PREDICTING OCCLUSAL VERTICAL DIMENSION USING FACIAL ANTHROPOMETRY: DEVELOPMENT OF POPULATION-SPECIFIC REGRESSION MODELS

Lejla Berhamović*, Emir Berhamović, Alma Kamber, Amela Đonlagić, Alma Gavranović-Glamoč

Department of Prosthodontics and Dental Implantology, Faculty of Dentistry, University of Sarajevo, Sarajevo, Bosnia and Herzegovina

***Corresponding author**

Lejla Berhamović
Faculty of Dentistry, University of Sarajevo
Bolnička 4A, Sarajevo, Bosnia and Herzegovina
Phone: 38761431901
E-mail: berhamovic.lejla@gmail.com

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ABSTRACT

Background: Determination of the occlusal vertical dimension, (OVD), remains one of the key challenges in prosthodontics, due to the lack of a universally accepted and sufficiently accurate method. Anthropometric approaches have been proposed as a simple and objective way to estimate OVD, although their applicability may vary across different populations.

Objective: To evaluate whether selected facial anthropometric dimensions can serve as reliable predictors of OVD and to develop regression models for estimating the nasion–menton distance in a sample of the Bosnia and Herzegovina population.

Materials and Methods: This descriptive-analytical cross-sectional study included 60 subjects aged 20–45 years with preserved occlusal relationships and normal facial morphology. A total of 30 anthropometric parameters were measured using standardized techniques. Reliability was assessed using intraclass correlation coefficients. Simple linear regression was used to assess individual predictors, while multiple regression analysis (stepwise method) was applied to develop two models based on the presence or absence of intraoral landmarks.

Results: All analyzed variables showed statistically significant associations with the nasion–menton distance ($p<0.001$), with the strongest correlations observed for bizygomatic width ($r=0.947$), nasion–incision ($r=0.895$), and nasion–gingival papilla tip ($r=0.891$). Both regression models showed high predictive accuracy ($R^2=0.958$ and $R^2=0.950$), with better performance when intraoral landmarks were included.

Conclusion: Selected facial anthropometric parameters can estimate the occlusal vertical dimension with high accuracy. Regression models provide a reliable approach for clinical estimation, particularly when intraoral landmarks are available.

Keywords: occlusal vertical dimension; anthropometry; facial measurements; regression analysis

Introduction

Occlusal vertical dimension (OVD) is defined as the height of the face in the inter-cuspal position of the mandible and is commonly assessed as the distance between two midline facial reference points [1].

OVD is not a static parameter, as it may change under the influence of various clinical and biological factors, including occlusal wear, loss of posterior teeth, alterations of the occlusal surfaces of prosthetic restorations, and progressive resorption of edentulous ridges beneath dentures [2,3].

Establishing OVD represents a critical step in determining maxillomandibular relationships. In most prosthetic rehabilitation procedures, the primary therapeutic goal is to restore a physiological OVD, as this ensures optimal function, acceptable aesthetics, and biological stability [4]. Accurate determination of the original OVD facilitates patient adaptation to prosthetic restorations and contributes to overall treatment satisfaction [5,6].

Due to its considerable clinical importance, OVD has been extensively investigated for nearly a century [7]. Nevertheless, accurately defining its optimal value remains challenging, making it one of the most debated topics in prosthodontics.

Although numerous methods for determining OVD have been proposed, based on functional, morphological, anthropometric, or combined parameters, they all have inherent limitations, and none has demonstrated complete accuracy or universal applicability in clinical practice [8]. Current evidence demonstrates considerable variability in the results obtained with different methods, indicating the absence of a widely accepted clinical consensus [9-12].

Therefore, the use of multiple complementary approaches is recommended in clinical practice to improve the reliability of OVD assessment [13,14].

Among these approaches, anthropometric methods are particularly important, as they enable the estimation of OVD based on measurable and relatively stable morphological relationships [15]. These methods are objective and can be applied using direct facial measurements, as well as modern two-dimensional [16, 17] and three-dimensional digital techniques [18]. Despite advances in digital technology, direct facial anthropometry remains a reliable, widely used method due to its simplicity, reproducibility, and minimal technical requirements [19].

However, the application of anthropometric parameters requires caution when extrapolating results across different populations, since facial dimensions are influenced by factors such as sex, age, ethnicity, and geographic characteristics [20, 21].

Therefore, validation of these parameters within specific populations is essential. Data regarding the relationship between OVD and facial dimensions in the population of Bosnia and Herzegovina remain limited, which highlights the need for further research in this field.

Objective

The objective of this study was to evaluate whether selected facial anthropometric dimensions can serve as reliable predictors of occlusal vertical dimension and to develop regression models for its estimation in a sample of the Bosnia and Herzegovina population.

Materials and Methods

In this descriptive-analytical cross-sectional study, 60 subjects of both sexes, aged between 20 and 45 years, were included. The study was conducted at the Department of Prosthodontics, Faculty of Dentistry, University of Sarajevo, with the approval of the institutional Ethics Committee (No. 09-874-4/2012) and in accordance with the principles of the Declaration of Helsinki. All participants provided written informed consent.

The sample was formed based on predefined inclusion and exclusion criteria. The study included citizens of Bosnia and Herzegovina with an average facial width (Facial index 85%–89.99% according to Banister's classification), natural dentition, Class I canine and molar relationships, and preserved occlusal vertical dimension (OVD). One restoration per quadrant (crown, inlay, or on-lay) was allowed, as well as minor rotations or inclinations not involving the maxillary central incisors. Participants were required to have intact incisal edges of the maxillary central incisors, without differences in their vertical position, and to present no signs of interdental papilla loss between these teeth.

Individuals with a history of orthodontic treatment, skeletal discrepancies, temporomandibular disorders, orthognathic or aesthetic facial surgery, craniofacial trauma, congenital or acquired maxillofacial defects, prosthetic restorations, marked facial asymmetry, or a midline diastema were excluded from the study.

A total of 16 anatomical or geometrically derived landmarks were used in the study (8 midline and 8 bilateral points). Their locations were defined according to the standardized nomenclature proposed by Caple and Stephan [22], or are well established in clinical practice.

Landmarks were identified by inspection and, when necessary, palpation. Facial landmarks were marked with a non-toxic pencil, while intraoral and periocular landmarks were assessed visually. A total of 26 distances between predefined landmarks were evaluated. As four variables were measured under both open (OE) and closed eye (CE) conditions, the final number of anthropometric parameters included in the analysis was 30.

Distances measured in the facial midline included nasion–menton, nasion–sub-nasale, nasion–gingival papilla tip, nasion–incision, glabella–sub-nasale, sub-nasale–interpupillary line, sub-nasale–stomion superius, sub-nasale–incision, and supra-mentale–menton.

Transverse distances between paired bilateral landmarks included zygion$_R$–zygion$_L$, e exocanthion$_R$–endocanthion$_L$, –alare$_L$, crista philtri$_R$–crista philtri$_L$, gonion$_R$–gonion$_L$, pupil center–pupil center$_L$.

Distances located on one side of the face were measured bilaterally and included exocanthion$_R$–endocanthion$_R$, exocanthion$_L$, –tragus facial groove$_L$–tragus facial groove$_L$.

Distances involving a midline and a lateral landmark were also evaluated, including subnasal and exocanthion–incision measurements. These were recorded bilaterally under both eye conditions (OE and CE).

Most variables were measured using a digital caliper with straight arms, with a resolution of 0.01 mm and a measuring range of 0–150 mm (Emil Lux GmbH & Co. KG, Wermelskirchen, Germany). Bizygomatic and bigonial widths were evaluated using a digital caliper with curved arms, with a measuring range of 0–203.2 mm and an accuracy of 0.254 mm (Digital outside diameter caliper 35-OD8, iGaging DigiCal, San Clemente, California, USA). Interpupillary distance was measured using a digital pupillometer (Digital PD Ruler PDM 30H, Traversal (CN) LLC, Hangzhou, Zhejiang, China). All measuring instruments were disinfected using an antimicrobial agent (Zeta 3 Wipes, Zhermack SpA, Badia Polesine (RO), Italy) before and after use on each participant. All measurements were performed by a single trained examiner.

During the measurements, participants were seated upright, with the head positioned such that the Frankfort horizontal plane and the interpupillary line were parallel to the floor.

For interpupillary distance assessment, both the participant and the examiner were seated upright facing each other, with their eyes at the same level.

The inter-cuspal position served as the reference for most measurements, with the lips in light contact. When intraoral landmarks were used, participants retracted their lips to facilitate the proper positioning of the measuring instrument. Measurements of sub-nasale-stomion superius and sub-nasale-incision were performed with the mouth open during continuous pronunciation of the vowel "i".

During most measurements, the participant's gaze was directed straight ahead. Measurements involving periocular landmarks were performed either with the participant looking upwards or with the eyes closed.

All measurements, except interpupillary distance, were contact and non-compressive, with intentional soft tissue compression applied when measuring bizygomatic and bi-gonial widths until bony resistance was reached.

Each variable was measured twice during the same session, and the mean value was used as the reference. For interpupillary distance, the mean of three measurements was used, in accordance with the manufacturer's instructions for the digital pupillometer.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics (version 21, IBM Corp). Descriptive statistics included means with 95% confidence intervals, standard deviations, minimum and maximum values, as well as absolute and percentage frequencies. Differences between mean values were analyzed using the paired samples t-test, with a significance level set at 5%.

Prediction of the dependent variable (nasion–menton distance) was initially performed using simple linear regression. Subsequently, based on clinical criteria, two multiple linear regression models were developed using a stepwise method: the first model was intended for individuals with preserved intraoral landmarks (incision and gingival papilla tip), while the second model was constructed for individuals in whom these landmarks were not preserved.

The reliability of repeated measurements was assessed using intraclass correlation coefficients ICC(3,1) and ICC(3,2), based on a two-way mixed-effects model with a consistency criterion. The normality of the mean values of the two measurements was tested using the Shapiro–Wilk test.

Assumptions of the regression models were evaluated by residual analysis, including assessment of the normality of residuals (Shapiro–Wilk test). Multicollinearity was assessed post hoc by calculating variance inflation factor (VIF) values for predictor variables in the final stepwise regression models.

Results

A total of 60 subjects were included in the study, with equal distribution of males and females. The mean age of the participants was 25.35±5.59 years. The mean facial index was 87.00±1.60%, with a range from 85.05% to 89.92%.

High intra-rater reliability between the two measurements was confirmed by intraclass correlation coefficients, with ICC (3,1) values ranging from 0.972 to 0.998 and ICC (3,2) values from 0.986 to 0.999. The Shapiro–Wilk test confirmed that the differences between the two measurements for most distances satisfied the assumption of approximate normality ($p>0.05$).

Descriptive values of the dimensions measured in this study are presented in Table 1.

Analysis of differences between the mean values of the nasion–menton distance and all other evaluated dimensions showed that all tested measurements were statistically significantly different in relation to the nasion–menton distance (paired samples t-test, $p<0.001$; 95% confidence level).

Comparison of the mean values of bilateral dimensions did not reveal statistically significant differences between the left and right sides of the face, except for the exocanthion$_R$–endocanthion$_L$ and exocanthion$_L$–endocanthion$_R$ distances, where a statistically significant difference was observed (paired samples t-test, $p=0.004$; 95% confidence level).

Values of the simple linear regression models used to assess the predictive ability of the analyzed dimensions for the nasion–menton distance are presented in Table 2. All variables demonstrated statistically significant regression coefficients ($p<0.001$). The strongest correlation was found for zygion$_R$–zygion$_L$ ($r=0.947$), followed by nasion–incision ($r=0.895$) and nasion–gingival papilla tip ($r=0.891$). The highest value of the regression coefficient b was observed for the exocanthion$_R$–endocanthion$_R$ dimension ($b=1.852$).

Table 1. Descriptive statistics of the measured dimensions (mm)

	n	Mean	Std.Dev.	Minimum	Maximum
$zygion_R$–$zygion_L$	60	133.230	7.133	120.800	150.000
nasion–menton	60	115.914	6.625	102.900	131.500
glabella–subnasale	60	64.832	4.563	54.740	77.750
nasion–subnasale	60	51.956	3.810	43.160	63.525
subnasale–$exocanthion_{L(OE)}$	60	73.082	4.104	66.195	86.535
subnasale–$exocanthion_{L(CE)}$	60	69.661	4.290	60.870	81.280
subnasale–$exocanthion_{R(OE)}$	60	73.615	4.401	66.495	88.005
subnasale–$exocanthion_{R(CE)}$	60	70.023	4.792	61.630	82.795
subnasale–interpupillary line	60	49.940	3.690	41.810	64.045
supramentale–menton	60	27.363	2.524	22.765	33.955
$exocanthion_R$–$exocanthion_L$	60	94.542	4.845	83.310	109.335
$exocanthion_R$–$endocanthion_L$	60	63.838	3.606	55.725	74.440
$exocanthion_R$–$endocanthion_R$	60	32.033	1.638	27.340	36.285
$exocanthion_L$–$endocanthion_L$	60	32.056	1.765	27.115	36.915
$exocanthion_L$–$endocanthion_R$	60	64.217	3.733	54.970	75.265
$endocanthion_R$–$endocanthion_L$	60	31.528	2.441	26.580	36.940
$alare_R$–$alare_L$	60	35.063	2.901	29.780	42.135
crista $philtri_R$–crista $philtri_L$	60	13.317	2.154	9.825	16.985
$gonion_R$–$gonion_L$	60	108.427	5.668	92.750	120.450
pupil $center_R$–pupil $center_L$	60	64.716	3.663	57.433	73.833
nasion–gingival papilla tip	60	69.361	4.359	59.990	81.205
nasion–incision	60	74.620	4.291	64.825	85.675
subnasale–stomion superius	60	21.767	2.440	16.980	27.955
subnasale–incision	60	26.074	2.582	21.115	31.865
$exocanthion_{R(OE)}$–incision	60	84.920	4.333	78.135	96.700
$exocanthion_{R(CE)}$–incision	60	80.685	4.400	73.020	91.430
$exocanthion_{L(OE)}$–incision	60	84.731	4.190	78.230	96.710
$exocanthion_{L(CE)}$–incision	60	80.582	4.295	73.505	91.465
$exocanthion_R$–tragus facial $groove_R$	60	77.886	4.631	68.735	91.930
$exocanthion_L$–tragus facial $groove_L$	60	77.584	4.548	67.330	88.925

The assumptions of simple linear regression were tested using residual analysis and were satisfied for all models presented in Table 2.

For the construction of the first multiple regression model to estimate the nasion–menton distance in individuals with preserved incision and gingival papilla tip landmarks, a total of 29 anthropometric measurements and the variable sex were included in the initial stepwise procedure. During the selection process, and according to the predefined criteria (Probability-of-F-to-enter ≤ 0.050; Probability-of-F-to-remove ≥ 0.100), the model retained five statistically most significant predictors: $zygion_R$–$zygion_L$, nasion–gingival papilla tip, supramentale–menton, $endocanthion_R$–$endocanthion_L$, and $gonion_R$–$gonion_L$.

The first multiple regression model showed a very strong association with the dependent variable ($R=0.979$; $R^2=0.958$; $p<0.001$), as demonstrated in Tables 3 and 4.

All regression coefficients in the first multiple regression model were statistically significant, with the strongest positive contribution from the nasion–gingival papilla tip distance (b=0.586). Other statistical parameters of the regression coefficients are presented in Table 5.

The obtained regression equation for predicting the nasion–menton distance in the first multiple regression model is as follows:

nasion–menton = $2.313 + 0.581\ X_1 + 0.586\ X_2 + 0.453\ X_3 - 0.214\ X_4 - 0.094\ X_5$

For the construction of the second multiple regression model to estimate the nasion–menton distance in individuals without preserved incision and gingival papilla tip landmarks, all variables from the previous model were included in the initial stepwise procedure, except those based on these specific landmarks.

Table 2. Prediction of the nasion–menton distance by simple linear regression

Variable X Variable Y	Mean	Mean X/Y	r	p	a	b
zygion$_R$–zygion$_L$ nasion–menton	133.230 115.914	1.149	0.947	<0.001	-1.248	0.879
glabella–subnasale nasion–menton	64.831 115.914	0.559	0.628	<0.001	56.813	0.912
nasion–subnasale nasion–menton	51.956 115.914	0.448	0.781	<0.001	45.383	1.358
subnasale–exocanthion$_{L(OE)}$/ nasion–menton	73.082 115.914	0.630	0.738	<0.001	28.805	1.192
subnasale–exocanthion$_{L(CE)}$/ nasion–menton	69.661 115.914	0.601	0.678	<0.001	43.023	1.046
subnasale–exocanthion$_{R(OE)}$/ nasion–menton	73.615 115.914	0.635	0.760	<0.001	31.685	1.144
subnasale–exocanthion$_{R(CE)}$/ nasion–menton	70.023 115.914	0.604	0.732	<0.001	45.022	1.012
subnasale–interpupillary line nasion–menton	49.940 115.914	0.431	0.623	<0.001	60.060	1.118
supramentale–menton nasion–menton	27.363 115.914	0.236	0.611	<0.001	72.029	1.604
exocanthion$_R$–exocanthion$_L$ nasion–menton	94.542 115.914	0.816	0.542	<0.001	45.825	0.741
exocanthion$_R$–endocanthion$_L$/ nasion–menton	63.838 115.914	0.551	0.516	<0.001	55.361	0.949
exocanthion$_R$–endocanthion$_R$/ nasion–menton	32.033 115.914	0.276	0.458	<0.001	56.580	1.852
exocanthion$_L$–endocanthion$_L$ nasion–menton	32.056 115.914	0.277	0.474	<0.001	58.907	1.778
exocanthion$_L$–endocanthion$_R$ nasion–menton	64.217 115.914	0.554	0.514	<0.001	57.390	0.911
endocanthion$_R$– endocanthion$_L$/nasion–menton	31.528 115.914	0.272	0.499	<0.001	73.248	1.353
alare$_R$–alare$_L$ nasion–menton	35.063 115.914	0.302	0.534	<0.001	73.168	1.219
crista philtri$_R$–crista philtri$_L$ nasion–menton	13.317 115.914	0.115	0.550	<0.001	93.382	1.692
gonion$_R$–gonion$_L$ nasion–menton	108.427 115.914	0.935	0.550	<0.001	46.218	0.643
pupil center$_R$–pupil center$_L$/nasion– menton	64.716 115.914	0.558	0.500	<0.001	57.418	0.904
nasion–gingival papilla tip nasion–menton	69.361 115.914	0.598	0.891	<0.001	22.007	1.354
nasion–incision nasion–menton	74.620 115.914	0.644	0.895	<0.001	12.753	1.382
subnasale–stomion superius nasion–menton	21.767 115.914	0.188	0.675	<0.001	76.039	1.832
subnasale–incision nasion–menton	26.074 115.914	0.225	0.576	<0.001	77.411	1.477
exocanthion$_{R(OE)}$–incision nasion–menton	84.920 115.914	0.733	0.827	<0.001	8.572	1.264
exocanthion$_{R(CE)}$–incision nasion–menton	80.685 115.914	0.696	0.790	<0.001	19.970	1.189
exocanthion$_{L(OE)}$–incision nasion–menton	84.731 115.914	0.731	0.829	<0.001	4.800	1.311
exocanthion$_{L(CE)}$–incision nasion–menton	80.582 115.914	0.695	0.776	<0.001	19.512	1.196
exocanthion$_R$–tragus facial groove$_R$/nasion–menton	77.886 115.914	0.672	0.534	<0.001	56.441	0.764
exocanthion$_L$–tragus facial groove$_L$/nasion–menton	77.584 115.914	0.669	0.602	<0.001	47.881	0.877

Table 3. Model summary for the first multiple regression model

R	R Square	Std. Error of the Estimate
0.979	0.958	1.413

Predictors: (Constant), $zygion_R$–$zygion_L$, nasion–gingival papilla tip, supramentale–menton, $endocanthion_R$–$endocanthion_L$, $gonion_R$–$gonion_L$

Dependent Variable: nasion–menton

Table 4. Analysis of variance (ANOVA) for the first multiple regression model

	Sum of Squares	df	Mean Square	F	p
Regression	2481.533	5	496.307	248.574	<0.001
Residual	107.817	54	1.997		
Total	2589.350	59			

Predictors: (Constant), $zygion_R$–$zygion_L$, nasion–gingival papilla tip, supramentale–menton, $endocanthion_R$–$endocanthion_L$, $gonion_R$–$gonion_L$

Dependent Variable: nasion–menton

Table 5. Regression coefficients for the first multiple regression model

Model	b	Std. Error	t	p
Constant (a)	2.313	3.880	0.596	0.554
X_1 $zygion_R$–$zygion_L$	0.581	0.061	9.500	<0.001
X_2 nasion–gingival papilla tip	0.586	0.078	7.528	<0.001
X_3 supramentale–menton	0.453	0.094	4.833	<0.001
X_4 $endocanthion_R$–$endocanthion_L$	-0.214	0.093	-2.303	0.025
X_5 $gonion_R$–$gonion_L$	-0.094	0.044	-2.117	0.039

Dependent Variable: nasion–menton

According to the same criteria, the model ultimately retained six statistically most significant predictors: $zygion_R$–$zygion_L$, sex, $exocanthion_R$–$exocanthion_L$, glabella–su-bnasale, supra-mentale–menton, and sub-nasale–stomion superius.

The second multiple regression model showed a very high level of association with the dependent variable (R=0.974; R^2=0.950; p<0.001), as shown in Tables 6 and 7.

All regression coefficients in the second multiple regression model were statistically significant, with the strongest positive contribution from the $zygion_R$–$zygion_L$ distance (b=0.818). Other statistical parameters of the regression coefficients are presented in Table 8.

The obtained regression equation for predicting the nasion–menton distance in the second multiple regression model is as follows:

nasion–menton = $-11.982 + 0.818 X_1 - 2.896 X_2 - 0.186 X_3 + 0.241 X_4 + 0.438 X_5 + 0.471 X_6$

In this model, the variable "sex" was retained as a predictor and was coded as 1 for male participants and 0 for female participants.

Normality of residuals was confirmed by the Shapiro–Wilk test in both multiple regression models (first model: W=0.992, p=0.967; second model: W=0.991, p=0.938). The distribution of residuals was symmetric and showed no marked deviations (first model: skewness=-0.018, kurtosis=-0.166; second model: skewness=-0.187, kurtosis=-0.208). Q–Q plots of the residuals demonstrated good agreement with normal distribution in both models, and no multicollinearity was detected, as all VIF values of the predictor variables retained in the final models were below the recommended thresholds.

Table 6. Model summary for the second multiple regression model

R	R Square	Std. Error of the Estimate
0.974	0.950	1.569

Predictors: (Constant), $zygion_R$ –$zygion_L$, sex, $exocanthion_R$–$exocanthion_L$, glabella–subnasale, supramentale–menton, subnasale–stomion superius

Dependent Variable: nasion–menton

Table 7. Analysis of variance (ANOVA) for the second multiple regression model

	Sum of Squares	df	Mean Square	F	p
Regression	2458.823	6	409.804	166.399	<0.001
Residual	130.527	53	2.463		
Total	2589.350	59			

Predictors: (Constant), $zygion_R$–$zygion_L$, sex, $exocanthion_R$–$exocanthion_L$, glabella–subnasale, supramentale–menton, subnasale–stomion superius

Dependent Variable: nasion–menton

Table 8. Regression coefficients for the second multiple regression model

Model	B	Std. Error	t	p
Constant (a)	-11.982	5.797	-2.067	0.044
X_1 $zygion_R$–$zygion_L$	0.818	0.067	12.240	<0.001
X_2 sex	-2.896	0.613	-4.725	<0.001
X_3 $exocanthion_R$–$exocanthion_L$	-0.186	0.056	-3.297	0.002
X_4 glabella–subnasale	0.241	0.059	4.085	<0.001
X_5 supramentale–menton	0.438	0.107	4.078	<0.001
X_6 subnasale–stomion superius	0.471	0.126	3.744	<0.001

Dependent Variable: nasion–menton

Discussion

Determining the occlusal vertical dimension (OVD) remains a fundamental and unresolved challenge in contemporary prosthodontics, largely due to the lack of a universally accepted and reliably accurate method. Within this framework, and given the well-documented variability of facial characteristics across populations, the present study aimed to evaluate the predictive value of selected facial anthropometric parameters for estimating OVD in a sample of the Bosnia and Herzegovina population, in accordance with the recommendations of Ouni et al. [23], who emphasized the need to validate anthropometric parameters within each population prior to their clinical application.

The methodology applied in this study, based on direct anthropometry, in combination with a standardized participant selection and precisely defined reference landmarks, ensured a reliable assessment of facial dimensions relevant to OVD determination. The use of high-precision digital measuring instruments, together with a rigorously controlled measurement protocol and a single calibrated examiner, further enhanced the accuracy and reproducibility of the obtained data. Moreover, the carefully established inclusion criteria minimized variability related to non-physiological occlusal and morphological deviations, thereby providing a valid basis for subsequent statistical analysis and regression model development.

Although OVD is most commonly assessed in clinical practice as the height of the lower third of the face (sub-nasale–menton distance) in the inter-cuspal position of the mandible, the present study adopted the nasion–menton distance as the dependent variable. This methodological choice was based on evidence from previous studies indicating that the nasion–menton distance can be assessed with greater reliability and consistency compared to the subnasale–menton distance [24,25].

According to the results of the present study, the mean nasion–menton distance was 115.914 mm, which is generally comparable to values reported in regional studies, although certain discrepancies were noted [24,26-28]. The observed differences between populations suggest that the nasion–menton distance exhibits considerable population-specific variability, which may limit the direct application of universal anthropometric predictors in clinical practice. A relatively high standard deviation, as an indicator of variability, together with a wide range of values, reflects considerable interindividual variation in the nasion–menton distance, both in the present study and in regional investigations. This variability highlights pronounced differences among subjects and supports the use of regression models for identifying its predictors.

The results of the regression analysis indicate that the selected anthropometric dimensions demonstrate significant predictive capacity for the nasion–menton distance. Simple linear regression demonstrated statistically significant associations for all analyzed variables ($p<0.001$). The strongest correlations were observed for bizygomatic width ($r=0.947$), nasion–incision ($r=0.895$), and nasion–gingival papilla tip ($r=0.891$). These findings suggest that certain craniofacial dimensions exhibit a strong linear relationship with the nasion–menton distance. However, no single variable in this study accounted for the full variability of the dependent variable. This highlights the limitations of relying on individual anthropometric measures in the clinical assessment of OVD, as biological systems are inherently complex, multifactorial, and characterized by variability [29].

The findings related to bizygomatic width in the present study are consistent with the results reported by Delić et al. ($r=0.9217$), who also identified this parameter as the strongest predictor [24], whereas a considerably weaker association was reported by Radović et al. ($r=0.39$) [26]. These results support the relevance of individual anthropometric parameters. However, the discrepancies observed between studies suggest that their predictive value is not universal but rather influenced by population-specific characteristics.

In this context, multiple regression models provide a more reliable approach than the analysis of individual predictors and are widely used in studies focused on OVD assessment, including those by Kaffaf et al. [30] and Morata et al.[31].

The present study also applied multiple regression analysis to develop clinically applicable models for predicting the nasion–menton distance. Two models were constructed for different clinical situations, depending on the presence or absence of intraoral reference landmarks (gingival papilla tip and incision). This approach was based on the assumption that the presence of these landmarks allows for a more precise estimation of the occlusal vertical dimension, which was confirmed by the present findings.

In the first model, developed for subjects with preserved intraoral landmarks, five significant predictors were retained. The model showed a very high level of association ($R=0.979$; $R^2=0.958$), indicating that it accounts for nearly all variability of the dependent variable. The strongest contribution was observed for the nasion–gingival papilla tip distance, while measurements related to the incision landmark were not significant predictors of OVD. Intercanthal and bigonial widths showed a negative association with the dependent variable.

The second model, developed for individuals without preserved intraoral landmarks, retained six predictors and showed a very high predictive value ($R=0.974$; $R^2=0.950$). In this model, sex was the strongest predictor. Slightly lower R^2 values in the second model suggest reduced precision when key intraoral landmarks are absent, although the model still shows strong clinical applicability.

Sex was a significant predictor only in the second regression model, which can be explained by the variables included in each model. In the first model, the nasion–gingival papilla tip distance represents a direct segment of the nasion–menton distance and closely reflects vertical facial proportions. This reduces the need for additional predictors such as sex. In the second model, where such a predictor is not available, this information is lacking. In that case, sex becomes a useful predictor, as it reflects general morphological differences between males and females and helps improve the estimation of the nasion–menton distance.

Compared to the results of simple regression analysis, both multiple regression models showed higher predictive accuracy, confirming that estimation of the nasion–menton distance is more reliable when based on the combined effect of multiple craniofacial parameters.

The lack of similar multivariate approaches in the available literature further highlights the contribution of this study, particularly in the context of developing models suited to different clinical situations. At the same time, this limits the possibility of direct comparison with existing studies.

The findings of this study should be considered in light of certain limitations, including the relatively small and population-specific sample. At the same time, clearly defined inclusion criteria and high measurement reliability support the consistency of the results. A strength of this study is the use of a standardized measurement approach and multivariate analysis, which enabled a more accurate assessment of craniofacial relationships and resulted in models with high predictive value and potential clinical use. However, further studies on larger and more diverse samples, along with external validation, are needed to confirm their wider applicability.

Conclusions

The results of this study suggest that selected facial anthropometric parameters can predict the occlusal vertical dimension with a high degree of accuracy. The developed regression models, particularly those including intraoral landmarks, provide a reliable basis for clinical estimation and highlight the importance of population-specific validation.

Declaration of interest: The authors declare no conflict of interest.

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