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ORIGINAL ARTICLE

COMPREHENSIVE MAXILLARY ANTERIOR TEETH AESTHETICS ANALYSIS WITH DEEP LEARNING IN DENTAL ANTHROPOMETRY

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The height and width of maxillary front teeth, their width-to-height ratio—W/H% (gold standard), their width ratio (gold proportion), smile width, buccal corridor, and marginal gingiva define smile form. The study examined the characteristics of dental students with complete sets of teeth and used deep learning in dental anthropometry. The study involved 88 subjects. The central incisor was measured in the subjects' mouths, while the gold proportion was photometrically established. Clinical examinations assessed smile breadth, buccal corridor visibility, and gingival contour class. The Adaptive Neuro-Fuzzy Inference System (ANFIS) was employed for deep learning analysis because of its ability to model complex, non-linear relationships in high-dimensional data. The average length of the central incisor in men amounted to 10.5 mm, whereas the value in women was 10.2 mm. The central incisor length and W/H% did not differ significantly between men and women. In the majority of subjects, the gold proportion in the width of the front teeth was established and was uniform between men and women. On average, 8 to 10 teeth were visible during smiling in the subjects. There was no significant difference in smile width between men and women. A pronounced buccal corridor was present in half of the subjects, without a statistically significant difference between the sexes. The results showed a much higher prevalence of class 1 gingiva than class 2 gingiva, with no significant gender-related difference. The results of ANFIS analyses, represented by Root Mean Square Error (RMSE) values, showed non-linear relations among anthropometric parameters. The study found similarities between anthropometric measurements obtained from the Serbian subjects and findings previously reported in the literature. Modelling complex dental anthropometric relationships using ANFIS helps improve understanding of interactions among dental parameters.

Keywords: gold standard, smile width, buccal corridor, ANFIS, deep learning

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INTRODUCTION

The teeth and dental arch, as prominent facial features, hold paramount aesthetic value. Thus, even a slight irregularity, discoloration, or tissue loss might disrupt their equilibrium. Since appearance often takes precedence over functionality, many young people see dentists to enhance their smile using less intrusive techniques. Advances in dental technology and materials have reduced constraints on tooth morphology, color, and texture, offering the precision necessary to achieve predictable aesthetic outcomes. Natural-looking teeth are generally perceived as more attractive. Despite media pressure to imitate celebrities and have white, large teeth (the "Hollywood smile"), a preference for more natural aesthetics has returned to routine dental practice (1,2). Therefore, it is crucial to understand the anthropometric proportions of natural teeth to provide a natural and attractive appearance of teeth and gums following conservative or prosthetic restorations (3).

The height and width of maxillary front teeth and their mutual ratio (gold standard), the ratio of their widths (gold proportion), the visibility of teeth—the width of the dental arch and the buccal corridor when smiling—and the condition and position of the marginal gingiva that surrounds them determine the shape of the smile (4,5). There has been no anthropometric research on these measures in a homogeneous Serbian group with a full dental arch.

The gold standard (GS) is the ratio of the width and height (W/H) values of maxillary upper incisors. The most attractive appearance of maxillary anterior teeth is obtained when W/H is 75-85% (6).

It is generally considered that individuals perceived as attractive have facial features in proportion to the mathematical formula of the gold proportion (GP) (7). The gold proportion in the dental arch is the ratio of the width of the maxillary central and lateral incisor and the mesial facet of the canine, where the lateral incisor is visible. If the maxillary lateral incisor width value is 1, the same value of the central incisor and the mesial facet of the canine amount to 1.618 and 0.618, respectively (8).

A smile's breadth is determined by the amount of exposed maxillary teeth, creating a feeling of depth via the buccal corridor or negative lateral space between the premolars and lips.

A triangular area is evident between maxillary canines, premolars, and lip corners when the mouth is slightly open. Frush and Fisher coined the term „buccal corridor" to create a more lifelike dental prosthesis (9). The breadth of the smile, maxillary dental arch, facial muscle tone, and upper premolar buccal surfaces affect the buccal corridor appearance. A "U"-shaped maxillary dental arch is excellent. While a small maxillary dental arch and a broad buccal corridor are generally considered less aesthetically pleasing, narrower buccal corridors enhance smile attractiveness (10,11).

The gingiva is visible when speaking and smiling; thus, smile reconstructions must preserve its curves to create a realistic smile. The gingival zenith is the highest point of the gingiva's exterior shape and is distal to the maxillary central incisors and canines (12). It aligns with the maxillary lateral incisors' longitudinal axes. Class 1 maxillary lateral incisors have a lower horizontal gingival contour (0.5-0.2 mm) than central incisors and canines (13). In class 2, the maxillary lateral incisor has a greater horizontal gingival contour than the central incisor and canine (14,15).

The ANFIS uses neural networks and fuzzy logic to describe complex systems more accurately and flexibly. This technique might improve the modelling of complicated interactions, prediction and optimization, individualized dental care, automation and decision assistance, and treatment quality (16-18). Using the ANFIS in dental data analysis and processing may improve accuracy, treatment customization, and decision-making. The study aimed to conduct anthropometric analysis of the proportions of maxillary anterior teeth, to demonstrate the existence of the gold standard, the gold proportion, and the buccal corridor (lateral negative space), and to investigate the potential applications of deep learning in the field of anthropometric analysis.

METHODS

Subjects

The study was conducted at the Clinic for Dental Medicine in Niš and included 88 subjects. The subjects were dental students at the Faculty of Medicine in Niš. The study included only students with a full set of teeth (with and without third molars). The exclusion criteria were front teeth destruction (caries, trauma, erosion), prosthetic and conservative restorations on front teeth, anomalies in the oral cavity, a history of orthodontic therapy, congenital or surgical facial defects, or pronounced facial asymmetry.

The subjects were familiarized with the study and signed their written informed consent. The study was approved by the Ethics Committee of the Clinic for Dental Medicine (decision No. 14/7-2019-5EO).

The anthropometric analysis of the maxillary front tooth proportions was used to evaluate the gold standard, gold proportion, and buccal corridor (lateral negative space), and to study the possible uses of deep learning in anthropometric analysis.

Anthropometric procedure

Each subject sat on the dental chair with the head supported by the backrest, so that the lower edge of the mandible was parallel to the floor. The dimensions of the maxillary central incisor were measured with a calliper directly in the mouth of the subject. The measured values involved the height and width of the teeth, and the W/H % value was calculated according to the formula:

W/H% = maximal mesiodistal width/maximal incisogingival height (mm) x 100

The subjects were photographed in the centric occlusion position from a distance of 1 meter using a Nikon D5100 (Japan) camera. Image processing was done in LightX and PhotoGrid. To determine the gold proportion of maxillary front teeth, the mesiodistal breadth of central and lateral incisors, canines, and their mesial facets was measured and compared. The measurements were expressed in millimetres.

The number of visible maxillary teeth and the presence of a clearly expressed buccal corridor during a voluntary smile were counted during the clinical examination and on the subject's maxillary dental arch image.

The gingival contour class was determined on the photograph of the subject's maxillary dental arch.

Statistical data processing

Statistical calculations of the entered data were performed using IBM SPSS Statistics 22 (IBM Corporation, Armonk, NY, USA). Standard statistical methods were used for the qualitative and quantitative assessment of the obtained results: absolute numbers, relative numbers (%), arithmetic mean, median (minimum-maximum), and standard deviation. The normality of distribution was tested using the Shapiro-Wilk test. The numerical data did not follow a normal distribution, and the difference between genders was tested using the non-parametric Mann-Whitney *U* test. The Chi-square test was used to assess the statistical significance of differences in absolute frequency among samples.

The statistical hypothesis was tested at a significance level of α = 0.05, with differences between samples considered statistically significant when $p < 0.05$.

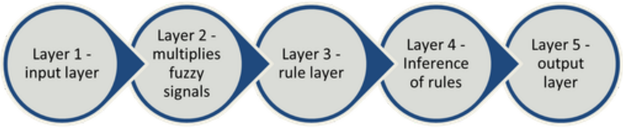

Figure 1. *ANFIS layers*

As shown in Figure 1, the ANFIS network contains five levels. The fuzzy inference system lies at the heart of the ANFIS network. Layer 1 accepts the inputs and uses membership functions to convert them to fuzzy values. The bell-shaped membership function was employed in this study because it has the best capability for non-linear data regression.

The bell-shaped membership function is defined as follows:

$$\mu(x) = bell(x; a_i, b_i, c_i) = \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^2\right]^{b_i}}$$

where (a_1, b_1, c_1) is the parameter set and is the input.

The second layer multiplies the first layer's fuzzy signals and produces the rule's firing strength. The rule layers are the third layer, and they normalize all of the signals from the second layer. The fourth layer performs rule inference and converts all signals to crisp values. The last layers summarize all of the signals and provide a clean output value.

RESULTS

The study included 88 subjects: 32 males (36.4%) and 56 females (63.6%). The mean age of the subjects was 22.14 ± 1.52 years, with the youngest being 20 and the oldest 27. The age structure was uniform, 22 years (20-25) in men and 22 years (20-27) in women (U = 858.0, p = 0.736).

Maxillary central incisor dimensions

The average height of the central incisor in men was 10.5 mm, whereas the same value in women was 10.2 mm. The central incisor height (U = 724.0; p = 0.125) and W/H % (U = 891.0; p = 0.965) were not statistically significantly different between men and women (Table 1).

Table 1. *Dimensions of the maxillary central incisor of the subjects*

Parameter	Men	Women	*p*
Central incisor height (mm)	10.5±1.3, 11.0 (7.0-12.0)	10.2±1.1, 10.0 (8.0-12.1)	0.125
Central incisor width/height W/H%	83.3±8.2, 82.5 (70.0-100.0)	83.6±8.0, 82.0 (68.0-100.0)	0.965

Data are presented as mean±standard deviation, Median (Min-Max), p values were based on Mann-Whitney U test.

The gold proportion of maxillary anterior teeth

The existence of the gold proportion regarding the width of maxillary front teeth was determined in the majority of subjects. The gold proportion was present in 60.2% of men and 65.5% of women, with no statistically significant difference in frequency between genders (χ^2= 0.612, p = 0.434) (Table 2).

Obtained results revealed the existence of the gold proportion in 65.6% of male and in 57.9% of female subjects (Figure 2a).

Smile width

The smile width in men was 10.0 mm (8.0 - 10.0), whereas in women it was smaller, measuring 8.0 mm (6.0 - 12.0). The difference in smile width between genders did not reach statistical significance (U = 702.5; p = 0.061), as shown in Table 3.

Buccal corridor

A pronounced buccal corridor was present in half of the subjects, with a frequency of 53.1% in men and 48.2% in women. There was no statistically significant difference between male and female subjects (χ^2 = 0.196, p = 0.658) (Table 4) (Figure 2b).

Table 2. *Frequency of the gold proportion of maxillary anterior teeth in the subjects*

Gold proportion of maxillary anterior teeth	Total	Gender		p
		Men	Women	
	n = 88	n = 32	n = 56	
No n (%)	35 (39.8)	11 (34.4)	24 (42.9)	0.434
Yes n (%)	53 (60.2)	21 (65.5)	32 (57.1)	

Data are presented as numbers (%), p values were based on Chi-square tests.

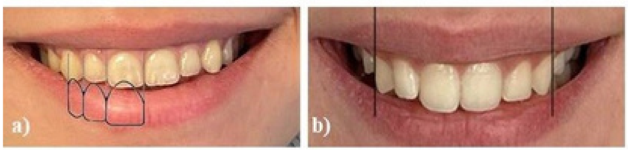

Figure 2. *a) Gold proportion on maxillary front teeth; b) The presence of buccal corridors*

Table 3. *Smile width*

Parameter	Men	Women	p
Smile width (mm)	9.2±1.0, 10.0 (8.0-10.0)	8.7±1.4, 8.0 (6.0-12.0)	0.061

Data are presented as mean±standard deviation, Median (Min-Max), p values were based on Mann-Whitney U- tests.

Table 4. *Presence of a pronounced buccal corridor regarding gender*

Presence of a pronounced buccal corridor	Total	Gender		p
		Men	Women	
	n = 88	n = 32	n = 56	
No n (%)	44 (50.0)	15 (46.9)	29 (51.8)	0.658
Yes n (%)	44 (50.0)	17 (53.1)	27 (48.2)	

Data are presented as numbers (%), p values were based on Chi-square tests.

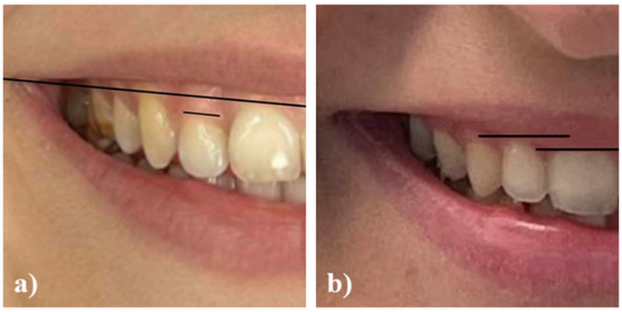

Figure 3. *a) Class 1 gingival contour; b) Class 2 gingival contour*

Table 5. *Gingival contour class—the balance of gingival heights regarding gender*

Gingival contour class	Total	Gender		p
		Men	Women	
	n = 88	n = 32	n = 56	
Class 1 n (%)	69 (78.4)	27 (84.4)	42 (75.0)	0.304
Class 2 n (%)	19 (21.6)	5 (15.6)	14 (25.0)	

Data are presented as number (%), p values were based on Chi-square tests.

Gingival contour class

The results suggest a far more frequent presence of class 1 gingival contours (Figure 3a) compared to class 2 (Figure 3b). There was no significant difference in the position of the gingival zeniths between male (15.6%) and female (25.0%) subjects (χ^2 = 1.057, p = 0.304) (Table 5).

The best predictors for different types of anthropometric parameters were chosen using the ANFIS approach. The selection is crucial, as is the preprocessing of the input parameters to eliminate irrelevant inputs. Following the command in MATLAB Software, the dataset is partitioned into a training set (odd-indexed samples) and a checking set (even-indexed samples):

```
>>[data] = anthropometric;
>>trn_data = data(1:2:end,:);
>>chk_data = data(2:2:end,:);
```

The function “exhsrch” conducts an exhaustive search of the available inputs to identify the set of inputs that have the greatest impact on anthropometric parameters. The function's first parameter defines the number of input combinations to be tested during the selection process. In essence, "exhsrch" creates an ANFIS model for each combination, trains it for one epoch, and then publishes the results. The command line below is used to find the one and two most important attributes in forecasting outputs:

```
>>exhsrch(1,trn_data,chk_data);
>>exhsrch(2,trn_data,chk_data);
```

Figures 4 and 5 show training and checking errors for the optimal one- and two-attribute anthropometric parameters. The minimal checking error occurs at the 55th epoch for both optimal combinations.

Figure 4. *Training and checking errors for optimal one-attribute for anthropometric parameters*

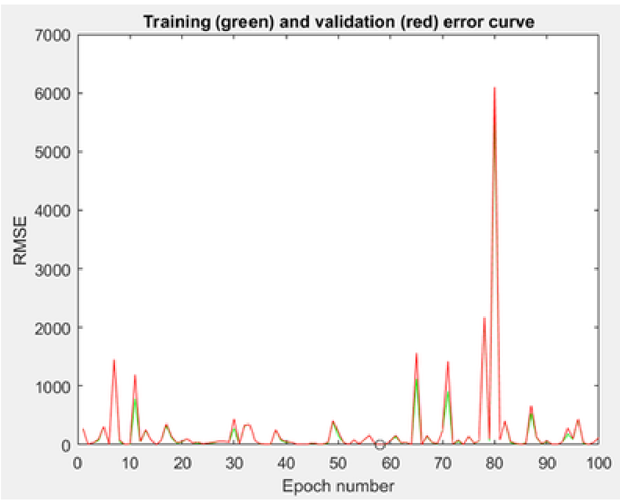

Figure 5. *Training and checking errors for optimal two-attributes for anthropometric parameters*

DISCUSSION

The size and shape of maxillary anterior teeth affect dental and facial aesthetics. The study aimed to analyze maxillary front tooth proportions, verify the existence of the gold standard, gold proportion, and buccal corridor, and identify the smile width and gingival contour class in young Serbian subjects with complete sets of teeth. The central incisor length findings corresponded favourably with those of other authors. Dietschi observed the average length of the upper central incisor anatomical crown to be 10.4 mm in women and 11.2 mm in men (19), whereas Gillen et al. reported values of 9.8 and 10.6 mm, respectively (20,21). Numerous studies have indicated that men generally have larger teeth than women and that ethnicity significantly influences tooth size (22). For instance, the average Saudi central incisor width was 8.74 mm, according to Alqahtani et al. (23). Furthermore, Asians have smaller anterior teeth than Caucasian cohorts (24). In younger patients, approximately 3.5 mm of the incisal section of the maxillary front teeth is visible when the mouth is slightly open, while mandibular teeth are scarcely visible. Maxillary teeth become less apparent with age due to falling upper lip tone and incisal edge abrasion, whereas mandibular teeth become more noticeable (19). Since maxillary front teeth are the cornerstone of an attractive smile, having a harmonic distribution of their form, size, and proportion is crucial. Reconstructing front teeth requires consideration of the tooth width-to-height ratio, as modifying a single dimension would result in inadequate aesthetics (25). The tooth width-to-height ratio varies with gender, ethnicity, and group (26). The maxillary central incisor, the most prominent tooth in the jaws, dominates in form, size, and location. The ratio of its proportions is significant (27). The gold standard for dental crown width is 75–85% of its height (28). Percent values below 60% form a tall, narrow crown, while those over 85% create a short, broad crown. This W/H percentage ratio is more attractive than tooth height or width alone (22,29). The clinical crown should be lengthened if the maxillary central incisor is too short (30). This study found a mean W/H percent of 83% in both sexes, aligning with the GS. These findings matched anthropometric data from a study by Abdallah et al. on various populations (6). Men and women also shared the gold proportion, which matches the results of Abdallah et al. (6). However, the literature does not demonstrate a preponderance of the gold proportion among maxillary front teeth across various groups (31-35). Similar to this study, dental students were tested for the gold proportion. This ratio was not common and men had broader maxillary anterior teeth than women (33,36). Fayyad et al. identified the gold proportion between maxillary central and lateral incisors in 31.3% of men and 27.1% of women (37). Ahmed et al. did not advocate the gold proportion for front tooth repair after reviewing the research (38). The current study found no significant gender difference in smile width. When smiling, the individuals showed 8–10 maxillary teeth. These findings correspond to those of previous authors who found maxillary second premolar exposure in 60% of patients (39-42). The exposed maxillary first premolar was most common (57%) according to Tjan and Miller, whereas 3.7% of participants had first molars visible while smiling (43). Koidou et al. found that celebrities had more visible teeth and a higher proportion than dental students, demonstrating the aesthetic advantages of a broad smile (44). Other authors who studied celebrity smiles found the most common visibility to be 10 teeth, without statistically significant variations between sexes (45-47). Side teeth need cosmetic repairs since they are visible while smiling. A buccal corridor or lateral negative space is vital during smiling. Maxillary premolars are medially situated relative to the vestibular tangent of canines and molars. Without buccal corridors, prosthetic literature describes a smile as denture-like; however, orthodontists remove these "negative" areas with transverse maxillary expansion (48). Wide maxillary dental arches narrow buccal passageways (48). This study found a noticeable buccal corridor in half of the individuals, with no statistically significant difference between men and women. Previous studies demonstrated a more prevalent and noticeable buccal corridor in the smiles of celebrities who are considered attractive (45,46). However, other authors concluded that a broader smile (minimum buccal corridor) was more appealing (49). In the study by Oshagh et al., dental and art students found that men prefer narrower buccal corridors, whereas women prefer wider ones (50).

In this study, Class 1 gingival contours were more common than Class 2 (Figures 3a and 3b). Other authors reported a greater Class 1 frequency (51,52). Humagain et al. found no statistically significant variations in the gingival zenith position between sexes (53). Respecting gingival zeniths and shapes is crucial to effective periodontal surgery, extending clinical tooth crowns, gingivoplasty as a pre-prosthetic treatment for maxillary anterior tooth restoration, and implant location planning (54).

Dental anthropometry includes tooth measurements, gingival curves, and buccal corridor widths. The aesthetics and function of dental structures depend on these intricate interactions. The presented ANFIS model can represent complex interactions using non-linear and high-dimensional data (Figures 4 and 5). Deep learning with the ANFIS may reveal dental anthropometry variable patterns and dependencies (17,18,55).

When reconstructing part of a tooth or multiple teeth in the jaw, the form and ratio of the teeth can be simply replicated by following the surviving teeth. After the loss of all teeth, reconstructing the dental arch and shaping a patient's smile requires additional approaches, such as the anthropometric measurements of values and proportions in individuals with full dentition. A balance between the patient's requests and suitable dental treatment for the patient's face and smile must be made. Smiles are formed using aesthetic factors that have been researched for decades and reflect the best ratio for aesthetic satisfaction. The findings of our study demonstrate that the anthropometric measurements of Serbian individuals align with the conclusions reported in the literature. Modelling complex dental anthropometric connections using the ANFIS enhances understanding of interactions among dental parameters. Dental treatments have become more personalized, precise, and effective, improving results and patient satisfaction.

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Author Contributions

Conceptualization: M.K. and N.S.Đ.; Methodology: M.M.; Software: A.I.; Validation: M.K., M.Đ., and N.G.; Formal analysis: G.J.; Investigation: M.I.; Resources: J.P.S.; Data curation: N.G.; Writing—original draft preparation: M.K.; Writing—review and editing: M.K., M.M., and N.S.Đ.; Visualization: M.I. and M.Đ.; Supervision: G.J.; Project administration: J.P.S. and A.I. All authors have read and approved the published version of the manuscript.

Statement of Ethics

This study protocol was reviewed and approved by the Ethics Committee of the Clinic for Dental Medicine, decision No. 14/7-2019-5EO, issued on 18.01.2022.

Statement of Competing Interest

The authors declare no relevant conflicts of interest.

Statement of Data Availability

All data analyzed during this study are included in this published article and available from the corresponding author in the form of anonymized data upon reasonable request.

Statement of Generative AI Use

No generative AI was used.

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