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Comparative Evaluation Of Accuracy And Time Efficiency Of Upper Airway Analysis Using Manual Tracing Method And Artificial Intelligence Application - A Cross-Sectional, Retrospective Study

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ABSTRACT

AIM: To evaluate and compare the accuracy, time efficiency and overall effectiveness of upper airway analysis performed using manual tracing techniques versus artificial intelligence-based applications.

METHOD: The digital cephalometric radiographs of orthodontic patients 60 between age group of 10-30 years of age with permanent and mixed dentition of male female. Tracings by manual method and on Ceph X computerized cephalometric tracing software will be performed by the author itself to minimize the variability of the measurements. McNamara airway analysis will be performed on the lateral cephalograms of patients by manual method of cephalometric tracings, then on computer with Ceph X Computerized Cephalometric Tracing Software.

RESULTS: Mean Distribution of the Time Taken for tracing for Manual and CephX was 27.05 ± 6.43 and 12.86 ± 2.58 respectively. When Comparison of the Time Taken for tracing between Manual Tracing and CephX was done it was observed that the difference was 14.18 and this difference in the time was statistically significant ($p<0.05$).

CONCLUSION: The study was carried out on 60 lateral cephalogram shot by the Carestream CS9600 traced by two different methods, tracing with manual tracing, computerized cephalometric tracing software showed statistically significant differences seen in upper airway analysis.

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1. INTRODUCTION

The digital epoch in health sciences have been a mark in the start by initial upheavals like CBCT, Artificial Intelligence, 3D printing[1]. Artificial Intelligence as a computerized manufactured human cognitive function was vocabularied by Dartmouth University in 1956[2]. The paradigm shift in the pluridisciplinary link between Artificial Intelligence and data sciences which is a live through scientific method, all recent advances and advancements have been possible[3,4].

Artificial Intelligence refers to fundamental technologies including deep learning, artificial neural network(ANN) and machine learning. Predictions about new data and set of conditions using statistical ornaments of previous learned data is machine learning. Computers which acquire a knowledge of utilizing structures inspired by the human brain is the process of of deep learning, whereas computers which gain an understanding of thinking and art with less human interlinkage is the process of machine learning. Since the craniofacial complex could be responsible for possible constrictions of upper airway, physicians used surgical and non-invasive methods to change the anatomy and resolve the airway constriction. The use of X-ray is important to assess the effectiveness and find the possible side effects of these treatments. In the past, 2-Dimensional lateral cephalometry was used to evaluate airway alterations in patients with dentofacial and skeletal anomalies during the stages of diagnosis, treatment planning and follow-up.[2]

Cephalometric analysis is a quantitative diagnostic tool routinely utilized by orthodontists, prosthodontists and maxillofacial and orthognathic surgeons to assess skeletal and dentoalveolar relationships, morphometric characteristics and growth pattern in patients. Since its introduction in 1931, this method has evolved significantly, the latest advancements in orthodontic radiology and diagnostics.

Despite technological advancements, the manual tracings of specific points in relation to key anatomical structures of the skull and neck on lateral, frontal and axial 2D radiographs remains the gold standard for this procedure. The primary challenges in accurately identifying cephalometric points include the time commitment, the high level of expertise required and the potential for variability between and within operators[4]. While software is now widely utilized for cephalometric measurements, the tracing of landmarks continues to be a manual process that must be carried out by an orthodontic specialist.

Artificial Intelligence technologies have the potential to aid in meeting these orthodontic needs by automating tasks, enhancing accuracy, minimizing variability. A number of studies have already utilized Artificial intelligence automation for manual orthodontic diagnosis tasks such as landmarks detection, cephalometric analysis and malocclusion diagnosis using both 2D and 3D imaging. However, these are still a need for comprehensive review and mapping of existing literature on the application of Artificial Intelligence for various orthodontic tasks, taking into account their performance, reliability and time efficiency[2]. Therefore, the basic aim of the study is to evaluate and compare the accuracy, time efficiency and overall effectiveness of upper airway analysis performed using manual tracing techniques versus artificial intelligence based applications.

2. OBJECTIVE

1. To compare the accuracy of upper airway measurements obtained via manual tracing with those derived from artificial intelligence (AI) applications, focusing on parameters.

2. To compare the reliability of upper airway measurements obtained via manual tracing with those derived from artificial intelligence (AI) applications, focusing on parameters

3. To evaluate the differences between the values obtained as a result of airway analysis performed manually and by the artificial intelligence application.

4. To compare the amount of time taken to perform cephalometric

analyses by both the methods.

5. To identify potential discrepancies and determine which method

provides more consistent and reproducible results.

3. METHODOLOGY

The digital cephalometric radiographs of orthodontic patients 60 between age group of 10-30 years of age with permanent and mixed dentition of male female is randomly selected from the database of the Department of Orthodontic and Dentofacial Orthopaedics in D.Y. Patil University School of Dentistry, Navi Mumbai.

The Lateral cephalogram of the patients will be shot by the machine Carestream CS9600 Department of Oral Medicine and Radiology is to be obtained at the Department Of Orthodontic itself. The patient's head to be parallel to the ground and perpendicular to the mid-sagittal plane in all the lateral cephalometric radiographs. Tracings by manual method and on Ceph X computerized cephalometric tracing software will be performed by the author itself to minimize the variability of the measurements. Transparent tracing paper (straight line acetate tracing paper) with dimensions of 8*10 inches and thickness of 0.003mm is placed on the hard copies of lateral cephalograms.

The manual tracing are subsequently performed using a a mechanical pencil with 0.5 mm lead. Mc Namara airway analysis will be performed on the lateral cephalograms of patients by manual method of cephalometric tracings, then on computer with Ceph X Computerized Cephalometric Tracing Software. For digital tracing, the lateral cephalograms will be placed on the light box and photographs of X-rays will be taken taken with DSLR camera . Proper standardization of the photographs will be maintained. The difference in the cephalometric values of the tracings carried out manually and by the computer software are compared with standard mean values and reliability of manual tracing and computer software is tested. The readings obtained by these traced cephalometric radiographs will be compared and subjected to appropriate statistical analysis. The time efficiency is measured by intra examiner reliability where one examiner will be used to compare the time taken for manual and Ceph X tracing simultaneously.

4. STANDARDIZATION DONE IN THE STUDY

1. All 60 lateral cephalograms were taken and developed by the same machine Carestream CS9600 in the Department of Oral Medicine and Radiology, with manual and digital tracing done by the operator to reduce measurement variability.

2. To standardize the lateral cephalograms, DSLR is used to click every photo of lateral cephalograms and is used in the study with a ratio of 4:5

3. To optimize landmark identification, the same operator undertook manual and digital tracing.

4. To irradicate intra-operator errors for the manual and digital method, all 60 lateral cephalogram were traced manually and digitally by the same operator.

5. Not more than 10 lateral cephalogram were traced regardless of the method at any time to avoid operator fatigue.

5. RESULTS

Distribution of the Participants According to Gender

		Frequency	Percent
Gender	Male	22	37.3
	Female	37	62.7
	Total	59	100.0

Mean Distribution of the Time Taken for tracing

	N	Min	Max	Mean	SD
Manual Tracing	59	18.00	39.00	27.0508	6.43381
Ceph X	59	8.00	18.00	12.8644	2.58282

Mean Distribution of the Deviation from mean (T)

	N	Min	Max	Mean	SD
Manual Tracing	59	10.00	27.00	16.1356	4.62697
Ceph X	59	12.60	20.10	16.8458	1.86818

Mean Distribution of the Error T

	N	Min	Max	Mean	SD
Manual Tracing	59	-7.50	10.50	-1.2763	4.97086
Ceph X	59	-5.30	3.50	-.6644	2.16761

Comparison of the Time Taken for tracing between Manual Tracing and Ceph X

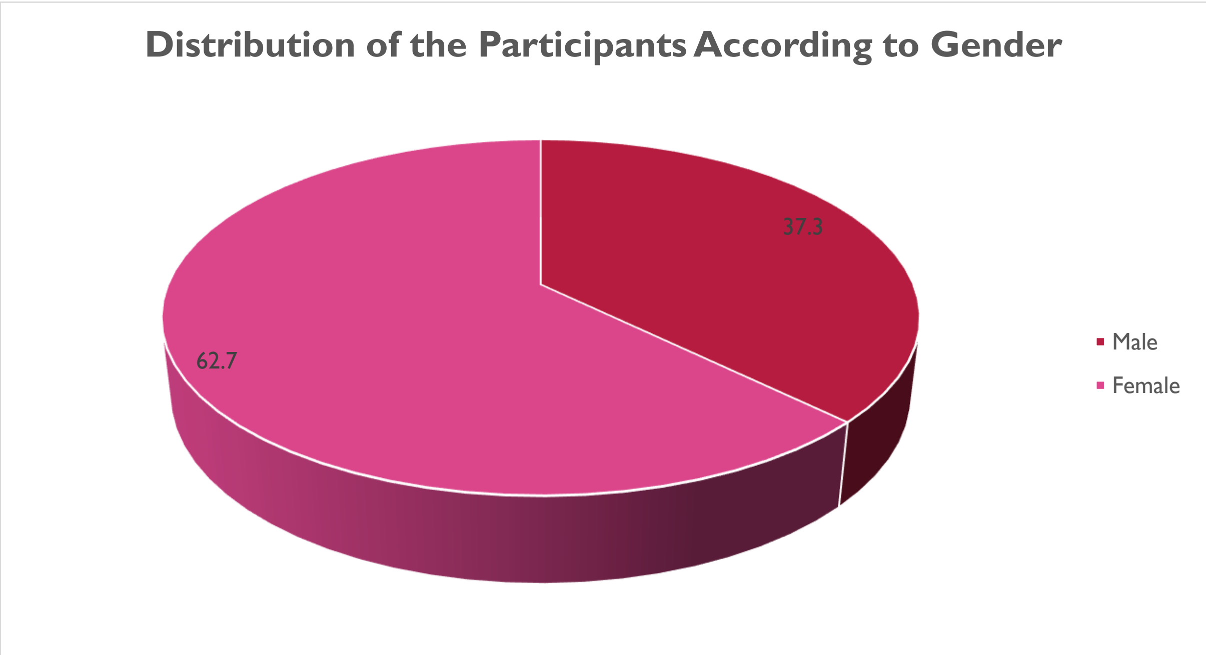
	Groups	N	Mean	Std. Deviation	Std. Error Mean	Mean Difference	T	p Value
Time Taken for tracing	Manual Tracing	59	27.0508	6.43381	0.83761	14.18644	15.718	.001
	Ceph X	59	12.8644	2.58282	0.33625			

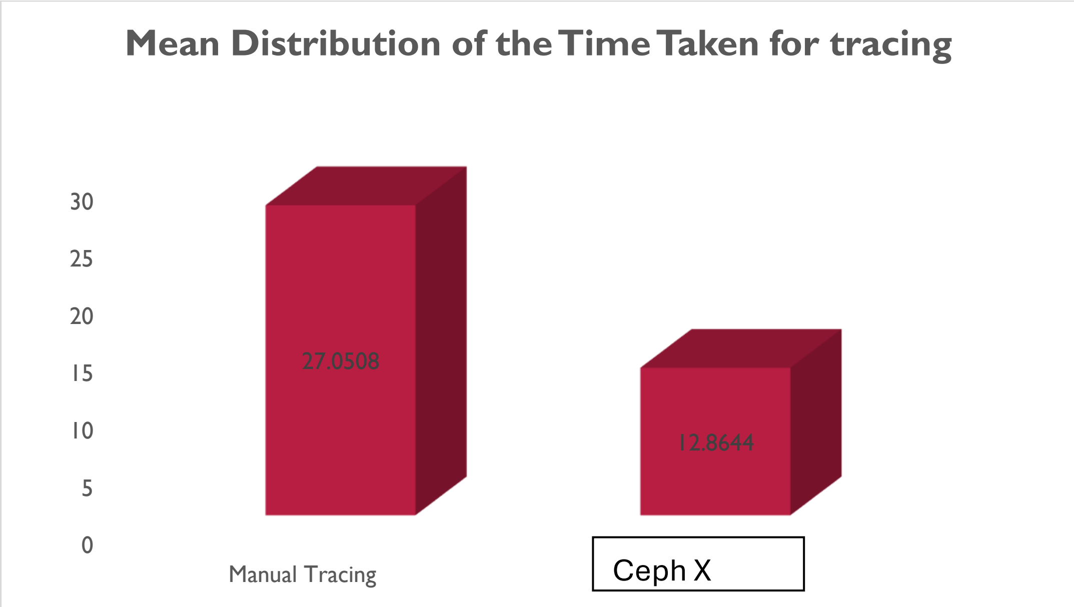
Comparison of the Deviation from mean (T) between Manual Tracing and Ceph X

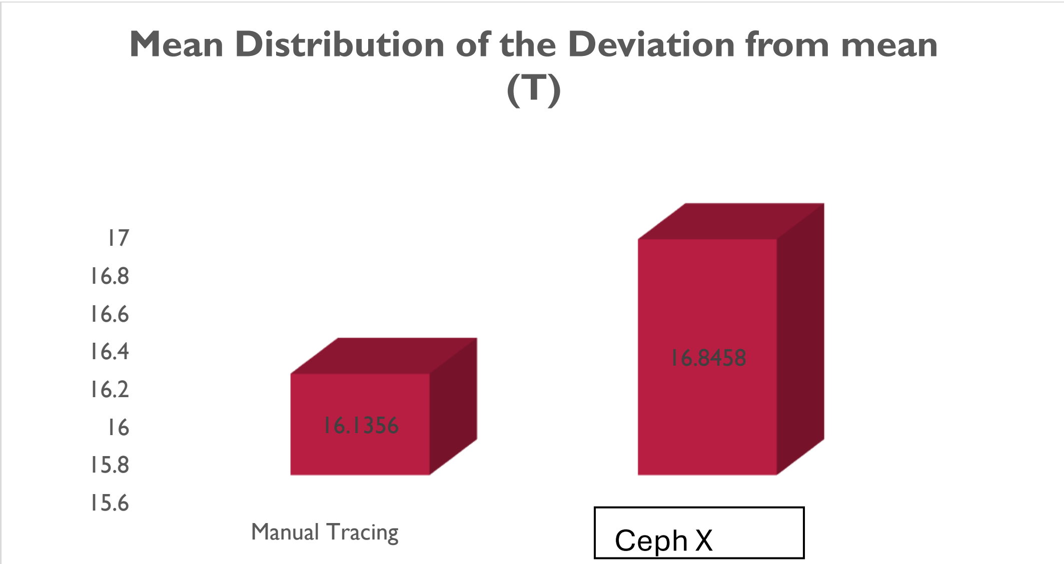
	Groups	N	Mean	Std. Deviation	Std. Error Mean	Mean Difference	T	p Value
Deviation from mean (T)	Manual Tracing	59	16.1356	4.62697	0.60238	-.71017	-1.093	.277
	Ceph X	59	16.8458	1.86818	0.24322			

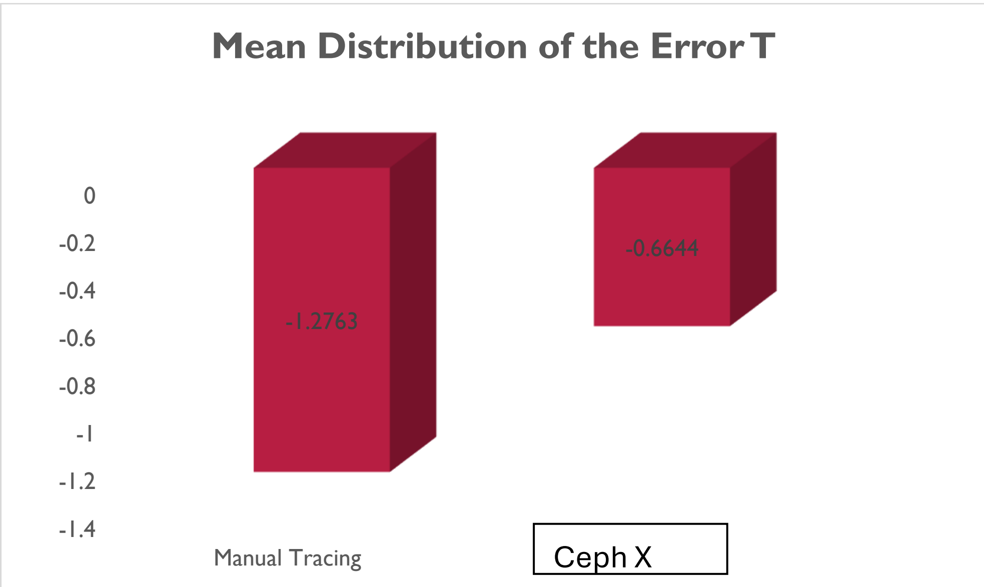
Comparison of the Error T between Manual Tracing and Ceph X

	Groups	N	Mean	Std. Deviation	Std. Error Mean	Mean Difference	t	p Value
Error T	Manual Tracing	59	-1.2763	4.97086	0.64715	-.61186	-.867	.388
	Ceph X	59	-0.6644	2.16761	0.2822			




Mean Distribution of the Time Taken for tracing
30
25
20
15
10
5
0
27.0508
12.8644
Manual Tracing
Ceph X


Mean Distribution of the Deviation from mean (T)
17
16.8
16.6
16.4
16.2
16
15.8
15.6
16.1356
16.8458
Manual Tracing
Ceph X


Mean Distribution of the Error T
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.2763
-0.6644
Manual Tracing
Ceph X

Interpretation

Of the 60 study participants there were 23 (37.3%) Male Participants and 37 (62.7%) Female Participants. Mean Distribution of the Time Taken for tracing for Manual and CephX was 27.05 ± 6.43 and 12.86 ± 2.58 respectively.

The Mean Distribution of the Deviation from mean (T) for Manual and CephX was 16.13 ± 4.62 and 16.84 ± 1.86. The Mean Distribution of the Error T for Manual and CephX was -1.27 ±4.97 and -0.66 ± 2.16.

When Comparison of the Time Taken for tracing between Manual Tracing and CephX was done it was observed that the difference was 14.18 and this difference in the time was statistically significant ($p<0.05$). When Comparison of the Deviation from mean (T) between Manual Tracing and CephX it was observed that the difference in the Mean was -0.71 and this difference in the Mean was found to be statistically significant ($p<0.05$).

When comparison of the Error T between Manual Tracing and CephX was done it was observed that the difference in the Mean was -0.611 and this difference in the Mean was found to be statistically significant ($p<0.05$).

6. DISCUSSSION

Orthodontics is a problem of relationships within the dentofacial complex. The profile pattern has commanded the most attention, probably because it affects the appearance of an individual so much and is of major concern in orthodontic therapy. The cephalometric roentgenograph has provided a means of accurately appraising the relationships of the parts of the face leading to a description of the mean or average facial form of normal occlusion. It also shows the range of variation that may occur. The abilities permit the attempt to classify facial types. This method of study and description of the skeletal and denture patterns of an individual at any particular time has been described as a STATIC ANALYSIS[1]. When comparisons are made of records taken of the same individual at different times, the result is a quantitative and qualitative interpretation of changes and may be called a DYNAMIC ANALYSIS. It is evident that variations occur in the manner in which the face grows.

Traditional cephalometric analysis is performed by tracing radiographic landmarks on acetate overlays and using these landmarks to measure the desired linear and angular values. This traditional hand- tracing process can be time consuming, and the linear and angular cephalometric measurements obtained manually with a ruler and protractor may be prone to error. Rapid advances in computer sciences have led to the wide application of computers in cephalometry[2,3,4].

Historically, UA space measurements started using lateral cephalometric radiographs; however, one of their major limitations was the restriction to two-dimensional (2D) analyses. Nowadays, CBCT is considered the gold standard exam because of its high accuracy and possibility to perform 3D measurements[5,6]. Also, this exam has become much more affordable in dentistry[7]. Furthermore, Cheng et al[8] presented that UA reconstruction and segmentation through CBCT's softwares is quite reliable [9,10,11]The UA evaluation through CBCT requires some at,,tention during image acquisition. There are some factors that may distort the results during or even before scanning, such as breathing, tongue position, and head movement[12]. Muto et al [13] stated that alterations of head and neck inclination produced by head extension were correlated with changes in the dimension of UA space.

Another limitation about measurements of UA space is the comparison between them, regarding the calculated volumes and regions. This problem occurs due to the differences among all studies regarding the determination of UA limits. As a matter of fact, there are no standard UA limits, and even some studies do not clearly show how the UA area was determined[14,15]. Another important point for UA measurements is the way how the volume is segmented: automatic or manual. Manual segmentation may enable great control by the operator, resulting in optimal accuracy; however, it requires more operation time. The sample evaluated in our study was analyzed manually. However, Ghoneima and Kula measured the volume and area of an acrylic airway model using CBCT data by Dolphin software. They found no statistically significant differences between the manual and the digital measurements, thus proving the accuracy and reliability of the software for both 2D and 3D analysis. Even while hand segmentation is the gold standard and provides the most precise replication of the anatomical structure, it is labor- and time-intensive. Numerous threshold-based semiautomatic software programs have been approved for volumetric assessment as well[16].

The study of Orhan et al. (2022) was characterized by two goals. The first goal of this work was to develop and verify an algorithm for automatically detecting the pharyngeal airway on CBCT data using artificial intelligence (AI) software called Diacat. The pharyngeal airway in obstructive sleep apnea (OSA) patients was automatically assessed for the first time in this study. The segmentation of the pharyngeal airways in OSA and non-OSA patients was performed using a machine learning technique based on convolutional neural networks. In all groups, there was no statistically significant difference between measures taken using the manual method and those taken using the Diagnocat ($p > 0.05$). For manual and automated segmentation, the interclass correlation coefficients were 0.954 for Diagnocat, and 0.956 for automatic segmentation.

A key element in the field of orthodontics involves translating intricate orthodontic requirements into clearly defined AI tasks, which requires careful attention to detail and methodological clarity. For example, tasks like cephalometric analysis involve the transformation of the task into a computational one, which includes the annotation or labeling of landmarks on lateral cephalograms. Similarly, predicting treatment outcomes necessitates the segmentation of teeth. In addition, when deciding on the optimal treatment plan, clinical parameters are used as training data. The training phase is crucial in enhancing the performance of AI algorithms and heavily depends on the expertise of the professionals involved. Therefore, those responsible for creating training datasets should have significant experience in this field[17].

AI has also been applied to upper airway assessment, a critical component in orthodontic treatment due to its influence on craniofacial growth and development[18]. Certain conditions, such as adenoid hypertrophy, can result in airway obstruction, altering the breathing pattern and potentially leading to malocclusion[19]. AI methodologies provide a more rapid assessment of these structures compared to traditional manual techniques, although issues with model generalizability persist[20]. Many studies are constrained by the limited datasets they employ, which restricts their wider applicability. When these models are applied to public datasets, their performance often decline, highlighting the necessity for ongoing research to ensure the reliability of AI-based tools in orthodontic practice.

In the articles reviewed, the most researched AI application was automatic landmark detection, which is a crucial step for orthodontic diagnosis. The accuracy of AI algorithms varied in different studies due to the use of diverse datasets and landmarks. Consistency is a key requirement when comparing different AI methods. Some studies have overcome this challenge by using publicly available datasets to ensure consistency[21].

Interestingly, when compared to manual methods by expert clinician, AI has the ability to show better reproducibility, which overcomes the limitation of observer variability. However, its accuracy has not yet consistently surpassed that of human experts, indicating that while AI is less prone to variability, further improvements are needed to ensure that landmarks are placed as precisely as those identified by expert clinicians[22]. Most studies used landmark detection on lateral cephalometric images. However, it is important to acknowledge that a 2D projection could lead to an inaccurate representation of 3D anatomical structures due to certain limitations, such as distortion, superimposition and magnification. The increasing use of 3D imaging in managing orthodontic cases has created a greater need to explore 3D landmark detection. Manual landmark localization on 3D images is time-consuming and demands a skilled operator, as it involves manual segmentation of anatomical structures and precise landmark positioning.

In the patients of skeletal class III malocclusion who were treated with the surgical procedure, it causes a change in the position of the tongue and hyoid bone and the tongue base moved to the posterior[23.24]. As a result, the contact surface would increase between the soft palate and the tongue and consequently decrease the pharyngeal airway space[25]. This mechanism brings about morphologic change of oro-pharyngeal area and causes problems such as sleep apnea and snoring[26].

The accuracy of cephalometric analysis is important for treatment planning so that the clinician can accurately assess various treatment options and provide the patient with a more realistic image of treatment outcome. Rapid advances in computer science have led to the wide application of computers in cephalometry. Landmark identification is greatly affected by operator experience, which might be as important as the tracing method itself. Because inter-operator error has in general been found to be greater than intra-operator error (Sayinsu et al. , 2007), all measurements in this study were carried out by one examiner to minimize error. Intra-operator error in hard and soft tissue landmark and angular measurements was assessed on the x -axis on manual and digital tracings of radiographs by determining reproducibility with a test – retest method. Error analysis of the manual tracings showed a high correlation between duplicate measurements: the operator had no difficulty in correctly reproducing measurements on traditional films, and the landmarks were easily identifiable.

Since literature in the last two decades have been showing either superiority or no clinically perceptible difference in manual and automatic digital tracing methods, the present study was conducted to determine the comparative accuracy of manual, semi-digital and fully digital cephalometric tracing methods in orthodontics as the fully digital method has been reported advantageous of being time-saving, improved contrast and reduced inter- and intra-observer variability, However, it comes with the extra cost of added cost of dedicated software which can be curbed by using semi-digital tracing method while retaining some associated advantages of both manual tracing and fully digital tracing. Albarakati *et al*. reported equal reliability, of conventional and digital cephalometry, i.e., both the digital (scanning a conventional film into digital format), in daily orthodontic routines as the statistically significant differences between both do not appear to be clinically significant.[27]Farooq *et al*. also reported that most of the commonly used measurements were accurate except few variables, between the digital tracing with FACAD® and manual methods; however, the advantages of digital imaging such as enhancement, transmission, archiving and low radiation dosages makes it to be preferred over conventional method in daily use.[28]Noush and Esmaily also reported that digital cephalometric analysis software is not only reliable but also saves time and reduces manual analysis errors[29].

Landmark identification, which is considered the major source of error, is greatly affected by operator experience. According to Santoro et al,[30] any investigation aiming to demonstrate the consistency of digital cephalometrics should focus on several significant factors, such as the use of measurements instead of landmarks as well as the sources of error. The use of measurements was preferred to landmark identification because the measurements are the end product of the cephalometric tracing process and provide data for treatment planning, and also because the differences in landmark location used in combination to generate measurements might cancel each other out or increase the magnitude of the discrepancy[31,32]. Regarding the source of error, landmark identification on digital images was carried out manually using a mouse-driven cursor and the measurements were determined automatically by the software. If the films are scanned and transferred to digital format as in this study, the quality of the original film is one of the most important criterion in the validity of the result[33,34].

According to AlBarakati et al., both methods of conventional and digital cephalometric analysis are highly reliable with some statistically significant differences in reproducibility but most were not clinically significant[35]. Similarly Prabhakar et al., provides support for computerized tracing method as these are easier and less time consuming with same reliability. In a recent study conducted by Hardik et al., concluded that digital tracing with FACAD software is similar to manual cephalometric tracings and sufficient for clinical purposes[36]. The study done by Chen et al. on estimating the time required for cephalometric measurement by the traditional method and by computer assisted digital cephalometric analysis system showed reduced time requirement. Uysal et al. conducted a study on evaluating the speed, repeatability, and reproducibility of digital radiography with manual versus computer-assisted cephalometric analyses found time advantage and inter and intra-examiner errors were less in digital analysis. A recent study shows that the CephX app is as reliable as Dolphin cephalometric method.

7. CONCLUSION

Cephalometric radiography is an important tool in the diagnosis and treatment of dental malocclusion and underlying skeletal discrepancies with serial cephalometric radiographs.

Traditionally, cephalometric images have been analysed by manually tracing radiographs, which is time consuming and has the disadvantages of being subject to random and systematic error. Cephalometric analysis is subject to error from multiple sources, which include landmark identification, radiographic exposure and development, and technical measurements. Most errors occur in landmark definition, and image density and sharpness. Landmark identification is greatly affected by operator experience, which might be as important as the tracing method itself.

One of the most significant causes of tracing error is uncertainty in landmark identification, which requires skills dependent on an examiner's experience. It is seen that there are significant differences in landmark identification between trained and untrained operators. In additional, it is well known that sufficient knowledge in digital cephalometric decreases the errors and improves the reliability. The study was carried out on 60 lateral cephalogram shot by the Carestream CS9600 traced by two different methods, tracing with manual tracing, computerized cephalometric tracing software showed statistically significant differences seen in upper airway analysis. It was witnessed that lesser time was taken to obtain the inferences of analysis done by computerized cephalometric using software compared to manual tracing method.

The digital cephalometric tracing enables user to adjust the brightness and contrast of radiographs, thus reducing the probability of error in making cephalometric landmarks. It can thus be concluded from above the study that in the era of digitalization, rapidly developing technology will be a potential game changer in the future of medical and dental clinic AI application

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