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A three-dimensional look for facial differences between males and females in a British-Caucasian sample aged 15½ years old

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Structured Abstract

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Background – Optical surface scanning accurately records the three-dimension (3D) shape of the face non-invasively. Many software programs have been developed to process and analyze the 3D data, enabling the clinicians to create average templates for groups of subjects to provide a comparison of facial shape.

Objective – Differences in facial morphology of males and females were identified using a laser scan imaging technology.

Subjects and Methods – This study was undertaken on 380 British-Caucasian children aged 15 and a half year old, recruited from the Avon Longitudinal Study of Parents and Children (ALSPAC). 3D facial images were obtained for each individual using two high resolution Konica/Minolta laser scanners. The scan quality was assessed and any unsuitable scans were excluded from the study. Average facial templates were created for males and females, and a registration technique was used to superimpose the facial shells of males and females so that facial differences can be quantified.

Results – Thirty unsuitable scans were excluded from the study. The final sample consisted of 350 subjects (166 females, 184 males). Females tend to have more prominent eyes and cheeks in relation to males with a maximum difference of 2.4 mm. Males tend to have more prominent noses and mouths with a maximum difference of 2.7 mm. About 31% of the facial shells match exactly (no difference), mainly in the forehead and chin regions of the face.

Conclusions – Differences in facial morphology can be accurately quantified and visualized using 3D imaging technology. This method of facial assessment can be recommended and applied for future research studies to assess facial soft tissue changes because of growth or healthcare intervention.

Key words: 3D imaging; ALSPAC; average face; color map; facial morphology

Introduction

Different techniques have been used to analyze and describe changes in facial morphology for the purposes of determining aetiology, diagnosis, treatment planning, and an assessment of outcome. Visual assessment (Anthroposcopy) involves judging the body's build by inspection and is one of the oldest methods of examination that is still being used in medicine today. However, it tends not to be reliable because it is highly subjective. Anthropometry is a method recommended for quantitative analysis of facial morphology using direct clinical measurements (1). Cephalometry is another method for describing facial shape in two dimensions (2). Photographs were commonly used to record facial features in two dimensions (3). Lastly, the three-dimensional (3D) imaging technology has been employed to assess facial soft tissue morphology in the different planes of space (*X-Y*: Frontal View, *Y-Z*: Lateral View, and *X-Z*: Plan View) (4–6).

The use of 3D imaging is becoming more widespread in a variety of commercial and healthcare fields. There are many systems available although not all of them have the appropriate levels of resolution and accuracy. There are static and dynamic 3D acquisition systems. The laser approach appears to have the greatest surface resolution and accuracy. The dynamic systems have great potential in understanding, describing, and quantifying facial changes as a result of function and healthcare intervention (7).

The applications of 3D imaging in orthodontics include: pre- and post-orthodontic assessment of the dentoskeletal relationships and facial aesthetics, auditing orthodontic outcomes with regard to soft and hard tissues, 3D treatment planning, and 3D soft and hard tissue prediction. 3D fabricated custom-made archwires and archiving 3D facial, skeletal and dental records for in-treatment planning and research and medico-legal purposes are also among the benefits of using 3D models in orthodontics (8, 9).

The 3D measurement and characterization of facial surface anatomy are fundamental to the objective analysis of facial deformity. Orthodontists and maxillofacial surgeons deal with the physical relationships among the components of the human head. Perhaps, the most popular 3D data acquisition technique successfully applied to human facial measurement is laser surface scanning. This technique is valuable for its ease of application and creation of accurate 3D images enabling creation of valuable resources for normative populations (10); cross-sectional growth changes (11); clinical outcomes in the surgical and non-surgical treatments in the head and neck regions (12, 13). This study aims to identify the differences in facial morphology between males and females using laser scan imaging system and software program to view the results.

Subjects and methods

The initial sample of the Avon Longitudinal Study of Parents and Children (ALSPAC) consisted of 14541 pregnancies. This was the number of pregnant women enrolled in the ALSPAC study with an estimated date of delivery between April 1991 and December 1992. Out of the initial 14541 pregnancies, all but 69 had known birth outcome. Of these 14472 pregnancies, 195 were twins, three were triplets and one was a quadruplet pregnancy; meaning that there were 14676 fetuses in the initial ALSPAC sample. Of these 14676 fetuses, 14062 were live births and 13988 were alive at 1 year.

The ALSPAC children were recalled in 2006/2007 for follow-up and as part of their overall assessment they provided consent for 3D facial scanning. The first 380 (15½ year old) ALSPAC children were involved in our study of facial morphology. The 3D facial scans were obtained in October and November 2006. This is only a small subset of all the ALSPAC children seen to date and still more to be seen for future investigations. Ethical approval for this study was obtained from the ALSPAC Law and Ethics Committee and the Local Research Ethics Committees.

Image capture and processing

Three-dimensional facial images were captured using two high resolution Konica Minolta Vivid (*VI900*) cameras (Konica Minolta Sensing Europe, Milton Keynes, UK) (14, 15). The 3D cameras were fitted with lenses of focal length 14.5 mm and were connected in serial via a small computer system interface (SCSI) cable to a desktop computer work station (Dell 8200 Inspirion with a 2 GHz Pentium 4 Processor, Dell, Inc., Bracknell, UK).

The set of left and right facial images for each subject were processed, registered, and merged using a locally developed subroutine in RAPIDFORM™ Software (RF6;

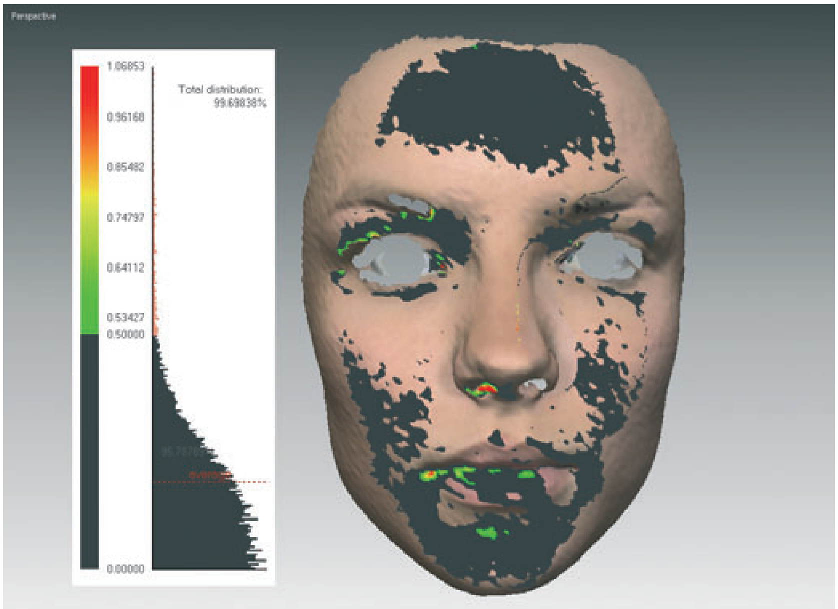

Fig. 1. Color map and histogram plot developed to assess left and right facial shells deviation and evaluate scan quality.

INUS Technology Inc., Seoul, South Korea). Figure 1 shows the color map and histogram plot created for the left and right facial shells for one of the subjects involved in our study. This figure illustrates the shell/shell deviation and the overlap area between the two shells before merging. The precision between the two shells at the overlap area was used to determine the accuracy and reliability of the facial scan. Generally, if 70–100% of the overlapped left and right facial shells coincide with each other with a difference between the shells <0.5 mm, then the scan was evaluated as having good quality. After merging the left and right facial shells of each subject, the final merged image was orientated within the reference framework using a standardized procedure where a facial template was constructed and each subject full face image was registered to this template (16).

Facial averaging

Average facial shells were created for males and females using a subroutine created from tools available within RAPIDFORM software. The averaging procedure is further outlined (17). The main steps required to produce an average face are summarized below:

- Standardizing the 3D facial images using a facial template.
- Pointwise averaging in the 'Z' direction to create the 'Point Cloud' which is just a set of unconnected points that may form a 3D shape.
- The point cloud is then triangulated to obtain an average face, that means the points are organized in the form of triangles to create the average 3D facial shell.
- The average face is later improved by filling in small holes and removing possible mesh defects.
- ±1 standard deviation (SD) shells were created.

Using a registration technique, the average facial shells of males and females were superimposed one over the other so that differences in facial morphology can be quantified. A color face map and histogram plot were developed to demonstrate areas of the face that show variation between males and females.

Results

Sample

Data were collected on 380 subjects, aged 15½ years. Three categories were considered to describe the scan quality according to the percentage of overlap between the left and right sides of the face with a tolerance level set as 0.5 mm.

- Good: 70–100% of the overlapped left and right facial shells coincide with each other with a difference between the shells <0.5 mm.
- Fair: 60–69% of the overlapped left and right facial shells coincide with each other with a difference between the shells <0.5 mm.

Table 1. **Scan quality**

Scan quality	Number of subjects	Percentage
Good (70–100%)	318	84%
Fair (60–69%)	38	10%
Poor (<60%)	24	6%
Total number of subjects = 380		

- Poor: <60% of the overlapped left and right facial shells coincide with each other with a difference between the shells <0.5 mm.

Table 1 shows that 84% of the facial scans were considered as good, 10% fair, and 6% poor. Unsuitable scans for 30 subjects were excluded (all 24 scans with poor quality and 6 scans for subjects with opened mouth, smile or deficient areas at the forehead and chin regions of the face). The final sample consisted of 350 subjects (166 females and 184 males) with either good or fair quality.

Comparing facial morphology of males and females

Figure 2 shows the superimposition of average male and female shells. Females tend to have more prominent eyes and cheeks in relation to males with a maximum difference being measured as 2.4 mm. Males tend to have more prominent noses and mouths with a maximum difference being measured as approximately 2.7 mm. Using the color deviation face map, 31% of the facial shells match was exactly (zero) distributed mainly in the forehead and chin regions of the face (Fig. 3).

Discussion

This study generally showed a high level of compliance being achieved by the scanned 15½ year old subjects recruited for the study. A large percentage of the scans (84%) showed good quality, 10% of the scans with fair quality, and only 6% of the scans have poor quality. Poorer quality images were because of the subjects moving during the scanning procedure which caused a gap between the facial right and left shells that was difficult to merge and process. This was noticed especially in the chin region of the face because of the fact that lower jaw is freely movable. Other minor muscular responses were noticed in the eyelid region and areas near the lips of the scanned children. Minor image distortions caused by these small movements were processed without affecting the overall shape and volume of the scanned image.

Many studies have been conducted making use of average faces to investigate the changing of facial morphology brought about by growth or healthcare intervention. A study conducted by Moss and Hennessy (18) in which an average face was obtained for groups of patients each year from 5 years to 18 years. Growth of an individual can be compared with the norm for

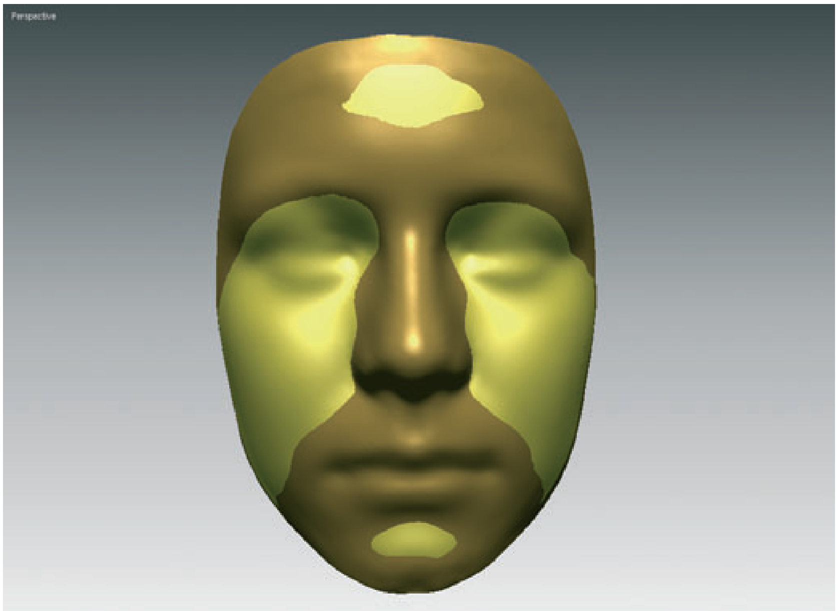

Fig. 2. Comparison of males and females facial morphology.

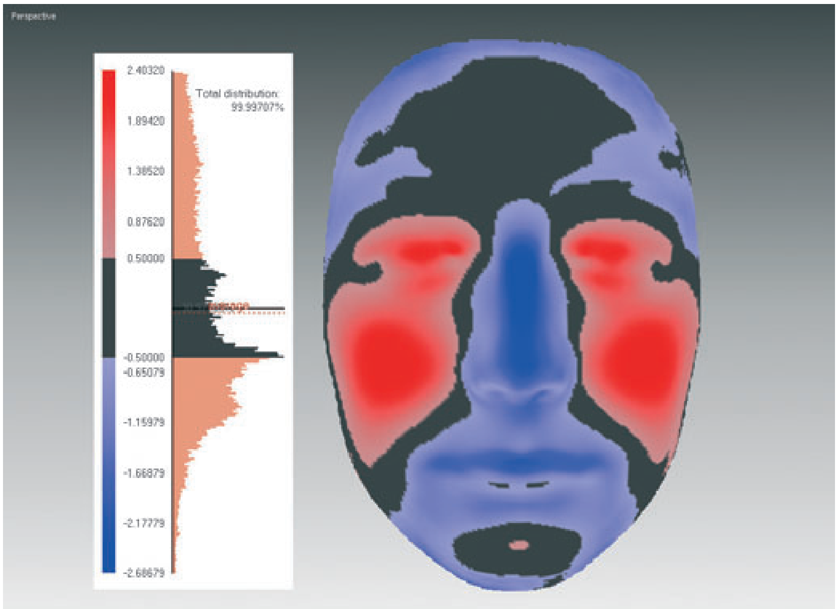

Fig. 3. Color map and histogram plot developed to compare superimposed average facial shells of males and females.

that age to determine which areas of the face show abnormal growth. Hammond et al. (19) used dense surface models to analyze facial morphology by establishing a correspondence of thousands of points across each 3D facial image. The models provided dramatic visualizations of 3D face shape variation to identify subtle features of craniofacial syndromes such as Noonan syndrome.

Other studies, making use of average faces, have investigated treatment changes amongst extraction versus non-extraction cases (20); also cross-sectional growth changes amongst children have been studied by Nute and Moss (11). In our study, the average faces were used to compare facial morphology of males and females. These average faces enabled determination of facial soft tissue morphological differences when they become superimposed one over the other to develop a color face map showing areas of maximum difference between males and females faces.

The results were similar to those obtained by Kau (21) in his study to analyze facial changes in children aged 11–14 year old. Generally, the areas of maximum difference were noticed in the eyes and cheeks, being more prominent in females than males; whereas males have more prominent noses and mouths. Other variation in facial morphology was ranged in between those extremes, with 31% of the facial shells correlate to each others with no difference (zero) distributed mainly in the forehead and chin regions of the face. Similar results were also conducted by other studies using different approaches (22, 23) for different age groups (5, 6, 11, 17) years of age, as well as adults.

Conclusions

- The three-dimensional laser-scan imaging technique used in this study is both accurate and reliable to <0.5 mm.
- Males and females show differences in facial morphology. Females tend to have more prominent eyes and cheeks, whereas males tend to have more prominent noses and mouths.
- Differences in facial morphology can be accurately quantified and visualized using three-dimensional imaging technology. This method of facial assessment can be recommended and applied for future research studies to assess facial soft tissue changes because of growth or healthcare intervention.

Clinical relevance

The 3D laser scanner is characterized by its ease of use, portability, non-invasiveness and creation of accurate 3D facial images. The results have shown that 3D laser scanning is both valid and reliable to identify facial differences between subjects. It is hoped that this study will form the basis for future applications on larger cohorts of subjects in different age groups. In addition, surface imaging in combination with other 3D imaging technologies like cone beam computed tomography (CBCT), magnetic resonance imaging, and ultrasonography will provide better understanding of the three-dimensional facial differences between males and females. The methods and techniques used in this study can be applied in future research to assess facial soft tissue changes due to growth, orthodontic treatment and orthognathic surgery.

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