# Three-dimensional comparison of facial morphology in white populations in Budapest, Hungary, and Houston, Texas

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Introduction: The aim of this study was to assess the use of 3-dimensional facial averages in determining facial morphologic differences in 2 white population groups. Methods: Three-dimensional images were obtained in a reproducible and controlled environment from a commercially available stereo-photogrammetric camera capture system. The 3dMDface system (3dMD, Atlanta, Ga) photographed 200 subjects from 2 population groups (Budapest, Hungary, and Houston, Tex); each group included 50 men and 50 women, aged 18 to 30 years. Each face was obtained as a facial mesh and orientated along a triangulated axis. All faces were overlaid, one on top of the other, and a complex mathematical algorithm was used until an average composite face of 1 man and 1 woman was obtained for each subgroup (Hungarian men, Hungarian women, Texas men, and Texas women). These average facial composites were superimposed (men and women) based on a previously validated superimposition method, and the facial differences were quantified. Results: Distinct facial differences were observed between the population groups. These differences could be seen in the nasal, malar, lips, and lower facial regions. In general, the mean facial differences were 0.55  $\pm$  0.60 mm between the Hungarian and Texas women, and 0.44  $\pm$  0.42 mm between the Hungarian and Texas men. The ranges of differences were -2.02 to 3.77 and -2.05 to 1.94 mm for the female and male pairings, respectively. Conclusions: Three-dimensional facial averages representing the facial soft-tissue morphology of adults can be used to assess diagnostic and treatment regimens for patients by population. Each population is different with respect to their soft-tissue structures, and traditional soft-tissue normative data (eg, white norms) should be altered and used for specific groups. (Am J Orthod Dentofacial Orthop 2010;137:424-32)

Three dimensional (3D) imaging in orthodontics is an exciting development that has evolved greatly in the last 2 decades and will provide many useful applications in this specialty in the future.<sup>1-3</sup> Study models have been the only 3D records routinely used by orthodontists; they have allowed clinicians to examine malocclusions from many viewpoints. These models have proven to be excellent diagnostic tools, but their disadvantages are that they not only

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Submitted, August 2008; revised and accepted, December 2008. 0889-5406/\$36.00

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take time for pouring and trimming, but also require storage space in the orthodontic office. When planning treatment for patients, the orthodontist must consider not only the models of the teeth but also what the planned treatment will do to the facial soft tissues. Because the soft tissues of the face largely determine the limitations of orthodontic treatment from the perspectives of function, stability, and esthetics, the orthodontist must plan treatment within the patient's limits of soft-tissue adaptation and contours.<sup>4</sup> Orthodontists use radiographs in addition to clinical photos to evaluate the patient's hard tissues, but this modality has only 2 dimensions. Current methods of evaluation include facial photographs, which are inadequate because of distortions in perspective, magnification, and patient positioning. This mode of evaluation does not provide a true 3D representation. With developments in technology, many clinicians have shifted toward digital computer-based records for quicker results, easier organization, the ability to enlarge and enhance images, and the ease of sharing this information with patients and colleagues.

Three-dimensional images of the facial soft tissues can help provide the clinician this same information with a more accurate representation of facial



**Fig 1.** Sample pictures taken with the 3dMDface system, illustrated by using the 3dMDpatient software platform. Three views are shown, but an image can be rotated 360° around any axis, providing any viewpoint desired.

morphologies<sup>5-7</sup> and can be useful to better understand, compare,  $^{3,8}$  and predict outcomes before and after treatment.  $^{9-11}$ 

Some applications of 3D imaging in orthodontics include before and after orthodontic assessment of dentoskeletal relationships and facial esthetics, auditing orthodontic outcomes with regard to soft and hard tissues, 3D treatment planning, and 3D soft- and hard-tissue predictions. Three dimensionally fabricated custom archwires, archiving 3D facial, skeletal, and dental records for in-treatment planning, research, and other medico-legal purposes are some other benefits of using 3D models in orthodontics.<sup>12</sup>

To date, little has been done to include the use of 3D imaging tools in the analysis of facial morphologies of various populations. This study was intended to establish and compare the facial morphologic differences between white subjects from different areas of the world by using 3D imaging.

### MATERIAL AND METHODS

Subjects were drawn from 2 sites: the dental school in Budapest, Hungary, and the University of Texas Health Science Center, Dental Branch, Houston. All subjects were dental students invited to participate in the study if they met the following inclusion criteria: white descent, between the ages of 18 and 30 years, no adverse skeletal deviations, normal body mass index values, and no gross craniofacial anomalies.

The sample size was determined from the parameters of the growth of the nose, which is normally unaffected by orthodontic treatment and is the parameter with the greatest variance. With the likely change of 3 mm overall during the growth period and a standard deviation of 2.8 mm, a power of 0.85 with significance of 0.05 would require a sample size of 35 in each group.

Ethical approval and informed consent for this study were given by the institutional review board of the



**Fig 2.** Sample of a completed facial shell after processing with the RF6 software.

University of Texas Health Science Center at Houston and the participants.

The imaging system we used was the portable 3dMDface system (3dMD, Atlanta, Ga), a structured light system combining stereophotogrammetry and the structured light technique.9 This system uses a multicamera configuration, with 3 cameras on each side (1 color, 2 infrared) that capture photo-realistic quality pictures. A random light pattern is projected onto a subject, and an image is captured with multiple synchronized digital cameras set at various angles in an optimum configuration. This system can capture full facial images from ear to ear and under the chin in 1.5 ms at the highest resolution. The manufacturer's accuracy is less than 0.5 mm, and the quoted clinical accuracy is 1.5% of the total observed variance.<sup>13</sup> Three-dimensional images captured by surface acquisition systems are highly repeatable, and 3D landmark data can be acquired with a high degree of precision.<sup>2,14</sup>

Images from the 3dMDface system were viewed on a dedicated computer by using the 3dMDpatient software platform (Fig 1).

Natural head posture was adopted for all subjects because it is clinically reproducible.<sup>15</sup> The subjects sat on an adjustable chair and were asked to look into a mirror with horizontal and vertical lines marked on it. They were asked to level their eyes to the horizontal line and align the midline of their face with the vertical line. Adjustments to the seating height were made to assist the subjects in achieving natural head posture. The subjects were asked to swallow hard and to keep their jaws relaxed just before the images were taken. Each image acquisition took 1.5 ms.

Images taken by the 3dMDface system were converted to OBJ files (also known as Wavefront object files, a geometry definition file format first developed by Wavefront Technologies, Ellicott City, Md) by using the proprietary software and then imported into a reversemodeling software program (Rapidform 2006, INUS Technology, Seoul, Korea) (RF6) for analysis. This software provided 9 different 3D work activities, including 3D scan data processing; polygon cleaning, editing, and optimization; rapid prototyping work preparation; curve modeling and editing; polygon to nonuniform rationale B-spline (NURBS) conversion, modeling, and editing; freeform inspection and geometric dimensioning and tolerance; and customized application development in VB, VBA, C++, and JAVA.

Together, these functions allowed high-quality polygon meshes, accurate freeform NURBS surfaces and geometrically perfect solid models to be created. RF6 generated data as absolute mean shell deviations, standard deviations of errors during shell-to-shell overlaps, maximum and minimum range maps, histogram plots, and color maps.

The initial OBJ files imported into RF6 had a semirough image texture because of the irregularity of the surface contours and the way in which light was reflected off the surfaces of different objects. Further data processing was carried out by a custom-built software subroutine to obtain a workable image that preserved shape, surface, and volume.<sup>16</sup> The images were checked individually, and unwanted areas that could not be automatically removed were done manually by dividing the unwanted areas from the main shell before the next stage. Surface meshes with "defects" or "holes" were filled in automatically by RF6. Finally, 1 composite whole face per subject was generated (Fig 2).

Average faces were constructed to represent the average, and their variations were based on the facial morphology of 2 white populations. The average facial constructs were carried out by using a previously validated software subroutine created from tools available in RF6.The steps required to produce an average face were reported previously and are summarized as follows.<sup>17</sup>

- 1. Prealignment of images by determining the principal axes of rotation, based on computing the tensor of inertia of each 3D image.
- 2. Manual positioning, when necessary, to improve the previous stage.
- 3. Best fit alignment by using the built-in algorithm in RF6.
- 4. Averaging the z coordinates of the images based on normal images to a facial template.
- 5. Point cloud triangulated to obtain an average face.
- 6. The average face improved by filling in small holes and removing possible mesh defects.
- 7. Color texture applied.
- 8. Shells with 1 positive and 1 negative SD created.

The 4 average facial shells—Houston female (HOU-F), Houston male (HOU-M), Hungarian female (HUN-F), and Hungarian male (HUN-M)—were superimposed by using a specialized superimposition technique to compare morphologic differences.<sup>18</sup> This systematic process involved manually aligning 5 points of the facial scans (2 points on the inner canthus of the eyes, 2 points on the outer commissure of the lips, and 1 point on the nasal tip) and subsequently by fine registration, with RF6 determining the best fit of the 2 scans.

The following paired groupings were analyzed in this order: HOU-F vs HOU-M, HUN-F vs HUN-M, HUN-F vs HOU-M, HOU-F vs HUN-M, HUN-F vs HOU-F, and HUN-M vs HOU-M.

The parameters used in this study were linear measurements, color histograms, and surface areas and shapes.

Linear measurements representing the mean differences between 2 surface shells were recorded in millimeters. This value represents the sum total of all differences recorded between overlapping surfaces of 2 shells, and the value could be used as an indicator of the best fit between 2 shells. Furthermore, it could also show the changes in surface fit or regions of changes on the full faces.

Color deviation maps, as previously mentioned, were produced by using the software tool RF6 Plus Pack 2. The color maps indicated the areas of change between the average facial shells. In this study, blue areas showed negative changes, and red areas showed positive changes (Fig 3).

Surface areas and shapes were automatically generated by RF6. These shapes were obtained when a previous tolerance of 0.425 mm was applied to the paired



**Fig 3.** The 4 pictures on the *left* were subjects from each subgroup taken with the 3dMDface system. Clockwise (starting from the upper left), the 4 pictures represent examples of HOU-F, HUN-F, HUN-M, and HOU-M subjects. The *right side* represents signed color histograms, comparing the differences between these women (*upper right*) and men (*lower right*). *Red* signifies a positive difference between the facial shells, and *blue* signifies a negative difference between the facial shells. The linear measurements, in millimeters, between the facial shells can be extrapolated from the adjacent scale.

 Table I. Absolute linear measurements indicating differences between facial shells

	Average distance (mm)	SD (mm)
HOU-F vs HOU-M	1.54	1.47
HUN-F vs HUN-M	1.33	1.40
HUN-F vs HOU-M	2.01	1.69
HOU-F vs HUN-M	2.57	1.80
HUN-F vs HOU-F	0.55	0.60
HUN-M vs HOU-M	0.44	0.42

surface shells studied. The areas that corresponded to 0.425 mm were deemed to be similar surfaces, whereas surface areas above this tolerance showed as surface shapes and color deviations.

## RESULTS

A sample of 217 subjects was acquired. Seventeen scans were excluded because they did not meet the inclusion criteria or had poor image quality. In total, 100 subjects (50 women, 50 men) from each group were obtained, making the final sample 200 subjects.

The mean ages were 23.5 years for the Texas group and 22.7 years for the Hungarian group.

The surface shells for each average subgroup were superimposed by using a previously denoted superimposition technique.<sup>14</sup> These results are as follows.

Table II.	Signed	color m	ap meas	surements	indicatin	g dif-
ferences	s in faci	ial shells				

	Average distance (mm)	SD (mm)	Similarity (%)
HOU-F vs HOU-M	0.23	2.12	23.77
HUN-F vs HUN-M	0.02	1.92	20.74
HUN-F vs HOU-M	-1.11	2.38	17.65
HOU-F vs HUN-M	-0.85	3.02	8.15
HUN-F vs HOU-F	0.09	0.81	54.73
HUN-M vs HOU-M	-0.04	0.61	63.11

Distinct differences in the absolute linear measurements between surface shells were noted in the subgroups. These linear differences ranged from 0.44 mm (HUN-M vs HOU-M) to 2.57 mm (HOU-F vs HUN-M). The results are shown in Table I.

The differences in absolute linear measurements for the Hungarian and Texas groups by sex were 0.55 mm (HUN-F vs HOU-F) and 0.44 mm (HUN-M vs HOU-M).

Differences were also noted between the facial shells from the subgroups when color histograms were used; these results are presented in Table II. The color histograms showed that the similarities in the facial shells between 2 subgroups ranged from 8.15% (HOU-F vs HUN-M) to 63.11% (HUN-M vs HOU-M).

The similarities in facial shells for the Hungarian and Texas groups by sex were 54.73% (HUN-F vs HOU-F) and 63.11% (HUN-M vs HOU-M).



**Fig 4.** Color histograms and facial mapping showing the facial differences between average shells: *row 1,* HOU-F vs HOU-M; *row 2,* HUN-F vs HUN-M; *row 3,* HUN-F vs HOU-M; *row 4,* HOU-F vs HUN-M; *row 5,* HUN-F vs HOU-F; *row 6,* HUN-M vs HOU-M.

The average linear distance from the signed color histograms for the subgroups ranged from -1.11 mm (HUN-F vs HOU-M) to 0.23 mm (HOU-F vs HOU-M).

The average linear distance in the signed color histograms for the Hungarian and Texas groups by sex ranged from -0.04 mm (HUN-M vs HOU-M) to 0.09 mm (HUN-F vs HOU-F).

Surface area and shape differences between the subgroups were illustrated by the color histograms, and surface mapping can be seen in the first four rows of Figures 4 and 5. Surface area comparisons between the sexes from the different populations (HUN-F vs HOU-M, and HOU-F vs HUN-M) varied the most, followed by the surface area comparisons from the same population (HOU-F vs HOU-M, and HUN-F vs HUN-M). These discrepancies were most notably seen in the malar regions, eyes, chin, and forehead.

Surface area comparisons between Hungarian and Texas groups by sex can be seen in the3 last 2 rows of Figures 4 and 5. These subgroup comparisons showed



**Fig 5.** Color histograms and facial mapping showing the facial differences between average shells: *row 1*, HOU-F vs HOU-M; *row 2*, HUN-F vs HUN-M; *row 3*, HUN-F vs HOU-M; *row 4*, HOU-F vs HUN-M; *row 5*, HUN-F vs HOU-F; *row 6*, HUN-M vs HOU-M.

more unique, site-specific differences in their surface areas. The HUN-F vs HOU-F comparison varied the most at the angle of the mandible, followed by differences in the eyes and malar region. Minor differences were seen in the nose, lips, and forehead. The HUN-M vs HOU-M comparison showed the largest differences in the nose, mandible, and lips, followed by minor changes in the malar region and brow area.

When comparing the 2 groups of women, the HUN-F had a larger mandible in the body and ramus areas (most notably in the angle of the mandible), and more prominent nose, lips, and upper forehead. They also have less prominent eyes, malar regions, subnasal areas, and areas between the eyes (Fig 6).

When comparing the 2 groups of men, the HUN-M have a more prominent nose, brow, malar region, and upper lip. They also have smaller, more retrusive mandible, chin, and eyelids (Fig 7).

## DISCUSSION

This study describes the technique required to construct average faces from 2 cohorts of white people. In



Fig 6. HUN-F vs HOU-F: signed color histograms comparing these average women.



Fig 7. HUN-M vs HOU-M: signed color histograms comparing these average men.

addition, the average faces were used as templates to compare the morphologic differences.

Three-dimensional average faces have been described in the literature and serve as an excellent basis to understand complex 3D data sets.<sup>18</sup> In 2001, Hutton et al<sup>19</sup> built dense surface models from 421 facial scans of subjects from 1 to 80 years old. In this study, the faces were aligned, based on 10 surface landmarks before a combination of complex algorithms was applied to the faces. The final dense surface model was used to help diagnose people with Noonan's syndrome.<sup>20</sup> Average faces have been described to compare treatment changes between extraction vs nonextraction groups<sup>21</sup> and also cross-sectional growth changes among children.<sup>22</sup> Our average face constructions represent true variations in the facial morphologies of 2 white groups from different areas of the world.

By comparing the absolute differences between all subgroups, we first determined that each average face was fundamentally unique (Figs 2 and 3). The diversity in the linear measurements, color histograms, and surface areas indicated morphologic differences in the facial averages in these groups. This variability meant that the subgroups were different and had to be treated as separate entities. These differences between subgrouping shells were expected; however, it was interesting to see exactly where most differences occurred. When looking at absolute color histograms between all subgroups, most differences appeared in the malar regions, eyes, and chin. More differences were seen when comparing the sexes, probably because of obvious average size differences and facial features commonly associated with either men or women. As a general rule, the men had larger noses, and the women had more prominent malar regions and eyes. Chins varied from subgroup to subgroup. When looking at all comparisons, the same sex comparisons differed the least. The men had a similarity of 63.11%, and the women had a similarity of 54.73%. The comparisons between the sexes of the same population were the next most similar.

Of the average female faces, the Hungarian women had slightly larger faces compared with the Texas women (Fig 6). This was most prominently seen at the angle of the mandible and led us to believe that Hungarian women might be either larger on average or might have more rectangular faces. According to our data, our Hungarian women were an average of 3 pounds heavier than the Texas women and were approximately 1 inch taller, yet both groups had an average body mass index of 21.45. The Hungarian women also had less prominent eyes and malar regions, but their noses and upper lips appeared to be more prominent than those of the Texas women.

Of the average male faces, the Hungarian men had larger noses, brows, malar regions, and upper lips (Fig 7). It was also evident that their mandibles were smaller and more retrusive, and they had more retrusive eyelids. This finding of more retrusive mandibles might lead us to believe that Hungarian men have more Class II skeletal patterns. The average Hungarian male participant was approximately 10 pounds lighter than the average Texas man and an average of 0.5 inches shorter, with an average body mass index difference of -0.82.

Most available information concerning facial soft tissues, particularly profiles, in orthodontics has been obtained from cephalometric data, with additional material from a few 3D studies. Three-dimensional surface acquisition imaging systems have been gaining in popularity and have proven to be an accurate and reliable way to capture facial soft tissues.<sup>23</sup> In this study, we used facial averages to compare the morphologic differences between white people from Hungary and Texas. These 2 groups represented their respective areas; although both groups were white, they exhibited distinct facial morphologic differences. Each group had unique differences, particularly in the mandible, nose, and malar regions. These findings are important in orthodontics because they set a baseline for facial morphologic norms for each population. Studies such as these can be used to formulate normative databases that clinicians can use when predicting treatment for specific populations.<sup>2</sup> If our facial averages truly represent the norms for each population, we can say that white Hungarian women tend to have more rectangular faces than do white Texas women, and that white Hungarian men tend to be more skeletally Class II, with smaller more retrusive mandibles than white Texas men. From these data, an orthodontist might extrapolate that Hungarian men have a greater need for functional appliance therapy than do men from Texas. We also noted that both sexes from Hungary had larger noses than those from Houston. This type of information might also dictate whether extractions will be more detrimental to the average Hungarian profile. Nevertheless, these suggestions are merely taken from the average facial constructions in our study and should not be used routinely with every patient. We also demonstrated that subgroups of white subjects are different according their specific population groups. Therefore, traditional cephalometric norms might need to be readdressed in white subgroups and new 3D norms created.

## CONCLUSIONS

- 1. Average faces can be efficiently and effectively created from a sample of 3D faces.
- Average faces can be used to compare differences in facial morphologies for different populations and sexes, even though they do not necessarily represent the exact facial morphology of a certain population.
- 3. Hungarian women tended to have distinct facial features when compared with Texas women; they are larger at the angle of the mandible, have larger noses, and have larger faces in general. They also had less prominent eyes and malar regions compared with the Houston women.
- 4. Hungarian men tended to have distinct facial features when compared with the Houston en; they have smaller, more retrusive mandibles, larger noses, larger upper lips, and larger malar regions.

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