

Article

Predictive Model for Occlusal Vertical Dimension Determination and Digital Preservation with Three-Dimensional Facial Scanning

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Abstract: (1) Background: Occlusal vertical dimension (OVD) in the optimal maxillo–mandibular relationship is an important parameter to establish when complex dental rehabilitation has to be done. The optimal method to measure OVD is still a challenge in everyday practice. The aim of the present study was to test the reliability of the correlation between OVD and some anthropometric and cephalometric methods described in the literature. The validity of OVD registration using a facial scanner was also assessed. (2) Materials and Methods: 150 dentate participants, aged 20–25 years, were randomly selected using sealed envelopes. Anthropometric measurements between specific standard points were performed: Subnasion–Prementon (Sn–PM) and Subnasion–Gnation (Sn–Gn) in maximum intercuspation and in the rest mandibular position, right and left pupil to the corresponding chelion. The cephalometric measurements registered were the lower facial angle and the angle between mandibular and Frankfurt planes. The distance Sn–Gn in maximum intercuspation was compared to all other parameters. Facial scanning, with a mobile phone and installed dedicated application, was performed on ten subjects, randomly selected using the same method among the participants, and the obtained 3D files were analyzed. The digital measurements were compared, for validity, to the clinical measurements. Pearson’s correlation coefficient was used, for comparing clinical Sn–Gn in maximum intercuspation position to the other parameters. (3) Results: A strong agreement between all measured anthropometric parameters of the facial scan and clinical contact measurement method was registered. None of the measured parameters could predict the exact OVD. (4) Conclusions: In the limits of our study, the facial scanning could be used for predictable registration of OVD and the stored digital information could be preserved through life and use for oral rehabilitation. However, if OVD needs to be determined, several measurement methods, including cephalometric measurements, need to be used simultaneously to reach a final decision.

Keywords: vertical dimension; anthropometry; cephalometry; prosthodontics

1. Introduction

Restoring occlusal vertical dimension (OVD), in an optimal maxilla–mandibular relationship, is a main parameter to be established when complex dental rehabilitation needs to be performed [1].

Loss of the vertical dimension of the lower third of the face in the clinical setting is mainly a result of tooth loss or tooth wear, leading to dramatic changes of the hard and soft tissue of the face and on the jaw complex [2,3].

If important factors, such as: aesthetics, achieving proper occlusion, space for restorations, are ignored and OVD is altered, there is a risk of instability, with clinical consequences: compromise aesthetic, diminished masticatory function, angular cheilitis, phonetic alteration, alteration of the minimum speech space, pain at the level of the edentulous ridges or temporomandibular joint (TMJ) dysfunctions [4]. Determining the OVD is still a challenge in everyday practice, especially in completely edentulous patients, and no generally accepted agreement or scientific consensus for the determination technique was envisaged so far [1]. Therefore, many OVD measurement techniques were described in the scientific literature, based on the vertical dimension of the lower face in the rest position, phonetic methods, swallowing-based methods, pre-extraction recordings, photographs, face measurement, intraoral measurements, cephalometry, telemetry and magnetic methods [5–8].

Although there are many studies [9–12] reporting rest mandibular position as a lifelong stable position and using it to determine the OVD, great variability in this parameter was found [13,14]. Rest mandibular position could vary with head position, body posture or fatigue [15] and was demonstrated that it is not a lifelong constant [16]. Moreover, especially when masticatory muscles or lip tonicity is low, like in the case of edentulous elder patients, or post cancer oral radiotherapy, this method cannot be considered reliable [17].

The most popular method in clinical practice for finding OVD value is by measuring the distance between the septum of the nose (subnasal [Sn]) and the tip of the chin (gnathion [Gn]), Sn–Gn, in the rest mandibular position and subtracting 4 mm [18].

Besides clinically measured Sn–Gn [19] or Sn–Gn measured on the profile photographs [20], various other landmarks have been used for facial measurements, showing a large number of possible statistical correlation to OVD, such as: nose tip to porion [21] or to menton [22], pupil to buccal commissure [23], ear to eye [23], external eye cantus to buccal commissure [24,25], external eye cantus to anterior point of external ear [19,24], the distance between the buccal commissures on the inferior lip contour, right external eye cantus to left internal eye cantus, twice the distance between internal eyes cantus [25], the length of the first finger [26], second finger [22,27] or fifth finger [27,28], inter-pupillary distance in men [29], nasion-sella distance in men [2], and so on. However, a common method of facial measurement reliability for OVD could not be established, due to a lack of consensus between authors, some of which [22,26] suggested that the distance nasion–gnathion could be the most suitable for OVD measurement, while others did not recommend the use of this measurement for large oral rehabilitations [30], due to the possible errors generated by the resilience of the skin [31] or racial and gender differences [32,33].

For increasing reliability, cephalometric measurements were suggested to determine the adequate OVD. Following Thomson's research [34], Slavicek proposed the orthodontic norms to be used to define OVD [35] by evaluation of the lower facial height angle (anterior nasal spine–Xi–protuberance menti). This method was also studied by Brzoza et al. [36], Orthlieb et al. [37], and recently by Enkling and co-workers [1].

However, if the ideal OVD could be registered and preserved through life, in the patient's virtual file, the rehabilitation of the dento-maxillary apparatus could be significantly simplified and more predictable.

The introduction of Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) systems in dentistry represents a revolution in all dental fields, especially in prosthodontics, for planning and performing the most appropriate rehabilitation, also being an excellent tool for communication with the patient and between clinicians and dental technicians [38]. Technological developments

in extraoral facial scanning in the last years have provided straightforward and affordable digital scanning systems based on mobile phones, which may offer a viable, cost-effective option for certain applications, mainly for esthetic rehabilitation [39] and full digital workflow for complete denture manufacturing [40].

For the volumetric acquisition of facial structures, 3D stereo photogrammetry is a consistent and valid method, being considered a reliable imaging method for the use in orthodontics [41].

However, the reliability of the facial scanning using accessible devices, such as mobile phones, for anthropometric measurement was not yet validated and, to date, the facial scanning 3D file was not taken into consideration for record keeping data on patient.

In order to be able to determine if a fixed parameter could be proposed as a lifelong stable parameter, and if facial scanning could be an option for long term preservation of the OVD, the aim of the present study was to test the reliability of the correlation between the OVD and some of the anthropometric and cephalometric methods described in the literature when referred to a sample of Caucasian dentate young people. The validity of OVD measured on facial scan was also assessed.

2. Materials and Methods

One hundred and fifty persons were randomly recruited, using sealed envelopes, among the dental students who attended the undergraduate program of “Carol Davila” University of Medicine and Pharmacy in Bucharest, Romania. Before receiving the randomization envelopes, each participant had to fulfill the inclusion criteria as follows: a full dentition set (except third molars), harmonious as well as symmetrical face, and agreed to perform a two dimension (2D) lateral cephalogram. The exclusion criteria were: previous or current orthodontic treatment, edentulous spaces treated or not, extensive direct restorations, systemic disorders, previous major stomatognathic/plastic surgery, or temporo-mandibular pathologies evaluated through carefully conducted clinical examination and history questionnaire. Ethical approval of the included participants was obtained (176/18) and a signed informed consent form was acquired from each subject prior to conducting this study.

The study was conducted in three steps: cephalometric analysis, anthropometric measurements direct (clinical) and indirect, digital, on facial scans, and data analysis.

2.1. Cephalometric Analysis

Digital lateral cephalograms were taken according to the standard protocol, with the subject in maximum intercuspation, film-focus distance of 3.3 m, output of 12 kV and 300 mA.

The Digital Imaging and Communications in Medicine (dicom) files were imported in Blue Sky Plan 4 (Blue Sky Bio, LLC, Libertyville, IL, USA) software and analyzed. Seven points were identified on the Ricketts lateral cephalometric analysis: anterior nasal spine (ANS), the apex of the nasal spine; (Xi) point, the point located at the geometrical center of the mandibular ramus; prementon (PM) point on the anterior edge of the symphysis that shows the profile's change from concave to convex; gnathion (Gn), the most outward and everted point on the profile curvature of the symphysis of the mandible; gonion (Go), the midpoint mediolaterally on the posterior border of each gonial angle of the mandible; porion (P), the highest point on the contour of the external auditory canal; and orbital point (Or), the lowest point of the inferior boundary of the orbit.

The following angles were measured for every subject (Figure 1):

- The lower facial height angle [LFH^ˆ], between [ANS], [Xi] point and [PM];
- The angle [ML^ˆFH], between mandibular plane (the plane tangent to the lower edge of the mandibular body, [Gn] and [Go]) and Frankfurt plane ([P] and [Or]).

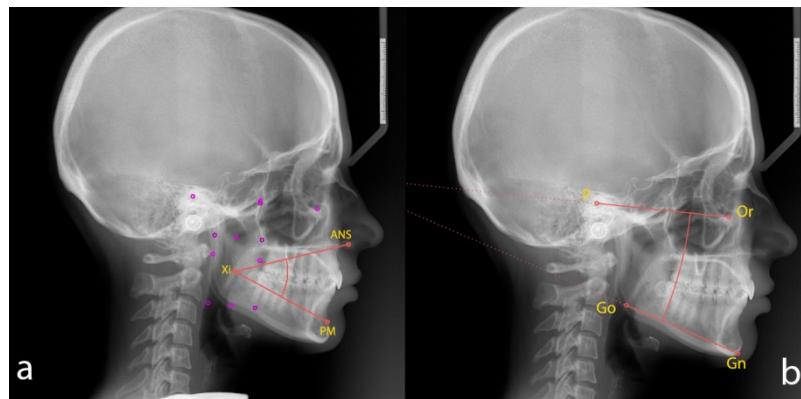


Figure 1. Cephalometric analysis: (a) The lower facial height angle [LFH], between anterior nasal spine [ANS], [Xi] point and prementon [PM]; (b) The angle [ML[^]FH], between mandibular plane (gnathion [Gn]–gonion [Go]) and Frankfurt plane (porion [P]–orbitale [Or]).

2.2. Anthropometric Measurements

2.2.1. Clinical Anthropometric Measurements

For the anthropometric facial measurements, each subject was asked to sit in an erect forward position with an unsupported head. Three readings have been made for every subject, between four groups of specific standard points (Figure 2a,b):

- Subnasion [Sn] and the point on the anterior edge of the symphysis that shows the profile's change from concave to convex (Prementon [PM]) (Sn–PM);
- Subnasion [Sn] - Gnathion [Gn] (Sn–Gn);
- Right pupil [Pu] to right buccal commissure (chelion [Ch]) (Pu–Ch_r);
- Left pupil to left buccal commissure (Pu–Ch_l).

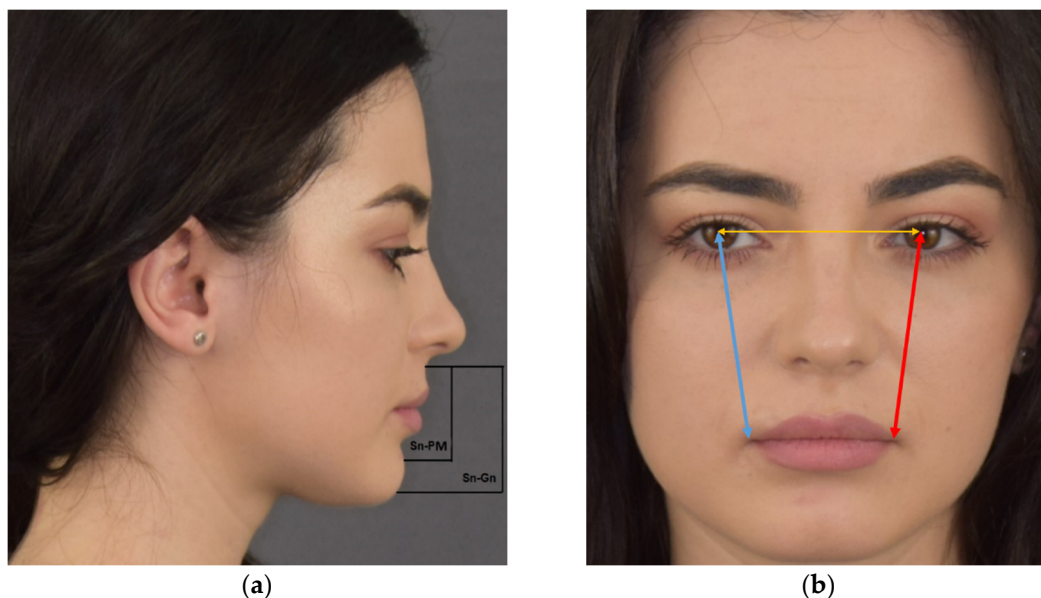


Figure 2. Anthropometric measurements in maximum intercuspation position: (a) Subnasion [Sn] to Prementon [PM] (Sn–PM), and Subnasion [Sn] to Gnathion [Gn] (Sn–Gn); (b) right pupil [Pu] to right buccal commissure (chelion [Ch]) (Pu–Ch_r), and left pupil to left buccal commissure (Pu–Ch_l).

The first two groups of measurements were performed in the maximum intercuspation and rest position; the following two groups were measured solely in the maximum intercuspation position.

For maximum intercuspation, the subjects were asked to bring their teeth into contact with their lips relaxed. Direct measurements were made using a digital caliper (Digimatic Caliper: CD-15CPX; Mitutoyo, Kawasaki, Japan) with an accuracy of 0.01 mm.

The Sn–Gn distance with teeth contact was considered, in the present study, as reference OVD and was compared to the other facial and cephalometric measurements. Sn–Gn without teeth contact was considered rest vertical dimension (RVD).

All sets of measurements were done twice, under uniform conditions, with at least a two-week interval between them, by a single calibrated operator and were recorded to the nearest 0.01 mm.

2.2.2. Anthropometric Measurements on Facial Scanning

Ten subjects, agreeing to participate, randomly selected from the present study group using sealed opaque envelopes, were prepared for facial scanning. For an effect size of 0.7 at a 0.5 significance level, the power is greater than 85% with a sample size of 10.

The complete face scan was performed with a mobile phone (iPhone X; Apple Inc, Cupertino, CA, USA), placed on a specific tripod, with an installed dedicated application (Bellus Dental Pro; Bellus3D Inc, Campbell, CA, USA). Each subject was asked to sit on a chair with the head in vertical position, eyes open and with the teeth in maximum intercuspation. Before the capture, the head position was calibrated with the software and the subject was required to move left, right, upwards and downwards till the face capture was complete. After checking, the face scan was exported as .obj. file (a geometry definition open file format developed by Wavefront Technologies, Annapolis Junction, MD, USA).

Facial scans .obj files and the corresponding cephalometric files with lower facial height angle and [ANS], [Xi] and [PM] landmarks marked, saved as dicom files, were imported in Exocad[®] DentalCAD, version 2.3 Matera software (Exocad GmbH, Darmstadt, Germany) and superimposed using best fit algorithm (Figure 3).

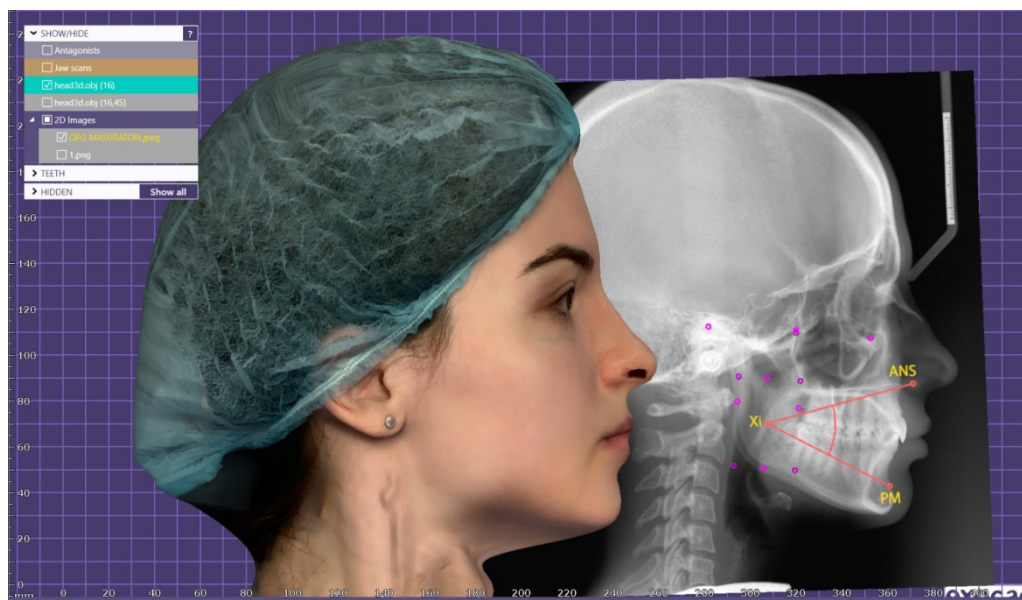


Figure 3. Superimposition, based on the best-fit algorithm, of .obj file (facial scan) with a dicom image of the lateral cephalogram performed in Exocad software.

The anthropometric measurements with teeth in maximum intercuspal position: Sn–PM, Sn–Gn, Pu–Ch_r and Pu–Ch_l were done in Exocad on facial scan files (Figure 4a–c). For the lateral measurements, the cephalometric landmarks obtained through the superimposed files were used to mark the corresponding anthropometric landmarks (Figure 4a).

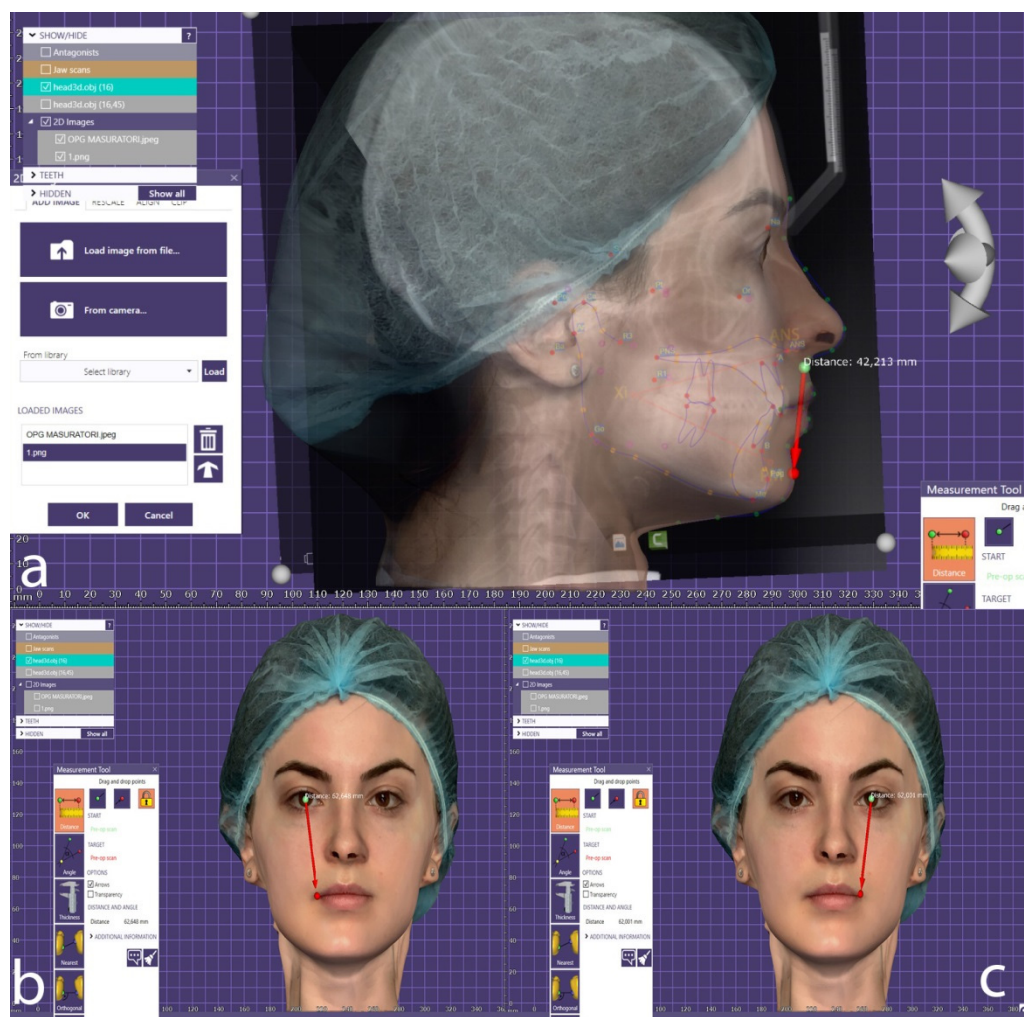


Figure 4. Digital anthropometric measurements on facial scans in maximum intercuspation position: (a) Subnasion [Sn] to Prementon [PM] (Sn–PM), (b) right pupil [Pu] to right buccal commissure (chelion [Ch]) (Pu–Ch_r) and (c) left pupil to left buccal commissure (Pu–Ch_l).

2.3. Data Analysis

All measured data were synthesized in an Excel table, compared and analyzed using statistical software (SPSS 12.0; SPSS Inc., Chicago, IL, USA). A *p*-value of <0.01 was considered statistically significant. Mean value and standard deviation were calculated for each group.

The sample size of the study was established based on the fact that a sample size of 150 subjects reaches 89% of power (1-β) to detect an effect size of 0.3 using a chi-square test with two degrees of freedom and a significance level (α) of 0.05.

The agreement between each set of anthropometric measurements performed by the same operator at two weeks interval was calculated by using the intraclass correlation coefficient.

Bland and Altman Plots were drawn to evaluate the correlation between the clinical anthropometric measurements and the same measurements performed on facial scans.

The Pearson's correlation coefficient was used to assess correlations between OVD (Sn–Gn) and the measured parameters. Simple linear regression analysis with a stepwise forward approach was used to develop a prediction formula for the OVD using other measured parameters as independent variables. The null hypothesis of the present study was that a strong correlation between anthropometric and cephalometric measurements of OVD will be determined.

3. Results

In the study group, 20 males and 130 females were included, with a mean age of 24 (± 1.51) years old, ranging from 20 to 25 years.

3.1. Descriptive Analyses of the Standard Measurements

Intraclass correlation coefficients of each group of clinical anthropometric measurement made at two weeks interval was between 0.91 and 0.93, showing excellent reliability for all the measures analyzed [42].

The agreements evaluations between the four groups of anthropometric measurements using the digital caliper (clinical) and their corresponding measurements on facial scans in Exocad software (digital) are presented in Figure 5a–d.

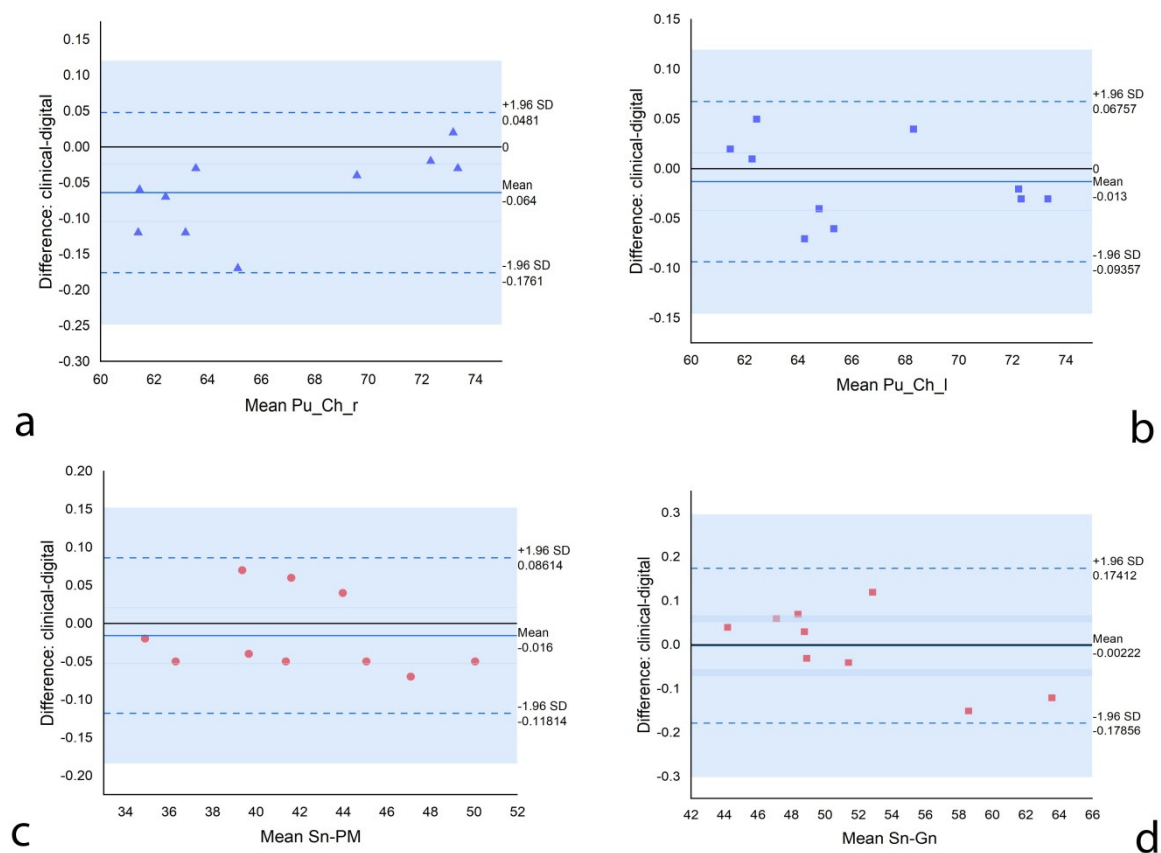


Figure 5. Bland–Altman plots showing the extent of agreement between the clinically performed anthropometric measurements and the corresponding measurement made on the facial scans in Exocad software for: (a) right pupil [Pu] to right buccal commissure (chelon [Ch]) (Pu–Ch_r), (b) left pupil to left buccal commissure (Pu–Ch_l), (c) Subnasion [Sn] to Prementon [PM] (Sn–PM) and (d) Subnasion [Sn] to Gnathion [Gn] (Sn–Gn), in maximum intercuspation position.

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 a strong agreement between the two measurement techniques for each of the four anthropometric measurements. The SD of the means also had lower values, less than 0.2 mm (Figure 5).

Means, standard deviation, minimum and maximum values for all measured variables are presented in Table 1. The highest standard deviation is observed at Sn–PM variable in the rest position.

Table 1. Descriptive data of the variables calculated from the clinical cephalometric analysis.

Variable	Min.	Max.	Mean (\pm SD)
Sn-PM in OVD (mm)	29	63	50.20 (\pm 9.06)
Sn-PM in RVD (mm)	31	67	52.33 (\pm 10.39)
Sn-Gn in OVD (mm)	44	73	62.47 (\pm 6.77)
Sn-Gn in RVD (mm)	48	76	66.07 (\pm 6.84)
Pu-Ch _r (mm)	63	78	70.07 (\pm 3.92)
Pu-Ch _l (mm)	66	76	71.40 (\pm 3.02)
LFH $^\wedge$	34.66 $^\circ$	51.04 $^\circ$	42.31 $^\circ$ (\pm 4.29)
ML $^\wedge$ FH	11.33 $^\circ$	34.36 $^\circ$	22.15 $^\circ$ (\pm 6.35)

SD = standard deviation; Sn-PM = distance subnasion-prementon; Sn-Gn = distance subnasion-gnathion; OVD = occlusal vertical dimension; RVD = rest vertical dimension; Pu-Ch_r = pupil to chelion right side; Pu-Ch_l = pupil to chelion left side; LFH $^\wedge$ = angle between anterior nasal spine [ANS], Xi (geometrical center of the mandibular ramus) and prementon [PM]; ML $^\wedge$ FH = angle between mandibular plane and Frankfurt plane.

3.2. Baseline Data of the Participants

The Ricketts lateral cephalometric analysis was selected in Blu Sky Plan 4 software to establish the pattern of growth of the subjects by relating ML $^\wedge$ FH value to the norm.

Facial typology is classified as dolichofacial, mesofacial, or brachyfacial. ML $^\wedge$ FH value could predict the facial growth, and, according to Bassetti [43], 26 $^\circ \pm 4$ is considered mesofacial, a dolichofacial typology has excessive vertical facial growth and is usually associated with an increased ML $^\wedge$ FH (>30 $^\circ$) and a brachyfacial typology has reduced vertical growth and is usually accompanied by reduced ML $^\wedge$ FH (<22 $^\circ$). The mean values of the LFH $^\wedge$ of the three different type of facial typology classify according to ML $^\wedge$ FH were correlated to OVD and the results were presented in Table 2.

Table 2. Correlation between LFH $^\wedge$ and OVD for different pattern of growth of the enrolled participants, classified according to ML $^\wedge$ FH [43].

Facial Profile	Number of Subjects (N)	Mean LFH $^\wedge$ (\pm SD)	Reference (\pm Accepted Variation)	Mean Difference	<i>p</i> Value
Brachyfacial	48	39.06 $^\circ$ (\pm 4.29 $^\circ$)	44 $^\circ$ (\pm 2.5 $^\circ$)	−4.94	0.758
Mesofacial	60	42.91 $^\circ$ (\pm 2.16 $^\circ$)	49 $^\circ$ (\pm 2.5 $^\circ$)	−6.09	0.990
Dolichofacial	42	45.48 $^\circ$ (\pm 4.70 $^\circ$)	54 $^\circ$ (\pm 2.5 $^\circ$)	−8.52	0.692

SD = standard deviation, LFH $^\wedge$ = angle between anterior nasal spine [ANS], Xi (geometrical center of the mandibular ramus) and prementon [PM], *p* value = statistical significance between different pattern of grow and mean LFH $^\wedge$. Pearson's correlation coefficient was used for statistical significance, *p* < 0.05.

According to the analysis, 32% of the subjects had a deep bite with a horizontal pattern of growth (brachiofacial profile) and a mean LFH $^\wedge$ (\pm SD) of 39.06 $^\circ$ (\pm 4.29 $^\circ$), 40% were in the normal values (mesiofacial profile), with a mean LFH $^\wedge$ (\pm SD) of 42.91 $^\circ$ (\pm 2.16 $^\circ$), and 28% had a vertical pattern of growth (dolichofacial profile) and a mean LFH $^\wedge$ (\pm SD) of 45.48 $^\circ \pm 4.70^\circ$. As can be observed from Table 2, no correlation between LFH $^\wedge$ and OVD could be noticed when considering the pattern of growth.

3.3. Correlations between Variable

The correlation between variables was calculated with Pearson Correlation Sig. (2-tailed) for each 150 pairs, and the results are synthetized in Table 3. For the statistically significant correlations (*p*-value < 0.01), the coefficients of correlation were between 0.005 and 0.967 (Table 3).

Table 3. Correlation between clinical anthropometric and cephalometric measurements.

		Sn-PM OVD	Sn-PM RVD	OVD	RVD	Pu-Ch_r	Pu-Ch_l	LFH°	ML°FH
Sn-PM OVD	Pearson Correlation	1	0.967 **	0.751 **	0.809 **	0.648 **	0.352	0.400	0.172
	<i>p</i> value	-	0.000	0.001	0.000	0.009	0.198	0.141	0.539
Sn-PM RVD	Pearson Correlation	0.967 **	1	0.851 **	0.907 **	0.687 *	0.344	0.414	0.096
	<i>p</i> value	0.00	-	0.000	0.000	0.005	0.210	0.125	0.735
OVD	Pearson Correlation	0.751 **	0.851 **	1	0.960 **	0.785 **	0.448	0.518 *	0.005
	<i>p</i> value	0.001	0.000	-	0.000	0.001	0.094	0.048	0.985
RVD	Pearson Correlation	0.809 **	0.907 **	0.960 **	1	0.778 **	0.331	0.565 *	0.057
	<i>p</i> value	0.000	0.000	0.000	-	0.001	0.229	0.028	0.839
Pu-Ch_r	Pearson Correlation	0.648 **	0.687 **	0.785 **	0.778 **	1	0.650 **	0.405	0.102
	<i>p</i> value	0.009	0.005	0.001	0.001	-	0.009	0.135	0.717
Pu-Ch_l	Pearson Correlation	0.352	0.344	0.448	0.331	0.650 **	1	0.100	0.148
	<i>p</i> value	0.198	0.210	0.094	0.229	0.009	-	0.723	0.599
LFH°	Pearson Correlation	0.399	0.414	0.518 *	0.565 *	0.405	0.100	1	0.611 *
	<i>p</i> value	0.141	0.125	0.048	0.028	0.135	0.723	-	0.016
ML°FH	Pearson Correlation	0.172	0.096	0.005	0.057	0.102	0.148	0.611 *	1
	<i>p</i> value	0.539	0.735	0.985	0.839	0.717	0.599	0.016	-

Pearson coefficient of correlation, is statistically significant for: * $p < 0.05$, ** $p < 0.01$; Sn-PM = distance subnasion-prementon; OVD = subnasion-gnathion occlusal vertical dimension; RVD = subnasion-gnathion rest vertical dimension; Pu-Ch_r = pupil to chelion right side; Pu-Ch_l = pupil to chelion left side; LFH° = angle between anterior nasal spine [ANS], Xi (geometrical center of the mandibular ramus) and prementon [PM]; ML°FH = angle between mandibular plane and Frankfurt plane.

3.4. Calculation of OVD Regression Formula

Multiple linear regression analysis with a prediction formula was performed for the statistically significant correlations (Table 4).

Table 4. Regression equation to predict the OVD from different anthropometric and cephalometric measurements ($R^2 > 0.2$).

Correlation	R^2	Regression Formula
OVD-RVD	0.9221	$y = 0.9505x - 0.3316$
OVD-Sn-PM RVD	0.7235	$y = 0.5543x + 33.461$
OVD-Sn-PM OVD	0.5638	$y = 0.5613x + 34.289$
OVD-Pu-Ch_r	0.6162	$y = 1.3564x - 32.571$
OVD-LFH°	0.2678	$y = 0.3284x + 21.794$

Sn-PM = distance subnasion-prementon; OVD = subnasion-gnathion occlusal vertical dimension; RVD = subnasion-gnathion rest vertical dimension; Pu-Ch_rl = pupil to chelion left side; Pu-Ch_r = pupil to chelion right side; LFH° = angle between anterior nasal spine [ANS], Xi (geometrical center of the mandibular ramus) and prementon [PM].

OVD could be correlated in 92% of cases with RVD, in 72% with the distance Sn-PM in the mandibular rest position, in 62% with right pupil to chelion distance, in 56% with Sn-PM in maximum intercuspation and only in 27% of the subjects with LFH° (Table 4). The left pupil to chelion distance is no statistically significant correlated with OVD ($p = 0.094$), but correlated ($p = 0.009$) in 42% of the cases ($R^2 = 0.4225$) with the right similar distance (Table 3).

4. Discussion

The absence of teeth or of any pre-extraction records makes the establishment of OVD arbitrary; therefore, the aim of the present study was to establish if a correlation between OVD and some anthropometric and cephalometric parameters exists, in order to be able to preserve and restore it in a predictable, correct, esthetic and functional manner, after tooth loss or tooth abrasion.

To our knowledge, this is the first attempt of proposing facial scanning software, installed on a mobile phone, for registering and preserving the OVD.

A facial scanner is a non-contact optical measuring instrument, with a large application in clinical practice for diagnosis and treatment plan and evaluation [39,44,45], and also with acceptable accuracy [46,47]. The use of smartphone software for face capture in dentistry is not unusual either. Lo Russo et al. used Bellus application for iPhone (Bellus3D FaceApp; Bellus3D Inc) as a diagnostic and treatment tool in addition to intraoral scans, perioral scans of the nose and mouth, incorporating the data into a digital patient for optimizing individual tooth arrangement during the design of a digital denture [40]. For personalized dental care, information on the patient's face and perioral environment is extremely useful for the communication between clinicians and a dental laboratory and also between different dental specialties; therefore, the concept of "digital patient" is more and more applied [48].

Various scanning technologies, such as laser triangulation, structured light, photogrammetry, contact based, and laser pulse, are used for 3D image acquisition, the contact-based technology being the most accurate for surface scanning [49]. However, among the great number of the existing devices, only a few scanners meet the requirements for clinical use.

For comparing the practical accuracy, Zhao et al. [47] used a high-accuracy industrial "line-laser" scanner (Faro) to evaluate two types of non-contact scanners using "stereophotography" (edMD), and "structured light" (FaceScan) technologies, in patients with facial deformities and found both scanners to be suitable for clinical use.

An in vitro assessment of four scanners—EinScan Pro, EinScan Pro 2X Plus using Shining Software, iPhone X, using the Bellus3D Face Application and Planmeca ProMax 3D Mid—was performed by Amorvrit and Sanohkan [50], using a face model, printed from polylactic acid, with marked reference points. Different measurements were performed in x, y and z axes, between the reference points and compared to the values obtained by using a digital caliper. None of the four devices used were recommended for measuring the depth of more than 2 mm, the accuracy of a 3D scanner being affected by the scanning length and pattern of scanning [50].

However, the validity of the use of mobile phones as data collection devices for dental diagnosis and treatment purpose, in a clinical setting, was not previously assessed.

In the present study, the "Reference" or "Gold Standard" measurement was the contact measurement method, very classical and commonly used in medical research, in agreement with previous studies [47,51], despite the touching deformation error of facial soft tissue for a real person. Therefore, the reference for OVD measurement was considered the clinical measurement between Sn–Gn using a digital calliper.

For assessing the validity of the use of facial scanning, four anthropometric measurements were used to evaluate the degree of agreement between contact measurements performed on subject faces and measurements performed digitally, on facial scanning. Ten subjects were evaluated, according to the sample size calculation and the in vivo study performed by Zhao et al. [47]. The results obtained are promising; a strong agreement between all measured parameters was registered (Figure 5). The 3D .obj file obtained through facial scanning can be stored on the patient's virtual file and also can be stored by the patient's itself for future use in oral rehabilitation and in preserving OVD through life, as proposed by the present study.

Moreover, the measurements on the facial scanning file could overcome the drawback caused by the touching deformation of the skin when clinical measurements are done. Moreover, cephalometric files with landmarks marked could be superimposed over the facial scanning, in computer-aided design (CAD) software, as shown in Figure 4a. The anthropometric landmarks could be set more precisely and OVD could be measured and preserved through life in patient's medical record.

However, an important aspect in complex oral rehabilitation is the restoration of lost OVD. Therefore, the correlation between clinical anthropometric and cephalometric measurements was assessed on 150 dentate subjects, considering the clinical measurements using a digital calliper as the "gold standard". Among the contact measurements, Sn–Gn distance with teeth contact was considered, as reference OVD and correlated to the other anthropometric measurements (Sn–Gn in rest position,

Sn-PM in OVD and RVD, Pu-Ch_r and Pu-Ch_l in OVD) and cephalometric measurements (LFH° and ML°FH).

For the cephalometric evaluations, the mean OVD reference value for our study group was 62.47 ± 6.77 , similar to Majeed's findings in an Arabian population [52].

OVD was strongly correlated to RVD, 92%, being in agreement with other research findings [9–12]. A prediction formula of the difference between RVD and OVD ($OVD = 0.9505 \text{ RVD} - 0.3316$, Table 4) was calculated, instead of the usual clinical relationship of just subtracting 4 mm ($OVD = RVD - 4\text{mm}$) [18]. For the mean values, a difference of 3.6 mm was determined between RVD and OVD, for our group.

The OVD was also found in statistically significant correlation to Sn-PM, with or without teeth in maximum intercuspal position and could be predicted through a regression formula (Table 4).

An alternative method proposed by different groups of researchers proposed to determine OVD by using other facial measurements was also tested in the present study. The mean value of the distance right pupil to chelion was 70.07 ± 3.92 , higher than that in Majeed's research [52] on Saudi Arabian subpopulations (64.86 ± 3.7) and also higher compared to Nagpal's results (67.22 ± 4.9) [24] measured on Indian dentate subjects. The mean value of the left pupil to buccal commissure was higher than the right one—the same results as other study findings [24]—the asymmetry being noticeable, in accordance to our studied population. The right and left distance of pupil to chelion was correlated in only 42% of the cases, with a greater mean distance on the left side (Table 1). This result is in agreement with other studies which reported the left side of the face commonly most dominant at both males and females [53].

In the present study, Sn-Gn in maximum intercuspation was statistically significant correlated to right pupil to chelion, in 62% of the cases (Table 4), different from Majeed's findings [52] who reported a 13% correlation for dentate patients, but similar to Basnets et al. [26] and Alhaji and co-workers [22] results. The left measured distance was not statistically significant correlated to OVD, in contrast to other authors findings [24,52,54], who concluded that the left facial measurements were more reliable in predicting OVD than the right side measurements. Hayakawa et al. [55] calculated a prediction model to determine OVD, $\text{Sn-Gn distance (vertical dimension)} = 16 + 0.65 (\text{pupil-buccal commissure})$, different from our obtained formula $OVD = 1.3564 \text{ Pu-Ch}_r - 32.571$ (Table 4). However, major individual differences in morphological features have been reported between races or ethnic groups and this could explain the differences obtained by our study, analyzing a Caucasian ethnic group of young individuals.

For the anthropometric assessments, in our study, the mean LFH° value measured was $42.31^\circ (\pm 4.29)$ (Table 1), close to Slavicek's results $43.6^\circ \pm 5.7$ [56] but very different from other researchers' values— 45.2° [43], $47^\circ \pm 4$ [57], 47.6° [36], $47.9^\circ \pm 4$ [58]—this probably being due to racial differences of the populations analyzed by the different studies. Correlations between LFH° and OVD have been found only in 27% of cases (Table 4) with a p value of 0.048 (>0.01)—results similar to Edward's observations on dentate patients [59], but different from Slavicek's and Bassetti's findings [43,56]. Moreover, Bassetti proposed a controlled increasing (or decreasing) of OVD, calculated with the difference of the LFH° measured angle related to the normal considered value (45.2), assuming that 1° is equivalent to 2 mm on the articulator pin [43].

Regarding ML°FH, no statistically significant correlation was found with OVD ($p = 0.985$), in accordance to Slavicek's and co-workers [56] observations who determined that the lower facial height significantly depends on the skeletal location of the maxilla ($p < 0.001$), but, for the skeletal location of the mandible, they did not obtain a statistically significant result ($p = 0.861$).

No statistically significant correlation was obtained between LFH° and ML°FH for our study group $p = 0.016$ (>0.01) (Table 3).

When different patterns of growth were analyzed (Table 2), the mean LFH° was $42.91^\circ (\pm 2.16^\circ)$ for mesiofacial subjects, $45.48^\circ (\pm 4.7^\circ)$ for dolichofacial subjects and $39.06^\circ (\pm 4.29^\circ)$ for brachyfacial subjects and no statistically significant correlation ($p > 0.01$) has been found between LFH° and OVD in any pattern of growth (Table 2).

This study was performed on young, dentate individuals. However, for fully and partially edentulous patients with reduced OVD and posterior occlusal collapse, it has to be taken into consideration that the values of selected cephalometric parameters are likely to be influenced, requiring further precise analysis. Moreover, in the cases of elderly patients [60], an increased lower facial high is also reported [61], the loss of posterior support could be asymmetric and cephalometric parameters could be modified in both lateral and frontal X-rays.

Study drawbacks: The analyzed sample consisted mostly of females 130 (86.6%) and only 20 males, due to the fact that the total number of male students of the Faculty of Dentistry, was fewer compared to the total number of the female students, with the ratio of approximately 1:7, the gender analysis being inconclusive. In the present study, only Caucasian individuals were included, hence the results and regression formula cannot be extrapolated to other ethnic groups.

For the facial scanning, only 10 subjects of the analyzed group were scanned and only 10 virtual files were assessed for validity. For some of the subjects, the scanning was repeated several times due to the occurrence of nostrils deformation, probably to the requirements of head rotation during image capture. However, the occurrence these artefacts did not influenced the measurements of OVD.

For the correlation between OVD and the other anthropometric and cephalometric parameters, the fact that none of analyzed parameters showed $R = 1$ (Table 3) means that no tested measurement could predict the exact OVD in the Caucasian group analyzed, rejecting the null hypothesis. The dispersion of the results may be explained by the Morales' concept of a vertical comfort range or vice versa [62]. So, it is better if OVD could be preserved through life, without being necessary to determine it.

Some advantages of the use of a facial scanner could be envisaged: first, data could be preserved through life, as a digital file, and used for future rehabilitations; second, this personal medical record could be used as a medico-legal document if orthodontic or other type of treatment is intended. Moreover, with the use of a CAD software, the simulation of different treatment options could facilitate the communication with the patient and also among the interdisciplinary dental team, including the dental technician, for improving the predictability of final treatment's results. However, by comparing files, the facial scan could be also used to assess the changes occurred during orthodontic treatment or post complex prosthetic rehabilitations. Further clinical studies need to be performed to validate this aspect.

The use of a simple registration with a smartphone and dedicated software could simplify and increase predictability of the restorative treatment.

The occlusal vertical dimension is a dynamic parameter so the anthropometric measurement in dentulous subjects can be an adjunct for utilizing in edentulous patients, and a non-invasive technique, such as facial scanning, could be routinely utilized to improve the accurate determination of OVD.

5. Conclusions

According to our results, the facial scanning could be used for the predictable registration of OVD, and the obtained information, stored in a digital file, could be preserved through life and use for patient's oral rehabilitation.

For OVD determination, a pluralistic method should be adopted at all the stages of rehabilitation in order to maximize the benefits and minimize damage to the stomatognathic system.

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