

# Comparative Analysis between Manual and Digital Cephalometric Tracing

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**Abstract:** *Cephalometric radiography is an important tool in diagnosis, prognosis, treatment planning and evaluation. The study is a comparative analysis between manual and digital cephalometric tracing to establish whether there is a statistically significant difference in the measured angular values. Materials and methods: 34 cephalograms were traced in 3 different methods - manual and digital using 2 different software programs. The manual cephalometric analyses were traced using x-ray lightbox, 0.5 mm HB pencil and protractor. For the digital profile analyses, cephalograms were scanned and traced with 3Txe 2.6.0.Inc (Korea) and OrthoDental (Bulgaria) software programs. All the analyses were performed by one operator 2 times within 30 days. Data from the three methods was processed by statistical package IBM SPSS Statistics 23.0 and level of significance  $p < 0.05$ . Results: The results showed closer values between the digital tracing with 3Txe and Orthodontal to manual tracing. The greatest relative difference (4.2%) occurred in the measurements of M/Occ angle, followed by the M/F angle (3.8%). The smallest relative difference was established in i/M angle (0.4%). Conclusion: The used comparative analysis showed there was no statistically significant difference between the number of maximal error between the three different methods.*

**Keywords:** Orthodontics, Cephalogram, Manual, Digital, Tracing

## 1. Introduction

The introduction of cephalometry by *Broadbent(1931)* and *Brodie* in the USA, and by *Hofrath* in Europe, allowed a depth evaluation of dental malocclusions and underlying skeletal discrepancies. [1,2] Cephalometric radiography now is an important tool in diagnosis, prognosis, treatment planning and evaluation, as well as in studies on growth and development of the dental and craniofacial complex. [3-5]

Cephalometrics is not an exact science. Even though headfilms can be measured with precision, the measurement error can vary greatly with any given landmark, as illustrated by the work of *Baumrind and Frantz (1971)*. [6] Cephalometric tracings can be performed by manual and / or computerized methods.

The manual method was, for a long time, the only method used for implementing and obtaining cephalometric tracing, and angular and linear measurements required for their interpretation. [7] The profile x-ray can be traced manually by the use of acetate paper, ruler, protractor and pencil. The operator determines the landmarks of the necessary anatomical structures. It is observed that in this type of cephalometric analysis there is a significant degree of error (projection errors, landmark identification and measurement errors). [8-10] The main disadvantage of this is that it is relatively time-consuming, particularly for orthodontists. [9,11]

Continuous technological advantages in computing combined with scientific advances in dental radiology resulted in the development of computer programs designed to perform cephalometric tracing and measurements, and different types of analysis. [6,7] In the digital cephalometric analysis, once the required landmarks have been entered, the software automatically calculates the angular and linear values, thus eliminating the errors that may occur by manual

tracing when drawing lines with ruler and measuring angles with protractor. [5,12,13] Furthermore, collecting computer-assessed cephalometrics is less time-consuming than manual tracing [14,15], and it allows the user to obtain several analyses at a time, [16] In addition, digital archiving overcomes the problem of film deterioration. [15,16]

Since more and more programs for cephalometric analysis are developed, it is necessary to assess their accuracy relative to one another and relative to the traditional manual tracing.

## 2. Aim

The aim of this study was to make a comparison between manual and digital cephalometric analyses to establish whether there is a statistically significant difference in the measured angular values.

## 3. Materials and Methods

The study included a total of 108 cephalometric radiographs of 108 orthodontic patients made between March 2014 and August 2015. The criteria for selection of patients' cephalograms were: patients between 18 and 36 years of age; no extracted teeth (except third molars), no history of hypodontia, no implants, lack of prosthodontic constructions and good x-ray quality without image artifacts. After forming the selection criteria 74 patients' cephalograms were excluded from the study. Only 34 profile cephalograms met the certain criteria and were included in the study.

All the profile x-rays were made with PlanmecaProMax 3D Classic and film focal length of 40 cm. Cephalometric tracing of each x-ray was done in 3 different methods - manual and digital using two different software programs - 3Txe 2.6.0.Inc (Korea) and Orthodontal (Bulgaria).

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For the purposes of the study were measured following angles:

- Angle SNA - the position of the upper jaw
- Angle SNB - the position of the lower jaw
- Angle ANB - the ratio between the both jaws in a sagittal direction and the skeletal class
- Angle I/SN - the axis of the upper incisors (I) to the plane of the base of the skull (SN)
- Angle i/MP - the axis of the lower incisors (i) to the mandibular plane (MP)
- Angle SN/MP –the angle between the planes SN and mandibular plane (MP)
- Angle F/MP - the angle between the Frankfurt plane (F) and mandibular plane (MP)
- Angle SpP/MP - the angle between the spinal plane(SpP) and mandibular plane (MP)
- Angle Occ/MP - the angle between the occlusal plane (Occ) and mandibular plane (MP)

The manual tracing was done using acetate paper, x-ray lightbox, 0.5 mm HB pencil to outline the points, ruler and protractor. The operator determined all the landmarks and anatomical structures alone.

For the digital tracing, the profile x-rays were scanned and uploaded in 3Txe 2.6.0.Inc (Korea) and OrthoDental (Bulgaria) software programs. The anatomical structures are set in advance in the both of the software programs. The operator should only point the landmarks during the tracing. After placing all the landmarks the programs automatically connect them and calculate the value of the angles.

All the analyses were performed by one operator two times within 30 days.

#### Statistical Methods

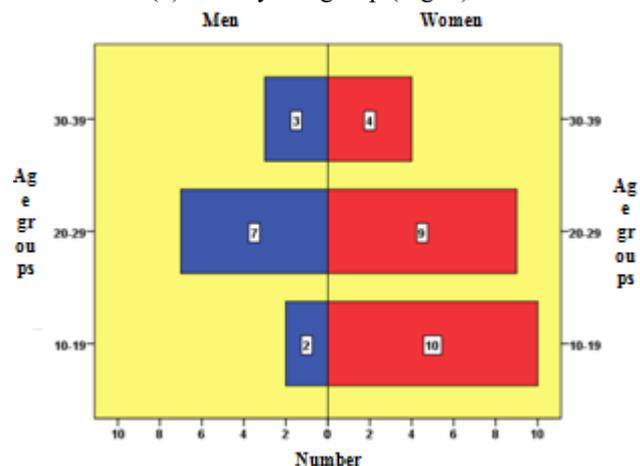
Data were entered and processed with statistical package IBM SPSS Statistics 23.0. For level of significance, rejecting the null hypothesis, was accepted  $p < 0.05$ . The following methods were applied:

- 1) **Variation analysis** - to assess the characteristics of central tendency and statistical dispersion.
- 2) **Test  $\chi^2$  for a sample** - to check the type of distribution.
- 3) **Nonparametric test of Shapiro-Wilk** - to check the distribution of normality.
- 4) **Mauchly test** - for checking multivariate normality.
- 5) **Single-factor analysis of variance for repeated measures** (Repeated measures ANOVA) - hypothesis testing for difference between means of several dependent samples.
- 6) **Students T-test** - hypothesis testing for difference between two dependent samples.

#### 4. Results

Study sample included 35 patients with an average age of  $24.29 \pm 5.97$  years in the range 18-36 years. Of these, 12 (34.3%) were men and 23 (65.7%) women. The age group with the highest number (7) in men was 20-29 years, followed by 30-39 years (3) and the least (2) - 10-19 years of age. Among women with the highest number (10) was the

age group from 10 to 19 years, followed by 20-29 years (9) and the least (4) 30-39 years group (Fig. 1).



**Figure 1:** Distribution of patients by gender and age

#### Statistical differences between the methods

Table 1 shows that:

- There was no significant difference between the three methods in the measurement of angles SNA, SNB, ANB and I/SN;
- Angle i/MP had significantly higher average value when measured with 3Txe compared to Orthodontal, but not compared to the manual tracing. There was no statistically significant difference between the values measured with the last two methods;
- Angle SN/MP had significantly higher average value measured with 3Txe compared to the manual, but not compared to Orthodontal. The results of the last two methods were not statistically different with each other;
- Angle F/MP had significantly higher average value measured with Orthodontal compared to the manual, but not compared to 3Txe. There was no statistically significant difference between the values measured with the last two methods;
- Angle SpP/MP had significantly higher average values measured with 3Txe and Orthodontal compared to the manual method. The results of the first two methods did not differ statistically between themselves;
- Angle Occ/MP had significantly higher average value measured with 3Txe compared to the manual and Orthodontal. There was no statistically significant difference between the values measured with the last two methods.

**Table 1:** Comparative analysis of the results obtained

Method Angles	n	3Txe		Orthodontal		Manual	
		$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
SNA	35	80,32 <sup>a</sup>	3,69	80,45 <sup>a</sup>	3,69	80,43 <sup>a</sup>	3,61
SNB	35	77,60 <sup>a</sup>	3,47	77,74 <sup>a</sup>	3,33	77,50 <sup>a</sup>	3,37
ANB	35	3,34 <sup>a</sup>	2,19	3,26 <sup>a</sup>	2,35	3,43 <sup>a</sup>	2,41
I/SN	35	99,48 <sup>a</sup>	9,07	99,36 <sup>a</sup>	9,14	99,28 <sup>a</sup>	8,79
i/M	35	96,16 <sup>a</sup>	6,82	95,74 <sup>bc</sup>	7,13	96,08 <sup>ac</sup>	6,95
SN/MP	35	31,27 <sup>a</sup>	5,48	31,05 <sup>ac</sup>	5,37	30,87 <sup>bc</sup>	5,36
F/MP	35	23,25 <sup>ac</sup>	5,22	23,74 <sup>a</sup>	5,04	22,83 <sup>bc</sup>	5,08
SpP/MP	35	22,55 <sup>a</sup>	4,77	22,51 <sup>a</sup>	5,01	22,07 <sup>b</sup>	5,05
Occ/MP	35	15,43 <sup>a</sup>	4,50	14,78 <sup>b</sup>	4,12	15,12 <sup>b</sup>	4,58

\* Identical letters in horizontals mean lack of significant difference and different letters - the existence of such ( $p < 0,05$ ).

**Statistical error between the methods**

In this case in the calculation of average values we compared purely algebraic standard errors. Table 2 shows that:

- In four of the measured angles maximum standard error in calculating the average value was made by 3T<sub>xer</sub> software (SNA, SNB, SN/MP and F/MP)
- Two of the maximum standard errors in calculating the average value were made by Orthodontal software (I/SN and i/MP);
- The remaining three maximum values of standard error in calculating the average value were made by the manual method (ANB, SpP/MP and Occ/MP);
- Application of  $\chi^2$  test on one sample showed no statistically significant difference in the number of cases with maximum error between the methods.

**Table 2:** Comparative analysis of the results obtained from the three methods

Methods Angles	n	3T <sub>xer</sub>		Orthodontal		Manual	
		$\bar{X}$	SEM	$\bar{X}$	SEM	$\bar{X}$	SEM
SNA	35	80,319	<b>0,624</b>	80,447	0,623	80,429	0,609
SNB	35	77,595	<b>0,587</b>	77,738	0,563	77,500	0,570
ANB	35	3,345	0,371	3,259	0,398	3,430	<b>0,408</b>
I/SN	35	99,484	1,533	99,359	<b>1,545</b>	99,280	1,485
i/MP	35	96,159	1,153	95,738	<b>1,205</b>	96,077	1,175
SN/MP	35	31,271	<b>0,926</b>	31,051	0,908	30,871	0,905
F/MP	35	23,250	<b>0,882</b>	23,741	0,853	22,829	0,859
SpP/MP	35	22,550	0,806	22,509	0,846	22,071	<b>0,854</b>
Occ/MP	35	15,425	0,761	14,778	0,697	15,123	<b>0,774</b>

\* Identical letters in horizontals mean lack of significant difference and different letters - the existence of such ( $p < 0,05$ )

**Reliability of the methods**

The results in Table 3 showed the most common lack of significant difference (3 times) between the averages was between 3T<sub>xer</sub> and Orthodontal (the five angles with provided statistically significant difference in values were considered).

**Table 3:** Indication of statistical identical results for the angles where there is a significant difference in results obtained with the three methods

Methods Angles	3T <sub>xer</sub>	Orthodontal	Manual
i/M	X		X
SN/MP	X	X	
F/MP	X	X	
SpP/MP	X	X	
Occ/MP		X	X

**Angles with the highest difference in the values**

Table 4 shows that:

- The greatest relative difference (4.2%) occurred in the measurement of Occ/MP, followed by F/MP (3,8%);
- The smallest relative difference was ini/MP (0,4%).

**Table 4:** Comparative analysis of the maximum differences between the three methods for the angles which have a significant difference

Methods Angles	3T <sub>xer</sub>	Orthodontal	Manual	Absolute max. difference	Relative max.diff erence (%)
	$\bar{X}$	$\bar{X}$	$\bar{X}$		
M/Occ	15,425	14,778	15,123	0,647	4,194
F/MP	23,250	23,741	22,829	0,912	3,841
SpP/MP	22,550	22,509	22,071	0,479	2,124
SN/M	31,271	31,051	30,871	0,400	1,279
i/M	96,159	95,738	96,077	0,421	0,438

**Minimum and maximum difference**

Table 5 shows that between the averages:

- The minimum difference (0.02%) was observed in SNA, followed by i/MP (0,09%);
- The maximum difference was observed in ANB (2,48%).

**Table 5:** Comparative analysis of the minimal differences between the three methods for measuring angles

Methods Angles	3T <sub>xer</sub>	Orthodontal	Manual	Absolute minimal difference	Relative minimal difference (%)
	$\bar{X}$	$\bar{X}$	$\bar{X}$		
SNA	80,319	80,447	80,429	0,018	0,02
i/M	96,159	95,738	96,077	0,082	0,09
I/SN	99,484	99,359	99,280	0,125	0,13
SNB	77,595	77,738	77,500	0,143	0,18
SpP/MP	22,550	22,509	22,071	0,041	0,18
SN/MP	31,271	31,051	30,871	0,22	0,70
Occ/MP	15,425	14,778	15,123	0,302	1,96
F/MP	23,250	23,741	22,829	0,491	2,07
ANB	3,345	3,259	3,430	0,085	2,48

**5. Discussion**

Various sources of error inherent in Cephalometry were well described by Hallett (1959), Baumrind and Frantz (1971) and Houston (1983).[17-19] Three types of errors were pointed out by Baumrind: 1) errors of projection; 2) errors of landmark location; 3) mechanical errors in drawing lines between points on tracings and in measuring with ruler or protractor.

Houston (1983) divided the errors into two different types – validity and reproducibility. Validity was the extent to which the value obtained represents the true value and reproducibility was the closeness of successive measurements of the same object. [20]

Enlarged and distorted radiographic image, care and skill of measurement, variations in the positioning of the patient in the cephalostat, variations in film density, sharpness and landmark identification could all possible contribute to the total errors in cephalometric analysis. [20]

Many investigators have shown that landmark identification errors are the most important source of error in lateral cephalometric analysis (Broadway 1962, Richardson 1966, Carisson 1967, Kvam 1969, Baumrind and Frantz 1971,

Gravelly 1974, Midtgard 1974, Broch 1981, Houston 1983, Cohen 1984, Houston 1986, Savage 1987).[20]

Landmarks involved in the position and inclination of incisors, such as Nasion, Sella, A point, B point and Pogonion have particularly lower levels of reliability (Baumrind Frantz 1971, Broadway 1962).[18]

Stabrún (1982) used one hundred cephalograms digitized by two examiners. For each registration of the landmark, Apex Inferior, the observer recorded the certainty or uncertainty with which it had been localized. He found that there were 75% of cases with a lack of certainty in locating the Apex Inferior and in which this should be taken into account when using the axial inclination of the Lower Incisor in diagnosis and treatment planning. [21]

Baumrind and Frantz (1971) have shown that the landmarks, Gonion and Lower Incisors apex were the least reliable landmarks among the sixteen standard cephalometric landmarks studied, with standard deviations being  $\pm 4.96$  mm. and  $\pm 2.36$  min. respectively. [18]

Contrary to these findings, our study showed the i/MP angle was the second most reliable value after SNA. Various studies have been carried out to determine the reliability of cephalometric tracing.

Carlsson (1967) investigated the precision in measurement of distance with a ruler graduated in half millimeters, with calipers graduated in tenths of a millimeter and in the measurement of angles with protractors when read to the nearest degree or half degrees. He found that the precision of the measurements could be improved by reading off the measurement values to a tenth of a millimeter or degree. The measuring instrument should be calibrated for determining and checking of random or systematic errors.[22]

The development of electronic plotting equipment has provided an additional approach to measuring radiographs. In this method, the radiograph or the tracing to be measured, is placed on the tracing table and a cursor is positioned and recorded for every measuring point in sequence. As the digitizer is a highly accurate measuring instrument one might have expected that it would be more accurate and reliable than measuring with a ruler and protractor. [20]

Sandler (1988) compared the errors involved using three different methods: hand instruments on tracings, digitization of tracings, and direct digitization of the radiographs. He found that hand measurements, if done carefully, agreed reasonably well with methods involving the digitizer. However, misreading the instruments, ruler or protractor, must be born in mind as a possible source of error. Although direct digitization was slightly more reproducible than the other two methods. [23]

By comparing the reproducibility of traditional and computerized methods of cephalometric analysis, Richardson (1981) concluded that the traditional method was inferior to the digitizing method but not alarmingly so. [24]

Tsorovas and Karsten (2010) traced 30 profile x-rays manually and through 5 different computer programs. The data obtained was compared within both methods as well as the necessary time required for preparation of analyzes by them. They found the digital method of analysis can be considered as less time consuming and just as reliable as the manual method. [5]

According to our study the digitizing method showed only a small advantage over the tracing technique in cephalometric analysis. The main advantages of the digitizer were in terms of speed of application and of preparation of data for computer analysis, especially when large numbers of records were to be analyzed. Although the digitizer had an additional advantage in terms of measuring accuracy.

Goracci and Ferrari (2014), in their study on 20 profile x-rays, compared results obtained with digital processing program (SmileCeph) and manually. The authors found that there was no statistically significant difference between the measured parameters in digital and manual methods. [25]

Iacob et al. (2014) examined 60 initial profile x-rays of 60 patients. The authors compare the results obtained by digital (Orthalis cephalometric software) and manual method. Parameters from the Steiner and Tweed analysis were used. It was found that there was no statistically significant difference between the measured parameters. [26]

Paixão et al. in a study of 50 profile x-rays, compared the results, measured manually and by a digital cephalometric program (Dolphin Imaging 11.0). The results showed there was no statistically significant difference in any of the measured values. [7]

Similar to the results of Goracci and Ferrari, Iacob et al. and Paixão et al., we found there was no statistically significant difference in the obtained results between the used methods.

## 5. Conclusion

As a conclusion it can be said that digital techniques for cephalometric tracing is similar in accuracy with manual technique. Digital cephalometric analysis is useful for placement of orthodontic diagnosis and to determine treatment plan. The main advantages are that it is time-saving and eliminates mathematical errors.

Replicate measurements can be taken and are averaged to further improved reliability by reducing the risk of gross errors due to incorrect identification of a landmark, and by reducing the size of random errors. Replicate digitization should be quick and simple. However replicate tracing is time consuming and it is rarely done other than in the evaluation of errors.

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