The Correlation between Anterior Tooth Form and Gender – A 3D Analysis in Humans

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Abstract

This study examined the correlation between maxillary anterior tooth form and gender with three-dimensional data. Three-dimensional digital models of the area between the maxillary right central incisor and the maxillary right canine were obtained from 120 Caucasian subjects (60 males and 60 females) with healthy dentitions. Correlation between gender and tooth form was assessed applying logistic regression, with and without size standardization. Success rates were estimated using 10-fold cross-validation. Principal components that correlated with gender were evaluated with a Wald test. Values for the significance of the predictors were provided with a likelihood ratio test ($P < 0.05$). Significant correlation between gender and tooth shape was found for the maxillary central incisor ($P = 0.003$), lateral incisor ($P \leq 0.001$), and canine individually ($P \leq 0.001$), and for the three teeth combined ($P \leq 0.001$) without size standardization. For the maxillary right lateral incisor ($P = 0.004$), canine ($P \leq 0.001$), and the combination of the teeth ($P \leq 0.001$), a correlation was also established after size standardization. Prediction of gender was not possible without information on tooth size for the maxillary right central incisor ($P = 0.15$). Maxillary anterior teeth have gender-specific differences. Differences in tooth size account for part of the correlation. However, tooth shapes are also gender specific.

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Fig 1 Exemplary photographs of natural dentitions. Note the distinctive differences between the illustrated tooth shapes.

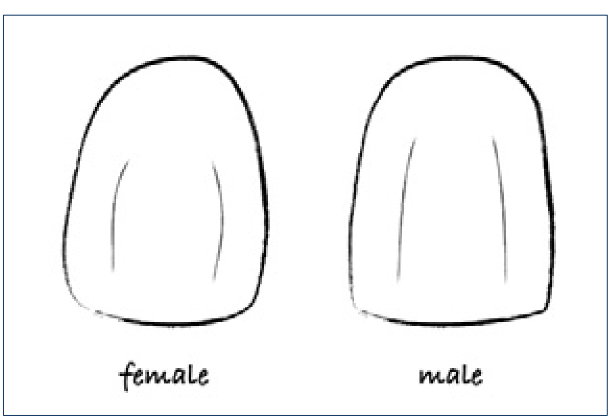

Fig 2 Frush and Fisher proposed that the females have an oval tooth form with round edges, whereas the masculine tooth form is of a cubical shape.[5]

Introduction

The esthetic appearance of the anterior teeth significantly influences a person's self-confidence[1] and how a person is judged by others.[2] Therefore, an esthetically pleasing result is a common aim of all dental treatment.

The attractiveness of a smile is characterized by numerous factors involving both the teeth and the surrounding soft tissues.[3] These factors have to be taken into consideration during tooth restoration. When only parts of the dentition have to be restored, the remaining natural dentition can serve as a guide. However, in cases where the entire dentition has to be restored and no information can be gained from remaining natural teeth, old photographs, or cast models, other methods have to be applied to select and design the missing teeth. One of the most crucial parameters in this context is the shape of the maxillary anterior teeth (Fig 1).

In 1955, Frush and Fisher proposed the "dentogenic theory," stating that the correct tooth form should be selected with regard to the patient's gender, personality, and age.[4] Gender-specific differences in tooth form seem natural, as gender-specific anatomical differences are ubiquitous throughout the human body. According to Frush and Fisher, femininity is characterized by roundness, smoothness, and softness, leading to an oval tooth form with round edges. In contrast, a masculine tooth form should express vigor, boldness, and hardness and, therefore, it should have a cubical shape (Fig 2).[5] Since then, this theory has become part of clinicians' everyday work and is taught in dental schools worldwide.

Scientific studies on the subject, however, have obtained differing results. Berksun et al[6] and Wolfart et al[7] evaluated the correlation between a subject's gender and the form of its maxillary central incisors using intraoral photographs independent of tooth size. Tooth form was classified into the categories tapered, ovoid, and square, as proposed by Williams.[8] No correlation could be established between tooth form and gender. Furthermore, in both studies, clinicians were not able to determine a subject's gender from intraoral photographs. In contrast, studies examining tooth size discovered significantly larger teeth in males than in females.[9-12] Different methods used to analyze tooth form are possible reasons for the differing results. The use of landmark points and shapes for classification and evaluation of three-dimensional objects minimizes the amount of data and simplifies understanding. However, these simplified points and shapes may not be able to reveal the proposed correlation. Furthermore, the evaluation of a three-dimensional (3D) object using two-dimensional (2D) images excludes a substantial amount of information from the analysis.

This study evaluated the correlation between all points of the tooth surface and gender using 3D data and investigated if this correlation is caused by tooth size or shape. It also visualized the tooth form variations that correlate with gender. The hypothesis for this study was that there are gender-specific differences in tooth form.

Materials and methods

Study population and experimental design

This study was conducted after approval by the institutional review board (IRB). Written informed consent was obtained from all subjects. The study population consisted of 120 adult subjects (60 males and 60 females), aged from 19 to 29 years old (mean 24.5 years) who met the inclusion criteria.

Inclusion criteria were: age between 18 and 30 years and Caucasian race. Exclusion criteria included: restorations; aplasia and/or hypoplasia; caries; gingival recession or hyperplasia > 1 mm; erosion; attrition; abrasion or abfraction > 1 mm in the area between the maxillary right first premolar and maxillary left central incisor; current orthodontic treatment; crowding hindering a scan of the complete tooth surface; and other problems that could affect an analysis of tooth shape.

Data collection

Polyvinylsiloxane impressions (Affinis Precious, Coltène Whaledent, Altstätten, Switzerland) of the area between the maxillary left central incisor and the maxillary right first premolar were performed and poured in type IV dental stone (Implantat-rock, Picodent, Wippenfürth, Germany) according to the manufacturer's specifications. Subsequently, 3D scans of the casts were performed (D700, 3shape, Copenhagen, Denmark) resulting in 15,000 to 21,000 data points per scan depending on the size of the cast (Fig 3a).

Fig 3a 3D cast models of the area between the maxillary left central incisor and the maxillary right first premolar were obtained from 120 subjects.

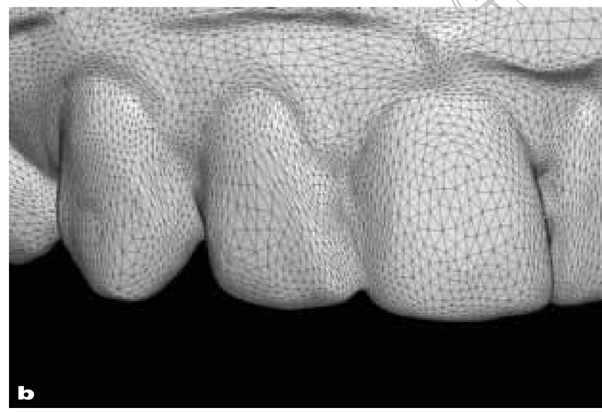

Fig 3b Depending on the size of the cast 15,000 to 2,000 data points per scan were recorded.

Data evaluation

Corresponding points in all examples were identified with a fully automated registration algorithm. One data set was chosen as a reference, and a registration was performed from this reference to all remaining surfaces with a variation of the Thirion's Demons algorithm[13] that was adapted for surface registration. For the statistical analysis, subsets of points limited to the surface of the maxillary right central incisor, the maxillary right lateral incisor, and the maxillary right canine were selected. The examples were standardized in orientation and automatically positioned with regard to their common mean shape with Generalized Procrustes Analysis.[14] For a part of the analysis, the teeth were standardized in size. In order to extract a set of features that best describe the given shape, principal component analysis was performed.[15] The goal of principal component analysis is the establishment of axes in a coordinate system that cover large parts of the variance in the data. The first principal component explains most of the variance, the second is sought to maximize the variance in the remaining directions, and so forth. The first 20 principal components were used to represent the shape during the following analysis. The prediction of the gender from the shape was learned with training shapes with known associated gender-applying logistic regression.[15]

Statistical analysis

Every experiment was once performed with and without size standardization. Analysis was performed for the maxillary right central incisor, the maxillary right lateral incisor, and the maxillary right canine individually, and for the three teeth combined. Success rates and standard deviations were estimated using 10-fold cross-validation. A Wald test was performed to evaluate the principal components that correlate with gender. Values for the significance of the predic-

Table 1 Success rates and standard deviations for the prediction of gender from tooth shape estimated using 10-fold cross-validation. Values for the significance of the predictors were provided with a likelihood ratio test. Every experiment was once performed with and without size standardization.

Tooth	Size	Prediction rate (%)	*P*-value
Maxillary right central incisor	Non-standardized	62 ± 13	0.003
	Standardized	53 ± 16	0.15
Maxillary right lateral incisor	Non-standardized	71 ± 12	≤ 0.001
	Standardized	60 ± 9	0.004
Maxillary right canine	Non-standardized	70 ± 14	≤ 0.001
	Standardized	63 ± 15	≤ 0.001
Combination of the three teeth	Non-standardized	73 ± 11	≤ 0.001
	Standardized	65 ± 9	≤ 0.001

tors were provided with a likelihood ratio test. The level of significance was set at $P < 0.05$.

Results

Without prior standardization of tooth size, prediction of gender from the tooth form of the maxillary right central incisor, the maxillary right lateral incisor, and the maxillary right canine individually, and for the combination of the three teeth were possible at statistically significant levels (prediction rate ± standard deviation; maxillary right central incisor: 0.62 ± 0.13, $P = 0.003$; maxillary right lateral incisor: 0.71 ± 0.12, $P \leq 0.001$; maxillary right canine: 0.70 ± 0.14, $P \leq 0.001$; combination: 0.73 ± 0.11, $P \leq 0.001$). For the maxillary right lateral incisor, the maxillary right lateral canine, and for the combination of the three teeth, significant values were also obtained after standardization of tooth size (maxillary right lateral incisor: 0.60 ± 0.09, $P = 0.004$; maxillary right canine: 0.63 ± 0.15, $P \leq 0.001$; combination: 0.65 ± 0.09, $P \leq 0.001$). For the maxillary right central incisor, however, prediction of gender was not possible without the information of tooth size (maxillary right central incisor: 0.53 ± 0.16, $P = 0.15$). The results are summarized in Table 1. The female, mean, and male shape variations for the standardized teeth are visualized in Figures 4 to 6. The combined effect of the significant principal components is illustrated for the female and male variation. Components were each manipulated to show the variations corresponding to one standard deviation from the mean shape. When compared to the mean shape, the female shape variation of the right maxillary central incisor has a rounded incisal edge and is of a triangular shape. The male shape variation is of a quadrangular shape. On the maxillary right lateral incisor, the female shape variation is of a rectangular shape, whereas the male shape variation has a round shape. The

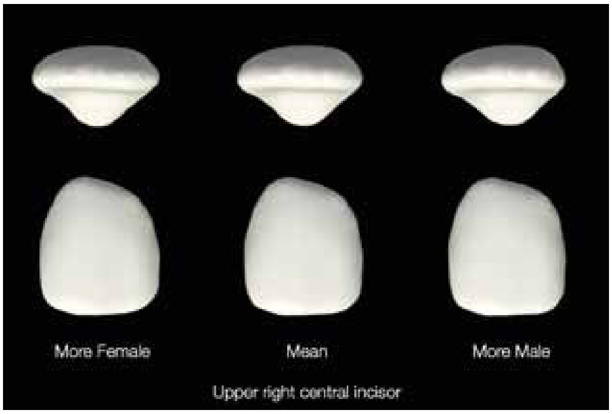

Fig 4 Top view and frontal view of the female, mean and male shape variations for the standardized maxillary right central incisor. The combined effect of the significant principal components is illustrated.

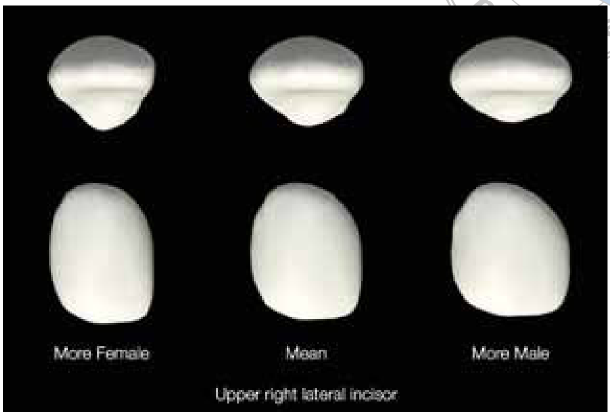

Fig 5 Top view and frontal view of the female, mean and male shape variations for the standardized maxillary right lateral incisor. The combined effect of the significant principal components is illustrated.

female shape variation of the maxillary right canine is of a rounder shape than the male shape variation that also shows a shift of its tip to the distal.

Discussion

The results of this study confirm our hypothesis that there are gender-specific differences in tooth form. Differences in tooth size account for part of the correlation. However, there are also gender-specific differences in tooth shape.

Among the investigated teeth, the highest correlations between tooth surface and gender were obtained for the maxillary right lateral incisor and the maxillary right canine at similar values. Prediction was also possible with the maxillary right central incisor, however, this tooth showed the lowest correlation. The best result was obtained for the combination of the three teeth because of the higher amount of information included in the analysis. These results are in contrast to the results of previous studies on the subject in which no correlation could be established. The reason for this is the way the data has been analyzed. Berksun et al[6] studied intraoral photographs of 60 subjects. No correlation was found after 13 clinicians subjectively classified the tooth shape into the categories tapered, ovoid, and square. More recently, Wolfart et al[7] examined portraits and anterior tooth photographs of 204 subjects. Tooth and face shapes were also classified according to Williams with a standardized protocol. A correlation was found between face shape and gender, but not between tooth shape and gender. However, the characterization of tooth shape using selected landmark points is problematic as it is difficult to find a good set of landmark points that character-

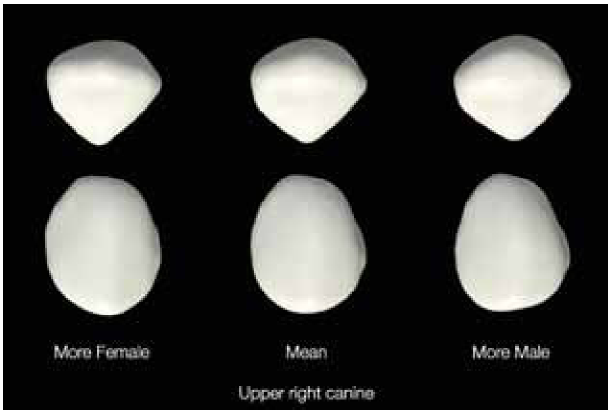

Fig 6 Top view and frontal view of the female, mean and male shape variations for the standardized maxillary right canine. The combined effect of the significant principal components is illustrated.

ize a shape well. There are usually only limited landmark points that can be accurately identified in all the shapes, and it may not be the case that these are the same points that would show the given correlation. This problem is aggravated if a 2D image is used to characterize a 3D shape. Furthermore, the consistent labeling of points in many examples is a laborious and error-prone task, which can itself introduce errors into the analysis. Therefore, in this study 3D scans of the teeth were used for the analysis. The landmarks were not manually selected but obtained with a fully automated registration algorithm. Thereby, all the points of the tooth surface could be included in our analysis. Thus, better use was made from the available information.

Another aspect of previous studies[6,7] was that clinicians were asked to determine a subject's gender based on an intraoral photograph. In accordance with the other findings of the studies, the clinicians were not able to correctly predict the gender. However, these results are only of a descriptive nature, as it is known that due to their professional background, clinicians assess tooth shapes with regard to gender differently than lay people.[16] Therefore, such analysis was not performed in this study.

Tooth size is known to correlate with gender.[9-12] To evaluate the correlation between gender and variations in tooth shape, standardization of tooth size was performed. Thereby, the influence of tooth size on the correlation was eliminated. Prediction of gender was still possible for the maxillary right lateral incisor (60 ± 9%), the maxillary right canine (63 ± 15%) and for the combination of the three teeth (65 ± 9%), however, at a level approximately 10% lower than without size standardization. These results confirm the correlation between tooth size and gender. However, there are also shape variations that correlate with gender independent of tooth size.

With principal component analysis, large percentages of the total variance can be captured with only a few components that describe large parts of the variance.[15] Therefore, the amount of data that had to be examined could be reduced. In this study, the first 20 principal components were used for the analysis, covering approximately 60% of the total variance. Components with smaller variance usually describe only small changes in shape that do not substantially change appearance. This was confirmed in the present study by visual inspection. Furthermore, 20 components gave a good compromise between variance and the number of degrees of freedom with regard to the size of the study population. However, it cannot be ruled out that discarded components do correlate with gender. The principal components, together with the features of tooth shape that correlate with gender, were identified with a Wald test (Figs 4–6). A description of the changes in tooth shape associated with a principal component using words, however, is only an approximation. The reason for this is that the principal components were mathematically calculated and not based on linguistic descriptions or measurements. Every principal component comprises a pool of features, which in turn may or may not be described with adjectives. Figures 4 to 6 illustrate the combined effect of the significant principle components for the female and male shape variation. Each component was manipulated to show the variations corresponding to one standard deviation from the mean shape. Thus, the illustrations do not represent true teeth, but are the result of a computing process. The value of one standard deviation was chosen as it represents a good compromise between the shape variations and naturally looking teeth. Higher values reveal greater differences. However, the computed teeth do not have the shape of natural teeth. Therefore, a quantitative assessment of the differences between the female and male shape variation is not useful. However, further research is necessary to investigate the shape variations associated with the single principle components, and describing these variations.

The maxillary right central incisor showed the lowest correlation of all investigated teeth and gender prediction was only possible without size standardization. This explains why no correlation was established in studies that focused on this tooth alone.[6,7] Furthermore, Wolfart et al[7] rated tooth shape using length / width ratios, thus removing the information of tooth size. Likewise, in this combination, no correlation could be established in our study.

The described variations in tooth shape are important for clinicians and dental laboratory technicians as guidelines for the selection and application of appropriate tooth forms for anterior dental restorations, increasing the predictability and success of clinical treatment. Furthermore, the results are fundamental in the virtual design process of restorations with modern computer-aided design/computer-assisted manufacture systems.

Conclusions

Maxillary anterior teeth have gender-specific differences. Differences in tooth size account for part of the correlation. However, tooth shapes are also gender specific.

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