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**Original Article**

# The assessment of accuracy and reproducibility of cephalometric analyses using Computer-Assisted Simulation System for Orthognathic Surgery (CASSOS) software

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**Abstract** Cephalometric analyses using computer software have more advantages than manual analyses. However, the software should be evaluated for the accuracy and reproducibility before it can be used. The aims of the present study were: 1) to compare the differences in accuracy and precision between utilizing scanned images and soft copy images with the software 2) to assess the reproducibility of software and manual cephalometric analyses. Fifteen cephalograms were selected randomly from the Record Unit, Hospital Universiti Sains Malaysia. All films had 10 fiducial points marked and were scanned at 75 dots per inch (dpi) and 300 dpi. Manual and digital measurements were compared to obtain magnification factors. Seven digital x-ray images of a caliper were taken. The mean differences were measured between the fixed caliper measurement and digital measurements. Subsequently, 37 cephalograms were traced manually and digitally with Computer-Assisted Simulation System for Orthognathic Surgery (CASSOS) software to assess its accuracy and reproducibility after applying the obtained magnification factor. Steiner analysis was utilized and T tests were used to evaluate the mean difference. $P<0.01$ was considered significant. The magnification factors of 300dpi and 75dpi for both horizontal and vertical measurements were 0.50 and 0.95 respectively, while magnification factor for softcopy image measurements was 0.89. Cephalometric comparisons between original and digital images showed statistically significant differences for several variables but the mean differences were clinically insignificant. Although some distortion was noted, it was clinically acceptable after correction of the enlarged images with magnification factors. The reproducibility of CASSOS is excellent and as good as other commercially available cephalometric software.

**Keywords:** CASSOS, cephalometry software, distortion factor, reproducibility assessment.

## Introduction

Digital imaging is well known for its lower radiation exposure and ability to enable correction of exposure errors, faster accessibility of images on screen, efficient and easier image storage, archiving or transmission, and also availability of hardcopy printout duplication (Forsyth *et al*., 1996; Bruntz *et al*., 2006; Tsorovas and Karsten, 2010). For digital tracing, landmark identification is facilitated by improving image quality, faster data processing, and acquisition of cephalometric values (Quintero *et al*., 1999; Uysal *et al*., 2009).

In order to gain the advantages of using digital cephalometric tracing and analysis, available X-ray films have to be converted into digital images by using commercially available flat bed scanners or medically specified X-ray scanners (Sayinsu *et al*., 2007). However, errors can occur either during the conversion process or when the softcopy images are imported into the cephalometry software, and these errors can influence the results of the cephalometric analysis.

Errors in cephalometric analysis are composed of systematic errors and random errors. Systematic errors may be due to scanning magnification and the software's inaccuracy, while random errors arise due to tracing, landmark identification and obtaining measurements. Radiographs can be easily scanned into a computerized digital format to perform various cephalometric functions but the scanned radiographic images may not accurately represent the original standard film. Besides that, there is a high tendency for image distortion when the softcopy images are imported into the cephalometry software. These systematic errors are consistent and can be corrected by appropriate correction factors but random errors are inconsistent and are greatly influenced by an individual's experience and knowledge in carrying out cephalometric tracing. The situation becomes worse if there is any error in the patient's position and a particular landmark may be potentially affected by its relative position in the skull (Chen *et al*., 2000; Ongkosuwito *et al*., 2002; Santoro *et al*., 2006; Grybauskas *et al*., 2007; Dvortsin *et al*., 2008; Lagravère *et al*., 2010).

Several studies have compared the accuracy and reproducibility of different cephalometric software systems, e.g. ScreenCeph (Turner and Weerakone, 2001), Dolphin Imaging 9.0 (California) (Uysal *et al*., 2009), Viewbox (Dvortsin *et al*., 2008), Vistadent 2.1 AT, Jiffy Orthodontic Evaluation (JOE) (Celik *et al*., 2009), and FACAD (Naoumova and Lindman, 2009), with hand traced measurements. All results indicate high accuracy, reproducibility and no clinically significant differences between software and hand tracing measurements. However, CASSOS (Computer-Assisted Simulation System for Orthognathic Surgery) has not yet been studied and little is known about how the CASSOS software performs in terms of the quantity and direction of magnification, and also its reproducibility.

The magnitude of distortion varies between different software systems (Bruntz *et al*., 2006) and methods of digitization (Geelen *et al*., 1998; Bruntz *et al*., 2006; Celik *et al*., 2009; Chen *et al*., 2000; Ongkosuwito *et al*., 2002). Therefore, our specific objectives in this study were: (1) to quantify the magnification of scanned images in CASSOS in two different resolutions; (2) to validate the correction factors with external samples; (3) to determine the amount of magnification of soft copy images imported into the CASSOS software; (4) to assess the reproducibility of CASSOS and manual cephalometric analyses.

## Materials and methods

Fifteen cephalograms were randomly selected from the Record Unit, Hospital University Sains Malaysia (HUSM). The number of films was determined based on power calculations using PS software with the following parameters (Dupont and Plummer, 1997), i.e. power=0.8, alpha=0.01, estimated standard deviation=0.5 mm (Bruntz *et al*., 2006), population mean difference=0.5 mm.

Ten fiducial points were marked on each film. Five linear variables, which represented the X- and Y-axes variables, were constructed from these fiducial points (Figure 1). Each horizontal and vertical fiducial point was represented by landmark identification according to the CASSOS program, using the CASSOS numbering system from 1 to 72. The linear distances of the variables on the films were measured with a Fowler-sliding calliper measuring instrument (Mitutoyo, Japan).

The films were then digitized twice with two different resolutions to produce soft copy images with a scanner VIDAR Film Digitizer Driver (USA). The images were stored as JPEG images, 8 bit colour with two resolutions, 75 dots per inch (dpi) and 300 dpi. All the scanned images were imported into CASSOS for analyses.

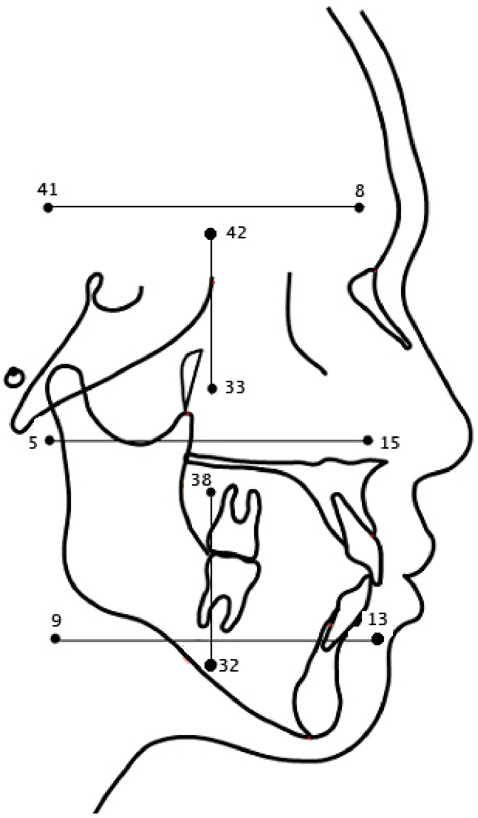


**Figure 1** Lateral cephalogram with five measurements labelled according to CASSOS software identification. Fiducial 41 represents point Ar, fiducial 8 represents point Ptm, fiducial 5 represents point N, fiducial 15 represents point A, fiducial 9 represents point PNS and fiducial 13 represents point ANS. Variables Ar-Ptm, N-A and PNS-ANS linear measurements from Burstone COGS analysis were used to determine the horizontal magnification in horizontal direction. While for vertical landmark identification, fiducial 42 represents point Cd, fiducial 33 represents point Gn, fiducial 38 represents point Go and fiducial 32 represents point Pog. Variable Cd-Gn linear measurement from McNamara analysis and Go-Pog linear measurement from Burstone COGS analysis were used to determine the vertical magnification in vertical direction.

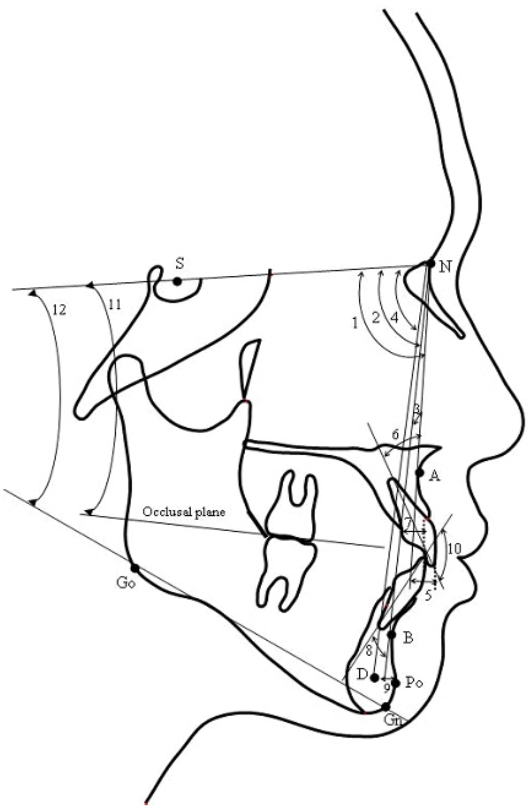


**Figure 2** Fifteen variables of Steiner analyses. 1) SNA: Relationship of cranial base to maxilla; 2) SNB: Relationship of cranial base to mandible; 3) ANB: Relationship of maxilla to mandible; 4) SND: Relationship of mandible to the skull; 5) U I to NA: Maxillary incisor position; 6) U I to NA (angle): Maxillary incisor angle; 7) Ll to NB: Mandibular incisor position; 8) Ll to NB (angle): Mandibular incisor angle; 9) Pog to NB: Prominence of chin; 10) U I to L I: Interincisal angle; 11) OP to SN (angle): Occlusal plane to SN plane; 12) GoGN to SN (angle): Mandibular plane angle; 13) Ll to GoGn (angle): Mandibular incisor to mandibular plane; 14) U6 to NA: Maxillary molar position; 15) L6 to NB: Mandibular molar position.

Five cephalogram films, acting as an external sample, were chosen randomly from the Record Unit HUSM, to validate the correction factors obtained from the first objective. The number of films was determined based on power calculations using PS software with these parameters (Dupont and Plummer, 1997), i.e. power=0.9, alpha=0.05, estimated standard deviation=0.5 mm (Bruntz *et al*., 2006). All films were digitized and scanned following the protocol for objective 1. The scanned images were imported into the CASSOS program and analyses were carried out. The output data were corrected using correction factors derived from objective (1). The same analysis was performed manually using a protractor (Leone, Italy).

For objective (3), the image of a Fowler-sliding calliper (Mitutoyo, Japan) which was fixed at the midsagittal plane in the X-ray machine was taken seven times using Orthoralix 9200 (Gendex, Germany). The recommended settings for a single exposure of the X-ray machine were 6mA, 74KvP, 0.80 sec with 18*24cm phosphor-coated plate (Gendex, Germany). The phosphor-coated plate was processed in a laser image scanner DenoOptix Ceph (Gendex, Germany) immediately after exposure. All digital images were stored in a computer database with the system manufacturer's software VIXWin 2000, version Pro (Gendex, Germany). The images were saved as JPEG images at 8 bit, resolution 1052*1341 pixels. The softcopy was imported into the CASSOS software program. The tips of the calliper were used as reference points for landmark identification. The reference landmarks of CASSOS software were two reference lines (5-15, 9-13). Variables N-A and PNS-ANS linear measurements from Burstone COGS analysis were used. By comparing the linear distances measured in CASSOS with the linear distances between calliper's beaks, the amount of magnification of the soft copy images imported into CASSOS software was determined.

To investigate objective (4), 37 cephalograms were randomly selected from Record Unit USM. The number of films was determined based on power calculations using PS software with these parameters (Dupont and Plummer, 1997), i.e. power=0.8, alpha=0.05, estimated standard deviation for variable L1NB=4.23 mm (Bruntz *et al*., 2006). The films were also scanned using VIDAR scanner (USA) at 300 dpi (ratio 1:1) saved in JPEG high resolution 8 bit. The scanned images were digitized in the CASSOS program for Steiner analysis output. A total of 15 cephalometric measurements (Steiner analysis) (Figure 2) were used to measure the dentofacial relationships. All linear measurements derived from CASSOS were corrected using the correction factor derived from objective (1) (for 300 dpi).

The same analysis was done manually on the 37 samples by using an 8 X 10-inch sheet of acetate tracing paper and a sharp pencil. Landmark identification for the Steiner analysis was performed in a dimmed tracing room and the measurements on the films were done using a protractor (Leone, Italy), with an accuracy of 0.5 mm, and an X-ray viewer. No more than 10 radiographs were traced in a single session to minimize errors due to the examiner's fatigue. Ethical clearance to access dental records was obtained from the Human Ethics and Research Committee of the Universiti Sains Malaysia.

*Statistical analyses*

All the data obtained in this study were entered and analysed with PASW 18 software. One sample t-tests with the test values set at 80 mm for horizontal variables and 50 mm for vertical variables were used to evaluate the systematic errors. The test value for soft copy images was 50 mm. The intra-operator error of using the CASSOS software program for the first 15-scanned cephalogram was re-analysed after a one-week interval. For the 37 films, intra-operator error was tested on 10 randomly selected cephalograms with a minimum of one week apart. Intra-class correlation coefficients, ICC, were used to assess the errors in the study, while paired t tests were used to evaluate statistical significance when comparing mean values between manual and digital tracing. A $p$ value <0.01 was considered as statistically significant.

## Results

### *Error study*

Intra-operator error analysis of the CASSOS software (n=15) showed an excellent reproducibility. Inter-operator errors were not calculated as the objectives of this study were specifically to evaluate the magnification and reproducibility of CASSOS compared with manual tracing.

### *Fiducial measurements (Distortion evaluation)*

Table 1 shows that all measurements were significantly enlarged in the scanned images at 300 dpi. The images were enlarged by 99.4%-99.9% for all horizontal and vertical measurements. The magnification factor for both horizontal and vertical measurements was 0.50. For 75 dpi resolution, all measurements were also significantly enlarged in the scanned images and the results are shown in Table 2. However, the enlargement percentages were much less than in the 300 dpi scanned images. At 75 dpi resolution, the horizontal and vertical measurements were enlarged by 4.2%. The magnification factor for both horizontal and vertical measurements was 0.95.

### *Fiducial measurements on external samples (To validate correction factors)*

All comparisons except for Go-Pog, $p$=0.03, (fiducial 38 and 32), were not statistically significant when comparing the manual linear measurements with their digital counterparts (Table 3).

### *Softcopy image measurements*

Table 4 shows a significant amount of magnification between the soft copy values and the CASSOS software values. The enlargement magnification was 6.2 mm (12.3%). The magnification factor for soft copy image measurements was 0.89.

**Table 1** Comparison of measurements between conventional film and CASSOS using scanned cephalometric image at 300 dpi

| Reference landmarks measurements on CASSOS software | Conventional film | Scanned image Mean (SD)[a] | Mean difference | Amount of magnification | 95% Confidence interval of difference | | $t$ statistic [b] | $df$ [c] | $p$ value |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Lower | Upper | | | |
| 41-8[d] | 80.00 | 159.9 (0.7) | 79.9 | 99.9% | 79.58 | 80.38 | 430.034 | 14 | <0.001 |
| 5-15[d] | 80.00 | 159.7 (0.6) | 79.7 | 99.6% | 79.35 | 80.01 | 521.415 | 14 | <0.001 |
| 9-13[d] | 80.00 | 159.8 (0.5) | 79.8 | 99.8% | 79.52 | 80.12 | 580.971 | 14 | <0.001 |
| 38-32[d] | 50.00 | 99.8 (0.7) | 49.8 | 99.6% | 49.41 | 50.20 | 271.078 | 14 | <0.001 |
| 42-33[e] | 50.00 | 99.7 (0.5) | 49.7 | 99.4% | 49.44 | 49.98 | 395.538 | 14 | <0.001 |

[a] Standard deviation; [b] One sample t-test; [c] degree of freedom; [d] Burstone COGS analyses; [e] McNamara analysis; n=15; Amount of magnification = 100*(Mean enlargement difference/Measurements on the film); all measurements were in mm.

**Table 2** Comparison of measurements between conventional film and CASSOS using scanned cephalometric image at 75 dpi

| Reference landmarks measurements on CASSOS software | Conventional film | Scanned image Mean (SD)[a] | Mean difference | Amount of magnification | 95% Confidence interval of difference | | *t* statistic [b] | *df* [c] | *p* value |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Lower | Upper | | | |
| 41-8[d] | 80.00 | 83.5 (0.188) | 3.5 | 4.4% | 3.38 | 3.59 | 71.647 | 14 | <0.001 |
| 5-15[d] | 80.00 | 83.3 (0.292) | 3.3 | 4.1% | 3.15 | 3.47 | 43.880 | 14 | <0.001 |
| 9-13[d] | 80.00 | 83.3 (0.402) | 3.3 | 4.1% | 3.08 | 3.53 | 31.809 | 14 | <0.001 |
| 38-32[d] | 50.00 | 52.1 (0.284) | 2.1 | 4.1% | 1.92 | 2.23 | 28.273 | 14 | <0.001 |
| 42-33[e] | 50.00 | 52.2 (0.321) | 2.2 | 4.4% | 2.05 | 2.05 | 26.803 | 14 | <0.001 |

[a] Standard deviation; [b] One sample t-test; [c] degree of freedom; [d] Burstone COGS analyses; [e] McNamara analysis; n=15; Amount of magnification = 100*(Mean enlargement difference/Measurements on the film); all measurements were in mm.

**Table 3** Comparison of fiducial points for manual and CASSOS (corrected) at 300 dpi

| Reference landmarks measurements on CASSOS software | Manual | Digital (x 0.5) | | Mean difference | 95% Confidence interval of difference | | *t* statistic [b] | *df* [c] | *p* value |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | Mean | SD[a] | | Lower | Upper | | | |
| 41-8[d] | 80.0 | 80.1 | 0.32 | -0.1 | -0.48 | 0.30 | -0.635 | 4 | 0.56 |
| 5-15[d] | 80.0 | 80.0 | 0.28 | 0.0 | -0.32 | 0.38 | 0.238 | 4 | 0.82 |
| 9-13[d] | 80.0 | 79.9 | 0.45 | 0.1 | -0.47 | 0.63 | 0.402 | 4 | 0.71 |
| 38-32[d] | 50.0 | 50.3 | 0.18 | -0.3 | -0.51 | -0.05 | -3.434 | 4 | 0.03 |
| 42-33[e] | 50.0 | 50.1 | 0.18 | 0.0 | -0.28 | 0.18 | -0.609 | 4 | 0.58 |

[a] Standard deviation; [b] paired t-test; [c] degree of freedom; [d] Burstone COGS analyses; [e] McNamara analysis; n=5 pairs; all measurements were in mm.

**Table 4** Comparison of measurements between imported digital images (Gendex) and CASSOS software measurement

| Reference landmarks measurements on CASSOS software | Imported digital images | Software value Mean (SD)[a] | Mean difference | Amount of magnification | 95% Confidence interval of difference | | *t* statistic[b] | *df*[c] | *p* value |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Lower | Upper | | | |
| 5-15[d] | 50.00 | 56.2 (0.198) | 6.2 | 12.3% | 5.97 | 6.34 | 81.941 | 6 | <0.001 |
| 9-13[d] | 50.00 | 56.2 (0.179) | 6.2 | 12.3% | 6.01 | 6.34 | 90.738 | 6 | <0.001 |

[a] Standard deviation; [b] One sample t-test; [c] degree of freedom; [d] Burstone COGS analyses; n=7; all measurements were in mm.

*Cephalometric measurements on external samples (To assess the reproducibility of CASSOS and manual methods)*

Statistically significant values were found for five of the 15 variables when the manually traced cephalograms and the computerized cephalometric analysis were compared (Table 5). The five statistically significant measurements included the SND, GoGn to SN, interincisal angle, maxillary incisor to NA and mandibular incisor to GoGn, of which SND had *p* value <.001. However, the differences were less than $1^0$ or 1 mm for each parameter.

## Discussion

The main focus of this study was to investigate the accuracy and reproducibility of the CASSOS software with consideration to the process of converting from films to digital format and also direct importation of digital X-ray format. The results of this study showed that magnification occurred during conversion process, with the scanned images being enlarged systematically in vertical and horizontal directions. The results also confirmed that the magnification of the scanned images varied with the resolutions at which the films were scanned. The magnification was increased significantly with higher dots per inch (dpi).

Even though the magnification of scanned images was larger in 300 dpi than in 75 dpi, the magnification was systematic, and thus magnification during scanning process for 300 dpi can be corrected by applying a correction factor of 0.5 which was validated with external samples. Images scanned at 300 dpi can be enlarged to facilitate landmark identification with better quality than those images scanned at 75 dpi (Ongkosuwito *et al*., 2002).

Further results from this study suggest that distortion was found when the digital images were imported from the digital films into the CASSOS software. The amount of magnification was around 12% enlargement which equates to 6 mm differences. With this finding, both types

**Table 5** Reproducibility of manual and CASSOS (corrected) at 300dpi

| Variables | Manual (mm) | | Digital (mm) (x0.5) | | Mean difference (mm) | SD[a] (mm) | 95% Confidence of interval | | t statistic[b] | df [c] | *p* value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD[a] | Mean | SD[a] | | | Lower | Upper | | | |
| SNA (⁰) | 90.6 | 4.06 | 90.5 | 4.13 | 0.1 | 1.15 | -0.31 | 0.46 | 0.413 | 36 | 0.68 |
| SNB (⁰) | 87.8 | 4.13 | 87.5 | 4.23 | 0.3 | 0.84 | -0.03 | 0.54 | 1.831 | 36 | 0.08 |
| ANB (⁰) | 2.8 | 3.50 | 3.2 | 3.32 | -0.4 | 1.37 | -0.86 | 0.06 | -1.782 | 36 | 0.08 |
| SND (⁰) | 84.7 | 4.23 | 84.0 | 4.49 | 0.7 | 1.12 | 0.34 | 1.09 | 3.877 | 36 | <0.001 |
| U1-NA | 5.5 | 3.01 | 5.4 | 3.05 | 0.1 | 0.65 | -0.13 | 0.30 | 0.787 | 36 | 0.44 |
| U1-NA (⁰) | 31.8 | 8.04 | 30.8 | 7.95 | 0.9 | 1.73 | 0.36 | 1.51 | 3.302 | 36 | <0.01 |
| L1-NB | 5.5 | 2.97 | 5.6 | 2.93 | -0.1 | 0.36 | -0.21 | 0.03 | -1.439 | 36 | 0.16 |
| L1-NB (⁰) | 32.4 | 10.05 | 32.2 | 10.28 | 0.1 | 1.39 | -0.36 | 0.57 | 0.460 | 36 | 0.65 |
| Pog-NB | 0.7 | 1.32 | 0.7 | 1.26 | <0.1 | 0.39 | -0.17 | 0.09 | -0.679 | 36 | 0.50 |
| U1-L1 (⁰) | 113.3 | 12.56 | 113.9 | 13.13 | -0.6 | 1.74 | -1.18 | -0.02 | -2.111 | 36 | 0.04 |
| OP-SN (⁰) | 7.2 | 5.40 | 7.2 | 5.25 | <0.1 | 1.38 | -0.47 | 0.46 | -0.024 | 36 | 0.98 |
| GoGn-SN (⁰) | 24.0 | 5.78 | 23.5 | 5.74 | 0.6 | 1.18 | 0.16 | 0.95 | 2.851 | 36 | 0.01 |
| L1-GoGn (⁰) | 100.6 | 10.11 | 101.2 | 11.00 | -0.7 | 1.83 | -1.29 | -0.07 | -2.259 | 36 | 0.03 |
| U6_to_NA | 20.1 | 3.82 | 20.1 | 3.84 | <0.1 | 0.75 | -0.28 | 0.22 | -0.231 | 36 | 0.82 |
| L6_to_NB | 16.3 | 3.10 | 16.4 | 3.15 | <0.1 | 0.54 | -0.22 | 0.14 | -0.454 | 36 | 0.65 |

*n*= 37 pairs; [a] standard deviation; [b] paired t-test; [c] degree of freedom.

of images, either the scanned images or digital images imported from Gendex VixWin software, must be corrected for cephalometric analysis. This emphasizes the need of ensuring Digital Imaging and Communications in Medicine (DICOM) compatibility. The hardware and software must be DICOM compatible so that there will be no data loss and no distortion or magnification.

The amount of magnification from our study was higher than what was reported by Bruntz *et al*. (2006). In their study, 0.5% vertical and 0.3% horizontal enlargement was reported. Bruntz *et al*. (2006) used Dolphin Imaging 9 and scanned the radiographs at 150 dpi. Therefore, the difference in the amount of enlargement was due to the differences in software and the resolution used during the scanning process. This conclusion can be made since both studies are comparable as the same size of monitor was used with screen errors of 0.276 mm in each X- and Y- axes. The screen error may influence the point of identification, which can be off by 50% of the distance between two screen pixels (Turner and Weerakone, 2001).

Even though the amount of magnification in our study (before correction) was clinically significant, the direction of the magnification was systematic. This allowed a correction to be made. The incorporation of five external samples confirmed that the correction factor x0.5 is valid. Linear measurements on the reference planes formed by 10 fiducial points were all non-significant except for fiducial 38-32 (Go-Pog) vertical plane. However, the linear distortion was minimal (mean difference=-0.3 mm) and was within a standard deviation. Although fine tip pen was used to mark fiducial points, the width of fiducial points enlarges together with the enlargement of digital images. Thus, this may contribute to the error or inaccuracy of the linear measurements by as much as a few millimeters as arrowheads can be placed either at the centre or at the circumference of the enlarged dots to digitize the particular fiducial point. Therefore, identification of fiducial points on conventional radiographs was easier and had better accuracy.

Five of 15 variables compared between manual and CASSOS (corrected) were statistically significant but the magnitude of the mean differences was too small to be clinically significant. SND was highly significantly different ($p$<0.001), most probably due to the incompatibility of landmark identification performed manually and digitally. In CASSOS, the software automatically identified the anatomical landmark D. The measurements involving mandibular plane (GoGn) were inconsistent and this may be due to subjectivity in identifying Go point. The Go point was determined by bisecting the two planes, i.e. posterior ramus and inferior border of mandible (Liu *et al*., 2000; Santoro *et al*., 2006; Lagravère *et al*., 2010).

Although computer software can facilitate landmark identification by enhancing the quality of the image, the initial quality of films is important as digital processing cannot improve overall outcomes if the film itself is of poor quality due to exposure issues or poor positioning of the patient's head leading to bilateral images of anatomic structures (Macrì and Wenzel, 1993; Lagravère *et al*., 2010). The films used in this study were randomly selected so that they represented the quality of daily routine work. In the CASSOS software, porion (Po) and orbitale (Or) are among the 72 landmarks that need to be identified before Steiner analysis can be done (Po and Or form Frankfort-Horizontal (FH) plane). Studies from Chen *et al*. (2000) and Bruntz *et al*. (2006) indicated that Po and Or had lower reliability in landmark identification. Since FH plane was referenced when the analysis was done, any discrepancy in Po and Or landmark identification could affect the cephalometric measurements.

Another cause of landmark identification error is difficulty in identifying landmarks on a curved anatomical boundary (Perillo *et al*., 2000; Chen *et al*., 2004; Lagravère *et al*., 2010), especially when certain structures appear as double images, for example landmarks A and B. Variable ANB was subjected to a greater range of variation as its value was dependent on both SNA and SNB. Any error in measuring either one or both variables could contribute to inconsistency in ANB value. Discrepancies in angular variables U1-NA could also be due to this factor. The interincisal angle (U1 to L1) was also significantly different from manual measurements. Possibly, the measurements involving maxillary central incisor (U1) or mandibular central incisor (L1) were prone to have larger measurement differences as inclination of the tooth axis was greatly affected by accuracy in marking the two points (incisor tip and root apex) especially if the points were closely located (Chen *et al*., 2004). The present study of reference landmark measurements indicates that CASSOS software shows excellent reproducibility. A similar trend can be observed with other softwares i.e. Viewbox 3.1.1.9 and Dolphin v 9.0, (Sayinsu *et al*., 2007) ScreenCeph 1.4, (Turner and Weerakone, 2001) Vistadent v 7.33 (Santoro *et al*., 2006) with ICC was 0.97, 0.90, 0.98 and 0.91 respectively. These studies indicate that the validity and reproducibility of several cephalometric software systems software are comparable with the conventional tracing method.

## Conclusions

The magnitude of uncorrected magnification using CASSOS software has clinical implications. However, this magnification can be corrected by using correction factors which depend on their resolutions during scanning process. The magnification of cephalometric measurements in CASSOS for scanning with 300 dpi is approximately 99%, while for scanning with 75 dpi it is approximately 4.1%, and for softcopy images it is 12.3%. Although cephalometric analysis using CASSOS software shows some significant differences when compared to manual tracing method, the differences were clinically acceptable after correction. Landmark identification errors on digital images were the main cause of discrepancies in cephalometric analysis. In our study, there were five variables which needed extra precaution. The reproducibility of the CASSOS system is excellent and as good as other commercial cephalometric software. However, caution must be exercised and patience must be practised because as many as 72 landmarks need to be identified before proceeding to software analysis.

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