第 49 卷 第 3 期
2022 年 3 月

湖南大学学报（自然科学版）
Journal of Hunan University (Natural Sciences)

Vol. 49 No. 3
March 2022

Open Access Article

Comparison of Cephalometric Measurements of On-Screen Images by CephX Software and Hard-Copy Printouts by Conventional Manual Tracing

Ribwar F. Khalid[1], Saya Mustafa Azeez[2] *

[1] Department of Diagnosis & Radiology, Faculty of Dentistry, Tishk International University, Erbil, Kurdistan Region, Iraq

[2] Department of Orthodontics, Faculty of Dentistry, Tishk International University, Erbil, Kurdistan Region, Iraq

Abstract: Newer diagnostic methods have become widespread in medicine nowadays as a result of extraordinary advancements in the field of electronics. On computers, various orthodontic programs are available as software. When it comes to orthodontics, diagnosis is critical, with the radiographic study being the most important phase. The goal of this research was to assess the level of liability of direct digital radiograph tracing using CephX and compare with hand tracing digital printouts and evaluate the two techniques concerning measurement reproducibility of individual methods. The material consisted of 25 digital lateral cephalometric images, fourteen linear and angular parameters were measured by a single operator digitally and manually. The intraclass correlation coefficient and confidence interval were used to compare the difference of the measurements obtained from manual and digital tracings, and intra-examiner error was evaluated by the coefficient of variation. A comparison of hand and CephX tracing showed a low level of agreement in the anterior facial height, anterior and posterior cranial base length. Only of (LI to A-Pog) line for both manual and digital methods showed poor intra-examiner duplicability. Thus, it can be concluded that digital tracing with CephX is adequate for clinical uses and similar to manual cephalometric tracings.

Keywords: CephX software, on-screen, printouts, duplicability, cephalometric.

CephX 软件对屏幕图像的头影测量与传统手动追踪的硬拷贝打印结果的比较

摘要：由于电子领域的非凡进步，新的诊断方法如今已在医学中广泛使用。在计算机上，各种正畸程序可作为软件使用。在正畸方面，诊断至关重要，而放射学研究是最重要的阶段。本研究的目的是评估使用 CephX 进行直接数字射线照相追踪的责任水平，并与手部追踪数字打印输出进行比较，并评估这两种技术有关单个方法的测量再现性。该材料由 25 个数字侧位头影测量图像组成，14 个线性和角度参数由单个操作员以数字和手动方式测量。组内相关系数和置信区间用于比较手动和数字跟踪获得的测量值的差异，并通过变异系数评估检查者内的误差。手部和 CephX 追踪的比较显示，前面部高度、前部和后部颅底长度的一致性较低。只有手动和数字方法的（下切牙到 A-Pog）线显示检查者内部重复性差。因此，可以得出结论，使用 CephX 进行数字追踪足以用于临床应用，并且类似于手动头部测量追踪。

关键词：CephX 软件、屏幕显示、打印输出、可复制性、头影测量。

Received: 11 December, 2021/ Revised: 19 January, 2022/ Accepted: 12 February, 2022/ Published:31 March, 2022

About the authors: Ribwar F. Khalid, Department of Diagnosis & Radiology, Faculty of Dentistry, Tishk International University, Erbil, Iraq; Saya Mustafa Azeez, Department of Orthodontics, Faculty of Dentistry, Tishk International University, Erbil, Iraq.

Corresponding author Saya Mustafa Azeez, saya.mustafa@tiu.edu.iq

1. Introduction

Cephalometric radiography is a vital technique for determining the growth and development of the facial skeleton, as well as identifying and planning treatment and comparing before and after treatment results [1-4]. Tracing cephalometric landmarks on acetate papers and computing linear and angular variables have traditionally been used in cephalometric studies. Even with its well-known usage in orthodontics, the procedure is consuming of time and has several disadvantages, involving a significant risk error of landmark recognition, tracing, and measurement errors [2-5].

Acquisition, identification, and technical measurement errors are the three types of cephalometric errors. The operator's ability to repeat measurements is also a key aspect in evaluating the validity of any analysis method. Computer-assisted cephalometric tracing has just become a possible choice for technical advancements. The advantage of using computers in the planning of treatment is predicted to minimize individual error while also providing uniform, quick, and accurate calculation with a high level of duplicability [6].

Digitizer pads, digital cameras, and scanners were the early innovations in computerized radiography to convert analog film to a digital format. Direct digital images, which have recently improved, offer benefits such as rapid image acquisition, reduced radiation doses, accelerated image augmentation, sharing and archiving of images, and the removal of technique-sensitive development procedures [7, 8]. Direct digital imaging eliminates errors caused by digitizing pads and scanners, as well as errors caused by operator tiredness. Converting conventional cephalometric film to digital format and digital radiography both demand less storage space, resulting in better archiving [9].

As a result, a variety of commercially accessible or specialized applications have been created to make cephalometric evaluations directly on the digital image shown on the computer. Such applications could significantly reduce the risk of digitizing pad errors and eliminate the necessity for hard copies of digitally born images for traditional cephalometric analysis [10, 11].

Systematic and random mistakes are both present in cephalometric analysis, with the latter involving tracing, landmark recognition, and measurements. Mechanical mistakes in sketching lines among landmarks and measuring with a protractor can be eliminated using computer-aided cephalometric analysis. The landmarks are frequently digitized first when employing computer-assisted software applications for cephalometric analysis. When the positions of all the relevant landmarks are entered, the software application may instantly create cephalometric measurement values [6, 12].

Consequently, the goal of this research was to assess the level of liability of direct digital radiograph tracing using CephX, which is artificial intelligence computerized technology making automatic analytical and diagnostic tasks, as cephalometric analyses and comparing with hand tracing digital printouts and evaluating the two techniques concerning measurement reproducibility of individual methods.

2. Materials and Methods

Twenty-five lateral cephalograms were randomly chosen from x-ray files at Tishk International University's department of radiology, dentistry faculty, based on the following criteria:

1) The X-ray images of good quality were selected to allow landmark detection;

2) The same machine should be used for all radiographs;

3) The calibration ruler should be visible on all radiographs;

4) There is no extra soft tissue that could block discovering anatomical sites (as determined by radiography);

5) The cephalogram which revealed significant asymmetry was excluded, indicating that the patient was not appropriately positioned as indicated by the ear-road markers.

The same Tele-X-ray cephalostat (NewTom GIANO/VG3, Imola, Italy) was used to obtain all lateral cephalometric radiographs, which were set at x1.11 magnifications with a source-detector distance (SID) of 1512 mm, a source-skin distance of > 1000 mm, and a scanning period of 4.6 s as indicated by the manufacturer. All patients' heads were positioned so that the Frankfort plane coincided with the horizontal light trace and the teeth were in centric occlusion with lips softly sealed together. The cephalometric sensor displays a pixel size of 48 x 48 m and a sensitive area of 6 x 220 mm, according to its specifications.

An expert orthodontist traced and evaluated all the radiographs manually and digitally. To avoid fatigue-related errors, only five cephalograms were traced per day. For the manual tracing approach, the films were printed on Directvista film 11x14 inches utilizing a multi-media Codonics horizon Xl imager (Ampronix Inc, Irvine, CA). The manual tracings were then done on cephalometric tracing film acetate (0.003″ 8″ 10) with a standardized light viewing box and 0.3mm lead pencil. A cephalometric protractor was used to make linear and angular measurements.

Digital images of selected cephalograms in DAT format were transferred to the CephX for digital cephalometric measurements. Two crosshairs 25 mm apart were used to calibrate the images. With the use of the mouse/cursor, image-enhancing elements such as brightness, contrast adjustment, and magnification were employed as needed to detect individual cephalometric landmarks as precisely as feasible. Once all of the landmarks had been noted, they were re-adjusted and rectified to ensure exact measurements. The tracing software calculated all angular and linear data automatically. The information gathered was statistically analyzed. Various measurements were done as follows; 5 angular skeletal measurements, 4 linear skeletal measurements, 3 angular dental measurements, 2 linear dental measurements (Table 1).

2.1. Statistical Analysis

Statistical analysis software (SPSS version 22) was used for the statistical analysis. An intra-examiner error was assessed by retracing of 5 randomly selected radiographs (at a 3-week interval). The Coefficient of variation (CV) was applied to calculate the reliability of intra-examiner, and the Intra-class correlation coefficient (ICC) and Confidence interval (CI) was applied to determine the agreement between digital and manual tracings. The low agreement is indicated by an ICC value of 0.75, whilst a strong agreement is indicated by an ICC value of >0.75.

Table 1 The cephalometric variables

Saddle angle	**An angle formed by connecting Articulare, Sella, and Nasion**
Articular angle	An angle formed by connecting Gonion, Articulare, and Sella
Gonial angle	An angle formed by connecting Menton, Gonion, and Articulare
Angle of convexity	An angle formed by the intersection of N- Point A line to point A-Pog line
Facial angle	An angle formed by the intersection of N-Pog line to Frankfort horizontal plane
ACBL	A line formed by the connection of Sella and Nasion
PCBL	A line formed by the connection of Sella and Articular
Posterior facial height	A line formed by the connection of Sella and Gonion
Anterior facial height	A line formed by the connection of Nasion and Gnathion
Interincisal angle	An angle formed by the intersection of the long axis of Upper and lower incisor
UI to SN	An angle formed by the intersection of Upper incisor long axis to the Sella-Nasion plane
LI to GoGn	An angle formed by the intersection of Lower incisor long axis to Gonion-Gnathion
UI to A-Pog	Horizontal distance between Upper incisor to A-pog line
LI to A-Pog	Horizontal distance between Lower incisor to A-pog line

3. Results

The CV value only of LI to A-Pog parameter for both manual and digital methods was over 10% regarding the intra-examiner tracing error (Table 2). The means and standard deviations of all the linear and angular measurements were assessed and tabulated in table 3. A comparison of hand and CephX tracing showed a low level of agreement in the following measurements: ACBL, PCBL, Anterior facial height.

Table 2 Intra-examiner reliability using coefficient of variation

Parameters	**Hand**		**Digital**	
	ICC	**CV%**	**ICC**	**CV%**
Saddle angle	0.944	3	0.980	1.9
Articular angle	0.778	3	0.891	1.9
Gonial angle	0.855	0.9	0.802	1.3
Angle of convexity	0.853	2.7	0.987	0.8
Facial angle	0.994	1.4	0.969	1.1
ACBL	0.856	4.3	0.780	3.2
PCBL	0.947	6.8	0.87	4.6
Posterior facial height	0.765	4.6	0.772	0.7
Anterior facial height	0.976	2.6	0.848	0.7
Interincisal angle	0.980	2.4	0.997	0.8
UI to A-Pog	0.960	7.4	0.990	6.8
LI to A-Pog	0.920	*19.3*	0.994	*14.1*
UI to SN	0.911	6.7	0.984	2.1
LI to GoGn	0.862	5.3	0.881	1.8

4. Discussion

With the rise in popularity of digital cephalometric, it's become more important to assess the accurateness of these novel on-screen software programs and evaluate them to conventional manual measuring approaches. The performance of this commercially accessible cephalometric analysis software has been studied by numerous researchers [11, 13, 14], but this appears to be the first study to assess the CephX direct digital cephalometric digitization on-screen software program.

Magnification, landmark identification, tracing, measuring, and documentation have all been identified as substantial causes of inaccuracy in the traditional cephalometric analysis [2, 3, 14, 15]. The majority of studies testing the precision of digital tracing software have scanned traditional cephalometric film into a digital format, which might cause visual distortion.

When the analog film was transformed to digital format utilizing a scanner, Bruntz et al. [16] detected distortion in both horizontal and vertical dimensions. Digital cephalometrics are becoming more widely used in orthodontic clinics, and direct image transmission to a computer database is now possible. The current investigation used digital radiographs instead of scanned pictures to reduce magnification-related problems.

Furthermore, conventional measures were taken using printouts of the digital radiographs because the 'sandwich approach,' in which digital and analog films are gained concurrently, was not possible [17]

Table 3 comparison of hand and CephX tracing using Intra-class correlation coefficient (ICC) and Confidence interval (CI)

Parameters	**Hand tracing Mean ± SD**	**CephX tracing Mean ± SD**	**ICC**	**CI 95%**
Saddle angle	123.49 ± 6.29	123.07 ± 6.62	0.977	0.948-0.990
Articular angle	143.83 ± 6.93	143.14 ± 634	0.963	0.917-0.984
Gonial angle	125.16 ± 4.46	123.29 ± 4.08	0.929	0.182-0.982
Angle of convexity	176.25 ± 6.61	176.81 ± 7.92	0.962	0.915-0.983
Facial angle	88.22 ± 4.57	88.02 ± 4.83	0.990	0.978-0.996
ACBL	72.37 ± 4	68.57 ± 4.12	*0.766*	-0.175-0.940
PCBL	37.69 ± 3.53	34.85 ±2.73	*0.730*	-0.198-0.920
Posterior facial height	81.36 ± 7.23	76.99 ± 6.91	0.879	-0.180-0.970
Anterior facial height	119.29 ± 6.86	112.79 ± 7.02	*0.755*	-0.192-0.935
Interincisal angle	126.38 ± 11.16	126.03 ± 10.49	0.977	0.949-0.990
UI to A-Pog	6.08 ± 3.08	5.91 ± 2.64	0.973	0.940-0.988
LI to A-Pog	2.64 ± 2.66	2.28 ± 2.47	0.976	0.935-0.990
UI to SN	103.44 ± 7.51	105.61 ± 7.21	0.959	0.648-0.988
LI to GoGn	99.79 ± 8.41	96.76 ± 8.5	0.952	0.319-0.988

Although a prior study discovered that hard copy printouts of digital cephalograms can result in small enlargement, the difference is minor and considered clinically acceptable [16].

In vivo investigations comparing traditional and digital radiography face a variety of challenges. Because of the increased radiation exposure, taking successive analog and digital radiographs is deemed unethical, and they cannot be depended on to generate equal data because of likely head position changes. It may be advantageous to employ a sandwich technique to gain both digital and traditional films at the same time; however, this may not always be practicable. In the current investigation, hand tracing was done on hard copy printouts of digital radiographs generated at 1:1. As a result, only the digital image was calibrated preceding on-screen digitalization.

The ICC compares the variability of multiple ratings of the same subject to the total variation across all ratings and all subjects to determine rating dependability. It is a measure of element homogeneity within clusters, with a maximum value of 1 indicating total homogeneity [18]. CI is also a precision indicator. A broader CI suggests a lesser level of precision, whereas a narrower CI indicates a higher level of precision [19]. T-tests were not employed to determine the degree of the agreement since they compare the means of two groups, which could lead to mathematical errors. Because a small divergence in a few numbers could quickly alter the group means, correlation and agreement were used to examine the data. This means that data from earlier studies of a similar nature should be analyzed properly.

The CV was utilized to assess intra-examiner error, and CV values below 10% were discovered, which were regarded low [21]. For both approaches, 13 out of 14 measurements had a CV of less than 10%. This is not surprising given that the majority of these metrics have been well investigated [11, 21, 22], indicating that they are highly repeatable. Because the inter-examiner error is higher than the intra-examiner error, all landmark identification, tracing, and measurements were done by one investigator in this study to reduce error [9]. Furthermore, no more than 5 cephalograms were traced per day to avoid fatigue-related mistakes.

Regardless of the tracing method utilized, LI to A-Pog measurements were the only ones that demonstrated poor intra-examiner repeatability, same results were reported by Gregston et al. [23], Santoro et al. [11], and Tsorovas and Karsten [24]. This can be explained by the difficulty in detecting Point A, which is difficult to locate because of the ANS and upper incisors overlapping in the 2D projection of the cranium. The apex of the lower incisors is difficult to find due to the superimposition of various anatomical elements and has demonstrated poor duplicability in tests conducted by Baumrind and Frantz [2, 3], Oliver et al. [25], Polat-Ozsoyet et al. [6], and Houston et al. [15]. Several studies have shown difficulty tracing incisor positions in addition to differences in angular measurements of incisors between tracing approaches [2, 26].

Comparing the agreement level between manual tracing cephalometric measurements and the CephX software application. Except for ACBL, PCBL, and anterior facial height (ICC < 0.75), most of the metrics exhibited significant levels of agreement. Santoro et al. [11], Tikku et al. [27], Celik et al. [28] also found disparities in anterior facial height for both tracing methods, which is like the findings of this study. Both the anterior and posterior cranial bases showed substantial changes, according to Tikku et al. [27] and

Agarwal et al. [29].

The disparity between the two approaches in measurements could be owing to the evidence that some tissue landmarks, as the Gnathion (Gn), Menton (Me), Orbitale (Or), Articulare (Ar), Porion (Po), and Point 'A', are situated on vague outlines or places with low contrast. Houston et al. [15], Gregston et al. [23], Ozsoy et al. [6], and Santaro et al. [11], for example, struggled positioning landmarks such as Gnathion (Gn), Articulare (Ar), Gonion (Go), Orbitale (Or), Porion (Po), Point 'A', Lower incisor apex, Menton (Me), Pogonion (Pog). When the frontonasal suture is not adequately visible, Nasion (N) may be difficult to recognize, according to Sekiguchi and Savara [30].

Various reference planes were built during manual tracing to aid in identifying points, which is not achievable with on-screen digitizing, when these points were indicated by the investigator with a single mouse click without any reference plane development may explain why some landmarks are difficult to record [21]. Although, image augmentation by changing brightness and contrast in direct digital cephalograms can improve the reliability of some landmark recognition, potentially leading to more accurate cephalometric analysis since the landmarks are not covered by tracing paper.

5. Conclusion

With the growing popularity of digital cephalometric, it's become more critical to evaluate the accuracy of these revolutionary on-screen software applications and compare them to traditional manual measuring methods. CephX is a 2D cephalometric analysis software that was created with current cephalometric software trends in mind. As a result, it can be used as a user-friendly and time-saving tool to meet the needs of modern clinical practices and clinical research. In this study, only three linear measurements (ACBL, PCBL, and anterior facial height) showed low-level agreement between the tracing methods out of 14 measurements. These measurements included anatomical landmarks such as Nasion, Sella, Articulare, and Gnathion, which have been proven to show a low level of reproducibility. Thus, it can be concluded that digital tracing with CephX is adequate for clinical uses and similar to manual cephalometric tracings. When the benefits of digital imaging are considered, such as archiving, augmentation, and transmission, the digitized approach may be preferable in daily usage and for research purposes without sacrificing quality.

One of the drawbacks is that only 25 lateral cephalograms were used to compare manual and digital tracing; more research with a larger sample size is needed to ensure this software is error-free. Another drawback was that, unlike manual tracing, it was not feasible to draw reference planes to indicate landmarks for digital tracing.

References

[1] BRODIE A. On the growth pattern of the human head. From the third month to the eighth year of life. *American Journal of Anatomy*, 1941, 68(2): 209-262. https://doi.org/10.1002/aja.1000680204

[2] BAUMRIND S., & FRANTZ R. C. The reliability of head film measurements 1. *Journal of Anatomy*, 1971, 60(2): 111-127. https://doi.org/10.1016/0002-9416(71)90028-5

[3] BAUMRIND S., & FRANTZ R. C. The reliability of head film measurements. 2. Conventional angular and linear measures. *American Journal of Anatomy*, 1971, 60(5): 505-517. https://doi.org/10.1016/0002-9416(71)90116-3

[4] RICKETTS R. M. Perspectives in the clinical application of cephalometrics. The first fifty years. *The Angle Orthodontist*, 1981, 51(2): 115-150. https://doi.org/10.1043/0003-3219(1981)051%3C0115:pitcao%3E2.0.co;2

[5] SANDLER P. J. Reproducibility of cephalometric measurements. *Journal of Orthodontics*, 1988, 15(2): 105-110. https://doi.org/10.1179/bjo.15.2.105

[6] POLAT-OZSOY O., GOKCELIK A., and TOYGAR MEMIKOGLU T. U. Differences in cephalometric measurements: a comparison of digital versus hand-tracing methods. *European Journal of Orthodontics*, 2009, 31(3): 254-259. https://doi.org/10.1093/ejo/cjn121

[7] QUINTERO J. C., TROSIEN A., HATCHER D., and KAPILA S. Craniofacial imaging in orthodontics: historical perspective, current status, and future developments. *The Angle Orthodontist*, 1999, 69(6): 491-506. https://doi.org/10.1043/0003-3219(1999)069<0491:CIIOHP>2.3.CO;2

[8] BRENNAN J. An introduction to digital radiography in dentistry. *Journal of Orthodontics*, 2002, 29(1): 66-69. https://doi.org/10.1093/ortho/29.1.66

[9] SAYINSU K., ISIK F., TRAKYALI G., and ARUN T. An evaluation of the errors in cephalometric measurements on scanned cephalometric images and conventional tracings. *European Journal of Orthodontics*, 2007, 29(1): 105-108. https://doi.org/10.1093/ejo/cjl065

[10] SINGH P., & DAVIES T. I. A comparison of cephalometric measurements: a picture archiving and communication system versus the hand-tracing method--a preliminary study. *European Journal of Orthodontics*, 2011, 33(4): 350-353. https://doi.org/10.1093/ejo/cjq087

[11] SANTORO M., JARJOURA K., and CANGIALOSI T. J. Accuracy of digital and analogue cephalometric measurements assessed with the sandwich technique. *American Journal of Orthodontics & Dentofacial Orthopedics*, 2006, 129(3): 345-351. https://doi.org/10.1016/j.ajodo.2005.12.010

[12] ONGKOSUWITO E. M., KATSAROS C., VAN'T HOF M. A., BODEGOM J. C., and KUIJPERS-JAGTMAN A. M. The reproducibility of cephalometric measurements: a comparison of analogue and digital methods. *European Journal of Orthodontics*, 2002, 24(6): 655-665. https://doi.org/10.1093/ejo/24.6.655

[13] NIMKARN Y., & MILES P. G. Reliability of computer-generated cephalometrics. *The International Journal of Adult Orthodontics and Orthognathic Surgery*, 1995, 10(1): 43-52. https://pubmed.ncbi.nlm.nih.gov/9081992/

[14] KUBLASHVILI T., KULA K., GLAROS A., HARDMAN P., and KULA T. A comparison of conventional

and digital radiographic methods and cephalometric analysis software: II. soft tissue. *Seminars in Orthodontics*, 2004, 10(3): 212-219. https://doi.org/10.1053/j.sodo.2004.05.005

[15] HOUSTON W. J., MAHER R. E., MCELROY D., and SHERRIFF M. Sources of error in measurements from cephalometric radiographs. *European Journal of Orthodontics*, 1986, 8(3): 149-51. https://doi.org/10.1093/ejo/8.3.149

[16] BRUNTZ L. Q., PALOMO J. M., BADEN S., and HANS M. G. A comparison of scanned lateral cephalograms with corresponding original radiographs. *American Journal of Orthodontics & Dentofacial Orthopedics*, 2006, 130(3): 340-348. https://doi.org/10.1016/j.ajodo.2004.12.029

[17] HOUSTON W. J. The analysis of errors in orthodontic measurements. *American Journal of Orthodontics*, 1983, 83(5): 382-390. https://doi.org/10.1016/0002-9416(83)90322-6

[18] KISH L. Cluster sampling and subsampling. In: *Survey sampling*. Wiley-Interscience, New York, 1995: 170–173.

[19] KIRKWOOD B., & STERNE J. Analysis of numerical outcome. In: *Essentials of medical statistics (2nd ed.)*. Blackwell Publishing Limited, Oxford, 2001: 50–80.

[20] MACHIN D., CAMPBELL M. J., and WALTERS S. J. Reliability and method comparison studies. In: *Medical statistics: textbook for the health sciences (4th ed.)*. John Wiley & Sons Ltd, Oxford, 2007: 202–213.

[21] GEELEN W., WENZEL A., GOTFREDSEN E., KRUGER M., and HANSSON L. G. Reproducibility of cephalometric landmarks on conventional film, hardcopy, and monitor-displayed images obtained by the storage phosphor technique. *European Journal of Orthodontics*, 1998, 20(3): 331-40. https://doi.org/10.1093/ejo/20.3.331

[22] CHEN Y. J., CHEN S. K., CHANG H. F., and CHEN K. C. Comparison of landmark identification in traditional versus computer-aided digital cephalometry. *The Angle Orthodontist*, 2000, 70(5): 387-392. https://doi.org/10.1043/0003-3219(2000)070<0387:COLIIT>2.0.CO;2

[23] GREGSTON M. D., KULA T., HARDMAN P., GLAROS A., and KULA K. A comparison of conventional and digital radiographic methods and cephalometric analysis software: I. hard tissue. *Seminars in Orthodontics*, 2004, 10(3): 204-211. https://doi.org/10.1053/j.sodo.2004.05.004

[24] TSOROVAS G., & KARSTEN A. L. A comparison of hand-tracing and cephalometric analysis computer programs with and without advanced features--accuracy and time demands. *European Journal of Orthodontics*, 2010, 32(6): 721-728. https://doi.org/10.1093/ejo/cjq009

[25] SINGH P., & DAVIES I. D. A comparison of cephalometric measurements: a picture archiving and communication system versus the hand-tracing method—a preliminary study. *European Journal of Orthodontics*, 2011, 33(4): 350-353. https://doi.org/10.1093/ejo/cjq087

[26] LIM K. F., & FOONG K. W. Phosphor-stimulated computed cephalometry: reliability of landmark identification. *British Journal of Orthodontics*, 1997, 24(4): 301-308. https://doi.org/10.1093/ortho/24.4.301

[27] TIKKU T., KHANNA R., MAURYA R. P., SRIVASTAVA K., and BHUSHAN R. Comparative evaluation of cephalometric measurements of monitor-displayed images by Nemoceph software and its hard copy by manual tracing. *Journal of Oral Biology and Craniofacial Research*, 2014, 4(1): 35-41. https://doi.org/10.1016/j.jobcr.2013.11.002

[28] CELIK E., POLAT-OZSOY O., and TOYGAR MEMIKOGLU T. U. Comparison of cephalometric measurements with digital versus conventional cephalometric analysis. *European Journal of Orthodontics*, 2009, 31(3): 241-246. https://doi.org/10.1093/ejo/cjn105

[29] AGARWAL N., BAGGA D. K., and SHARMA P. A comparative study of cephalometric measurements with digital versus manual methods. *The Journal of Indian Orthodontic Society*, 2011, 45(2): 84-90. https://doi.org/10.5005/jp-journals-10021-1014

[30] SEKIGUCHI T., & SAVARA B. S. Variability of cephalometric landmarks used for face growth studies. *American Journal of Orthodontics*, 1972, 61(6): 603-618. https://doi.org/10.1016/0002-9416(72)90109-1

参考文:

[1] BRODIE A. 关于人体头部的生长规律。从生命的第三个月到第八年。美国解剖学杂志, 1941, 68(2): 209-262. https://doi.org/10.1002/aja.1000680204

[2] BAUMRIND S., 和 FRANTZ R. C. 头膜测量的可靠性 1. 解剖学杂志, 1971, 60(2): 111-127. https://doi.org/10.1016/0002-9416(71)90028-5

[3] BAUMRIND S., 和 FRANTZ R. C. 头膜测量的可靠性。2. 常规角度和线性测量。美国解剖学杂志, 1971, 60(5): 505-517. https://doi.org/10.1016/0002-9416(71)90116-3

[4] RICKETTS R. M. 头影测量临床应用的展望。第一个五十年。角度正畸医生, 1981, 51(2): 115-150. https://doi.org/10.1043/0003-3219(1981)051%3C0115:pitcao%3E2.0.co;2

[5] SANDLER P. J. 头影测量的可重复性。口腔正畸杂志, 1988, 15(2): 105-110. https://doi.org/10.1179/bjo.15.2.105

[6] POLAT-OZSOY O., GOKCELIK A., 和 TOYGAR MEMIKOGLU T. U. 头影测量的差异：数字与手动追踪方法的比较。欧洲正畸杂志, 2009, 31(3): 254-259. https://doi.org/10.1093/ejo/cjn121

[7] QUINTERO J. C., TROSIEN A., HATCHER D., 和 KAPILA S. 正畸中的颅面成像：历史视角、现状和未来发展。角度正畸医生, 1999, 69(6): 491-506. https://doi.org/10.1043/0003-3219(1999)069<0491:CIIOHP>2.3.CO;2

[8] BRENNAN J. 牙科数字射线照相术简介。口腔正畸杂志, 2002, 29(1): 66-69. https://doi.org/10.1093/ortho/29.1.66

[9] SAYINSU K., ISIK F., TRAKYALI G., and ARUN T. 对扫描的头影测量图像和常规追踪的头影测量误差的评估。欧洲正畸杂志, 2007, 29(1): 105-108. https://doi.org/10.1093/ejo/cjl065

[10] SINGH P., 和 DAVIES T. I. 头影测量的比较：图片存档和通信系统与手部追踪方法的比较——初步研究。欧洲正畸杂志, 2011, 33(4): 350-353.

https://doi.org/10.1093/ejo/cjq087

[11] SANTORO M., JARJOURA K., 和 CANGIALOSI T. J. 用夹心技术评估的数字和模拟头影测量的准确性。美国正畸与牙面骨科杂志，2006, 129(3): 345-351. https://doi.org/10.1016/j.ajodo.2005.12.010

[12] ONGKOSUWITO E. M., KATSAROS C., VAN'T HOF M. A., BODEGOM J. C., 和 KUIJPERS-JAGTMAN A. M. 头影测量的再现性：模拟和数字方法的比较。欧洲正畸杂志，2002, 24(6): 655-665. https://doi.org/10.1093/ejo/24.6.655

[13] NIMKARN Y., 和 MILES P. G. 计算机生成的头影测量的可靠性。国际成人正畸和正颌外科杂志, 1995, 10(1): 43-52. https://pubmed.ncbi.nlm.nih.gov/9081992/

[14] KUBLASHVILI T., KULA K., GLAROS A., HARDMAN P., 和 KULA T. 传统和数字射线照相方法和头影测量分析软件的比较：II。软组织。正畸研讨会, 2004, 10(3): 212-219. https://doi.org/10.1053/j.sodo.2004.05.005

[15] HOUSTON W. J., MAHER R. E., MCELROY D., 和 SHERRIFF M. 头影测量 X 光片测量误差的来源。欧洲正畸杂志，1986, 8(3): 149-51. https://doi.org/10.1093/ejo/8.3.149

[16] BRUNTZ L. Q., PALOMO J. M., BADEN S., 和 HANS M. G. 扫描的侧位头影图与相应的原始 X 光片的比较。美国正畸与牙面骨科杂志, 2006, 130(3): 340-348. https://doi.org/10.1016/j.ajodo.2004.12.029

[17] HOUSTON W. J. 正畸测量误差分析。美国正畸杂志, 1983, 83(5): 382-390. https://doi.org/10.1016/0002-9416(83)90322-6

[18] KISH L. 整群抽样和子抽样。在：调查抽样。威利-跨科学, 纽约, 1995: 170–173.

[19] KIRKWOOD B., 和 STERNE J. 数值结果分析。在：医学统计学要点（第 2 版）。布莱克威尔出版有限公司，牛津, 2001: 50–80.

[20] MACHIN D., CAMPBELL M. J., 和 WALTERS S. J. 可靠性和方法比较研究。在：医学统计学：健康科学教科书（第 4 版）。约翰威利父子公司, 牛津, 2007: 202–213.

[21] GEELEN W., WENZEL A., GOTFREDSEN E., KRUGER M., 和 HANSSON L. G. 通过存储磷光体技术获得的传统胶片、硬拷贝和监视器显示图像上的头部测量标志的再现性。欧洲正畸杂志, 1998, 20(3): 331-40. https://doi.org/10.1093/ejo/20.3.331

[22] CHEN Y. J., CHEN S. K., CHANG H. F., 和 CHEN K. C. 传统与计算机辅助数字头影测量中地标识别的比较。角度正畸医生，2000, 70(5): 387-392. https://doi.org/10.1043/0003-3219(2000)070<0387:COLIIT>2.0.CO;2

[23] GREGSTON M. D., KULA T., HARDMAN P., GLAROS A., 和 KULA K. 常规和数字射线照相方法和头影测量分析软件的比较： I. 硬组织。正畸研讨会, 2004, 10(3): 204-211. https://doi.org/10.1053/j.sodo.2004.05.004

[24] TSOROVAS G., 和 KARSTEN A. L. 具有和不具有高级功能的手部追踪和头部测量分析计算机程序的比较——准确性和时间要求。欧洲正畸杂志, 2010, 32(6): 721-728. https://doi.org/10.1093/ejo/cjq009

[25] SINGH P., 和 DAVIES I. D. 头影测量的比较：图片存档和通信系统与手部追踪方法的比较——初步研究。欧洲正畸杂志，2011, 33(4): 350-353. https://doi.org/10.1093/ejo/cjq087

[26] LIM K. F., 和 FOONG K. W. 磷刺激计算机头影测量：地标识别的可靠性。英国正畸杂志, 1997, 24(4): 301-308. https://doi.org/10.1093/ortho/24.4.301

[27] TIKKU T., KHANNA R., MAURYA R. P., SRIVASTAVA K., 和 BHUSHAN R. 尼莫头软件对监视器显示图像的头影测量测量结果与手动追踪硬拷贝的比较评估。口腔生物学与颅面研究杂志, 2014, 4(1): 35-41. https://doi.org/10.1016/j.jobcr.2013.11.002

[28] CELIK E., POLAT-OZSOY O., 和 TOYGAR MEMIKOGLU T. U. 头影测量测量与数字与传统头影测量分析的比较。欧洲正畸杂志, 2009, 31(3): 241-246. https://doi.org/10.1093/ejo/cjn105

[29] AGARWAL N., BAGGA D. K., and SHARMA P. 头影测量与数字与手动方法的比较研究。印度正畸学会杂志, 2011, 45(2): 84-90. https://doi.org/10.5005/jp-journals-10021-1014

[30] SEKIGUCHI T., 和 SAVARA B. S. 用于面部生长研究的头部测量标志的可变性。美国正畸杂志, 1972, 61(6): 603-618. https://doi.org/10.1016/0002-9416(72)90109-1