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# Comparison of Landmark Identification in Traditional Versus Computer-Aided Digital Cephalometry

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**ABSTRACT**

The aim of this study was to assess landmark identification on digital images in comparison with those obtained from original radiographs. Ten cephalometric radiographs were selected randomly. Seven orthodontic residents identified 19 cephalometric landmarks on both the original radiographs and the digital images. To assess the concordance between landmarks identified on the original radiographs and on their digital counterparts, the x, y coordinates for each landmark in the 2 modalities were transformed with the identical references. The placement differences for 19 landmarks between 2 methods were calculated and their components in horizontal and vertical directions were analyzed respectively. Multivariate analysis of variance showed that the “cephalometric radiograph” and “landmark” variation had greater influence than that from “ method” (landmark identification on digital / original radiograph). It was also noted that the differences of landmark identification between original radiographs and their digital counterparts were statistically significant. The landmarks with significant differences of horizontal component on the x-axis were Me, Gn, ANS, PNS, LIA. The differences were generally under 1 mm with the exception of Or, Me, PNS, LIA. The landmarks with significant differences of vertical component on the y-axis were Po, Or, Gn. The inter-observer error for each landmark in digital images was generally larger than that in the original radiographs. However, statistically significant differences of inter-observer errors between 2 modalities were only found for 4 of the 19 landmarks. These 4 landmarks, Po, Ar, ANS, and UM, should be scrutinized more carefully during potential applications of digital cephalometry.

**KEY WORDS:** Computer-aided cephalometric analysis, Digital imaging, Landmark identification.

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## INTRODUCTION Return to TOC

Cephalometry is an important tool in orthodontic diagnosis, treatment planning, evaluation of treatment results and prediction of growth. The major sources of error in cephalometric analysis include radiographic film magnification, tracing, measuring, recording, and landmark identification. Previous studies revealed that inconsistency in landmark identification is an important source of error in conventional cephalometry.[1–3] This error is specific to each landmark and affected by experience and training of the observers.[4]

Rapid advances in computer science have led to its wide application in cephalometry. Computer-aided cephalometric analysis is faster in data acquisition and analysis than conventional methods. Many cephalometric programs have been developed to perform computer-aided cephalometric analysis by digitizing the landmarks. However, digitizing may introduce errors such as head film movement and improper sequencing of digitized points. To take advantage of image processing and computer-based filing systems that can integrate patients' records and images, the original cephalometric radiographic films may be transformed into a digital format by a scanner or video camera. A radiographic system for taking direct-digital lateral cephalograms at reduced radiation dose is presently available.[5,6] Consequently, many commercially available or customized programs have been developed to conduct cephalometric analyses directly on the screen-displayed digital image.[7–9] Such applications could substantially reduce the potential errors in the use of digitizing pads and totally eliminate the need of hardcopies of digitally born images for conventional cephalometric analysis.[9] Digital cephalometry also has the benefits of image storage, transmission and processing.[10]

Great efforts have been made to develop systems for automatic computerized identification of cephalometric landmarks.[11,12] However, automated systems are at present unable to compete with manual identification in terms of accuracy of landmark position. The landmarks lying on poorly defined structures are difficult to automatically identify due to poor signal-to-noise ratio.[10] Earlier studies revealed that computer-aided cephalometric analysis does not introduce more measurement error than hand tracing, as long as landmarks are identified manually.[13,14] Therefore, manually identifying landmarks on screen-displayed digital images for cephalometric analysis may still be the better strategy. However, for digital imaging to offer significant advantages in cephalometry, the images must yield as much information as is available on conventional radiographic film. The main question is whether landmark identification in digital images is comparable to that performed on original radiographic films. The aim of this study, therefore, was to compare landmark identification on conventional cephalometric radiographs with that of digital images.

## MATERIALS AND METHODS Return to TOC

Ten cephalometric radiographs taken randomly from the data files in the Department of Orthodontics at the National Taiwan University Hospital were used in this study. Exclusion criteria were: 1) unerupted or missing incisors or 2) unerupted teeth overlying the incisors' apices. The cephalometric radiographs were scanned to transform the analogue image into a digital format using a scanner (VXR-12, Vidar System Corporation) and displayed on a high-resolution monochromic monitor. The digital image resolution was 150 dpi with 64 gray levels. The images displayed consisted of a 512 x 512 pixel matrix, which gives a pixel size of 0.17 mm.

A Vision C++ programmer developed a program of computerized cephalometric analysis for digital cephalometry. The 19 commonly used cephalometric landmarks (Table 1) were included in this analysis. Landmark identification for 19 landmarks and 2 fiducial points was carried out on the original radiograph by manually dot tracing and on the digital image using a mouse-driven cursor in a predetermined sequence.

Seven orthodontic residents identified the landmarks on the 10 digital images and their original radiographic films, with an intervening time interval of at least 1 week. The orthodontic residents had reached agreement on the definition of landmarks prior to carrying out this study. For the digital images, landmark identification was performed directly on the monitor-displayed image with a mouse-controlled cursor in connection with the computerized program for cephalometric analysis. After recording a landmark with the mouse, a dot on the monitor-displayed image indicated its position. The landmark position could be corrected until the operator was satisfied. The positions of the landmarks were recorded in the format of x, y coordinates. The system of x, y coordinates was constructed with the x-axis determined by the 2 fiducial points and a calculated y-axis perpendicular to the x-axis. The x-axis was almost parallel with the upper margin of the cephalometric radiographic film. For the original radiograph, the landmarks were identified on a superimposed transparent film, which was then scanned and converted to digital format. The landmarks' location on the transparent film could be described using x, y coordinates with the aid of the computerized program described previously. This procedure was performed by 1 of the authors to prevent introducing additional random error.

For each landmark, placement differences between the original radiographs and their digital counterparts were assessed by transforming the 2 sets of x, y-coordinates with identical fiducial reference points. The x-coordinate and y-coordinates were further analyzed to evaluate the pattern of recording differences in horizontal and vertical directions. Moreover, the mean position for each of 19 landmarks identified by the seven observers was defined as the “gold standard” in this study. The gold standard was used to determine the inter-observer errors in both modalities of original film and digital image. The mean distance in millimeters between the gold standard and the 7 locations identified by the 7 observers was defined as inter-observer error, which was used as the variable determining reliability for each landmark. Consequently, the reliability of landmark identification in each of the 2 modalities (original radiograph and digital image) could be compared.

### Statistical analysis

To analyze the variation of landmark identification on 10 cephalometric radiographs by the 2 methods, the multivariate analysis of variance (MANOVA) with the procedure of block design for 2 factors[15] was used to analyze the effect of examined variables (landmark, radiograph, and method). The mean and standard deviation of the differences in landmark location between the original films and digital images were calculated for each of the 19 landmarks. The statistical significance of location difference and inter-observer errors in landmark identification between the 2 groups was checked by paired student t-test.

## RESULTS Return to TOC

MANOVA showed that all the effects of examined variables and interaction between two variables were significant, and that the power of this analysis was high (Table 2). However, the effect of the variable "method" was relatively low (effect size = 0.008). It meant the effect of "method" was statistically significant, but its influence was far less than that from either "radiograph" or "landmark." The variation from cephalometric "radiograph" and "landmark" explained much of the total variation.

The mean and standard deviation of location differences for 19 landmarks between original radiographs and their digital counterparts are presented in Table 3. Their mean difference ranged from 0.93 to 3.48 mm, with large variations. All the location differences for each of these 19 landmarks were statistically significant ($p<.05$). The landmark with minimal difference was the S point and that with maximal difference was the Or point. Moreover, the location differences of the 19 landmarks were generally greater than the respective inter-observer error in the 2 modalities.

To investigate the pattern of distribution, the placement difference was further analyzed by comparing the differences of x-coordinate and y-coordinate, respectively (Table 4). For the horizontal component on the x-axis, we found that the differences for the Me, Gn, ANS, PNS and LIA points reached statistically significant levels. As for the vertical component on the y-axis, the differences for the Po, Or and Gn points were significant. Generally, the horizontal and vertical components of differences in landmark locations were less than 1 mm, with the exception of Or, Me, PNS, and LIA.

As to the comparison of inter-observer errors in the 2 methods, larger errors were noted for the digital images in 16 of the 19 landmarks (Table 3). On the original film, the most accurately identified landmark was the S point (error=0.39 mm). The errors for the S, Ar, Me, Gn, Pog, and LIE points were less than 1 mm. On the digital images, the most accurately identified point was the Ar point (error = 0.79 mm), and the landmarks with error smaller than 1 mm were only the S and Ar points. However, statistically significant differences in inter-observer errors between 2 modalities were found for only 4 of the 19 landmarks: Po, Ar, ANS, and UM. To our surprise, the reliability of Ar point in digital image was not as good as in the original radiographs; even the Ar point was the most reliable one of the 19 landmarks in digital images.

## DISCUSSION Return to TOC

The major errors in conventional cephalometry may include projection errors and tracing errors. The most important source of tracing errors is uncertainty in landmark identification, and intra-observer error is generally less than inter-observer error.[13] When we take advantage of digital cephalometry, it is important to question whether the digital image yields the same level of performance in terms of landmark identification as conventional radiographic film. In our study, the overall differences of landmark location between the 2 modalities were statistically significant. The extent of difference for each landmark depends on the radiographic complexities, which are also associated with the reliability of landmarks.

In the experimental design of our study, the best estimate for each landmark or "gold standard" for determining the inter-observer errors was defined as the mean position identified by 7 observers. The inter-observer error was used as a variable determining the reliability, i.e., the dispersion of error around the best estimate for each landmark. We found that the inter-observer errors, ranging from 0.39 to 2.51 mm for 19 landmarks in original cephalometric radiographs, were generally smaller than those obtained in digital images (0.79 to 3.60 mm). However, the statistically significant differences between the 2 modalities were revealed only at the Po, Ar, ANS, and UM points. In other words, the reliability of landmark identification in digital image was generally comparable to that obtained in original radiographs. Differences in the methodological design made it difficult to compare the absolute value of landmark reliability between different studies.

The results of the present study are at least partly in agreement with the findings of Macri and Wenzel.[16] They reported that it was possible to achieve reliability in digital images comparable to that obtained with conventional equipment for radiographs with good quality. In contrast, Geelen et al reported that the precision of landmark recording was lower for enhanced monitor-displayed images than for both film and digitally enhanced hardcopies in 11 of 21 landmarks.[17]

Some cephalometric landmarks are more reliable in either the horizontal or vertical plane, making the distribution of errors follow a pattern of a non-circular envelope.[1] In our study, the differences of landmark placement between the 2 modalities were also distributed differently along the horizontal and vertical axes. Significant differences on the horizontal axis were located at the Me, Gn, ANS, PNS and LIA points. On the vertical axis, the significant differences were located at the Po, Or and Gn points. This pattern was approximately similar to that of error distribution for landmark identification which is associated with complex radiographic images and the topographic orientation of the delineated anatomic boundary.[1,18] The difficulty of identifying LIA, Po, and Or precisely may originate from blurred image due to superimposed structures. The uncertainty in locating the Me and Gn points may be caused by the difficulty of delineating a landmark on a curved anatomical boundary. In both modalities used in our study, landmarks were identified without the aid of reference planes or construction lines. The construction lines or planes may be helpful during locating landmarks defined as, eg, "the most anterior point of" something. However, it has been reported that tracing for construction line or reference plane did not increase reliability in landmark identification.[18] It seems that the more direct the identification, the higher the landmark reliability.

In the comparison of inter-observer errors between 2 modalities, statistically significant differences were found only at Po, Ar, ANS, and

UM point. It meant that the reliability of Po, Ar, ANS, UM in digital images was inferior to that in original radiographs. The contributing factors to these differences included the nature of cephalometric landmarks, quality of original radiographs, resolution of digital images, and the training level or experience of observers. The most important factor seemed to be the nature of landmark itself. Among these 4 landmarks, Po and UM point had the similar difficulty in identification due to image complexities from superimposed bilateral structures. The uncertainty in locating ANS point may result from delineating the most anterior point of blurred anatomical outlines. We did not investigate whether digital image processing could be helpful in identifying the landmarks on poorly defined structures. However, Wenzels et al reported that digital processing did not improve the landmark reliability in radiographs with lower quality.[16]

One of the efforts to improve the precision of landmark identification should be directed toward improvement in the image quality.[19] In our study, the 7 observers did not receive their original training in digital imaging and commented that working on the PC monitor occasionally felt fatiguing for the eyes. Increased familiarity with the medium in our digital cephalometric system may reduce the error and improve the reliability in landmark identification.

A radiographic film is an analogue image in which a continuous gray level represents elements. A digital image is composed of many picture elements (pixels). The quality of a digital image strongly depends on both the number of pixels and the number of gray levels. It was reported that the reliability of landmark identification on digital images with pixel size of 0.47 mm was inferior to those on conventional radiographs.[16] However, a digital cephalogram with higher spatial resolution (pixel size = 0.03mm) can yield greater reliability than the original radiographs with conventional equipment.[2] The cephalometric radiographs used in this study were randomly selected and represented the quality of daily routine work. The image resolution setting was 150 dpi with the pixel size of 0.17 mm, which was the reasonable choice for both memory size and image quality.

With the aid of computer science, the 2 x, y-coordinate systems of our 2 modalities were transformed with identical fiducial reference points to facilitate the comparison for exact placements of 19 landmarks between original radiographs and digital images. Statistically significant lower landmark reliability in digital images was revealed at Po, Ar, ANS, and UM only. The inferiority of the digital image in terms of landmark reliability in 4 of the 19 landmarks may have a little impact in our application of digital cephalometry, because the lateral cephalometric analysis is not the sole available source of diagnostic information. To evaluate growth change or treatment effect, however, it is better to interpret carefully the minute differences obtained in digital cephalometry.

## CONCLUSION Return to TOC

In our computerized digital cephalometric analysis, the differences of landmark location between original cephalometric radiographs and their digital counterparts were statistically significant. The reliability of landmark identification in digital images was comparable to that in original radiographs except for the points Po, Ar, PNS, and UM. These landmarks with significant lower reliability in digital images should be scrutinized more carefully when we take potential advantages of the use of digital cephalometry.

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**TABLE 1.** Nineteen Landmarks Evaluated in This Study

| | |
|---|---|
| N: Nasion | ANS: Anterior nasal spine |
| S: Sella | PNS: Posterior nasal spine |
| Po: Porion | UIA: Upper incisor apex |
| Or: Orbitale | UIE: Upper incisor edge |
| Ar: Articulare | LIA: Lower incisor apex |
| Go: Gonion | LIE: Lower incisor edge |
| Me: Menton | UM: Mesiobuccal cusp of upper first molar |
| Gn: Gnathion | LM: Mesiobuccal cusp of lower first molar |
| Pog: Pogonion | |
| B: *B* point | |
| A: *A* point | |

**TABLE 2.** Summary of Statistic Analysis by MANOVA[a]

| Variable | Effect Size | Power |
|---|---|---|
| Radiograph × Landmark | 0.81 | 1.0 |
| Method × Landmark | 0.02 | 1.0 |
| Method × Radiograph | 0.02 | 1.0 |
| Landmark | 0.99 | 1.0 |
| Radiograph | 0.91 | 1.0 |
| Method | 0.008 | 0.98 |

[a] $P < .05$.

**TABLE 3.** Differences of Landmark Location Between Two Modalities and Statistical Analysis for Interobserver Errors

| Land-mark | Location Difference, mm[a] | Interobserver Error on Original Radiograph, mm | Interobserver Error on Digital Image, mm |
|---|---|---|---|
| N | 1.87 ± 3.02 | 1.34 ± 1.64 | 1.26 ± 2.00 |
| S | 0.93 ± 1.76 | 0.39 ± 0.22 | 0.97 ± 1.45 |
| Po | 1.91 ± 1.66 | 1.16 ± 1.16 | 1.58 ± 1.42* |
| Or | 3.48 ± 9.92 | 1.46 ± 1.23 | 3.60 ± 8.72 |
| Ar | 1.14 ± 1.11 | 0.56 ± 0.40 | 0.79 ± 0.77* |
| Go | 2.14 ± 2.37 | 1.73 ± 1.31 | 1.92 ± 1.75 |
| Me | 2.42 ± 2.79 | 0.78 ± 0.46 | 2.22 ± 2.28 |
| Gn | 1.82 ± 2.46 | 0.78 ± 0.39 | 1.68 ± 2.11 |
| Pog | 1.64 ± 2.30 | 0.63 ± 0.51 | 1.53 ± 1.91 |
| B | 2.03 ± 2.19 | 1.42 ± 1.17 | 1.74 ± 1.85 |
| A | 1.87 ± 1.58 | 1.25 ± 0.82 | 1.32 ± 1.16 |
| ANS | 2.28 ± 1.74 | 1.17 ± 0.95 | 1.74 ± 1.17* |
| PNS | 2.01 ± 1.99 | 1.21 ± 1.00 | 1.17 ± 1.38 |
| UIA | 2.99 ± 3.59 | 2.51 ± 3.06 | 1.98 ± 1.62 |
| UIE | 1.96 ± 4.18 | 1.07 ± 3.07 | 1.50 ± 2.19 |
| LIE | 1.71 ± 3.01 | 0.45 ± 0.36 | 1.70 ± 2.54 |
| LIA | 2.89 ± 3.80 | 1.75 ± 1.19 | 2.68 ± 3.30 |
| UM | 2.61 ± 3.33 | 1.87 ± 1.94 | 2.35 ± 2.36* |
| LM | 3.13 ± 5.36 | 2.42 ± 2.74 | 2.67 ± 1.78 |

[a] The location differences for all items reached significant level ($P < .05$).

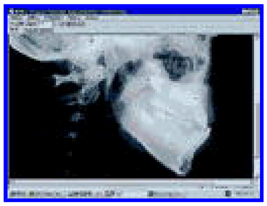
* Significant difference of interobserver errors between 2 modalities was detected by paired t-test ($P < .05$).

**TABLE 4.** Differences of Landmark Between Original Radiograph and Digital Image

| Land-mark | Difference on x Axis, mm | Difference on y Axis, mm |
|---|---|---|
| N | 0.42 ± 1.99 | 0.21 ± 2.90 |
| S | 0.16 ± 1.55 | 0.28 ± 1.20 |
| Po | 0.21 ± 1.85 | 0.61 ± 1.62* |
| Or | 1.26 ± 7.98 | 1.90 ± 6.45* |
| Ar | 0.21 ± 1.05 | 0.09 ± 1.18 |
| Go | 0.34 ± 1.65 | 0.30 ± 2.71 |
| Me | 1.61 ± 2.33* | 0.06 ± 2.38 |
| Gn | 0.46 ± 1.67* | 0.70 ± 2.43* |
| Pog | 0.22 ± 1.12 | 0.17 ± 2.58 |
| B | 0.03 ± 1.37 | 0.58 ± 2.60 |
| A | 0.06 ± 2.33 | 0.05 ± 1.79 |
| ANS | 0.54 ± 2.27* | 0.36 ± 1.64 |
| PNS | 1.06 ± 2.09* | 0.29 ± 1.57 |
| UIA | 0.04 ± 2.43 | 0.13 ± 4.01 |
| UIE | 0.02 ± 1.48 | 0.77 ± 4.32 |
| LIE | 0.29 ± 1.68 | 0.67 ± 2.95 |
| LIA | 1.20 ± 2.82* | 0.84 ± 3.56 |
| UM | 0.17 ± 3.39 | 0.08 ± 2.54 |
| LM | 0.08 ± 5.00 | 0.10 ± 3.69 |

* Significant differnce revealed by paired t-test ($P < .05$).

**FIGURES** Return to TOC



Click on thumbnail for full-sized image.

**FIGURE 1.** Part of a monitor-displayed digital cephalogram. Some cephalometric landmarks and derivative points are illustrated

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