz, 1971b). According to Sekiguchi and Savara (1972), nasion may be difficult to identify when the nasofrontal suture is not accurately visualized. Significant differences in gonion localization showed both horizontal and vertical variations (Chen *et al.*, 2000) and lead to errors in measurements (Altuna *et al.*, 1971; Graber, 1972). Santoro *et al.* (2006) stated that gonion identification is

**Table 4** Total and mean time needed for each procedure ($n$ = 100) of the manual and Dolphin cephalometric analysis.

| Tracing method | Total time | | Mean tracing time | |
|---|---|---|---|---|
| | Examiner 1 | Examiner 2 | Examiner 1 | Examiner 2 |
| Manual | 11 hour 3 minutes | 11 hour 47 minutes | 6 minutes 38 seconds | 7 minutes 4 seconds |
| | Mean: 11 hour 25 minutes | | Mean: 6 minutes 51 seconds | |
| Dolphin | 5 hour 33 minutes | 3 hour 25 minutes | 3 minutes 20 seconds | 2 minutes 3 seconds |
| | Mean: 4 hour 29 minutes | | Mean: 2 minutes 41 seconds | |

difficult due to a poorly defined anatomical outline, a double image and localization away from the midsagittal plane. The present results indicate consistency in the parameters related to gonion and do not agree with the findings of those authors.

Sayinsu *et al.* (2007) investigated observer errors for tracing and digitizing to compare the classic method of tracing by hand with a computerized method. For both manual and digital measurements, intra- and inter-rater agreement showed a high correlation. They also indicated that the maxillary height, maxillary depth, y-axis, FMA, and nasolabial angle, and the distances to N perpendicular, showed lower correlation. Similar to Sayinsu *et al.* (2007), inter-examiner measurements for Na┴A and Na┴Pog distances and nasolabial angle measurements in the current study showed lower ICC for both the manual and Dolphin techniques. This indicates that, regardless of the technique, these measurements produce errors. Na┴Pog distance showed the lowest inter-examiner correlation both for manual ($r$ = 0.365) and Dolphin ($r$ = 0.449) tracings and lowest intra-examiner correlation with the manual ($r$ = 0.483) and Dolphin ($r$ = 0.596) technique for both examiners. Nasion perpendicular distances were based on the Frankfort horizontal (FH) plane and were mostly affected by FH localization. Several studies indicated differences in Po and Or point localizations (Chen *et al.*, 2000; Bruntz *et al.*, 2006; Sayinsu *et al.*, 2007) and the measurements based on these points showed statistical differences. Likewise measurements of nasolabial angle showed relatively greater measurement errors (Baumrind and Frantz, 1971a; Sayinsu *et al.*, 2007).

When the differences in measurements were compared between the two examiners, a decrease in standard deviations was observed with the Dolphin method (Table 1). This was more obvious for examiner 1, in that, a positive correlation was found between the time taken during digitized tracing and decreased standard deviations. As shown in Table 4, examiner 1 spent approximately 60 per cent more time than examiner 2, and the decreased standard deviations for examiner 1 may be attributed to the accuracy of the measurements. On the other hand, correlation coefficients for examiner 1 with the Dolphin method seem to be higher than with the manual method. In view of the relatively short tracing period with the Dolphin system for both examiners, digitized tracings seems to be time efficient. However, it may be that for more detailed analyses, more time may be needed whatever method is used. All these results were examiner dependent and were deemed to be too difficult to determine within the scope of this article.

Chen *et al.* (2004b) demonstrated that the time tracing anatomical structures and identifying landmarks was significantly different between experienced and inexperienced operators. However, they concluded that experience and expertise could not accelerate the hand-measuring process. Chen *et al.* (2004b) also evaluated the time performance of the computer-assisted digital cephalometric analysis method and found that the time necessary for undertaking cephalometric measurements can be reduced by this method. Similarly, İşeri *et al.* (1992) evaluated the time taken for computer-assisted and conventional cephalometric tracing methods and found that the examiners spent less time when computer-assisted tracing was performed. In the present study, the time taken by the two experienced operators was nearly twice that for the manual method. The mean tracing times of the two operators for a single tracing was 2 minutes 41 seconds for Dolphin and 6 minutes 51 seconds for manual tracings. However, the time needed for preparation of the films for manual tracing and scanning of the lateral cephalograms for the Dolphin method was not taken into account.

## Conclusions

Intra-examiner repeatability of landmarks both with the manual and Dolphin techniques are highly correlated. Inter-examiner reproducibility of landmarks is unacceptable but measurement errors were generally comparable. Compared with the manual method, computerized measurements using Dolphin Imaging Software provides a significant time advantage. Computer-assisted cephalometric analyses do not increase intra- and inter-examiner error and can provide more benefits to clinicians when the time advantages are taken into account.

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## Funding

Erciyes University Scientific Research Projects Unit (DHA 05-01).

## References

Altuna G, Clar E, Friesfel M, Schmuth G 1971 Errors in determination of landmarks in connection with methodological problems in roentgenographic growth studies. Transactions of the European Orthodontic Society pp. 373–386

Baumrind S, Frantz R C 1971a The reliability of cephalometric radiograph measurements. 1. Landmark identification. American Journal of Orthodontics 60: 111–127

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

Björk A, Solow B 1961 Measurements on radiographs. Journal of Dental Research 41: 672–683

Broadbent B H 1931 A new X-ray technique and its application to orthodontia. Angle Orthodontist 1: 93–114

Bruntz L Q, Palomo J M, Baden S, Hans M G 2006 A comparison of scanned lateral cephalograms with corresponding original radiographs. American Journal of Orthodontics and Dentofacial Orthopedics 130: 340–348

Chen S K, Chen Y J, Yao C C, Chang H F 2004b 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 C, Chang H F, Chen K C 2000 Comparison of landmark identification in traditional versus computer-aided digital cephalometry. Angle Orthodontist 70: 387–392

Chen Y J, Chen S K, Yao J C C, Chang H F 2004a The effects of differences in landmark identification on the cephalometric measurements in traditional versus digitized cephalometry. Angle Orthodontist 74: 155–161

Graber T M 1972 Orthodontics, principles and practice, 3rd edn, W.B. Saunders Co., Philadelphia, p. 433

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

Held C L, Ferguson D J, Gallo M W 2001 Cephalometric digitization: a determination of the minimum scanner settings necessary for precise landmark identification. American Journal of Orthodontics and Dentofacial Orthopedics 119: 472–481

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

İşeri H, Açıkbaş A, Yılmaz O 1992 Bilgisayar metodu ve geleneksel metod ile yapılan sefalometrik ölçümlerin hassasiyet, tekrarlanabilirlik ve zaman açısından değerlendirilmesi. Turkish Journal of Orthodontics 5: 1–6 (English abstract)

Liu J K, Chen Y T, Cheng K S 2000 Accuracy of computerized automatic identification of cephalometric landmarks. American Journal of Orthodontics and Dentofacial Orthopedics 118: 535–540

Macrì V, Wenzel A 1993 Reliability of landmark recording on film and digital lateral cephalograms. European Journal of Orthodontics 15: 137–148

Mitgård J, Björk G, Linder-Aronson S 1974 Reproducibility of cephalometric landmarks and errors of measurements of cephalometric cranial distances. Angle Orthodontist 44: 56–61

Onkosuwito E M, Katsaros C, van't Hof M A, Bodegom J C, Kuipers-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 1981 A comparison of traditional and computerized methods of cephalometric analysis. European Journal of Orthodontics 3: 15–20

Rogers M B 2002 Duplication of X-rays by scanning. Journal of Clinical Orthodontics 36: 208–209

Sandler P J 1988 Reproducibility of cephalometric measurements. British Journal of Orthodontics 15: 105–110

Santoro M, Jarjoura K, Cangialosi T J 2006 Accuracy of digital and analogue cephalometric measurements assessed with the sandwich technique. American Journal of Orthodontics and Dentofacial Orthopedics 129: 345–351

Sayinsu K, Isik F, Trakyali G, Arun T 2007 An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. European Journal of Orthodontics 29: 105–108

Sekiguchi T, Savara B S 1972 Variability of cephalometric landmarks used for face growth studies. American Journal of Orthodontics 61: 603–618