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ORIGINAL RESEARCH

Is the app-aided cephalometric analysis reliable in terms of airway measurements?

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Abstract

Background: Airway analysis, encompassing both upper and lower airway measurements, is essential for cephalometric analysis for orthodontic diagnosis. This retrospective study aimed to evaluate the reliability of the app-aided cephalometric analysis method for airway measurements. **Methods**: This study utilized pretreatment lateral cephalometric radiographs from 70 individuals (29 boys, 41 girls) with an average age of 14.4 years. Cephalometric landmarks, including soft palate, tongue posterior, pharyngeal wall for both upper pharynx and pharyngeal wall for lower pharynx points were identified. Linear dimensions of the upper and lower pharynx were measured manually and with the assistance of the App-aided OneCeph program. To determine the repeatability and intra-observer reliability, airway dimensions of 20 randomly selected radiographs were measured again by the same researcher. Intraclass Correlation (ICC) was used for intra-observer reliability, while Interclass Correlation (ICC) was used to evaluate inter-method reliability. A paired *t*-test was applied to analyze the data obtained from these paired measurements. **Results**: This study found no significant difference between the airway measurements obtained manually and those acquired using the OneCeph application. Both upper and lower airway measurements showed a very high and statistically significant agreement between the manual method and the OneCeph application. Furthermore, the observer's reliability was found to be high. **Conclusions**: Our study demonstrated a very high level of agreement between manual and app-aided OneCeph methods for both upper and lower airway measurements. Consequently, the OneCeph application is confirmed as a reliable tool for the cephalometric measurement of airway dimensions.

Keywords

Airway; App-aided; Cephalometry; Cephalometric analysis

1. Introduction

Cephalometric analysis in orthodontics involves analysing hard and soft tissues based on anatomical points determined on the two-dimensional radiographic image taken from the lateral aspect of the head in its natural position. This type of analysis allows for angular, linear, proportional and areal evaluations. A crucial component of cephalometric analysis is airway analysis, which includes measurements of both the upper and lower airways [1].

Airway is an important anatomical region that has an effect on facial growth. It has been reported in the literature that issues with the airway during the growth and development periods of individuals negatively impact the development of the hard and soft tissues of the jaws and face [2]. Enlargements in the nasal turbinates, adenoid tissue and tonsils constrict the airway, directing individuals to mouth breathing. This mode of breathing necessitates that the tongue be positioned lower [3]. As a result, since the maxillary teeth, which are normally balanced by the pressure from both cheeks and tongue, are only exposed to cheek pressure due to the tongue's lowered position, this imbalance leads to transverse maxillary deficiency and posterior crossbite [4].

Pharyngeal airway dimensions may vary between individuals. Age, gender, skeletal maturity, craniofacial morphology, head posture and body mass index are the factors affecting pharyngeal dimensions [5]. Adenoid, allergy, hypertrophy of tonsils, deformity of the nose, infections and polyps are among the predisposing factors affecting airway obstructions. The airway may become narrowed due to such factors [6]. Various studies show that nasopharyngeal and oropharyngeal airway problems negatively impact the development of the upper and lower jaws during the growth and development period [2, 7, 8]. These studies have shown that airway problems are significantly associated with different types of malocclusion and that nasal obstructions are important etiological factors for dentofacial anomalies.

Evaluation of the airway is an important diagnostic tool for patients with respiratory disorders and is also critically important for the treatment of craniofacial anomalies as well as for the stability of their outcome in patients in the growth period. Methods, such as lateral cephalometric radiography, computed tomography, magnetic resonance imaging, acoustic rhinometry and rhinomanometry, can be used to evaluate airway width [7]. Lateral cephalometric radiographs, which are widely used to evaluate upper airway obstruction, are one of the most common analysis methods where pharyngeal airway size and hyoid measurements are easily performed on 2-dimensional cephalograms. The dimensions of the nasopharyngeal and retropalatal regions can be assessed using linear measurements. Despite the advantages of the technique, such as ease of use, repeatability, cheapness and low radiation dose, its most important disadvantage is that it provides only 2-dimensional images. This limitation may make it insufficient for accessing information about three-dimensional aspects such as airway volume [9, 10].

Airway dimensions on lateral cephalometric radiography can be measured as the distance between the posterior nasal spine and the pharyngeal wall for the nasopharynx, the distance between the tip of the soft palate and the pharyngeal wall for the oropharynx, and the distance between the epiglottis and the pharyngeal wall for the laryngopharynx [11]. Measurements of these anatomical parts can be made by various methods. The first of these methods is the traditional or manual method, which involves measurements made manually with a protractor after making anatomical points on the radiographic images [8]. Digital cephalometric analysis programs have been developed, making cephalometric measurements more practical; these programs can perform measurements within seconds of marking anatomical points on the radiographs displayed on the computer screen [12]. With rapid advances in technology, smartphones have become ubiquitous, essentially putting computers in our pockets. Through applications, most of which are free or require an annual membership fee, we can quickly complete tasks in various fields using smartphones. Among these, some applications allow us to perform cephalometric analysis with smartphones. While there are some studies on the reliability of these relatively new applications in cephalometric measurements [13–16]; no studies on airway measurements were found.

Therefore, this retrospective study aimed to evaluate the reliability of the app-aided cephalometric analysis method, which can be downloaded free of charge to smartphones, in airway measurements.

2. Materials and methods

2.1 Study approval and sample size

This retrospective study has received approval from the Ethics Committee of Ankara Yıldırım Beyazıt University (Date: 16 June 2023; Approval no: 242/05). The sample size of the study was calculated using the G*Power software (version 3.1.9.213, University of Düsseldorf, Düsseldorf, NRW, Germany) developed by the Institute of Experimental Psychology at Heinrich Heine University in Düsseldorf, NRW, Germany. For this study, which will be conducted with paired groups, an α error of 0.05, a power of 80%, and an effect size of 0.35 determined a minimum of 67 cases. To compensate for potential case loss, we increased the sample size by 5%, setting it at 70. The sample group consists of a total of 70 individuals, 29 boys and 41 girls, with an average age of 14.4 years.

2.2 Data collection

The research material consists of pretreatment lateral cephalometric radiographs of patients undergoing orthodontic treatment at Ankara Yıldırım Beyazıt University Faculty of Dentistry between June 2023 and December 2023. The study utilized digital lateral cephalometric radiographs obtained using a Planmeca Promax x-ray device (Planmeca OY Asentajankatu 6, 00880 Helsinki, Finland). Each radiograph was standardized by aligning the patient's midsagittal plane perpendicular to the floor and parallel to the film cassette, ensuring the patient's head was immobilized at the ear and nasion points using cephalostats. The x-ray parameters were set at 66 kVp and 10 mA with an exposure time of 6.7 seconds. The system maintained a magnification ratio of 1:1.

2.3 Inclusion criteria

1. High-quality cephalograms that accurately demonstrated the cephalostat position without any artifacts that could obstruct the identification of anatomical sites.

2. Patients who did not have prior orthodontic treatment or orthognathical surgical treatment.

3. Patients who did not have craniofacial deformities.

2.4 Exclusion criteria

1. Cephalograms where the landmarks were not clearly defined.

2. Cephalograms with significant double borders of the mandible.

3. Individuals with craniofacial anomalies, asymmetries or a history of craniofacial surgery.

4. Individuals with significant dental abnormalities, diseases affecting cephalogram analysis, multiple missing teeth or extensive crown-bridge restoration.

A total of 400 radiographs were reviewed, of which 360 met the eligibility criteria. The radiographs fully anonymized before analysis.

2.5 Cephalometric points used in the study

1. Soft palate: The point on the posterior outline of the soft palate (Fig. 1A).

2. Tongue Posterior: The point of intersection of the posterior border of the tongue and the inferior border of the mandible (Fig. 1B).

3. Pharyngeal wall (for upper pharynx): The closest point of soft palate point on the posterior pharyngeal wall (Fig. 1C).

4. Pharyngeal wall (for lower pharynx): The closest point of tongue posterior point on the posterior pharyngeal wall (Fig. 1D).

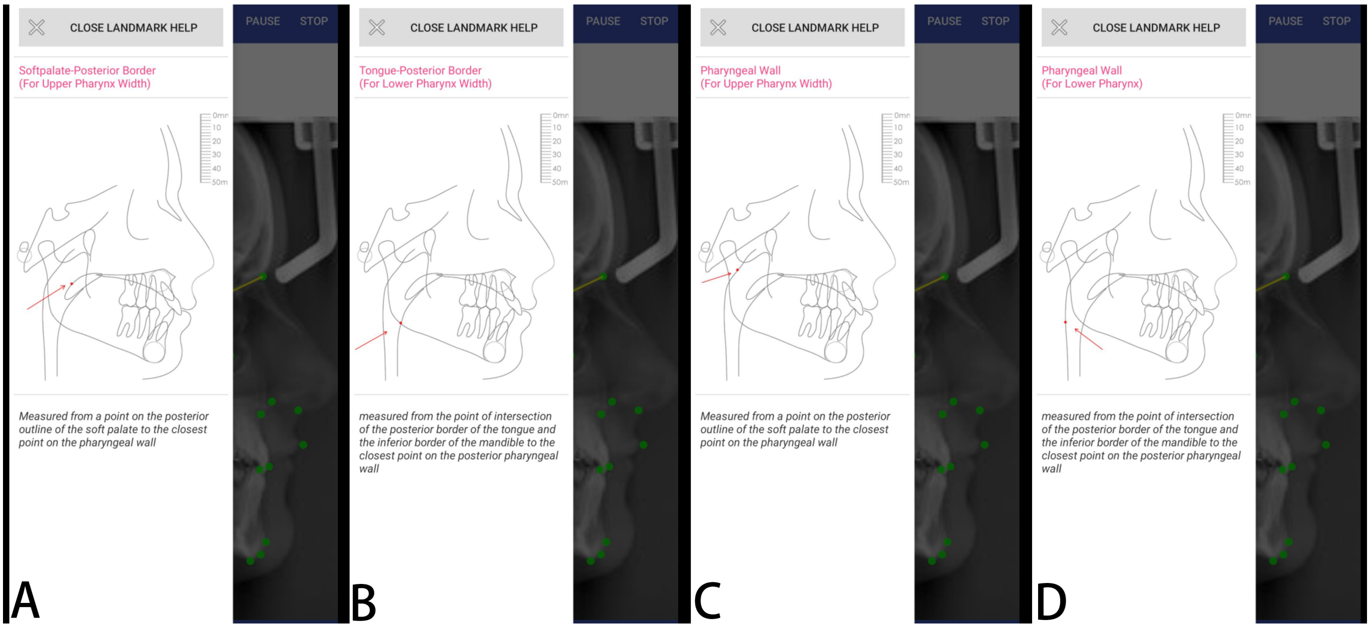

FIGURE 1. Cephalometric points used in the study. (A) soft palate, (B) tongue posterior, (C) pharyngeal wall for upper pharynx, (D) pharyngeal wall for lower pharynx.

2.6 Cephalometric measurements made in the study

1. Upper pharynx: Measured from a point on the posterior outline of the soft palate to the closest point on the pharyngeal wall.
2. Lower pharynx: Measured from the point of intersection of the posterior border of the tongue and the inferior border of the mandible to the closest point on the posterior pharyngeal wall.

2.7 Cephalometric analysis methods used in the study

Two methods were employed for cephalometric analysis. The measurements were conducted by an author with 3 years of experience (SK) and were verified by the other author with 20 years of experience (OUA) in order to eliminate the experience-related errors. Measurements were limited to 5 analyses for each method per day, and a 30-minute rest break was given between each analysis to minimize fatigue-caused errors.

2.7.1 Manual analysis method

Translucent acetate paper (0.003 inches thick, 8″ × 10″ inches in size) specifically designed for orthodontic analysis was fixed to radiographic printouts. They were placed on a negatoscope in a darkened drawing room, and anatomical points used in the present study were carefully marked using a Rotring drawing pen (0.3 mm) for both hard and soft tissue drawings. Angular and linear measurements were performed by the same author using a protractor (Fig. 2).

2.7.2 App-aided OneCeph program

The OneCeph (version Beta 15, Dr. M. Pavan Kumar, NXS Corp., Hyderabad, India) application was downloaded free of charge to the Samsung Galaxy S20 FE smartphone. 300 dpi high resolution JPEG images of the lateral cephalometric radiographs were uploaded to the program. The calibration protocol was applied using the dimensions of the ruler on the cephalometric radiography. After calibration, McNamara analysis was selected. Anatomical points were marked manually on the phone screen using the index finger, and the measurements were performed (Fig. 3).

2.8 Method error

To determine the repeatability and intra-observer reliability, airway measurements of 20 randomly selected radiographs were made again by the same researcher 2 weeks after the first measurements. Repetition coefficients (r^2) for each parameter were calculated.

2.9 Statistical analysis

The data was analyzed using SPSS 21 (IBM, Armonk, NY, USA) package program. Intraclass Correlation (ICC) was used for intraobserver reliability, and Intraclass Correlation (ICC) was used for intermethod reliability. A paired t-test was used to compare the data obtained in paired groups. A significance of 0.05 was used as the significance level, and it was stated that there was a significant agreement if $p < 0.05$.

3. Results

The mean value of upper airway measurement using the manual analysis method was 10.14 ± 2.57 mm. The mean value of upper airway measurement with the OneCeph application was 10.4 ± 2.5 mm (Table 1, Fig. 4).

For upper airway measurement, there was a very high and statistically significant agreement between the manual analysis method and the OneCeph application ($p < 0.05$; ICC = 0.926) (Table 1, Fig. 4).

The mean value of lower airway measurement with the

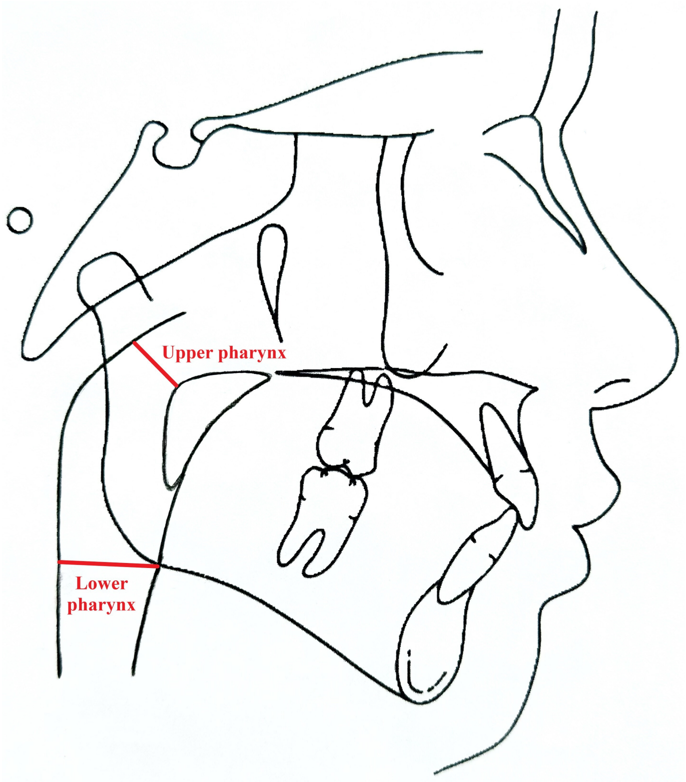

FIGURE 2. Manual cephalometric analysis of upper and lower pharynx.

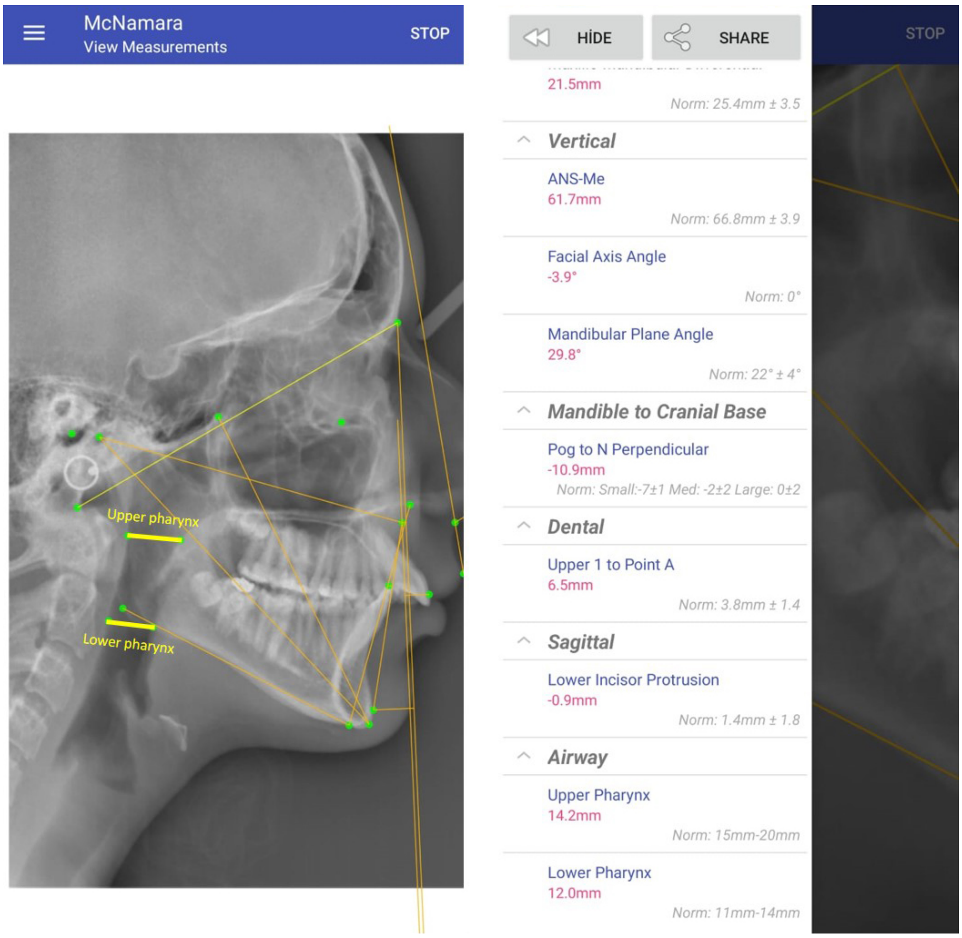

FIGURE 3. Screen image of app-aided OneCeph cephalometric analysis.

TABLE 1. Interclass correlation (ICC) of upper and lower pharynx measurements between manual and OneCeph app-aided cephalometric analysis.

Cephalometric measurements	n	Mean	Minimum	Maximum	sd	ICC	95% Confidence Interval		p
							Lower Bound	Upper Bound	
Upper airway measurement Manual analysis	70	10.14	5.04	18.38	2.57	0.926	0.881	0.954	0.0001
Upper airway measurement OneCeph app	70	10.4	5.5	18.2	2.5				
Lower airway measurement Manual analysis	70	8.37	3.91	14.40	2.35	0.949	0.917	0.969	0.0001
Lower airway measurement OneCeph app	70	8.62	3.90	13.00	2.27				

sd: standard deviation; ICC: Intraclass Correlation.

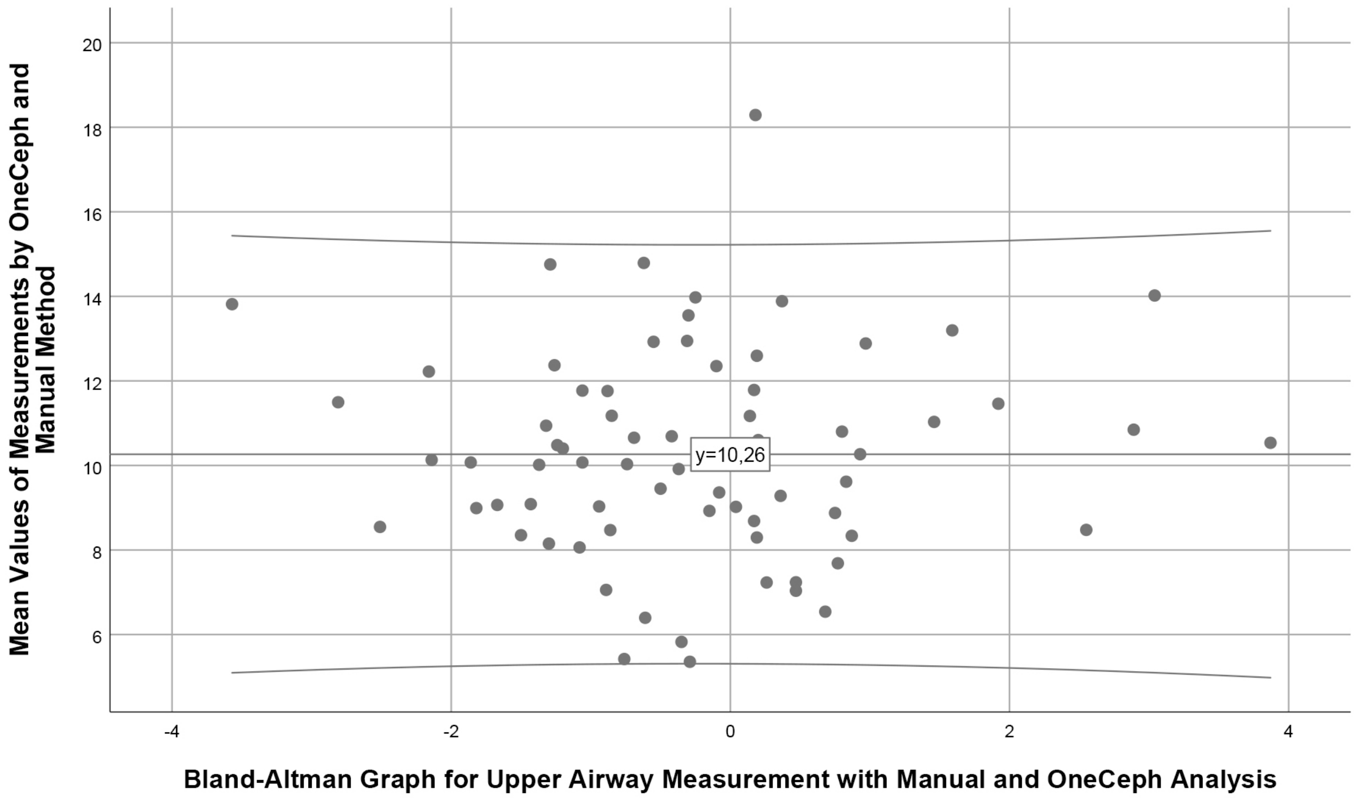

FIGURE 4. Blant-Altman graph for upper airway measurement with manual analysis method and OneCeph application.

manual analysis method was 8.37 ± 2.35 mm. The mean value of lower airway measurement with the OneCeph application was found to be 8.62 ± 2.27 mm (Table 1, Fig. 5).

For the lower airway measurement, there was a very high and statistically significant agreement between the manual analysis method and the OneCeph application ($p < 0.05$; ICC = 0.949) (Table 1, Fig. 5).

It was determined that there was no significant difference between the upper airway measurements performed manually and those performed with the OneCeph application ($p = 0.110$). Thus, it can be concluded that the measurements using two different methods on the same sample were not different from each other (Table 2).

Similarly, no significant difference was found between the lower airway measurements made manually and with the OneCeph application ($p = 0.057$). The measurements using the two different methods on the same samples were not different from each other. It can be concluded that they are similar (Table 3). The compatibility of the results obtained between the two methods is further supported by the ICC analysis results.

In the repeated measurements of 20 randomly selected cases, intraobserver correlation coefficients were high (ICC 0.882–0.995). This indicates that observer reliability was high (Table 4).

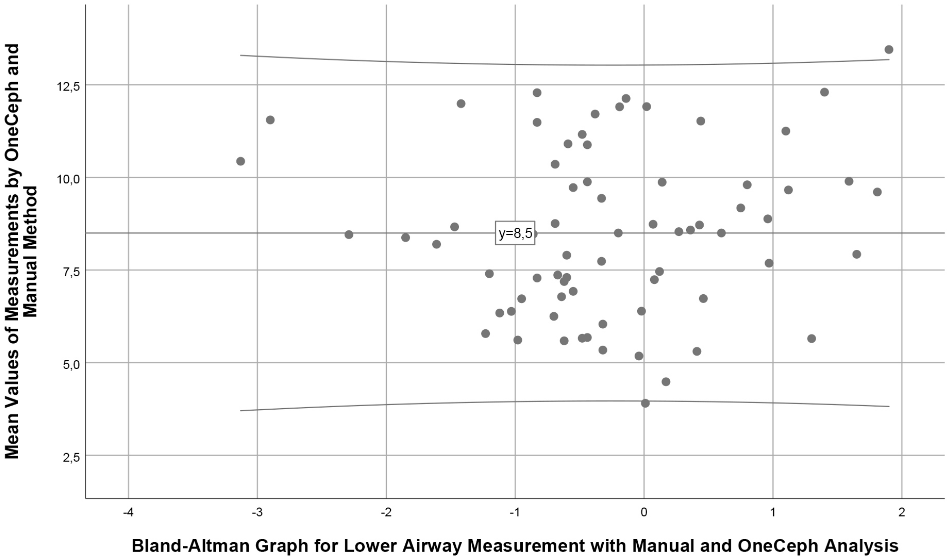

FIGURE 5. Blant-Altman graph for lower airway measurement with manual analysis method and OneCeph application.

TABLE 2. Paired *t*-test results for upper airway measurements.

Paired Samples Statistics			Paired Differences				*t*	*p*
	Mean	sd	Mean	sd	95% Confidence Interval of the Difference			
					Lower	Upper		
Pair 1								
Upper airway manual 1	10.14	2.57						
Upper airway OneCeph 1	10.39	2.54	−0.26	1.33	−0.57	0.06	−1.62	0.110

sd: standard deviation.

TABLE 3. Paired *t*-test results for lower airway measurements.

Paired Samples Statistics			Paired Differences				*t*	*p*
	Mean	sd	Mean	sd	95% Confidence Interval of the Difference			
					Lower	Upper		
Pair 1								
Lower airway manual 1	8.37	2.35						
Lower airway OneCeph 1	8.62	2.27	−0.25	0.99	−0.49	−0.02	−2.12	0.057

sd: standard deviation.

TABLE 4. Intraclass correlation (ICC) of first and second measurements of 20 cases.

Cephalometric Measurements	ICC	95% Confidence Interval		*p*
		Lower Bound	Upper Bound	
Upper airway measurement Manual analysis 1 Upper airway measurement Manual analysis 2	0.995	0.986	0.998	0.0001
Upper airway measurement OneCeph app 1 Upper airway measurement OneCeph app 2	0.882	0.673	0.955	0.0001
Lower airway measurement Manual analysis 1 Lower airway measurement Manual analysis 2	0.991	0.973	0.996	0.0001
Lower airway measurement OneCeph app 1 Lower airway measurement OneCeph app 2	0.969	0.921	0.988	0.0001

4. Discussion

This study aimed to evaluate the reliability and reproducibility of the airway measurements using the app-aided OneCeph program, which operates on a Samsung Galaxy S20 FE smartphone (Samsung, Yeongtong Suwon, Korea) and to compare it with the gold standard manual analysis method.

All lateral cephalometric radiographs measured in our study were digital radiographs obtained through direct digital imaging. Digital radiographs must have sufficient clarity, contrast, and brightness to identify anatomical reference points [17]. Previous studies have shown that the JPEG image format does not negatively impact image quality [18]. Therefore, the JPEG format was the preferred choice for the radiographs used in our study. The image quality of the radiograph is also an important factor influencing the analysis. Ongkosuwito *et al.* [19] stated that the image quality should be at least 300 dpi to ensure a robust analysis. Consequently, the resolution of the radiographs in our study was determined to be at least 300 dpi.

One of the most important factors to ensure standardization is calibration. Many studies on this subject have shown that dimensional measurements tend to be more unreliable than angular measurements [20, 21]. To eliminate this factor in our study, careful calibration was performed before proceeding the measurements.

Despite the advantages of lateral cephalometry, such as technical ease, accessibility, low cost and low dose radiation, its accuracy and reliability have been debated in many studies because it reduces the three-dimensional image of the pharyngeal airway to two dimensions [22–25].

Lateral cephalometric x-rays can be used to examine the airway space and adenoids, while frontal cephalometric x-rays can be used to measure the width and height of the nasal cavity. In a study comparing airway linear measurements with lateral cephalograms and Cone Beam Computed Tomography (CBCT), it was reported that these measurements were reliable in both groups and that there was a positive correlation in measurements related to axial areas [26].

Riley and Powell found that pharyngeal airway area measurement using cephalometric x-rays had a high correlation with measurements using CBCT [25]. Linder-Aronson evaluated adenoid dimensions with rhinoscopy and cephalometric radiographs and found a high correlation between the measurements [27]. Malkoc *et al.* [28] reported that lateral cephalometric radiographs are reproducible and reliable in determining airway dimensions, tongue and hyoid bone position.

At the beginning of orthodontic therapy, airway changes should be clinically assessed using CBCT or lateral cephalograms. There is little information available because cephalometry only reconstructs three-dimensional features in two dimensions. A lot of diagnostic information is provided by the CBCT, which displays three dimensional (3D) structures, builds projections on various planes, and lets us quantify the volume of various structures. It is not a standard examination, though, and the radiation dose is higher. CBCT imaging was suggested for the analysis of the upper airway. Subsequent publications have investigated its reliability [29, 30], presented various segmentation techniques [31], and used this technology for assessing treatment outcomes in patients with sleepdisordered breathing. CBCT allows quantitative measurements of distances, areas and volumes, which are particularly important for upper airway assessment in both clinical and research settings.

Intraobserver error is an important issue in reserches. Erkan *et al.* [32] concluded that when evaluating the reliability of computerized cephalometric software, the intraobserver error was significantly lower than the interobserver error. In our study, intraobserver reliability for airway measurements was calculated. The reliability analysis in Table 4 revealed a strong correlation between the repeated measurements acquired using both digital and manual methods (ICC 0.892–0.995). This suggests that the observer was able to consistently and accurately replicate measurements using both techniques.

A factor that may have interfered with the OneCeph methods' accuracy, and has described in the literature by Amorim *et al.* [33] is the type of pointer used for landmark location. Generally smart phone applications used with index fingers. The app displays an opaque circle shape to pinpoint the landmark. The size of this marker may not remain constant in different magnifications. Although this has little to do with the examiner's incorrect location of the point when the landmark is first identified, it can affect error detection. For landmark identification on the smartphone, a capacitive stylus, finer, ball-point pen-like tips can be used.

Kanpittaya, assessed the reliability of the OneCeph application according to computer, tablet and smartphone screen size and sensitivities in comparison with Dolphin software on computer as a gold standard [34]. It is recommended to use OneCeph on smartphone and tablet rather than computer as the application is designed to use with portable devices and the limitation of application on computer.

The number of studies that investigated the reproducibility of smartphone cephalometric apps is limited in the literature. The available studies primarily targeted apps that run mainly on the iPhone (Apple Inc., Cupertino, Calif). Sayar and Kilinc, examined the reproducibility of the CephNinja 3.10 (Cycronus LLC, Bothell, WA, USA) app, which operates on Apple's iPhone operating system (IOS), comparing it with the hand-tracing method [35]. They found statistically significant differences for all measured parameters, but the differences were clinically insignificant. On the other hand, Aksakalli *et al.* [20] investigated the accuracy of two cephalometric apps, CephNinja 3.3 and SmartCeph Pro 1.1 (La Compagnia Orodontica SRL, Via Montefiore, Italy), which run on iPad (Pro, Apple Inc., Cupertino, CA, USA), comparing them with the computerized Dolphin imaging software (13.01, Imaging and Management Solutions, Chatsworth, CA, USA) [20]. The authors concluded that smartphone apps should be developed to provide more accurate results, as most of the measurements differed significantly from those obtained with the Dolphin imaging software. Zamrik and İşeri, found statistically significant differences for only five measurements, including angle between Sella-Nasion-B point, Nasion perpendicular line to Pogonion, distance between Upper incisor-A point, Upper lip to Steiner S line and nasiolabial angle [15]. The nasolabial angle measurements were inconsistent between the digital and the conventional methods. Sayinsu *et al.* [36] reported similar results, explaining the difference as due to the nasolabial angle being calculated based on landmarks located on curves with wide radii, which show proportionally greater errors.

The OneCeph app, which is available for free download on smartphones, removes the need for a computer for cephalometric analysis and gives medical professionals the chance to conduct cephalometric analysis quickly and efficiently. The SNB and Mandibular incisor-Mandibular plane angle values, as well as the Frankfurt horizontal plane-Mandibular plane angle measurements, showed statistically low agreement in a research by Shettigar *et al*. [37] that compared the OneCeph application with the Dolphin computerized analysis tool. The OneCeph program was compared to manual cephalometric analysis in a study by Shresta and Kandel, and the results showed consistency, with the exception of the Lower incisor to Nasion B line linear measurement [38]. Barbhuiya *et al*. [39] compared the manual method to the OneCeph application and found consistent measurements for all parameters.

The learning curve associated with using the app effectively is an important issue as intra- and inter-examiner reliability may depend on the level of expertise. At the beginning of learning, there is a relatively slow process. Then there is a process in which learning accelerates and then there is a process of reaching sufficient information. Therefore, before the study, the researchers read articles and watched training videos to master the use of the program. A trial analysis of 50 cases was conducted. Then, the measurements of the study started.

Although this study was conducted on a larger sample size than previous studies, further studies with even larger samples will allow orthodontists to benefit from this technology and make more accurate measurements. The addition of different anatomical airway measurements may also be considered. Additionally, comparing several app-aided cephalometric analysis programs with a widely used desktop software may help to identify the most reliable program. Further studies considering the issue of possible variations in measurement accuracy due to varying user proficiency can be usefull. The limitations of using 2D analytical methods to study 3D anatomical structures can be considered.

In previous studies on the reliability of the app-aided cephalometric analysis, the reliability of hard tissue measurements, dental measurements, and soft tissue measurements were examined and compared with different analysis methods. No previous study has evaluated app-aided cephalometric analysis specifically for airway measurements. This emphasizes the importance of our study.

The airway is an important anatomical place that should be carefully examined in orthodontic diagnosis and treatment planning. The ability to analyze the airway measurements, quickly and accurately using an application that can be downloaded for free to a mobile phone, will provide significant convenience to orthodontists, pediatricians and otolaryngologists alike.

5. Conclusions

The airway is a critical anatomical region for the development of the craniofacial structures. Since it is an area of close interest to pediatricians, orthodontists and otolaryngologists, analyzing it with a practical and reliable method is crucial. At the beginning of orthodontic therapy, airway dimensions should be clinically assessed using lateral cephalograms or alternative 3D technologies like CBCT.

For both upper airway and lower airway linear measurements, our study determined a very high agreement between the manual cephalometric analysis method and the OneCeph application. Therefore, the app-aided OneCeph program can be used for these two cephalometric measurements of airway dimensions. Future studies with more samples and different airway measurements are needed.

AVAILABILITY OF DATA AND MATERIALS

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

AUTHOR CONTRIBUTIONS

OUA—designed the research study; provided help and advice. OUA and SK—performed the research; wrote the manuscript. Both authors contributed to editorial changes in the manuscript. Both authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The research protocol was reviewed and approved by the Health Sciences Ethics Committee of Ankara Yıldırım Beyazıt University (Date: 16 June 2023; Approval no: 242/05), while the study was carried out in accordance with the Declaration of Helsinki. Informed consent to participate was obtained from all of the subjects and/or their legal guardian(s).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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