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# Comparison of Reliability and Accuracy in Cephalometric Landmark Plotting and Cephalometric Analysis between Manual and Computerized Cephalometric Methods

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## Abstract

Since the introduction of computerized cephalometric tracing, there has been flooding of various software in the recent years which has led to confusion of which particular software to choose. Hence this study was done to evaluate reliability and accuracy of cephalometric measurements obtained from three different computerized cephalometric analysis software as compared to manual tracings. Aim of the study was to compare reliability and accuracy of cephalometric landmark plotting and analyses between Manual tracing and two Computerized cephalometric tracing software, namely, NemoCeph NX 2006 and AutoCeph (1.1.2). A total of 60 lateral cephalogram records of the patients were chosen satisfying the inclusion criteria. Each cephalogram is traced and analysed manually and using AutoCeph and NemoCeph software for 10 angular and 4 linear measurements. Reliability between the measurements of three groups were statistically determined using ANOVA test (P <0.05). Most of the measurements showed high correlation except SNA, FMA, IMPA (P>0.05); however clinically insignificant. the difference in the measurements were found to be associated with inconsistent landmark identification with respect to point A, Nasion, Gonion, Gnathion. The difference in groups were minimal and clinically acceptable. All the angular and linear measurements were accurate and reliable except SNA, FMA, IMPA values even though clinically insignificant. So it can be concluded that both NemoCeph and AutoCeph can be preferred over manual tracing for its user friendly and time saving attributes.

**Keywords:** Lateral cephalogram, Manual tracing, NemoCeph, AutoCeph.

## Introduction

In 1895, the discovery of X rays by Wilhelm Roentgen stunned the world and himself as this improved the diagnosis and treatment planning, as he eventually was awarded with Nobel prize in 1917[1]. It also revolutionized the dental sector as it made possible to record and measure the cranium in two dimensions. Introduction of X rays to orthodontics did not take much time as the first X ray images of a skull in a lateral view were taken by Pacini and Carrera in 1922[2].

The search for proportionate analysis and to relate the traits to the physical reality is seen since antiquity. It was B Holly Broadbent in 1931, in USA and Hofrath from Germany during the same period started using a head holder as they called it a 'cephalostat'[3]. This helped the radiologists massively in adjusting the head in a consistent position during exposure. As a result of this calibration, clinicians started to collect precise measurements and study of craniofacial structures became much easier.

Cephalometry is defined as the assessment of head from bony and soft tissue land marks on the radiographic image (Krogman & Sassouni 1957)[4]. Lateral cephalograms have become indispensable to orthodontists in diagnosis and treatment planning Conventional cephalometric analysis is usually done on an acetate sheet placed over the lateral cephalogram after tracing the necessary landmarks and planes. Although widely used in orthodontics, this method of tracing consumes a lot of time and has the shortcoming of being subjected to errors. The main sources of errors include bad quality radiographs, landmark identification and technical errors during measurements[5].

With the advancement in digital radiography, manual tracing is slowly being replaced by digital tracing. Radiographic digitization can be either by conversion of manual film to a digital format or by direct digital radiographic unit, which can produce formats which are recognisable to the modern computers[6]. This digital cephalograms can be exported to a software to perform various analysis.

There has been a flooding of various cephalometric software for cephalometric analysis, across the globe since its first introduction. It also allows us to have a better look at the radiograph by using graphic and image processing software, which can reverse colour scale, increase the brightness and contrast as well as the sharpness and many other features. Hence, the present study was undertaken to evaluate the significant differences the parameters acquired from the lateral cephalogram analysis between the manual method of tracing and analysis on computer namely NemoCeph NX 2006 (ver 6.0) and AutoCeph (ver 1.1.2) and to check the reliability and accuracy of computerized tracing software over conventional manual tracing.

The purpose of the study was

1. To compare the reliability and accuracy of landmark identification and analysis between manual tracing and NemoCeph (ver.6.0) and AutoCeph (ver1.1.2) software.

## Methodology

A total of 60 lateral cephalogram records of the patients were selected from the Department of Orthodontics and Dentofacial Orthopedics at JSS Dental College and Hospital, Mysore,India for the study. No differentiations for age or gender were made. The radiographs were selected matched with the following criteria:

**Inclusion Criteria**

1. Lateral cephalograms of good landmark visibility and Good quality.
2. Patient biting in occlusion (maximum intercuspation).
3. Permanent dentition with no missing teeth.
4. Radiographs of patients with no history of trauma, facial deformity or previous history of orthognathic surgery.

**Exclusion Criteria**

1. Records of Orthodontic patients with history of trauma, syndromes, craniofacial deformity or missing teeth.
2. Radiographs with artefacts and excess soft tissues that might hinder the landmark identification.

The study was designed to compare the conventional method of manual tracing with two computerized tracing method, where 60 lateral cephalograms were scanned and analysed using NemoCeph NX 2006 and AutoCeph 1.1.2 software to test for the correlation of measurements attained from each groups. Three analysis, namely Steiner's analysis, Down's analysis and Tweeds analysis were done. All parameters of the analysis were obtained both manually and with the digital method.

The cephalometric analysis was done by two methods:

- Manual method.
- Digital method.

**Manual Methods**

Once the sample selection is done, a single examiner was allotted to perform the cephalometric tracings manually. The tracings were performed over a period of time to reduce the fatigue caused to the operator thereby reducing the error. A sheet of lead acetate tracing paper measuring 8 × 10 in and 0.003-in thickness was used. The tracings were done on a view box with the tracing paper securely positioned over the radiograph with a masking tape. After completion of the tracing of hard tissue and soft tissue structures using the manual methods, cephalometric landmarks associated with Steiner's, Downs and Tweeds analysis were identified and marked, with bilateral structures considered to produce a single structure or landmark.

**Digital Methods**

The 60 cephalometric radiographs were scanned using an Epson perfection v700 scanner into digital format and exported to the NemoCeph NX 2006 Version 6.0 (Fig.1) (Nemotec Software SRL, Madrid, Spain and Autoceph 1.1.2. (Fig.2) - developed by CSIR-Central Scientific Instruments Organization. Clarity of the image scanned was kept to 300 dpi resolution. Required correction of the image is done and landmark identification is initiated. Once the respective landmarks for Steiner's, Tweeds and Downs analyses is marked on the lateral cephalogram, program is run to acquire the values (table 1).

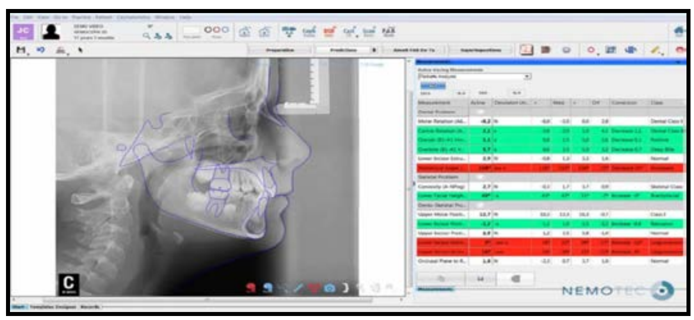

Fig. 1: NemoCeph Software – landmark plotting and analyses

Fig. 2: AutoCeph software - landmark plotting and analysis.

| Parameters | Measurements |
|---|---|
| **Skeletal** | |
| SNA | Antero posterior position of point A relative to the anterior cranial base. |
| SNB | Antero posterior position of the mandible in relation to the anterior cranial base. |
| ANB | The difference between SNA and SNB angles and expresses the mutual relationship of maxilla and mandible in the sagittal plane. |
| GoGn – SN | Anteroposterior positioning of mandible to the upper face. |
| Facial angle | Angle formed between N- point A to Pogonion |
| Angle of convexity | Angle between A-Point B to N-Pog |
| AB plane - NPog | Angle formed by mandibular plane to SN plane. |
| FMA | Angle formed by intersection of mandibular plane and Frankfort horizontal plane |
| FMIA | Angle between Frankfort horizontal plane and lower incisor plane. |
| IMPA | Angle formed between long axis of lower incisor to the mandibular plane. |
| **Dental** | |
| UI – NA (angle) | Angle formed between long axis of the foremost maxillary incisor and the line joining N to point A. |
| UI – NA (linear) | Linear measurement from tip of the foremost upper incisor and the line joining N to point A. |
| LI – NB (angle) | Angle formed between long axis of most protruded mandibular incisor and line joining N to point A. |
| LI – NB (linear) | Linear measurement from tip of the most advanced lower incisor and line joining N to point A. |

Table 1: Parameters recorded on the lateral cephalogram

**Calibration for Accuracy**

Before performing analysis on each cephalograms exported on to the programs, it was necessary to calibrate the image by determining the initial and final points of the ruler (100 mm) with the idea of adapting the actual size of each radiographic image. The actual size of each image was calibrated in millimeters based on the known distance of 10 mm between the two fixed points (fig.3) on the cephalostat rod seen on the radiograph. This calibration was normalized for all the images.

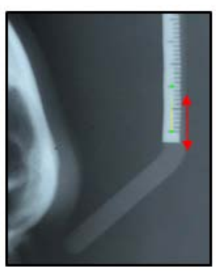

Fig. 3: Calibration on cephalostat rod (10mm) on software

**Descriptive Statistics**

Data was subjected to Shapiro-Wilk test for normality to see whether the data is normally distributed. The results revealed the data follows significantly normal distribution (P>0.05). Therefore, a parametric one-way analysis of variance (ANOVA) was carried out to see the significant influence of groups on all the measurements separately. If there is a significant difference in the values, further LSD (least square difference) pairwise comparison is carried out. So the P values are compared with 0.05 level of significance.

**Results**

Comparison between the measurements of the conventional and digital tracings were done and the results were made into two tables for skeletal and dental parameters (table 2&3). LSD test for pairwise comparison is carried out among the parameters that showed statistically significant differences. (Table 4).

**Skeletal parameters**

When the groups were compared using one-way ANOVA, there was a significant difference between the groups in terms of SNA, FMA and IMPA values (P<0.05) while all the other skeletal parameters gave statistically insignificant values. The mean SNA value recorded by AutoCeph and NemoCeph was 82.16 ± 3.908 and 81.25 ±3.502 respectively which was significantly higher than manual tracing values (80.33 ± 3.785). Mean FMA values recorded in manual tracing was 26.33 ±5.405 which was significantly lesser when compared to both AutoCeph (28.42 ±5.290) and NemoCeph (29.42 ±5.755). While mean values for IMPA was recorded highest in NemoCeph software (103.47 ± 7.267) which was statistically significant when compared to manual tracing (100.02 ± 9.293) and AutoCeph (100.11 ± 9.212) values.

**Dental parameters**

No statistically significant differences were found in dental measurements (table.3) between the three groups (*P* > 0.05).

| Parameters | Groups | Mean ± SD | F (2,177) | P value |
|---|---|---|---|---|
| SNA | Manual | 80.33 ± 3.785 | 3.581 | 0.030 |
| | Autoceph | 82.16 ± 3.908 | | |
| | Nemoceph | 81.25 ±3.502 | | |
| SNB | Manual | 77.08 ± 3.572 | 2.549 | 0.081 |
| | Autoceph | 78.55 ± 3.933 | | |
| | Nemoceph | 78.23 ± 3.733 | | |
| ANB | Manual | 3.30 ± 2.878 | 0.608 | 0.545 |
| | Autoceph | 3.62 ± 3.005 | | |
| | Nemoceph | 3.02 ±3.052 | | |
| GoGn-SN | Manual | 30.97 ±6.415 | 0.703 | 0.497 |
| | Autoceph | 30.90 ±6.442 | | |
| | Nemoceph | 32.16 ± 6.804 | | |
| Facial angle | Manual | 84.47 ±3.402 | 0.013 | 0.988 |
| | Autoceph | 84.47 ±4.020 | | |
| | Nemoceph | 84.38 ± 2.884 | | |
| Angle of convexity | manual | 4.82 ±6.813 | 0.571 | 0.566 |
| | Autoceph | 5.41 ±7.258 | | |
| | Nemoceph | 4.04 ±7.121 | | |
| A-B plane to N-Pog | Manual | -4.58 ± 4.473 | 1.056 | 0.350 |
| | Autoceph | -5.44 ± 4.007 | | |
| | Nemoceph | -4.38 ± 4.246 | | |
| FMA | Manual | 26.33 ±5.405 | 4.472 | 0.013 |
| | Autoceph | 28.42 ±5.290 | | |
| | Nemoceph | 29.42 ±5.755 | | |
| IMPA | Manual | 100.02 ± 9.293 | 3.116 | 0.047 |
| | Autoceph | 100.11 ± 9.212 | | |
| | Nemoceph | 103.47 ± 7.267 | | |
| FMIA | Manual | 53.37 ± 11.007 | 1.686 | 0.188 |
| | Autoceph | 50.62 ± 10.520 | | |
| | Nemoceph | 50.32 ± 8.333 | | |

Table 2: Skeletal parameters – Mean, Standard deviation, F value, P value

| Parameters | Group | Mean ± SD | F value | P value |
|---|---|---|---|---|
| UI – NA (deg) | Manual | 35 ± 7.330 | 0.647 | 0.525 |
| | Autoceph | 35.26 ± 7.486 | | |
| | Nemoceph | 33.79 ± 7.746 | | |
| LI –NB (deg) | Manual | 31.90 ± 7.501 | 0.360 | 0.698 |
| | Autoceph | 32.80 ± 7.766 | | |
| | Nemoceph | 33.01 ± 7.615 | | |
| UI - NA (mm) | Manual | 8.98 ± 3.160 | 0.151 | 0.860 |
| | Autoceph | 9.15 ± 4.276 | | |
| | Nemoceph | 8.79 ± 3.175 | | |
| LI – NB (mm) | Manual | 7.35 ± 2.968 | 1.817 | 0.166 |
| | Autoceph | 8.34 ± 4.116 | | |
| | nemoceph | 7.23 ± 3.291 | | |

Table 3: Dental parameters – Mean, Standard deviation, F value, P value

A post hoc test (LSD) was performed on the values which were found to be statistically significant in order to get a pairwise comparison. The results from the table of values (table 4) gave multiple comparison of SNA, FMA, IMPA values. SNA values when compared showed statistically significant difference between manual tracing and AutoCeph methods (p = 0.008) while it was insignificant when compared to NemoCeph (p=0.181). FMA values from manual tracing when compared with digital methods showed significant difference in AutoCeph as well as NemoCeph (p=0.039 and 0.004 respectively). IMPA value from NemoCeph software showed significance (p=0.030) when compared to the values from manual tracing but had no significant difference between manual and AutoCeph readings (p=0.953).

| Parameters | Group | Group | Sig. |
|---|---|---|---|
| SNA | Manual | Autoceph | .008 |
| | | Nemoceph | .181 |
| | Autoceph | Manual | .008 |
| | | Nemoceph | .184 |
| | Nemoceph | Manual | .181 |
| | | autoceph | .184 |
| FMA | Manual | Autoceph | .039 |
| | | Nemoceph | .004 |
| | Autoceph | Manual | .039 |
| | | Nemoceph | .415 |
| | Nemoceph | Manual | .004 |
| | | autoceph | .415 |
| IMPA | Manual | Autoceph | .953 |
| | | Nemoceph | .030 |
| | Autoceph | Manual | .953 |
| | | Nemoceph | .034 |
| | Nemoceph | Manual | .030 |
| | | autoceph | .034 |

Table 4: Post hoc test for significant values (pairwise comparison)

**Discussion**

The accuracy of analysis done on a cephalogram is an essential part in the diagnosis and treatment planning so that the clinician can assess the different treatment options and to predict the results from the treatment. Heretofore, manual tracing of lateral cephalograms was the mainstay in identifying landmarks and performing analyses by measuring distances and angles between different landmark locations and it is considered to be the gold standard in profile analysis using radiographs even after rapid evolution of the diagnosing tools.

With the advent of digital radiography, it became easier for the evaluation, manipulation and storage of the cephalograms. It also helped the clinicians to tune the image to desired brightness and contrast[7]. Digital radiography with the help of modern computers developed software that were capable of tracing, measuring and analysing the lateral cephalograms using various landmarks and planes.

In the current study, all hard and soft tissue landmarks were traced, with bilateral structures recorded to make a single structure or landmark. Literatures have proved that the bilateral structures form cloudiness and blurriness over the area making the identification of landmarks difficult. According to a study conducted by Forsyth et al[8] on automated cephalometric analysis system, they found it difficult to identify landmarks which lie on poorly defined structures when the signal to noise ratio was poor. They concluded that structures like, Menton and Glabella coming under high signal to noise ratio was located consistently than the structures under poor signal to noise ratio (Porion and Orbitale).

The current study examined the ability of two computerized cephalometric analysis programs namely AutoCeph and NemoCeph and compared them with conventional analysis technique by manual tracing over acetate sheet for their reliability. 60 lateral cephalograms were acquired from the records available and measurements were recorded from the analyses performed on the software as well as from conventional tracing. Previous studies have concluded that landmark identification one of the main source of error which is mainly due to inter examiner error. In order to minimize this error, landmark identification, tracing, analyses and measuring were carried out by a single examiner.

Most of the studies showed excellent accuracy in identifying the landmarks using a digital method. Chen et al[9] studied the effects of differences in landmark plotting on the values of cephalometric measurements, and found out differences between all cephalometric measurements between manual and digital tracing were statistically significant but clinically acceptable.

In the current study a total of 14 measurements were recorded (10 skeletal parameters and 4 dental parameters) which comes under Steiner's, Downs and Tweeds analyses (table 1). Most of the parameters showed excellent correlation among the groups except for SNA, FMA and IMPA. SNA values after one-way ANOVA showed significant difference between the groups ($p = 0.030$). the mean SNA value obtained from manual was $80.33 \pm 3.785$ while AutoCeph produced a mean of $82.16 \pm 3.908$ and NemoCeph showed slightly lesser value $81.25 \pm 3.502$. Pairwise comparison using LSD test proved that measurements from AutoCeph exhibited statistically significant difference to the values from manual tracing ($p = 0.08$).

Previous literatures have already proven that SNA is a difficult measurement to carry out[10] which testify that the cephalometric points on curved and poorly defined edges, such as point A and Nasion, tends to show higher error rates. Landmarks such as Nasion, Sella, A point, B point, and pogonion had shown low levels of reliability according to the study done by Baumrind Frantz[11]. Therefore, the reason for a significant difference in SNA in AutoCeph could be due to the difficulty in locating Nasion as well as point A. This result was in agreement with the study conducted by Al Barakati et al[12] as they found statistically significant difference in values while measuring SNA in manual and digital software. This difference in values was however clinically insignificant.

Another skeletal parameter which showed a statistical difference among the group was FMA (p =0.013) which is in accordance with the findings of V Kumar et al[13]. FMA according to Tweeds analysis is the angle obtained connecting Frankfort horizontal plane to mandibular plane. The mandibular plane connects the gonion (Go) and gnathion (Gn). The results from the current study inferred that when pairwise comparison was carried out, AutoCeph showed a significant difference when compared to the value obtained from manual tracing with P value at .039. While NemoCeph measurements when compared to values from conventional tracing attained an even significant difference (p = .004). this significant difference could possibly be due to the difficulty in identification of landmarks in curved areas as stated in previous literatures namely Go and Gn[5].

Gravely and Benzies[14] had narrated about difficulties in variation of angular measurements related to the incisors between two tracing procedures. IMPA values when compared between three groups gave a p value of 0.047 and it was NemoCeph which showed least correlation. Multiple comparison of groups revealed AutoCeph showing greater similarity to manual tracing (p=0.953) while NemoCeph gave a significant difference (p = 0.030). Since the dental parameter which included incisor angulations however showed no significant differences, it is possible that the dissimilarity in FMA and IMPA could be due to the difficulty in landmark plotting with respect to Go and Gn. This was in agreement with the study done by Mauricio Barbosa Guerra da Silva et al[15].

According to Gregston et al[16], the parameters with measurement variation of more than 2 units is found to be clinically significant, which means values within groups showing statistical difference also is clinically significant.

So from the current study we confirm that the non-correspondence between the values obtained from manual tracing method and digital methods could be mainly due to the difficulty in locating landmarks namely Point A, Nasion, Gonion and Gnathion. Both AutoCeph and NemoCeph showed significant difference in FMA values, which affirms the difficulty of plotting Go and Gn which connects the mandibular plane. This difference in values of FMA in the software could also be due to the difficulty in plotting Po which is the landmark to create the Frankfort Horizontal plane. These findings were in accordance with the previous literatures. This inconsistency was however clinically insignificant.

To conclude, this study confirms that both the digital cephalometric tracing software is highly reliable in case of landmark plotting and analysis and can replace classical cephalometric standards in the coming years. It also provides several advantages such as saving time, reducing use of paper in the office, easier storage and retrieval. As AutoCeph is inexpensive and readily available online, it is considered to be more feasible than NemoCeph which was rather expensive.

As the information technology is advancing every minute, the errors can get minimal as older algorithm will be replaced by newer ones resulting in a much more accurate measurement. Hence it is understood that both the digital cephalometric software was reliable and can be used in office by the orthodontists on a regular basis.

## Conclusion

The current study concludes that the cephalometric measurements acquired form all three methods were highly correlated except for three parameters.

1. The reliability and accuracy of the angular and linear measurements obtained from various analyses of manual, NemoCeph and AutoCeph methods showed excellent correlation between all parameters except SNA, FMA, IMPA. SNA values from AutoCeph showed significant difference in comparison to manual and NemoCeph tracings. IMPA values were significantly different in NemoCeph in comparison with manual and AutoCeph. FMA values showed significant difference in both the software when compared to manual. However, the difference in the values were clinically insignificant.
2. The current study demonstrated significant difference in values in which point A, Gonion, Gnathion and Porion were involved. This may be due to the inconsistency in these landmark plotting. This values were also clinically insignificant.
3. Both the computerized software showed consistency in their measurements and the differences were minimal. So it can be concluded that both NemoCeph and AutoCeph can be preferred over manual tracing for its user friendly and time saving attributes.

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