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Comparison of manual vs. Digital cephalometric tracing

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Abstract

Cephalometry is an essential tool in orthodontics for assessing skeletal, dental, and soft tissue relationships. Traditionally, it was performed manually, but with technological advancements, digital tracing software has become available, promising greater speed and reproducibility.

Objective: To compare manual and digital cephalometric tracing in terms of accuracy, reproducibility, time, cost, and clinical impact.

Materials and methods: This study is a narrative review of literature in English and Spanish based on information collected from databases such as PubMed, MEDLINE, Scielo, and Google Scholar.

Conclusions: The manual method is inexpensive and useful in academic training, but slower and more operator-dependent. The digital method is faster, more reproducible, and facilitates data storage and communication, although it requires an initial investment and training. Both methods are comparable in diagnostic accuracy. The digital method stands out for its efficiency and long-term sustainability, while the manual method retains its pedagogical value and applicability in resource-limited settings.

Keywords: Cephalometry; Manual Tracing; Digital Analysis; Artificial Intelligence**.**

1. Introduction

Cephalometry is one of the most important diagnostic tools in orthodontics, as it allows for an objective analysis of the skeletal, dental, and soft tissue relationships of the craniofacial complex. Since its origins in anthropometry and craniometry, and with the introduction of cephalometric radiography, this discipline has evolved significantly, moving from a descriptive approach to becoming a fundamental pillar for the diagnosis, planning, and evaluation of orthodontic and orthopedic treatments. Traditionally, cephalometric tracing was performed manually, using printed radiographs and acetates. This required a high degree of precision on the part of the clinician, but at the same time entailed limitations such as interobserver variability, time required, and dependence on physical materials. With the advancement of computing and the development of specialized software, digital cephalometry emerged, introducing improvements in speed, reproducibility, and storage, while also facilitating integration with three-dimensional images and treatment simulation tools. However, despite its advantages, this method entails high initial costs and is dependent on available technology. In this context, it is important to compare both approaches to assess their benefits, limitations, and clinical impact, in order to determine which is more effective in orthodontic practice and how they complement each other in academic training and research.

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2. Materials and methods

This qualitative, narrative review study was based on the collection, analysis, critique, and interpretation of bibliographic data. A literature search was conducted in English and Spanish on the platforms MEDLINE, Google Scholar, PubMed, Wiley, Lilacs, and Scielo, as well as journals, theses, and books. The search was compiled by reading and reviewing the referenced bibliographies in the selected documents. The following keywords were used: cephalometry, manual tracing, digital analysis, artificial intelligence.

3. Literature review

3.1. Theoretical Foundations of Cephalometry

3.1.1. History and Evolution of Cephalometric Analysis

Cephalometrics arises from anthropometry and craniometry. The term cephalometry, which comes from the Greek "kephale" meaning "head" and "metron" meaning "measure," is a set of procedures for measuring the head and describing and quantifying the structures involved in malocclusion, such as bones, teeth, and soft tissues. (1)

Cephalometrics, an essential diagnostic tool in orthodontics, allows for the evaluation of the relationship between the skeletal, dental, and soft tissue components of the face. It is important to observe both the anteroposterior (AP) and vertical dimensions to determine the severity of a malocclusion, especially in the AP direction, which can affect changes in the vertical direction. (2)

Cephalometric radiography appeared in 1931 thanks to Broadbent in the USA and Hofrath in Germany, becoming a major advance in orthodontics. Until then, diagnoses were based solely on clinical examination and plaster models. This technique made it possible to relate malocclusion to bone and dental structure, offering a more complete view of the facial complex. (3)

Initially, it was used only for descriptive purposes of morphology, but with limitations for predicting growth. Later, fundamental analyses were developed, such as those by Downs (1948), Steiner (1953), Tweed (1954), Sassouni (1955), Ricketts (1960), Björk (1963), Harvold (1974), Jarabak (1972), and McNamara (1983), which strengthened diagnostic practice. (3)

3.1.2. Evolution of Cephalometrics

- 1931: Broadbent and Hofrath introduced the cephalostat, allowing for serial radiographs in a single position. This marked a turning point in orthodontics, enabling more precise studies of facial growth and development.
- 1960s: Computerized cephalometry appeared, which, with the help of digital programs, reduced manual labor, streamlined research, and facilitated the calculation of angular and linear measurements.
- Advances in tomography: With the incorporation of computed tomography (CT) and later cone beam computed tomography (CBCT), it became possible to generate three-dimensional images and simulate panoramic and cephalometric radiographs from a single examination.
- Present: The transition from 2D to 3D diagnosis allows for a more complete view of the craniofacial complex, maintaining the possibility of obtaining 2D images to continue using traditional analyses, while consolidating three-dimensional cephalometric protocols. (4)

3.1.3. Objectives of cephalometric tracing

- Evaluate facial growth and development, allowing for the identification of skeletal and dental patterns.
- Diagnose dentofacial anomalies, differentiating between sagittal and vertical abnormalities.
- Plan orthodontic and orthopedic treatments, establishing the most appropriate mechanics for each patient.
- Assess treatment outcomes, comparing changes before, during, and after therapy.
- Standardize measurements for research and comparison between patients. (5)

3.2. Manual Cephalometric Tracing

3.2.1. Materials needed for manual cephalometric tracing

- Acetate paper: 210 mm x 160 mm sheet
- X-ray film

- Cephalometric ruler
- 30 cm ruler
- Tracing template
- Adhesive tape
- Eraser
- 0.5 mm lead pencil
- Sharpened 4H pencil
- Blue, red, and green colored pencils
- Lateral cephalic radiographs (6)

3.2.2. Step-by-step procedure for manual tracing

Lateral skull radiographs provide a two-dimensional representation of the head and neck and measure the sagittal and vertical dimensions of the skull. Sagittal measurements assess the position and inclination of the maxilla and mandible, while vertical measurements assess the height of the facial structures and the relationship between the jaws. In clinical practice, cephalometric analysis relies primarily on lateral radiographs, as posteroanterior projections are more difficult to interpret. (7)

Lateral cephalometric radiographs are traditionally traced manually. First, a tracing acetate is placed on the film. Anatomical landmarks are identified and marked on the acetate with a sharp 4H pencil. These points are connected using a 0.5 mm mechanical pencil to form lines and angles, and the resulting measurements are recorded and interpreted. (7)

3.2.3. Main points used in cephalometry

Hard Tissues

- Point A (Subspinal). This is the deepest point in the concavity of the superior alveolar bone.
- Anterior Nasal Spine (ANS). Corresponds to the point of the anterior nasal spine at the inferior margin of the pyriform aperture in the midsagittal plane.
- Articular (Ar). Represents the intersection of three radiographic images: the inferior surface of the skull base and the posterior line of the ascending ramus and mandibular condyles.
- Point B (Supramental). It is the deepest point of the concavity of the inferior alveolar bone.
- Basion (Ba). It is the most posterior and inferior point of the occipital bone and the anterior border of the foramen magnum.
- Condylion (Co). Most superior and posterior point of the head of the condyle.
- Gnation (Gn). Most anterior and inferior point of the mandibular symphysis.
- Gonion (Go). Most inferior, posterior, and external point of the mandibular angle.
- Lower incisor (Il). Intersection of the axial axis of the lower central incisor with the incisal edge.
- Upper incisor (Is). Intersection of the axial axis of the central incisor with the incisal edge.
- Menton (Me). Most inferior point of the mandibular symphysis.
- Nasion (Na). Most anterior point of the fronto-nasal suture.
- Orbital (Or). Most inferior point of the orbital margin (where the two orbits intersect).
- Pogonion (Pg). Most anterior point on the contour of the symphysis.
- Posterior nasal spine (PNS). Most posterior point of the hard palate in the midsagittal plane.
- Sella (S). Geometric center of the pituitary fossa.

Soft Tissue

- Cervical point (C). Point between the submental area and the neck in the submental plane.
- Inferior labial sulcus (Ils). Point found in the concavity on the contour of the lower lip between the lip and the chin.
- Lower lip (Li) Point denoted between the vermillion border of the lower lip.
- Upper lip (Ls) Point denoted between the vermillion border of the upper lip.
- Pronasal (Pn) Most prominent point of the nose in the midsagittal plane.
- Soft glabella (G'). Most prominent point in the soft tissue of the forehead.
- Soft menton (Me'). Most inferior point in the soft tissue of the chin.
- Soft nasion (Na'). Deepest point in the concavity between the forehead and the soft tissues surrounding the nose.
- Soft pogonion (Pg'). Most prominent point in the soft tissue surrounding the chin.

- Inferior stomion (Sti). Highest median point of the lower lip.
- Superior stomion (Sts). Most inferior median point of the upper lip.
- Subnasal (Sn): Point in the midsagittal plane where the base of the nose meets the upper lip.
- Superior labial sulcus (Sls): Point located in the concavity of the upper lip contour, between the subnasal and upper lips. (8)

3.2.4. Advantages of manual tracing

- Learning base: It is essential in academic training, as it helps the orthodontist understand the location of reference points and facial geometry.
- Greater familiarity with anatomy: By tracing manually, the clinician develops better visual and diagnostic judgment.
- Does not depend on software or digital equipment: It can be performed with conventional radiography, acetate paper, a ruler, and a protractor, making it accessible and economical.
- Direct control of the process: The orthodontist verifies the identification of points and lines step by step, which reduces automatic errors that can occur in digital programs.
- Useful in contexts without advanced technology: It remains a valid alternative in places where computerized cephalometry or CBCT is not available.

3.2.5. Limitations and Common Errors of the Manual Method

Manual cephalogram tracing is highly susceptible to variability and interobserver subjectivity, as different professionals can interpret and perform tracings with varying degrees of accuracy. While the rigorous use of standardized tools helps reduce these difficulties, it is essential to recognize that human error remains an inherent limitation in manual cephalometric analysis. (9)

Linder et al. point out that the accuracy of manual annotations on cephalometric measurements can vary depending on factors such as the operator's level of training and experience, as well as external circumstances, including time pressure or fatigue present at a given time. Aguilar-Hernández and Alba-Cruz, for their part, emphasize that manual analysis requires the use of various equipment such as a film viewer, protractor, and mechanical pencil, among others, making it an impractical procedure. Furthermore, they warn that the thickness of the lines and dots used can influence the results, given that these measurements require millimeter precision. (10)

3.3. Digital Cephalometric Tracing

Recent advances in digital technology have marked a new stage in the practice of cephalometry. Currently, cephalometric analysis can be performed using computerized software capable of automatically identifying and measuring anatomical landmarks, allowing for more consistent and efficient assessments [6, 15]. This approach significantly reduces the margin of human error, observer bias, and the time required for analysis, while increasing the validity and reproducibility of the results. Furthermore, digital cephalometry, supported by specialized software and electronic devices, offers additional advantages, such as greater efficiency, superior reproducibility, and the possibility of performing three-dimensional analyses. (9)

3.3.1. Most widely used software (Dolphin, Nemoceph, WebCeph, OnyxCeph, etc.)

The first software designed to assist orthodontists in diagnosis and prognosis was Jiff Orthodontic Evaluation, developed by Rocky Mountain Orthodontics (RMO, Denver, USA) in the late 1960s. This static analysis program allowed for both lateral and frontal cephalometric studies based on the Ricketts, Jarabak, Sassouni-Plus, Steiner, and Grummons methods, facilitating its application and optimization and offering the user the ability to customize their own analysis. (11)

Nemoceph

NemoCeph software was presented in 1996 during the Spanish Society of Orthodontics meeting in Burgos, becoming the first European cephalometric program based on digital images in a Windows environment. Between 1996 and 1999, new cephalometric analyses were progressively incorporated, as well as innovative tools such as visual treatment target plans, Ricketts growth predictions, and the superposition of photographs with radiographs, a feature that enabled the development of morphing. Subsequently, Dr. Roth introduced significant improvements, including the creation of time series captures, a document viewer, and short-term cephalometric and orthodontic conversion predictions, particularly useful in surgical treatment planning. (12)

Dolphin

Dolphin (Dolphin Imaging & Management Solutions, Woodland Hills, California, USA) is a modular and scalable software that facilitates the analysis, diagnosis, and comprehensive management of orthodontic treatment. It is characterized by its ability to integrate with diagnostic radiology units, CBCT systems, telephone communication solutions, and web platforms, and is compatible with both Windows and MacOS. The company's first product was DigiGraph, an ultrasound-based system that allowed for imaging and measurements without radiation exposure. Despite advantages such as the absence of radiation, rapid examination, and ease of communication with the patient, the market did not favorably adopt it, leading the company to not renew ownership of the DigiGraph trademark.

In 1995, Dolphin redirected its focus toward the development of digital tracing software, integrating with digital cameras and the most widely used clinical management systems. By 1999, the company had expanded into international markets such as Australia and the United Kingdom, and later the rest of Europe. Between 2000 and 2002, collaborations with leading specialists, such as Drs. Arnett and McLaughlin, were instrumental in developing more comprehensive diagnostic and planning tools tailored to the needs of orthodontists. (12,13)

Quick Ceph

This is a cephalometric study software developed by Quick Ceph Systems (San Diego, California, USA), a company founded in 1986 by Günther Blaseio (Doctor of Dental Medicine & Master of Science), an orthodontist and specialist in healthcare informatics. Since its inception, the company has been dedicated to creating digital tools for diagnosis and treatment planning, primarily targeting orthodontists and maxillofacial surgeons.

That same year, Dr. Blaseio introduced Quick Ceph as an innovative program for orthodontic planning, differentiating itself from other systems that focused solely on dentition and occlusion. His revolutionary approach consisted of integrating facial and profile analysis, allowing for a more comprehensive assessment of the relationship between facial aesthetics and final occlusion, thus providing a more holistic view of the treatment. (14)

OnyxCeph™

This is a software system designed for the comprehensive management of dental images, developed for archiving, diagnosis, treatment planning, and patient education. Its operation is based on the processing of both two-dimensional (2D) and three-dimensional (3D) data, which significantly expands its clinical applications.

The program allows for image import, classification, cropping, and adjustment, as well as high-precision cephalometric analysis and measurements. Its features include image reflection and overlay, advanced editing, segmentation and adjustment of digital models, integration of the Ricketts visual treatment objective, and the ability to join bases and complete structures.

Additionally, OnyxCeph™ offers tools for treatment simulation, online and offline report generation, slideshow creation, and data export and sharing in various formats, optimizing communication with both patients and professionals. These features make it one of the most versatile and comprehensive platforms in the field of contemporary digital orthodontics. (15)

WebCeph

This is an online platform for orthodontics and orthognathic surgery based on artificial intelligence, which has recently gained popularity due to its multiple tools that facilitate treatment planning and medical record management. Its features include automatic cephalometric tracing, cephalometric analysis, visual treatment simulation, automatic overlay, image archiving, and a photo gallery. It also allows manual editing of reference points with automatic measurement calculations, combining efficiency and accuracy.

For its part, AutoCAD offers the ability to determine linear and angular measurements, as well as other metrics such as surface area, in any digital image. Although not specifically designed for cephalometric analysis, it allows scaling, image manipulation, and simplified reference point identification, facilitating precise line drawing and measurements in digital studies. (15,16)

3.3.2. Advantages of Digital Tracing

Digital cephalometry provides multiple potential benefits in orthodontic practice. Among the most notable are time savings, ease of use, and automation in locating cephalometric points, which reduces subjectivity and improves measurement accuracy. These features directly impact clinical workflow, enabling more streamlined, organized, and efficient patient care. Furthermore, it offers additional advantages such as greater reproducibility of results, the ability to store and compare records digitally, integration with three-dimensional images, and ease of sharing information between professionals, which favors interdisciplinary work. Although there is still a need for greater standardization and validation of digital protocols, digital cephalometry represents a significant and promising advance for optimizing diagnosis, improving treatment planning, and elevating the quality of orthodontic care. (9)

3.3.3. Limitations of Digital Tracing

One of the main disadvantages of digital methods is the dependence on specialized software, which requires the acquisition of licenses and the need for devices (computers or smartphones) that meet specific technical requirements for proper operation (de Alba-Cruz & Aguilar-Hernández, 2020). Furthermore, the high cost may limit access in certain clinics or regions. Other limitations include the software's learning curve, which requires specialized training, potential technological obsolescence with new updates, vulnerability to hardware or software failures, and dependence on internet connectivity on cloud-based platforms. It has also been noted that, in some cases, automation can lead to errors in identifying cephalometric points, requiring manual review, which can reduce expected efficiency. (10)

3.4. Comparison between manual and digital tracing

3.4.1. Accuracy and reproducibility

Numerous studies have compared computer-assisted cephalometric analysis programs with conventional cephalometric analysis, evaluating aspects such as reliability, accuracy, repeatability, and time required. In a study by Iseri et al., 14 parameters were analyzed in 50 cephalometric radiographs, which were measured twice using both methods. The results showed no statistically significant differences between the means of the primary and secondary measurements of both approaches. However, computer-assisted analysis presented a significant advantage in terms of time, being approximately seven times faster than conventional methods.

Similarly, Uysal et al. evaluated inter- and intra-examiner reproducibility using conventional methods and Dolphin software. Although computer-assisted analysis did not significantly reduce inter- or intra-examiner errors, it was considered preferable for clinicians due to the time savings. In general, inter-examiner errors were greater than within-examiner errors, so in that study all measurements were performed by a single evaluator to minimize variations.

Several studies have indicated that the main source of error in cephalometric analysis is the identification of landmarks. For example, the Frankfurt horizontal plane has shown a low coefficient of repeatability, indicating difficulty in its consistent location. Likewise, parameters such as the nasolabial angle, commonly used in cephalometry, have been considered difficult to determine and have low reproducibility. However, when soft tissue determination is clear and radiographic contrast is adequate, the reproducibility of this angle can be high, suggesting that image quality and the visibility of anatomical landmarks significantly influence measurement consistency. (15)

A comparative study by Mitra et al. (2020) evaluated the accuracy of cephalometric tracing using manual, semi-digital, and fully digital methods in orthodontics. The results showed that the intraclass correlation coefficients indicated acceptable agreement in the three groups: Group I (0.281), Group II (0.11), and Group III (0.056). The authors concluded that there were no significant differences between the methods, demonstrating good agreement among all variables analyzed and suggesting that digital methods, although faster, offer comparable results to traditional methods. (12)

3.4.2. Time required for each technique

The studies conducted clearly and firmly show that digital tracing is faster and more efficient than manual tracing. For example, some research indicates that software significantly reduces the time required to perform measurements and corrections compared to the traditional method (18).

Other studies confirm that the digital technique allows for faster tracings and fewer repetitions, particularly useful in research and daily clinical practice (19).

In a study by Ye et al., which compared the accuracy of manually traced lateral cephalograms with automated or AI-assisted programs, it was found that the AI-assisted software group required less time than the manual group to perform the cephalometric tracing and locate anatomical landmarks (17).

3.4.3. Short- and Long-Term Costs

Short-Term Costs

Manual tracing requires only printed radiographs, graph paper, and drawing materials, which entails a low initial cost. In contrast, digital tracing requires an initial investment in specialized software and computer equipment, making it more expensive in the short term (18).

Long-Term Costs

In the long term, the digital technique is more cost-effective because it eliminates the costs of printing, physical materials, and storage, and the speed of tracing reduces clinical work hours. Likewise, the use of digital databases facilitates the storage, retrieval, and comparison of records over time, reducing logistical costs in research and clinical practice (19).

3.5. Reliability and Validation Analysis

3.5.1. Comparative Studies between Manual and Digital Methods

- In the study conducted by Ibrahimagić et al., no statistically significant differences in measurement accuracy were found between the two methods. However, digital tracing was faster and more efficient. (18).
- In another study conducted by Barbosa et al., it was determined that digital and manual analysis presented similar results in accuracy, although digital tracing reduced tracing errors and execution time. (19).
- According to the study by Celik et al., both methods were comparable in terms of accuracy. However, digital tracing showed advantages in interobserver reproducibility. (20)
- Another study by Sayinsu et al. concluded that inter- and intra-observer variability was lower with the digital method. Thus, digitalization improves diagnostic consistency. (21)
- On the other hand, according to Paixão and Sobral, they mention that the accuracy was equivalent in both methods, but the digital method showed operational and data storage advantages. (22)

Thus, most studies agree that the accuracy of manual and digital tracing is comparable, the execution time and reproducibility are significantly better in digital tracing, and digital tracing requires a higher initial investment, but offers advantages in clinical efficiency, storage, and reduction of human error.

3.5.2. Clinical Impact of the Differences

Diagnostic Accuracy and Treatment Planning

- Most studies agree that the measurement accuracy is comparable between both techniques (18,20).
- However, digital tracing minimizes human error in locating cephalometric points and improves inter- and intra-observer reproducibility (21).
- This translates into greater diagnostic reliability, especially in complex cases (severe malocclusions, facial asymmetries), where small variations can influence the treatment plan.

3.5.3. Clinical time and workflow

Manual tracing requires between 15 and 25 minutes, depending on the clinician's experience, while digital tracing can reduce the time to 5–10 minutes (19).

In clinical practice, this reduction in time means:

- More efficient care and the ability to evaluate more patients in less time.
- Greater availability of the specialist for additional analysis or explanation of results to the patient.

3.5.4. Reproducibility and longitudinal follow-up

Digital tracing allows for precise superimposition of radiographs over time, optimizing growth monitoring and the assessment of orthodontic changes (22).

In long-term treatments, this directly impacts the ability to objectively measure results, minimizing operator bias.

3.5.5. Costs and clinical sustainability

Manual tracing requires a low initial cost (acetate paper, pencil, X-ray film viewer), but it entails high costs in accumulated clinical time and physical storage.

On the other hand, the digital technique requires a higher initial investment (software, digitizer, or integrated systems), but reduces long-term costs due to shorter clinical time.

It facilitates storage, replication, and transmission of records without deterioration. At the clinical level, this favors comprehensive practice management and improves the patient experience by allowing for a clearer and faster visual explanation (18).

3.5.6. Education and training of orthodontists

Manual tracing maintains its pedagogical value in teaching cephalometry, as it forces the student to identify anatomical landmarks in detail. However, routine clinical use clearly benefits from digital tracing, as it optimizes professional practice without compromising precision (19).

4. Discussion

The comparison between manual and digital cephalometric tracing has been the subject of multiple studies, with consensus regarding their reproducibility, although with important nuances depending on the software used and the variables measured.

The work of Agarwal et al. (2011) showed a high correlation between both methods, but with statistically significant differences in certain parameters such as cranial base, facial height, and nasolabial angle. This indicates that, although the digital method is reliable in most cases, it still has limitations in anatomical structures that are difficult to delimit. (Agarwal et al. 2011) In contrast, the study by Esteva Segura et al. (2014) found no significant differences between the Nemoceph Nx software and manual tracing on digital radiographs, confirming excellent reliability for routine clinical use. (24)

In turn, Abreu et al. (2016) comparatively evaluated manual and digital tracing using Dolphin Imaging 11.0 and Dentofacial Planner 7.02 on 45 radiographs. Although all three methodologies showed few systematic errors, the Dentofacial Planner software was found to be the most reliable, followed by manual tracing, while Dolphin Imaging presented more systematic errors. (25)

Meanwhile, the systematic review and meta-analysis by Narkhede et al. (2024) included 20 comparative studies from different countries and software (Dolphin, FACAD, NemoCeph, OneCeph, WebCeph, among others). The authors concluded that, in general, digital cephalometry offers comparable results to the manual method, but with added advantages such as speed, portability, digital storage capacity, and cloud access.

Among the reviewed studies, the following stand out:

- Navarro (2013, Brazil) and Iacob (2014, Romania), who reported virtually identical results between the two methods.
- Goracci (2014, Italy) and Zamrik (2021, Turkey) noted that the observed differences were not clinically relevant, highlighting the practicality of digital methods.
- Tanwani (2014, India) and Kamath (2016, India) found discrepancies in some specific analyses (Burstone, McNamara, Steiner), although they did not compromise clinical applicability.
- Farooq (2016, India) and Izgi (2019, Turkey) confirmed that most digital measurements are reliable and more convenient in daily practice.
- Hassan (2019, Pakistan) and Mohan (2021, India) emphasized that digital imaging represents a faster and easier option to perform.
- The study by Anuwongnukroh (2018, Thailand) was one of the few that considered digital imaging to be less consistent than manual imaging, recommending its use only as a diagnostic aid.
- Recent research using artificial intelligence-based software, such as WebCeph (Katyal 2022; Khattri 2023; Prince 2023), points to a promising future in terms of speed and convenience, although further validation is still required to definitively replace traditional methods (9,20).

Consistent with this, in the study by Khan et al. (2023), no significant differences were found in cephalometric analysis based on manual and digital tracings for any of the selected angular and linear measurements. Computerized cephalometric analysis is reliable and time-efficient, and its accuracy is comparable to that of manual analysis. (26)

Overall, the evidence reviewed suggests that manual tracing remains the gold standard, especially for complex anatomical landmarks, but the digital method is consolidating as an accurate and increasingly reliable alternative. Furthermore, its practicality, reduced work time, and ease of archiving and sharing data make it a very valuable tool in contemporary clinical practice.

It can be stated that both methods are complementary and clinically valid, although the current trend indicates that digital tracing will gain prominence as automatic detection algorithms become more accurate.

5. Conclusions

Both manual and digital tracing offer comparable results in terms of accuracy for most cephalometric parameters. However, digital cephalometry offers advantages by reducing inter- and intra-observer variability, thanks to the automation of anatomical landmark location and the ability to reproduce measurements more consistently.

Manual tracing requires between 15–25 minutes, while digital tracing reduces this time to approximately 5–10 minutes. This savings has a direct impact on clinical workflow, allowing more patients to be seen, more time to be devoted to explaining results, and optimizing human resources in the practice.

The coexistence of both methods reflects complementarity rather than substitution. Manual tracing retains a fundamental pedagogical role, as it fosters a detailed understanding of cephalometric anatomy and the critical identification of landmarks. However, in routine clinical practice, digital tracing prevails as the preferred tool, optimizing diagnosis, planning, and follow-up without sacrificing accuracy.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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