Journal of Oral Rehabilitation 2004 **31**; 972–978

Morphometric relationships between tooth and face shapes

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SUMMARY **The shape of a patient's face is commonly used as a reference to select the shape of the maxillary central incisors in edentulous patients. The validity of this relationship has not been proved. The objective of this clinical study was to determine whether a relationship exists between maxillary central incisors and face shapes. Casts were made of the maxillas of 50 men and 50 women. A standardized digital photographic procedure was used to record frontal views of each subject's face and of the maxillary central incisors of the dental casts. The shapes of the maxillary central incisors were compared with the face forms. Shape matches were evaluated according to their Hausdorff distance (HDD). The function *h*(A,B) is called the directed HDD from shape A to shape B (this function is not a true distance). It reflects the distance of the point of shape A that is farthest from any point of shape B and vice versa. The similarity of both shapes is given as a non-negative number. The value 0·0 indicates that the figures are identical (after scaling and shifting). Higher values indicate that shapes differ more substantially. Significant differences on the 5% level were calculated using the non-parametric Mann–Whitney *U* and Kruskal–Wallis tests. The face shape from the chin margin to the eyebrow line (superior edges of the eyebrows) produced a better match than the one from the chin to the hairline ($P < 0{\cdot}0001$). On average, the maxillary central incisors displayed a variability (0·084 ± 0·028) that was higher by a factor of 1·9 than the face shapes (chin margin to the eyebrow line, 0·045 ± 0·015). In the interindividual comparison, the shapes of the maxillary central incisors of women displayed a significantly smaller HDD than the ones of the men ($P < 0{\cdot}0001$).**

KEYWORDS: **tooth and face shapes, maxillary central incisors, Hausdorff distance**

Accepted for publication 8 December 2003

Introduction

Reconstruction of anterior teeth can be a challenge in dental prosthetics. By the end of the 19th century attempts had been made to find individual features in the patient that might provide clues to the shape of the maxillary anterior teeth. In 1911, specific relationships between face and tooth form were described and a classification of maxillary central incisor shapes was stated (1), followed by various studies, which tried to find other correlations (2–5). Metric correlations between the nose width and the width of the lateral and central incisors were postulated (6), and it was proved that the distance between the maxillary canines (intercanine distance) was similar to the width of the nose (7). The width of the maxillary central incisors was found to be similar to the bizygomatical distance divided by 16 (8) and it was stated that maxillary incisors of women were smaller than those of men (9).

Several attempts have been made to describe a relationship between the shape of maxillary incisors and the face form. Only a limited number of studies on this subject have been published over the past 20 years (10–15). Some studies postulated that the face form was helpful to select the tooth form (16, 17), whereas others did not find shape relationships between face and tooth shape (5, 18). When the outline forms of both maxillary central incisors were compared with face forms in 70 patients (18), it was found, that more than two-thirds of the patients showed no similarity between face form and incisor tooth form. To date, comparing face shape to the inverted tooth form (square, tapered or ovoid) based on Williams's classification is currently advised (19, 20). In daily dental routine, shape cards are normally used to select a specific set of teeth (17, 20). The arrangement of shapes is frequently based on a classification of three to four types (1, 2, 19).

The objective of this clinical study was to compare tooth and face form based on the hypothesis that a relationship exists between maxillary anterior teeth and face shape.

Materials and methods

Fifty men (age range: 18–74 years, mean: 45·8 ± 17·7 years) and 50 women (19–79 years, 43·2 ± 16·8 years) from a private dental practice (Steinheim, Germany) were selected for the study. Only patients who still had a complete dentition in the maxilla and mandible, without any enamel dysplasia and crown reconstructions, veneers, etc., and whose tooth widths had not been changed by stripping or similar methods were selected. In addition, patients with little or no incisal wear were included. Only patients with hairlines that could be seen in the frontal projection were selected.

Determination of facial shape

After palpation, the mental protuberances were marked with a water-soluble pen on the skin of each patient (Fig. 1a). The patients wore a hairband so that the hairline and the forehead could be seen. The distance between the markings was measured with a calliper and a slide gauge.* A frontal photograph of each patient was taken using a digital camera (DKC ID-1).†

Determination of the tooth shape

The tooth shapes should be regarded as two-dimensional, orthogonal projections (Fig. 2a,b) (13). Irreversible hydrocolloid impressions‡ of the maxillary anterior teeth were made using partial impression trays (RimLock®).§ These impressions were used to fabricate the corresponding plaster casts (Moldano®).¶ For enhanced contrast, a circular marking around each anterior tooth was prepared with a lead pencil (Fig. 2a).

The casts were then measured and photographed. To obtain an orthogonal projection type, each tooth was photographed individually with the digital camera (DKC ID-1).†

For digital surveying of the face and tooth photographs, the images were transferred to a Macintosh PowerBook** via a flash card†† or via the onboard Small Computer Systems Interface (SCSI) controller to a Power Macintosh 7600/120,** so that they could be measured and edited (Figs 1c,d and 2b). For this purpose, the freeware software program NIH Image V.1.59‡‡ were used. The distance between the mental protuberances was used to calibrate the digital frontal picture (Fig. 1b). The data from the *in vivo* measurement were supplied for the distance between the mental protuberances on the digital image.

Editing was carried out using the following steps. First, the picture was converted into grey scale (Figs 1a and 2a). Secondly, the projection type was selected manually – with use of the lasso function of a graphics program (Figs 1a,b and 2b). Thirdly, all non-relevant data were deleted and the contour shape was generated as a black and white bitmap file (Figs 1c,d and 2c) and then converted to a vector graphic.

The face forms were determined from the hairline to the chin margin (group hairline/chin: HC; Fig. 1a) as well as from the eyebrow line (superior edges of the eyebrows) to the chin margin (group eyebrow line/chin: EC; Fig. 1b).

Mathematical basis of the comparison algorithm

The similarity of contour shapes was determined using the Hausdorff distance (HDD) method (21–23). The HDD measures the degree of mismatch between two shapes A and B. Before determining HDD, scaling and shifting of shape B are applied to adapt shape B to shape A for maximum matching. The function $h(A,B)$ is called the directed HDD from shape A to shape B (this function is not a true distance and has no SI unit). It

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¶Heraeus Kulzer, Dormagen, Germany.
**Apple, Cupertino, CA, USA.
††SanDisk, Sunnyvale, CA, USA.
‡‡National Institutes of Health, Bethesda, MD, USA.

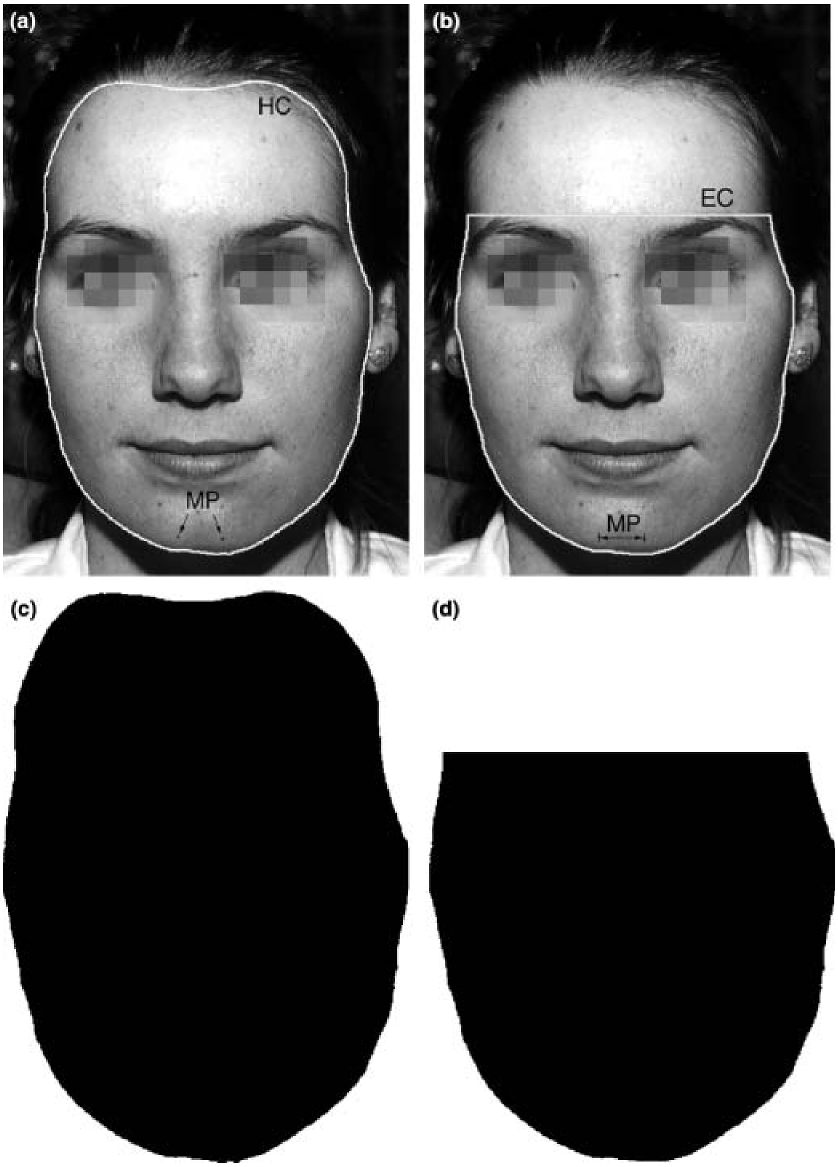

Fig. 1. The orthogonal projection of the patient's face was selected manually with use of the lasso function of a graphics programme. The face forms were determined from the hairline to the chin margin (a: group hairline/chin: HC) as well as from the eyebrow line (superior edges of the eyebrows) to the chin margin (b: group eyebrow line/chin: EC). The distance between the mental protuberances (MP) was used to calibrate the digital frontal picture (a, b). The contour shapes of the patient's face were generated as a black and white bitmap file (c: group HC; d: group EC).

reflects the distance of the point of shape A that is farthest from any point of shape B and vice versa (Fig. 3). Details of the mathematical basis of the HDD can be reviewed in several studies (21–23). As there are no efficient algorithms known to compute this measure exactly, an approximation algorithm is used (22). The similarity (HDD) of both shapes is given as a non-negative number (no SI unit). The value 0·0 indicates that the figures are identical (after scaling and shifting), whereas higher values indicate that the shapes differ more substantially.

The comparisons of the shapes (Computational Geometry Algorithms Library) (24) were carried out using the operating system Linux.

To determine the best facial shape fit to the silhouette of the maxillary central incisors (Fig. 3), the HDDs of each maxillary central incisor in all 100 patients were measured using the different facial shapes (HC, EC) and the average HDD of the maxillary central incisors of each patient was calculated.

In order to examine the hypothesis of a three- or four-class pattern of the tooth and facial forms, the distribution of the HDD values in the interindividual comparisons of tooth and face shapes were analysed.

For verification of the statement that men and women tooth shapes are different, tooth shapes of maxillary left and right central incisors were compared within two groups of 50 men and women each.

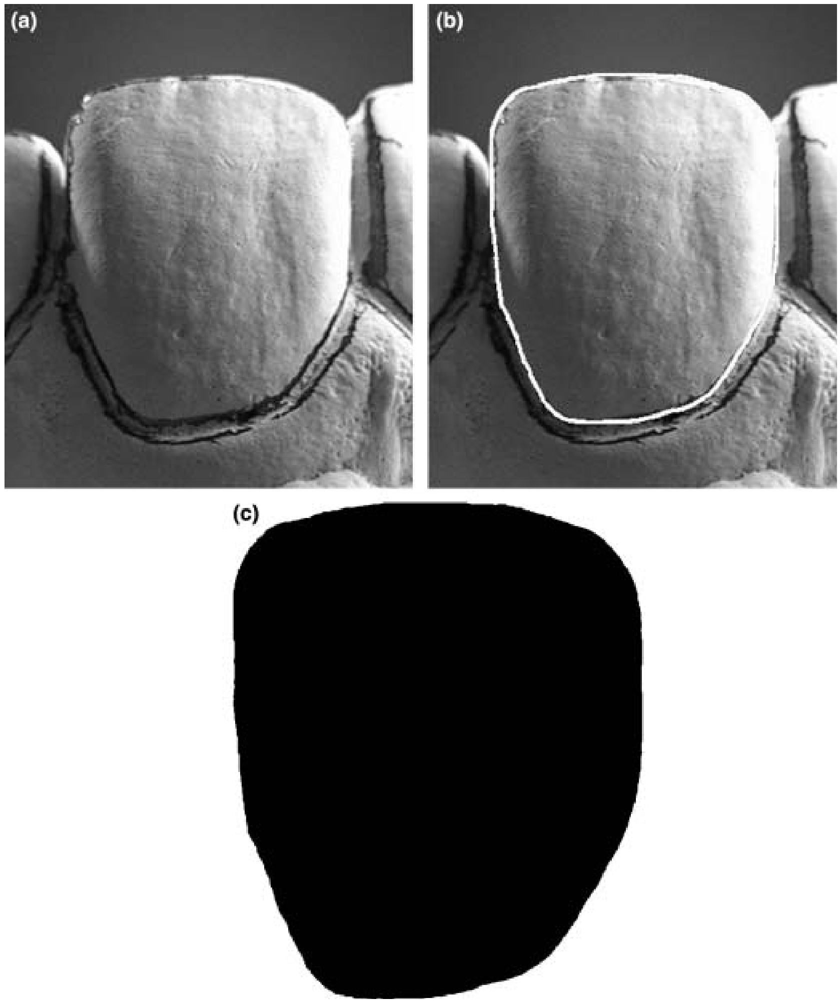

Fig. 2. For enhanced contrast, a circular marking around the maxillary central incisor was prepared with a lead pencil (a). The orthogonal projection of the tooth was selected manually with use of the lasso function of a graphics programme (b). The contour shape of each anterior tooth was generated as a black and white bitmap file (c).

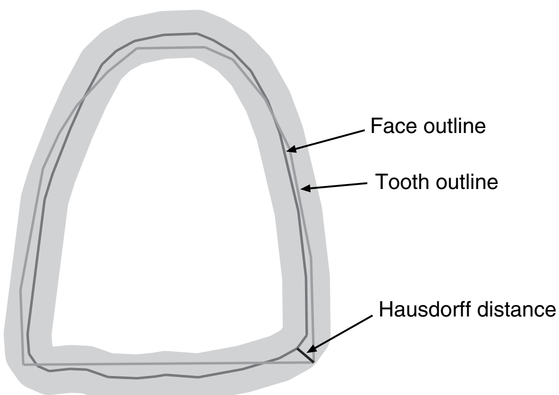

Fig. 3. The similarity of contour shapes was determined using the Hausdorff distance (HDD). It identifies the point that is farthest from any point of B, and measures the distance from B to its nearest neighbour in B. Illustration of the HDD between the face and the tooth outlines.

Another point of interest was to investigate the theory that men's teeth have a larger volume than those of women (9). As the tooth shapes were analysed using two-dimensional projections, no direct information on the volume of the teeth could be drawn from the images, so the area of the tooth silhouette was used as a criterion of evidence. The area of each maxillary central incisor was determined by calculating the percentage of the black content of the tooth shape projections.

Significant differences on the 5% level were calculated using the non parametric Mann–Whitney *U* and Kruskal–Wallis (maxillary central incisor versus face shape) tests.

Results

Table 1 shows the results of the HDDs of intra- and interindividual comparisons. The study revealed that

Table 1. Hausdorff distances of intra- and interindividual comparisons

	Mean	Standard deviation
Comparisons of the maxillary central incisors		
Left/right	0·065	0·023
Interindividual	0·084	0·028
Men	0·085	0·025
Women	0·081	0·024
Comparisons of maxillary central incisor and face shapes		
Eyebrow line/chin margin*	0·075	0·030
Eyebrow line/chin margin†	0·084	0·022
Hairline/chin margin	0·108	0·027
Men (eyebrow line/chin margin)*	0·080	0·033
Women (eyebrow line/chin margin)*	0·071	0·028

*Without consideration of the incisal edge.
†With consideration of the incisal edge.

the tooth shapes of maxillary left and right central incisors of each patient are more similar than the tooth shapes of the respective maxillary incisors of different patients, i.e. the HDD is smaller ($P < 0{\cdot}0001$). However, maxillary left and right central incisors are not completely identical.

The comparisons of the tooth shapes with different face shapes are displayed in Table 1. The face shapes of the EC group produced a better match than the one of the HC group ($P < 0{\cdot}0001$).

On average, the maxillary central incisors displayed a variability (0·084 ± 0·028) that was higher by a factor of 1·9 than the face shapes (group EC, 0·045 ± 0·015). From the values calculated for each tooth pair no relationship can be deduced.

The HDD distributions of the maxillary central incisors and the face shapes (EC) are shown in histograms (Figs 4 and 5). The curves revealed a slightly shifted Gaussian distribution in relation to the values of their arithmetical mean and standard deviations.

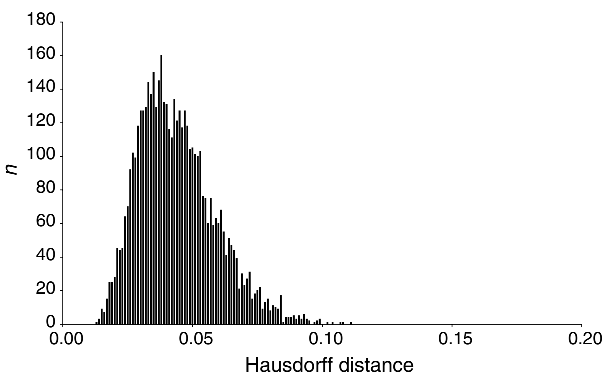

Fig. 4. Distribution of the Hausdorff distances of the face shapes (eyebrow line/chin margin) in interindividual comparisons.

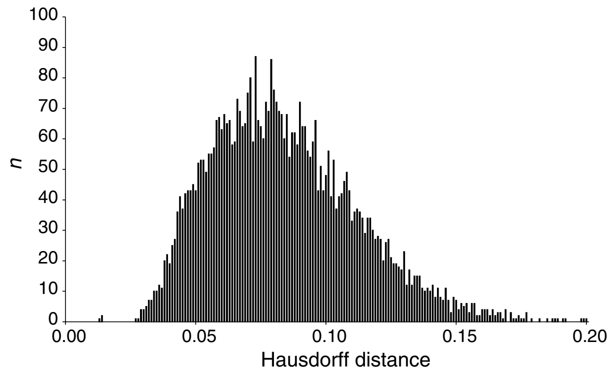

Fig. 5. Distribution of the Hausdorff distances of the maxillary central incisors in interindividual comparisons.

The values for the average HDD and the standard deviation are included in Table 1. In the interindividual comparison, the shapes of the maxillary central incisors of women displayed a significantly smaller HDD than the men's ($P < 0{\cdot}0001$). Women's tooth shapes of maxillary central incisors exhibited a smaller variation range than those of men. HDDs of the maxillary central incisors without consideration of the incisal edge

Table 2. Height and width of maxillary central incisors of men and women

	Height (cm)		Width (cm)	
	Mean	Standard deviation	Mean	Standard deviation
Men	1·09	0·14	0·91	0·06
Women	1·04	0·11	0·89	0·08

compared with face shapes (EC) revealed significant, sex-specific differences (Table 1, $P = 0{\cdot}038$).

The height of maxillary central incisors displayed significant sex-specific differences ($P = 0{\cdot}023$, Table 2). The maxillary central incisors of men are longer. The average deviation in height is *c.* 5%. There were no significant differences between the width of maxillary central incisors of men or women ($P = 0{\cdot}088$, Table 2).

Discussion

Fifty men and 50 women older than 18 years were examined. The two gender-based groups, however, did not include subjects with extremely worn maxillary anterior teeth, as they occur as a result of parafunction. The methods used for calibration and acquisition of specific data were examined in various pre-studies and revealed only minor deviations of 1%.

Precise areas were obtained by the bitmap graphics of the orthogonal projections of the maxillary anterior teeth and the face shapes. Furthermore, using the method of determination of the smallest-directed HDD (22), a non-negative number was obtained to describe the relationship between all shapes. The reliability of the method was confirmed for the shape matching of binary images (21) as well as for the automatic face recognition of an HDD-based measure (23).

This study revealed, that a classification into three or four types could not be made in relation to the orthoradial contour shapes of maxillary left and right central incisors and of the faces. A classification into three types was first postulated by Williams (1, 2). Other authors (3, 4) confirmed Williams's classification; the theory of shapes was even extended to four types of shape (19). In the present study, a slightly shifted Gaussian distribution of the HDD values of the maxillary central incisors and the face shapes was obtained (Figs 4 and 5). The type theory (1, 2, 16) can be refused, because shape comparisons of the same type should provide better matches and thus smaller HDDs. This should become obvious throughout the accumulation of values in various peaks not in a Gaussian distribution. Thus, further adherence to this theory would not be useful.

The silhouettes of the faces below the eyebrow level exhibited a correlation with those of the maxillary central incisors. In this respect, the results that were found correspond with those of Williams (1, 2) and other authors (3, 16, 19). In the orthogonal projection, the shape of the maxillary central incisors revealed a variation that is twice as high as the one of the lower half of the faces, but the face contour below the eyebrows can limit the variation of shapes for the cervical contour of the maxillary central incisors and thus provide information on the tooth shape.

It is conceivable that manufacturers could offer shape cards in the form of software. The shape of the artificial teeth offered would be stored in the program. A systematic comparison of the lower face contour with artificial tooth shapes would provide corresponding HDD numbers. The tooth shape with the lowest HDD would be selected.

For long-term patient treatment, it would be useful to save digital photographs of casts of the maxillary anterior teeth in the dental practice software. In case of loss of the anteriors, the graphics could be evaluated and – using software shape cards – the shapes that offered the best match could be selected. This procedure would offer the highest precision of reproduction and could be helpful in particular for reconstruction work in patient's with trauma in the anterior maxillary region or rapidly progressing juvenile periodontitis.

Based on a mathematical approach on shape matching, the results of the present study can be helpful for selecting the tooth form for edentulous patients. This study refuted the three to four type theory, revealed that the face contour below the eyebrows can provide information on the tooth shape and showed sex-specific differences in the height of maxillary central incisors.

Conclusions

Within the limitations of this study, the following conclusions were drawn:

1 Neither maxillary central incisor nor face shapes could be classified in a three- or four-class pattern.

2 The height of maxillary central incisors displayed significant sex-specific differences. The maxillary central incisors of men were longer. There were no significant differences between the width of maxillary central incisors of men or women. Women's tooth shapes of maxillary central incisors exhibited a smaller variation range than those of men.

3 Maxillary central incisors displayed a variability that was higher by a factor of 1·9 than the face shapes (chin margin to the eyebrow line). Maxillary central incisors produced a better match with the face shape from the chin margin to the eyebrow line than from the chin to the hairline.

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