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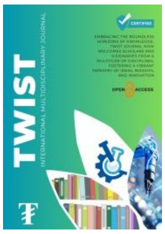

Reliability of Artificial Intelligence in Estimation of Vertical Dimension of Occlusion in Completely Edentulous Patients (A Randomized Cross-Over Trail)

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Abstract

Objectives: The current study was conducted to evaluate the reliability of artificial intelligence software in determining the precise vertical dimension of occlusion necessary for the full-mouth rehabilitation of edentulous patients and to investigate its impact on patient satisfaction.

Methods: The vertical dimension of occlusion of 11 edentulous patients was determined by the association of 3 different protocols Protocol A: Vertical dimension of occlusion was determined using the manual conventional clinical method , Protocol B: Manual measurement of the 'Cephalometric linear reconstruction' and Protocol C: Dentures fabricated using 'Cephalometric linear reconstruction' by artificial intelligence measurement (Software), Patient satisfaction of different protocols was assessed and compared as well.

Results: Comparison between 3 protocols demonstrated insignificant difference between as P=0.79, in protocol A; vertical dimension of occlusion was (68.65 ± 3.53), protocol B was (67.97 ± 3.49), while protocol C was (68.15 ± 2.87), Interclass correlation coefficient of each protocol revealed excellent reliability as ICC= 0.99, 0.98, 0.97 regarding Protocol A, B, and C respectively. Concerning patient satisfaction with different protocols, no significant difference was observed among them, with a p-value of 0.56.

Conclusion: Linear cephalometric measurements, whether conducted manually or utilizing existing Artificial Intelligence software, hold the potential to ascertain the ideal vertical dimension of occlusion necessary for the production of complete dentures, ensuring a satisfactory experience for patients.

Keywords
Vertical dimension, Complete denture, Artificial Intelligence software

INTRODUCTION

Restoring both the missing teeth and the supporting structures is crucial to fulfill the social requirements of patient's besides improve their functional rehabilitation. Complete dentures are a widely popular form of prosthetic treatment; The primary challenge in constructing dentures lies in replicating the original vertical dimension. Avoiding alterations to this dimension and achieving ideal facial proportions are crucial to prevent failure (Batra et al., 2017).

The vertical dimension of occlusion (VDO) refers to the lower part of the face's height when the upper and lower dental arches are in centric occlusion. It measures the distance between specific sagittal points: one above the upper lip and the other below the lower lip (Ousehal et al., 2012). Essentially, it indicates the height of the lower face when the dental arches are in their maximum intercuspation (Ajayi., 2005)

Insufficient Vertical Dimension of Occlusion (VDO) can lead to unavoidable issues related to aesthetics, functional efficiency, and structural balance. Correcting VDO is essential in various clinical situations, including tooth loss, collapse of posterior occlusion, periodontal disorders, and occasional bruxism. Precisely determining VDO is vital for patients' functional and facial rehabilitation. It is crucial to meticulously recreate the original normal VDO, considering current knowledge about the morphological and functional aspects of the maxillofacial complex. This involves understanding the genetic complexities of specific morphological structures and recognizing the unique relationship between morphology and function (Ousehal et al., 2012; Ajayi., 2005; Sharma., 2011; Misch., 2000).

Numerous clinical techniques have been released for determining the vertical dimension of occlusion (VDO), however none of them have consistently outperformed the others. Each recommended approach has drawbacks of its own. They are either tiresome, time-consuming, or call for specialized tools or equipment (Turrell., 2006)

The commonly used clinical method to establish the Vertical Dimension of Occlusion (VDO) involves measuring the distance between the nose septum (subnasal [Sn]) and the chin tip (gnathion [Gn]) in the natural, relaxed position of the lower jaw and then subtracting 4 mm. The vertical dimension of rest (VDR), on the other hand, acts as a benchmark for calculating the VDO. In order to produce dentures that are not only functional but also aesthetically pleasing to the patient's facial features, it is crucial to precisely define the VDR before calculating the VDO (Rahn et al.,2009).

Cephalometric analysis can be a useful method for developing optimal treatment plans for complex artificial occlusion cases. It helps determine the vertical dimension of rest (VDR) by examining craniofacial skeletal structures that were unaffected by tooth loss. Cephalometric analysis enables clinicians to evaluate key parts of the craniofacial complex when planning artificial occlusions for edentulous patients(Aggarwal et al., 2019; Sudhir et al., 2015).

Cephalometric analysis used to determine the vertical dimension in edentulous patients have been proven to be one of the most accurate and acceptable method (Qamar et al., 2013). As computer technology has advanced, digital methods are being used more frequently for both tracing and analyzing cephalometric films. In contrast to manual cephalometric analysis, Computer-Assisted Cephalometric analysis is more resistant to human variation errors in identifying and measuring landmarks, and it demands less time for calculations (Strajnić & Mišković., 2012).

In the past twenty years, artificial intelligence (AI) has undergone tremendous advancement and growth. Owing to improvements in computer capabilities, machine learning algorithms, and digital data accumulation, AI systems have started to encroach on areas of expertise historically dominated by human cognition alone. Within prosthodontics, AI applications are proliferating and transforming patient rehabilitation through pioneering techniques (Alshadidi et al., 2023).

The advent of the artificial intelligence era in prosthodontics has demonstrated its effectiveness as a valuable tool for automatic diagnosis, analyzing landmark measurements, and facilitating treatment planning (Abouzeid et al., 2021). Progress in AI holds promise for various healthcare benefits, including reducing complications following procedure, enhancing quality of life, optimizing decision-making, and minimizing unnecessary medical procedures (Topol., 2019).

As there are no studies have compared the reliability of determining VDO using cephalometric approach utilizing artificial intelligence, the present crossover study has been planned to assess the reliability of lateral cephalometric analysis (manual and A.I based) relative to the conventional clinical method and evaluate the variation in wearers' overall satisfaction with complete dentures fabricated using different techniques to detect the VDO.

MATERIALS AND METHODS

Subjects

This study selected 11 completely edentulous patients aged 45-75 years from the outpatient clinics of the Medical Excellence Centre of the National Research Centre, Cairo, Egypt and the College of Oral and Dental Surgery, Misr University for Science and Technology. All included Patients had normal maxillary-mandibular relationships, healthy oral mucosa, and normal salivary flow. Patients were excluded if they smoked, had any hard or soft tissue pathology, significant ridge undercut, painful oral conditions like traumatic ulcers or aphthous stomatitis, or prior radiation therapy to the head and neck region.

Study Design

The current study was a cross-over clinical trial. Each patient received three sets of complete dentures according to the technique of vertical dimensions determination. Protocol A: Dentures fabricated using a traditional procedure, Protocol B: Dentures fabricated using 'Cephalometric linear reconstruction' by manual measurement. and Protocol C: Dentures fabricated using 'Cephalometric linear reconstruction' by artificial intelligence measurement (Software). The patients` level of satisfaction was assessed after one month of the insertion of each set. Then, after one week wash out period to eliminate the effect of the previous denture set each patient received the other set.

Sample size calculations

Sample size calculated depending on a previous study (Turker et al., 2009) as reference. If mean ± standard deviation of patient's satisfaction in conventional group is 53.2 ± 13.58, while estimated mean difference is 15, with 1.11 effect size. When the power was 80 % & type I error probability was 0.05. The minimal needed sample is 9 dentures in each group (27 in 3 groups), total sample size increased to 11 dentures per group (33 in 3 groups) to compensate 20 % drop out. Sample size was performed by using Paired t test by using G. power 3.1.9.7.

ETHICAL APPROVAL

According to the values outlined in the 1975 Declaration of Helsinki, the current study was carried out in accordance with the World Medical Association's Code of Ethics. The Medical Research Ethical Committee of the National Research Center, Cairo, Egypt, has given its approval to this study with approval number **1013042023.** All patients received information regarding the actual procedures of this study and gave their written consent.

Workflow for the complete denture fabrication

Primary impressions were created using irreversible hydrocolloid impression material, and then border molding was carried out with Putty-C-Silicone. Final impressions were taken using silicone impression material (poly-C-silicone impression material, thixoflex M, medium, Zhermack, Italy) to obtain casts. Maxillary and mandibular casts were mounted on a semi adjustable articulator (Bio-art semi adjustable articulator A7 Plus, BIOART Company, Brazil) using maxillary face bow transfer (Bio-art face bow; Brazil), whereas the lower cast was mounted using centric relation record at the predetermined vertical dimension of occlusion (depending on the followed protocol) The protrusive record was done following the wax-wafer technique to modify the horizontal guidance of the articulator.

The articulator with the mounted casts was sent to the laboratory for the artificial teeth setup. After careful selection in accordance with the patient's demands, acrylic resin teeth were set up, and then waxing up was carried out and checked in the patient's mouth. Denture's fabrication was performed by using heat-cured acrylic resin (Acron Duo, Associated Dental Products Ltd., Kemdent, Purton, Swindon, Wiltshire, UK).

The denture processing involved an extended polymerization cycle, with a duration of 9 hours in a water bath at 73°C ±1°C, followed by an additional 30 minutes in boiling water as per the manufacturer's guidelines. Subsequently, the dentures were removed from the flask, finished, and polished using the traditional routine method. Upon ensuring proper extension, retention, and stability, as well as performing occlusal adjustments, the dentures were delivered to the patient. Additionally, the patient received instructions on maintaining proper oral hygiene.

- ***Regarding protocol A***

The Vertical Dimension of Occlusion (VDO) was determined using the traditional clinical approach. The patient was comfortably seated in an upright position on the dental chair without head support. A Fox Plane (NMD NEXUS MEDODENT, India) was utilized to assess the frontal plane. It was placed on the anterior bite block, ensuring its parallel alignment with the interpupillary line. To examine the occlusal plane, the Fox Plane was maintained in the same position, and a ruler was placed from the ala of the nose to the tragus of the ear, ensuring parallel alignment with the Fox Plane.

The midline was determined based on the philtrum, while the canine line was determined by the width of the nose. To record the resting position of the mandible, two dots were marked, one below the nose and the other on the chin. Using a millimeter ruler (Makzoumé., 2017), the distance between these points was measured while the patient pronounced the labial 'M' sound without tensing the lips. The Vertical Dimension of Occlusion (VDO) was established by subtracting the interocclusal distance (freeway space) of 2-4 mm from the resting position, as mentioned in figure (1).

Fig 1 Measurement of VDR from conventional clinical method

- ***Regarding Protocol B***

Lateral cephalometric radiographs of the patients were performed using the “FONA XPAN DG” (FONA S.r.l, Galilei 11 - 20090 Assago, Italy) scanner. The scan specifications were as follows: CCD sensor Receptor technology, focal spot size (0.5 mm), tube potential (79 kV), tube current (8 mA), and scan time (8 s) . All the lateral cephalometric radiographs undergone adjustment of the contrast and brightness for optimum visual and assessment conditions. On the lateral cephalometric images, the Anterior nasal spine (ANS) and Menton (Me) landmarks were used for determining VDO. The ANS-ME distance was calculated manually using the distance measurement tool of wepceph platform free version viewer option. after calibration of the image to avoid measurement errors caused by magnification variations, as mentioned in figure (2).

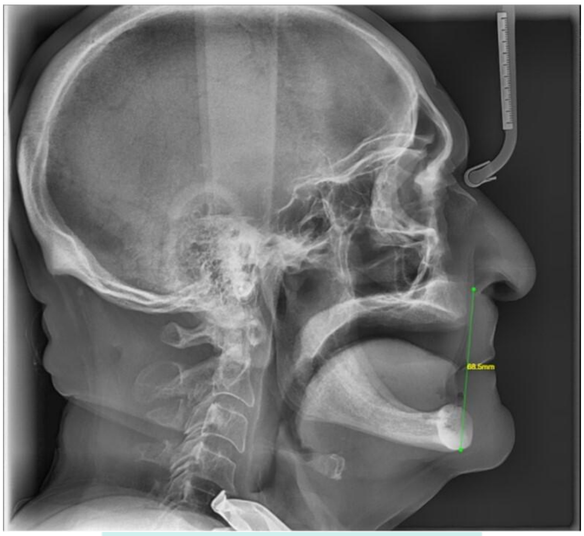

Fig 2 Measurement of VDR using manual measurements on lateral cephalometry

- ***Regarding protocol C***

Dentures were fabricated based on the lower anterior facial Hight determined by the analysis obtained through the aforementioned cephalometric platform. A.I. digitization of the image was performed to automatically detect and trace the landmarks and after calibration of the image, cephalometric analysis caried out based on McNamara method to automatically detect the ANS-ME distance, as presented in figure (3).

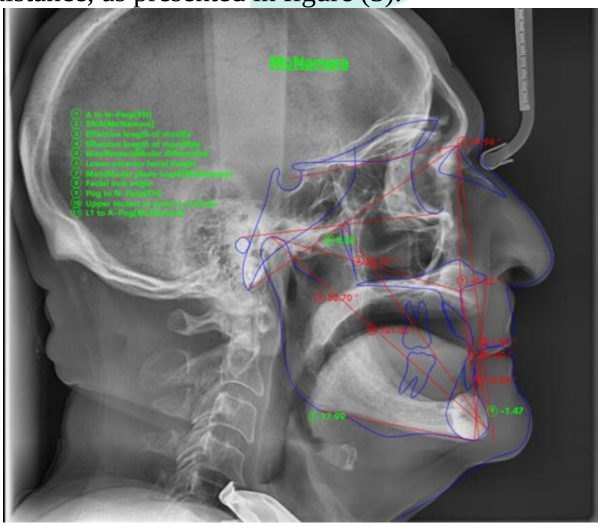

Fig 3 Measurement of VDR using AI digitization on lateral cephalometry

PATIENTS` SATISFACTION ASSESSMENT

The patients' level of satisfaction was assessed using a questionnaire that employed the Visual Analog Scale (VAS). This questionnaire comprised a total of 8 questions designed to evaluate various aspects, including the consistency of prosthesis wear, comfort during denture use, pain experienced during chewing and swallowing, occurrences of gagging, assessment of facial appearance, functional performance, and the desire to replace the denture. Each question was scored on a scale of 0 to 10. These individual scores were then summed to calculate the overall satisfaction score, which ranged from 0 to 80. A cutoff point of 40 was utilized for evaluation.

Statistical analysis

Data was compiled on Excel and analysis was done using SPSS 20 software. Normality of data distribution was checked by Kolmogorov-Smirnov and Shapiro-Wilk tests. Parametric data was expressed as mean and standard deviation while non-parametric data was expressed as median and interquartile range. One-way ANOVA test compared OVD between protocols. Intra-class correlation assessed reliability. Bland-Altman plots were constructed to evaluate agreement. Chi-square test was applied for patient satisfaction data. A p-value less than 0.05 was considered statistically significant for all tests.

RESULTS

Comparison between 3 protocols demonstrated insignificant difference between as P=0.79, in protocol A VDO was (68.65 ± 3.53), protocol B was (67.97 ± 3.49), while protocol C was (68.15 ± 2.87), as presented in table (1,2).

The intraobserver reliability in 3 protocols was assessed by interclass correlation coefficient which revealed excellent reliability between 1st and 2nd read in each protocol as ICC= 0.99, 0.98, 0.97 regarding Protocol A, B, and C respectively, as presented in table (3).

The agreement between 3 protocols was evaluated by using Bland–Altman plots as presented in table and figure (4). As could be observed, all the obtained values were clustered around the mean of the differences (the bias) and were, at least, within the two standard deviations (SD) of the mean (95% prediction interval), meaning that all measurements fell within the agreement limits as depicted in the Bland-Altman plots. The limits of agreement were narrower between protocol B and C, indicating a stronger agreement between these two methods.

Patient satisfaction of different protocols was presented in table (5), in protocol A satisfied patients 9 (81.18%) and unsatisfied 2 (18.81%), in protocol B and C satisfied patients 10 (90.9%) and unsatisfied 1 (9.1%). Comparison between different protocols was performed by using Chi square test which revealed insignificant difference between them as P=0.56.

Table 1 Minimum, maximum, mean and standard deviation of OVD in different protocols and comparison between them using Repetitive One-Way analysis of variance (ANOVA)

	Minimum	Maximum	Median	Inter quartile range	95% Confidence interval		Mean	SD	Repetitive One-Way ANOVA test
					Lower arm	Upper arm			
Protocol A (Wills method)	62.92	74.03	69.64	6.60	66.28	71.02	68.65	3.53	0.79
Protocol B (Manual Cephalometric)	63.45	73.25	65.93	6.30	65.63	70.31	67.97	3.49	
Protocol C (AI Cephalometric)	64.14	72.83	68.14	5.68	66.22	70.08	68.15	2.87	

Table 2 Mean differences and 95% confidence interval of the different protocols between two methods, the Tukey`s Post Hoc test was used for multiple comparisons

	Mean difference	Standard Error difference	95% confidence interval	P value
Protocol A X Protocol B	0.68	1.67	-3.894 to 5.254	0.9133
Protocol A X Protocol C	0.50	1.50	-3.598 to 4.598	0.9405
Protocol B X Protocol C	0.18	0.78	-2.330 to 1.970	0.9715

Table 3 Interclass correlation coefficient to evaluate intra-observer reliability in 3 protocols

Intraobserver reliability	ICC Interclass correlation coefficient	95% confidence interval		P value
		Lower arm	Upper arm	
Protocol A (Convectional clinical)	0.99	0.99	0.99	<0.0001 *
Protocol B (Manual Cephalometric)	0.98	0.97	0.98	<0.0001 *
Protocol C (AI Cephalometric)	0.97	0.97	0.98	<0.0001 *

*Highly significant difference s P<0.01

Table 4 Bland-Altman analysis for 3 protocols to evaluate level of agreement

Agreement	95% confidence interval		Width
	Lower arm	Upper arm	
Protocol A & B	-9.22	12.48	21.69
Protocol A & C	-8.30	11.13	19.43
Protocol B & C	-5.31	4.88	10.20

Table 5 Satisfation level in different protocols and comparison between them using Chi square test

Protocol	Satisfaction level				P value
	Satisfied		Not satisfied		
	N	%	N	%	
Protocol A	9	81.8	2	18.18	0.56 ns
Protocol B	10	90.9	1	9.1	
Protocol C	10	90.9	1	9.1	

N: frequency **%**: percentages **ns**: non-significant difference as P>0.05

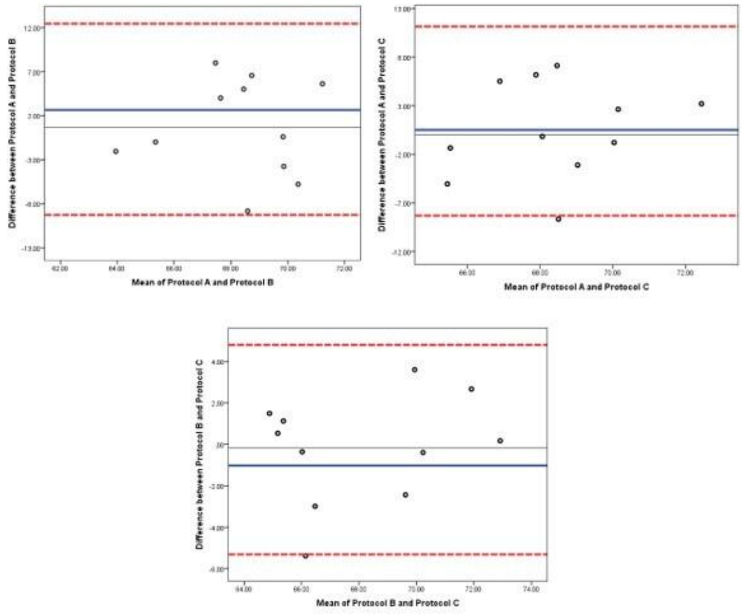

Fig 4 Bland-Altman plots were generated for the measurements of Occlusal Vertical Dimension (OVD) in all protocols

In these plots, the x-axis shows the average of the compared measurements, while the y-axis illustrates the disparity between these measurements. The blue line indicates the bias, and the red-hashed lines signify the upper and lower boundaries of agreement.

DISCUSSION

In this research, a crossover design was chosen to alleviate the differences among patients, including factors like age, gender, muscle activity, neuromuscular control, and anatomical variations, all of which could impact patient satisfaction. This reduction in variability is achieved by comparing different prostheses within the same group of patients. Furthermore, crossover studies offer the benefit of needing a smaller sample size compared to parallel group studies, as evidenced in this specific study (Elsyad & Shawky., 2017).

Restoring the Vertical Dimension of Occlusion (VDO) in completely edentulous patients is a significant challenge for dentists due to the absence of posterior teeth (Alhajj et al., 2017). VDO defines the upper limit of mandibular closure around the bicondylar hinge axis. Failing to determine VDO accurately can lead to various issues like temporomandibular joint disorders, muscle problems, bone loss, soft tissue injuries, speech difficulties, aesthetics concerns, and chewing and swallowing problems. An increased VDO can cause tissue trauma and aesthetic and speech issues, while a decreased VDO may affect chewing efficiency and aesthetics (Discacciati et al., 2013). Thus, establishing the correct VDO is crucial for improving function, aesthetics, patient satisfaction, and overall quality of life (Tavano et al., 2012).

Various studies have discussed the determination of vertical dimension for rehabilitating edentulous patients. However, using facial points as a reference remains a prevalent method in clinical practice. Establishing the centric occlusion position is particularly challenging, especially for edentulous patients, requiring significant skill. Moreover, facial references based on soft tissues tend to be unstable and exhibit variations with age (Singh et al., 2017; Qamar, & Chaudry., 2007).

Utilizing specific craniofacial references that remain stable even after tooth loss (Orthlieb et al., 2000), cephalometric radiographs provide the advantage of an initial evaluation of Vertical Dimension of Occlusion (VDO) that can be confirmed clinically (Ascher,., (1971). These radiographs establish the correlation between certain craniofacial components (points, lines, and/or angles) that remain largely unchanged following tooth loss (Orthlieb et al., 2000)**.**

In this study, we measured Vertical Rest Position (VRO) without employing occlusion blocks to calculate VDO, aligning with previous researches (Sudhir et al., 2015 & Brzoza et al., 2005). demonstrating insignificant differences in values obtained when compared to lateral cephalometric radiographs of the same patient with and without dentures.

Regarding prosthodontics, AI can be of a great value in a diversity of treatment protocols; aiding in the design and the fabrication of functional maxillofacial appliances. It also powerful in the processes of patient diagnosis, treatment planning, and patient management decision(Zaheer et al., 2023). Hence the fully automatic AI software has the most reproducible and accurate analysis of the hard and soft tissue anatomy and relationship (Ye et al., 2023), so the aim of the current study to assess the reliability of lateral cephalometric analysis (manual and A.I based) relative to the conventional clinical method Chin-Nose distance.in measuring VDO. Of the lower anterior facial height and assess its effect on patient satisfaction.

The current study showed that the mean VDO was 68.65mm ± 3.53 for protocol A, 67.97mm ± 3.49 for protocol B and 68.15mm ± 2.87 for protocol C **(table 1)** with no significant difference between the three used protocols as tested by One-Way ANOVA test. That matches another study which stated that the mean VDO measured through Niswonger method at rest was 64mm (Singh et al., 2017). also stated that ANS-Me showed a strong correlation with the other compared clinical methods used to evaluate VDO (Chin-Nose, Glabella-Subnasion, Pupil-Stomion, Pupil- Pupil, Angle of the mouth to Angle of the mouth) especially Chin-Nose distance one which showed a deviation percentage of 2% (Singh et al., 2017).

In the current study the mean difference of the three protocols was insignificant (p value nearly 1) **table2.** Moreover**,** there was a strong agreement between the three used protocols regarding VDO especially the manual and automated cephalometric measurements (protocol B& C), where all the recorded values were centered around the mean differences (the bias) and were, at a minimum, within the two standard deviations (SD) of the mean (representing the 95% prediction interval). This indicates that all measurements fell within the agreement limits, as illustrated by the Bland-Altman plots. Particularly, the agreement between protocol B and C was superior, as evidenced by the narrower limits of agreement between them. Table 4. Figu 4

Moreover, in previous study ANS-Me distance was used, to assess the accuracy of lateral cephalometric skeletal landmarks in evaluation of VDO and it was concluded that lateral cephalometric radiographs should be considered as an inexpensive, simple and harmonizing to the other traditional methods used to evaluate VDO (Qamar et al., 2013). In another cephalometric study of VDO using AI it was found that the AI cephalometric analysis software are capable of making the needed linear and angular measurement to assess VDO in the edentulous patients (Sudhir et al., 2015). In recurrent study protocol C (AI aided analysis) shown the closest results relative to the clinical method (protocol A) with no significant difference giving us the vantage of saving both effort and time with gaining the same results precision. Table 1, 2 and 4

Regarding the patient satisfaction, all protocols recorded high satisfaction scores with no statistical difference between the three protocols although the protocol B and C showed higher satisfaction scores than protocol A with no significate difference that may revealed to the fact of the Computerized Cephalometric analysis eliminates the mechanical errors introduced by conventional calibrated instrumentation (Strajnić, & Mišković., 2012).

CONCLUSION

Linear cephalometric measurements, whether conducted manually or utilizing existing Artificial Intelligence software, hold the potential to ascertain the ideal vertical dimension of occlusion necessary for the production of complete dentures, ensuring a satisfactory experience for patients.

CONFLICT OF INTEREST

All authors have declared no conflicts of interest.

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