ABSTRACT

Objective: To evaluate the accuracy of measurements obtained with a digital cephalometric software program.

Materials and methods: Digital photographs of 32 cephalograms were imported into the Nemotec digital imaging software. Digital measurements of 41 hard and soft tissue variables generated by the software were compared to those obtained by manual tracings. Reproducibility for each method was assessed using Pearson’s correlation coefficient by repeating measurements of all radiographs at an interval of 3 months. A paired t-test was used to detect differences between the manual and digital methods.

Results: Both the methods demonstrated a high correlation (r > 0.7) between the first and second measurements indicating good reproducibility. SN-Occ, anterior cranial base length, posterior cranial base length, nasolabial angle, facial height and lower lip length showed clinically significant differences between the measurements obtained from digital and manual methods.

Conclusion: Digital measurements obtained with the Nemotec digital imaging software using digital photographs of analog cephalograms were found to be reproducible and comparable to the manual method for most of the variables used in clinical practice except a few which could not be measured accurately with the digital method.

Keywords: Cephalometric measurements, Digital imaging, Cephalometric software.

INTRODUCTION

Cephalometrics has played a vital role in orthodontic diagnosis and treatment planning and for monitoring treatment and growth changes. Cephalometric analysis performed manually using a tracing sheet on the radiograph is the oldest and the most widely used method. Although radiographic film is quite stable and can retain its information for many years, it is not always a dependable archive medium due to its physical nature. Film deterioration has been a major source of information loss in craniofacial biology.

Digital imaging offers several advantages over conventional film-based radiography: Faster data processing, elimination of chemicals and associated environmental hazards and the ability to alter and improve the image to correct for exposure errors, thus virtually eliminating the need for a second exposure.

Digital radiographic images are easy to store and facilitate communication. They also require lower levels of radiation. Numerous digital cephalometric software programs have been introduced like AO Ceph, Quick Ceph 2000, Dolphin, etc.

First generation computer-based analysis systems used digitizer pads for tracing conventional cephalometric films and software programs to compute the measurements. Second generation systems used scanners or digital cameras to export cephalometric images to measurement programs. The third generation systems acquired the digital image by two methods—a charged couple device (direct digitization), where the digital image is produced instantaneously and storage phosphor plates (indirect digitization) to capture the film. But the devices required in both the methods were expensive.

Computerized cephalometric analysis may use either a manual or automatic identification of landmarks. Automated systems at present are 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. Earlier studies have shown that computer-aided cephalometric analysis does not introduce more measurement error than hand tracing, as long as landmarks are identified manually. Therefore, manually identifying landmarks on screen-displayed digital images for cephalometric analysis may still be the better strategy. For digital cephalometry to be a better tool in clinical orthodontics, the cephalometric analysis, represented by widely
used linear and angular measurements, must be as comparable and reliable as it is on a conventional radiographic film.

The objectives of the present study were to evaluate the accuracy of digital measurements obtained with a cephalometric software program and compare them to manual measurements from the traditional hand-traced method.

MATERIALS AND METHODS
Thirty-two pretreatment cephalometric radiographs of adequate diagnostic quality with identifiable craniofacial structures and landmarks were selected for the study (Fig. 1). The cephalometric analysis was done by two methods:

1. Manual
2. Digital

Manual Method
Each lateral cephalogram was traced using a 0.3 mm lead pencil on an acetate matte tracing paper, 0.003 inch × 8 inch × 10 inch. The tracings were done on a view box with the tracing paper securely positioned over the radiograph with a masking tape. Both midline and bilateral images were traced, with all bilateral images bisected and, thereafter, treated as midline structures. All linear measurements were rounded to the nearest 0.5 mm and angular measurements to the nearest 0.5°.

Digital Method
The digital image of each cephalogram was acquired using a digital camera (SONY DSC H50, 9.1 Megapixel) after taping it to the view box. The images were imported to the Nemotec digital imaging software (version 6.0) and the cephalometric landmarks were identified on the displayed image by using a mouse controlled cursor linked to the tracing software (Fig. 2). The image enhancement features of the software, like brightness, contrast adjustment and magnification were used as needed to identify individual landmarks as precisely as possible. The images were calibrated by identifying two crosshairs 10 mm apart. All measurements were automatically calculated by the tracing software.

The following cephalometric measurements were obtained:

Hard Tissue Measurements

Angular Measurements
Rakosi-Jarabak Analysis
1. Saddle angle (N-S-Ar)
2. Articular angle (S-Ar-Go)

Steiners Analysis
1. SNA angle
2. SNB angle
3. ANB angle
4. U1 to NA
5. L1 to NB
6. Interincisal angle
7. SN-mandibular plane angle (SN-GoGn)
8. SN-occlusal plane angle.

Downs Analysis
1. Facial angle (FH-N-pog)

Tweed's Analysis
1. FMA
2. IMPA
3. FMIA.

Linear Measurements
Rakosi-Jarabak Analysis
1. Anterior cranial base length (Se-N)
2. Posterior cranial base length (S-Ar).
Steiners Analysis
1. U1 to NA
2. L1 to NB.

Downs Analysis
U1 to A-Pog

Ratios
1. Jarabak ratio—Posterior facial height (S-Go) × 100:
   Anterior facial height (N-Me)
2. UAFH (N-ANS)/LAFH (ANS-Me).

Soft Tissue Measurements

Angular Measurements

Arnett-Bergman Analysis
1. Nasolabial angle
2. Upper lip angle
3. Angle of convexity.

Linear Measurements

Arnett-Bergman Analysis
1. Upper lip thickness
2. Lower lip thickness
3. Chin thickness (Pog-Pog’)
4. Facial height (N’-Me’)
5. Upper lip length (Sn-upper lip inferior)
6. Lower lip length (lower lip superior –Me’)
7. Maxillary height (Sn-maxillary incisor tip)
8. Mandibular height (mandibular incisor tip-Me’)
9. TVL-Pog’
10. TVL-Nasal projection
11. TVL-Point A’
12. TVL-Point B’
13. TVL-Glabella.

Ratios
1. Upper lip –lower lip length ratio
2. UAFH (G-Sn)/LAFH (Sn-Me’).

The digital measurements obtained with the cephalometric software were compared to those of the manual method.

Method of Determining Accuracy

The accuracy of the measurements obtained by the digital method would be considered acceptable provided they met the following conditions:7,8
1. The intraclass correlation coefficient, r > 0.75, which would show good reproducibility of the method
2. Mean measurement differences between digital and manual methods were less than 2 units (1 unit = 1 mm for linear measurements and 1° for angular measurements).

Statistical Analysis

Intraexaminer error was evaluated by repeating tracings of all radiographs (performed 3 months apart) and using the Pearson’s correlation coefficient as a measure of standardized covariance. Systematic error (differences in measurements related to the methods investigated) was calculated by using paired t tests based on equality of variance between the digital and manual tracings. A p-value of 0.05 was used as the minimal level of statistical significance.

RESULTS

Table 1 shows that the correlations between first and second observations were strong (r > 0.7) for both the methods showing good reproducibility of measurements due to minimal intraexaminer variability.

Hard Tissue Measurements

Table 2 shows that the saddle angle, articular angle, SNB, L1-NB, interincisal angle, facial angle and FMA did not show statistically significant differences between the digital and manual methods, but gonial angle, SNA, ANB, U1-NA, SN-GoGn, SN-Occ, angle of convexity, IMPA and FMIA showed significant differences in the two methods.

The linear measurements for the anterior cranial base, posterior cranial base, U1-NA and U1-A-Pog were found to be significantly different in the two methods except L1-NB which showed no statistically significant difference.

For both the hard tissue ratios, Jarabak ratio and U AFH/ LAFH, the differences between the two methods were found to be statistically significant.

Soft Tissue Measurements

Table 3 shows that the difference between the measurements by the two methods was found to be statistically significant for the angular variables of nasolabial angle and angle of convexity, whereas no difference was seen in upper lip angle.

Statistically, significant differences in the linear measurements of upper lip thickness, facial height, upper lip length, lower lip length, maxillary height, mandibular height, TVL-nasal projection and TVL-Point A’ were observed. No statistically significant difference was seen in lower lip thickness, chin thickness, TVL-Pog’, TVL-Point B’ and TVL-Glabella.

A statistically significant difference between the measurements by the two methods was seen for the soft tissue ratio UAFH/LAFH. No statistically significant difference was seen in UL/LL.

Table 4 shows that saddle angle, articular angle, SNB, ANB, U1-NA, L1-NB, interincisal angle, facial angle, FMA, U1-NA (linear), L1-NB (linear), U1-A-Pog, Jarabak ratio, UAFH/LAFH, upper lip angle, lower lip thickness, chin thickness, TVL-Pog’, TVL-point A’, TVL-Glabella showed measurement differences
Table 1: Reproducibility of measurements for manual and digital methods

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Parameter</th>
<th>Manual</th>
<th>Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Difference* (mean ± SD)</td>
<td>Correlation coefficient</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>1.</td>
<td>Saddle angle</td>
<td>0.03 ± 1.03</td>
<td>0.98</td>
</tr>
<tr>
<td>2.</td>
<td>Articular angle</td>
<td>−0.06 ± 1.10</td>
<td>0.99</td>
</tr>
<tr>
<td>3.</td>
<td>Gonial angle</td>
<td>−0.15 ± 0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>4.</td>
<td>SNA angle</td>
<td>−0.09 ± 0.96</td>
<td>0.92</td>
</tr>
<tr>
<td>5.</td>
<td>SNB angle</td>
<td>−0.31 ± 0.96</td>
<td>0.95</td>
</tr>
<tr>
<td>6.</td>
<td>ANB angle</td>
<td>0.21 ± 1.36</td>
<td>0.86</td>
</tr>
<tr>
<td>7.</td>
<td>U1-NA</td>
<td>−0.31 ± 0.93</td>
<td>1.00</td>
</tr>
<tr>
<td>8.</td>
<td>L1-NB</td>
<td>−0.21 ± 0.94</td>
<td>0.99</td>
</tr>
<tr>
<td>9.</td>
<td>Interincisal angle</td>
<td>−0.09 ± 0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>10.</td>
<td>SN-GoGn</td>
<td>0.12 ± 1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>11.</td>
<td>SN-Occ</td>
<td>−0.28 ± 0.95</td>
<td>0.98</td>
</tr>
<tr>
<td>12.</td>
<td>Facial angle</td>
<td>−0.21 ± 0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>13.</td>
<td>Angle of convexity</td>
<td>−0.12 ± 0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>14.</td>
<td>FMA</td>
<td>−0.18 ± 0.96</td>
<td>0.99</td>
</tr>
<tr>
<td>15.</td>
<td>IMPA</td>
<td>−0.18 ± 0.96</td>
<td>0.99</td>
</tr>
<tr>
<td>16.</td>
<td>FMIA</td>
<td>0.37 ± 1.40</td>
<td>0.99</td>
</tr>
<tr>
<td>17.</td>
<td>Ant. cranial base</td>
<td>−0.5 ± 0.80</td>
<td>0.98</td>
</tr>
<tr>
<td>18.</td>
<td>Post. cranial base</td>
<td>−0.18 ± 0.99</td>
<td>0.98</td>
</tr>
<tr>
<td>19.</td>
<td>U1-NA</td>
<td>0.12 ± 1.00</td>
<td>0.97</td>
</tr>
<tr>
<td>20.</td>
<td>L1-NB</td>
<td>−0.12 ± 0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>21.</td>
<td>U1 to A-Pog</td>
<td>0 ± 1.00</td>
<td>0.98</td>
</tr>
<tr>
<td>22.</td>
<td>Jarabak ratio</td>
<td>−0.18 ± 0.64</td>
<td>0.99</td>
</tr>
<tr>
<td>23.</td>
<td>UAFH/LAFH ratio</td>
<td>−0.01 ± 0.03</td>
<td>0.85</td>
</tr>
</tbody>
</table>

*Difference between two duplicate measurements

r > 0.9—almost perfect correlation; r > 0.7—strong correlation; 0.5 < r > 0.7—moderate correlation; 0.3 < r > 0.5—mild correlation

of less than one unit. The parameters with measurement differences between 1 and 2 units were gonial angle, SNA, SN-GoGn, angle of convexity, IMPA, angle of convexity (soft tissue), TVL-nasal projection, TVL-B’, FMIA, upper lip thickness, maxillary height and mandibular height. The parameters showing measurement differences of less than 2 units have fair degree of accuracy to be clinically acceptable. The parameters showing measurement differences of more than two units by the two methods were:

1. Hard tissue parameters:
   1. SN-Occ angle
   2. Anterior cranial base length
   3. Posterior cranial base length

II. Soft tissue parameters:
   1. Nasolabial angle
   2. Facial height
   3. Lower lip length

DISCUSSION

15 out of 23 hard tissue measurements showed statistically significant differences in the digital and manual methods. A majority of these measurements depend on landmarks, such as articulare, gonion, porion, menton, gnathion, orbitale and point A, which lie on poorly defined outlines or low contrast areas. Previous studies by Houston et al, Gregston et al and Santoro et al on manual and computerized methods have found
Table 3: Comparison of soft tissue measurements obtained by manual and digital methods using student’s t test

<table>
<thead>
<tr>
<th>S.no.</th>
<th>Parameter</th>
<th>Manual (mean ± SD)</th>
<th>Digital (mean ± SD)</th>
<th>Difference (mean ± SD)</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Angular measurements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Nasolabial angle</td>
<td>103.28 ± 16.12</td>
<td>106.95 ± 15.94</td>
<td>−3.67 ± 2.38</td>
<td>−8.707</td>
<td>&lt; 0.001***</td>
</tr>
<tr>
<td>2.</td>
<td>Angle of convexity</td>
<td>18.03 ± 6.35</td>
<td>19.11 ± 5.67</td>
<td>−1.08 ± 2.10</td>
<td>−2.612</td>
<td>0.014**</td>
</tr>
<tr>
<td>3.</td>
<td>Upper lip angle</td>
<td>15 ± 8.95</td>
<td>13.93 ± 8.79</td>
<td>0.95 ± 3.14</td>
<td>1.707</td>
<td>0.098</td>
</tr>
<tr>
<td></td>
<td><strong>Linear measurements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Upper lip thickness</td>
<td>13.34 ± 2.29</td>
<td>11.60 ± 1.91</td>
<td>1.74 ± 1.68</td>
<td>3.29 ± 1.70</td>
<td>0.015***</td>
</tr>
<tr>
<td>2.</td>
<td>Lower lip thickness</td>
<td>13.53 ± 1.85</td>
<td>14.18 ± 1.78</td>
<td>−0.64 ± 2.08</td>
<td>−1.750</td>
<td>0.090</td>
</tr>
<tr>
<td>3.</td>
<td>Chin thickness</td>
<td>12.09 ± 1.49</td>
<td>11.98 ± 1.36</td>
<td>0.12 ± 1.40</td>
<td>0.479</td>
<td>0.636</td>
</tr>
<tr>
<td>4.</td>
<td>Facial height</td>
<td>122.84 ± 7.8</td>
<td>118.81 ± 6.53</td>
<td>4.04 ± 3.57</td>
<td>4.04 ± 3.57</td>
<td>0.001***</td>
</tr>
<tr>
<td>5.</td>
<td>Upper lip length</td>
<td>21.38 ± 2.32</td>
<td>19.59 ± 2.18</td>
<td>1.78 ± 1.44</td>
<td>7.017</td>
<td>0.001***</td>
</tr>
<tr>
<td>6.</td>
<td>Lower lip length</td>
<td>44.56 ± 3.88</td>
<td>40.91 ± 4.35</td>
<td>3.65 ± 2.61</td>
<td>7.920</td>
<td>0.001***</td>
</tr>
<tr>
<td>7.</td>
<td>Maxillary height</td>
<td>25.56 ± 2.68</td>
<td>24.03 ± 2.72</td>
<td>1.53 ± 1.49</td>
<td>5.825</td>
<td>0.001***</td>
</tr>
<tr>
<td>8.</td>
<td>Mandibular height</td>
<td>47.75 ± 3.99</td>
<td>46.09 ± 4.43</td>
<td>1.66 ± 2.44</td>
<td>3.854</td>
<td>0.001***</td>
</tr>
<tr>
<td>9.</td>
<td>TVL-Pog</td>
<td>−10.91 ± 5.73</td>
<td>−10.37 ± 5.43</td>
<td>−0.54 ± 1.57</td>
<td>−1.948</td>
<td>0.061</td>
</tr>
<tr>
<td>10.</td>
<td>TVL-nasal projection</td>
<td>14.78 ± 2.15</td>
<td>13.62 ± 2.8</td>
<td>1.17 ± 1.84</td>
<td>3.583</td>
<td>0.001***</td>
</tr>
<tr>
<td>11.</td>
<td>TVL-point A</td>
<td>−1.80 ± 1.23</td>
<td>−1.17 ± 1.34</td>
<td>−0.63 ± 1.04</td>
<td>−3.422</td>
<td>0.002***</td>
</tr>
<tr>
<td>12.</td>
<td>TVL-point B</td>
<td>−11.02 ± 4.48</td>
<td>−9.99 ± 6.32</td>
<td>−1.03 ± 6.26</td>
<td>−1.831</td>
<td>0.077</td>
</tr>
<tr>
<td>13.</td>
<td>TVL-glabella</td>
<td>−8.00 ± 4.1</td>
<td>−8.53 ± 3.5</td>
<td>0.53 ± 1.68</td>
<td>1.768</td>
<td>0.087</td>
</tr>
<tr>
<td></td>
<td><strong>Ratios</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>1.</td>
<td>UAFH/LAFH</td>
<td>0.98 ± 0.1</td>
<td>1.05 ± 0.09</td>
<td>−0.06 ± 0.07</td>
<td>−5.270</td>
<td>&lt; 0.001***</td>
</tr>
<tr>
<td>2.</td>
<td>UL/LL</td>
<td>0.47 ± 0.06</td>
<td>0.48 ± 0.06</td>
<td>−0.01 ± 0.03</td>
<td>−1.284</td>
<td>0.209</td>
</tr>
</tbody>
</table>

NS—not statistically significant; *p < 0.05—significant; **p < 0.01—very significant; ***p < 0.001—most significant
difficulties in locating the landmarks Ar, Gn, Go, Po, Or, lower incisor apex, Me, Point A and Pog. While different reference planes may be constructed to assist in identifying points Gn, Go and Me during hand tracing, this may not be possible with on-screen digitization. Previous studies by Baumrind and Frantz, Lim and Foong, Gravely and Benzies have reported tracing difficulties of the incisor position and variation in incisor angular measurements between tracing methods. The SN-Occ measurement is affected by the double images of the occlusal surfaces of the teeth, interfering with easy identification of the occlusal plane. Also the occlusal plane is marked automatically on the digital image and may not correspond to that drawn in the manual method. The differences in the UAFH/LAFH (N-ANS/ANS-Me) ratio can be explained by the difficulty in locating the Me point may be caused by the difficulty of delineating a landmark on a curved anatomical boundary. The uncertainty in locating ANS point may result from delineating the most anterior point of blurred anatomical outlines.

11 out of 18 soft tissue measurements showed significant differences in the manual and digital methods. Very few studies in the literature have evaluated soft tissue measurements due to the uncertainty in identifying soft tissue landmarks. The landmarks Li, Ls, Me, Pog, Sn and Point A were difficult to locate which may account for the measurement differences. According to Cooke and Wei lip prominence points are poor landmarks to identify. During conventional hand tracing, different reference planes may be constructed to identify the innermost point of a curve; therefore nasolabial angle, which is constructed on a curve, may show great variation.

According to Chen et al the measurement differences of less than 2 units (mm or degree) are generally within one standard deviation of norm values in conventional cephalometric analysis. The parameters with measurement differences of more than 2 units were hard tissue measurements SN-Occ, anterior cranial base length and posterior cranial base length as well as soft tissue measurements nasolabial angle, facial height and lower lip length.

Thus, out of a total 41 hard and soft tissue measurements, only six measurements showed clinically significant differences. This is in agreement with the results of Chen et al and Schulze et al who stated that although statistically significant differences between digitized and analog measurements existed, they were clinically insignificant (less than 2 units).

CONCLUSIONS

The following conclusions were drawn from the study:
1. All the measurements showed clinically acceptable reproducibility in the digital method ($r > 0.7$—strong correlation)
2. Digital measurements obtained from digital photographs of analog cephalograms were found to be reproducible and
comparable to the manual method for all the measurements undertaken in this study except the hard tissue variables of SN-Occ, anterior cranial base length and posterior cranial base length and soft tissue variables nasolabial angle, facial height and lower lip length, which showed clinically significant differences. These parameters could not be measured accurately with the digital method.

3. Nemotec digital imaging software can be reliably used with good accuracy for the measurements of most of the parameters used in routine clinical practice.

4. Further research needs to be done on the evaluation of growth changes or treatment effects by superimposition of radiographs by the digital method.

REFERENCES


