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Facial templates: a new perspective in three dimensions

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Structured Abstract
Authors – Kau CH, Zhurov A, Richmond S, Cronin A, Savio C, Mallorie C
Purpose – This paper describes the use of adult facial template in gender-specific facial analysis.
Subjects and Methods – Eighty adults, mean age 24.5, were selected for the study. Laser-scanned images of the subjects were obtained under a reproducible and controlled environment with two Minolta Vivid 900 (Osaka, Japan) optical laser-scanning devices assembled as a stereo-pair. A set of left and right scanned images was taken for each subject and each scan took an average of 2.5 s. These scanned images were processed and merged to form a composite three-dimensional soft tissue reproduction of the subjects using commercially available reverse modelling software. The differences in facial morphology were measured using shell deviation colour maps. The facial template was used to compare differences between males vs. females groups and two subjects with facial disproportions.
Results – The difference between the male and female facial templates was 1.28 ± 1.02 mm. The areas of greatest deviation were at the nasal, zygomatic area and lower jaw line. The results of the surface deviation maps between the templates and subjects with facial disproportion showed that the results could be applied for orthodontic diagnosis.
Conclusions – The construction of the adult facial templates provides an interesting perspective into measuring changes in groups of patients and also acts as a useful template for the comparison of skeletal disproportion.

Key words: facial templates; 3D imaging; laser scanning; orthodontics

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Introduction

The craniofacial form has been of great interest to the orthodontist for more than a century. This is because evidence in the literature suggests that different types of orthodontic treatment can alter the facial balance and soft tissue contours of the face. Some of these procedures include dentofacial orthopaedics with functional appliances, extraction/non-extraction treatment and orthognathic surgery).

One clinical tool still used today is the cephalometric template in the orthodontic analysis of facial disproportion and growth prediction. Cephalometric radiographs of an individual are superimposed onto hard tissue landmarks on the constructed templates (age and gender specific) and a variety of measurements or predictions are made. These templates are diagnostic (1) and predictive in nature (2) and give clinicians an opportunity to identify craniofacial anomalies and to predict the future changes in facial morphology for groups of patients. However, these two-dimensional methods were successful at a time where technology constrained the types of analysis available (for example: evaluating the hard tissue in two dimensions).

Recently, there appears to be a paradigm shift (2,3) for clinicians to work from the external soft tissues 'inwards' as these features are pertinent and pleasing to the human eye. The advancement in three-dimensional technology now allows the capture of facial morphology using efficient and non-invasive procedures and also without the risks of radiation exposure (4–7). A number of clinical applications have been created from these three-dimensional images and include growth analysis (8,9), orthognathic surgery (10,11) and integrated three-dimensional analysis (12,13).

This paper describes the use of a previously validated laser scanning device (14–16) and its use in the construction of three-dimensional facial templates from adult facial scans. Furthermore, applications in clinical orthodontics are also discussed.

Subjects and methods

Subjects

Eighty adult subjects with normal Class I facial features were selected from a facial study project to represent the gender-specific facial templates of adults. The sample was made up of 40 male and 40 female dental students with a mean age of 24.5 years of age. All subjects received no previous orthodontic treatment. Written approval for the study was obtained from the relevant ethics committees and participants.

Three-dimensional imaging system and image processing

The laser scanning system consisting of two high-resolution Minolta Vivid VI900 3D cameras, with a reported manufacturing accuracy of 0.3 mm, operating as a stereo-pair, was used. The technical set-up has been previously reported on by the authors (14,16) and only a brief description will be provided in this article. Information from the scanners was transferred to a reverse modelling software package Rapidform^{TM} 2004 PP2 (@ INUS Technology Inc., Seoul, Korea) – RF4 for image processing and analysis (17).

A custom-made portable studio facilitated standardized light conditions. Natural Head Posture (NHP) was adopted for this study as this has been shown to be clinically reproducible (18,19). The technique for positioning the patient and image capture has also been reported and previously described (15).

Within RF4, a shell-to-shell deviation map was computed and automatically produced. The results include the maximum and minimum range of shell deviations, the average distance between the two shells and the standard deviation. This function was used to statistically analyse the mean shell deviations and standard deviations for left and right premerged scans in the male and female groups. The RF4 features described were also used to measure differences in the shells of whole faces.

The mean shell deviations for left and right scans were tested for normality and differences between the groups measured were analysed using the Student's *t*-test (SPSS 12.0.1, Chicago, IL, USA). p values <0.05 were considered significant.

Construction of the facial templates

The three-dimensional facial template representing an adult male and female subject was constructed from the facial meshes of 40 males and 40 females, respectively. This in-house procedure was created from tools available within RF4 and provided the platform for the construction of the average faces. These steps may be summarized as follows:

(1) Pre-alignment of images by determining the principal axes of rotation (based on computing the tensor of inertia of each three-dimensional image).

(2) Manual positioning, when necessary, to improve the previous stage.
(3) Best-fit alignment using the built-in algorithm in RF4.
(4) Averaging of coordinates of the images normally to a facial template.
(5) Point cloud is triangulated to obtain an average face.
(6) The average face is improved by filling in small holes and removing possible mesh defects.
(7) Colour texture is applied.
(8) Standard deviation shells are created.

The averaging procedure may be outlined mathematically as follows.

Suppose there are K facial masks appropriately aligned at steps (1)–(3). All of them are bounded within a box $\{X_{\min} \le X \le X_{\max},\ Y_{\min} \le Y \le Y_{\max},\ Z_{\min} \le Z \le Z_{\max}\}$. Suppose that all the faces 'look' in the Z-direction, with the Y-axis pointing vertically from chin to forehead and the X-axis pointing horizontally from right eye to left eye. Each face is considered to a function $Z = f_k(X,Y)$, where k represents the number of the face. In order to perform the averaging, the functions f_k are evaluated at nodes (i, j) of a rectangular mesh, so that

$$Z_{ij}^k = f_k(X_i, Y_j),\ \ k=1,\ldots,K,\ \ i=0,\ldots,M,\ \ j=0,\ldots,N;$$
$$X_i = X_{\min} + i\Delta X,\ \ \Delta X = \frac{X_{\max} - X_{\min}}{M},\ \ X_0 = X_{\min},\ \ X_M = X_{\max};$$
$$Y_j = Y_{\min} + j\Delta Y,\ \ \Delta Y = \frac{Y_{\max} - Y_{\min}}{N},\ \ Y_0 = Y_{\min},\ \ Y_N = Y_{\max}. \tag{1}$$

The averaging is performed along the Z-coordinate and hence

$$Z_{ij}^{\text{ave}} = \frac{1}{K}\sum_{k=1}^{K} Z_{ij}^k. \tag{2}$$

The average face is thus defined by the point cloud $\{X_i, Y_j, Z_{ij}^{\text{ave}}\}$. The point cloud is then triangulated to obtain an average facial surface.

Next, two standard deviation faces are created. The respective Z-coordinates are evaluated by the formulas

$$(a)\ Z_{ij}^{\text{ave}+1\text{SD}} = Z_{ij}^{\text{ave}} + \frac{1}{K-1}\sqrt{\sum_{k=1}^{K}(Z_{ij}^{\text{ave}} - Z_{ij}^k)^2}, \tag{3}$$

$$(b)\ Z_{ij}^{\text{ave}-1\text{SD}} = Z_{ij}^{\text{ave}} - \frac{1}{K-1}\sqrt{\sum_{k=1}^{K}(Z_{ij}^{\text{ave}} - Z_{ij}^k)^2}, \tag{4}$$

and the respective point clouds are defined by the sets $\{X_i, Y_j, Z_{ij}^{\text{ave}+1\text{SD}}\}$ and $\{X_i, Y_j, Z_{ij}^{\text{ave}-1\text{SD}}\}$. The point clouds are then triangulated.

The facial templates were further improved by removing possible mesh defects and by filling in small holes, using built-in tools within Rapidform 2004. Each average face is given a coloured surface texture. The resulting faces are illustrated in Fig. 1a,b.

Clinical applications

The facial templates for an adult male and female were evaluated to determine facial differences between gender groups (Fig. 2a,b). Furthermore, gender-specific templates for males and females were overlaid individually for subjects presenting with skeletal disproportion using a validated alignment algorithm – ICP algorithm (15). In this report, one subject in each of the following categories is presented:

(1) Patient with facial asymmetry;
(2) Analysis of patients before and after facial surgery.

Results

Eighty normal subjects and two subjects with different facial disproportions were analysed and compared. The mean ages for the normal subjects was 24.5 years.

Analysis and comparison of normal facial templates

The mean scores of the left and right scans for individual male and female faces were 0.29 ± 0.07 and 0.32 ± 0.11 mm, respectively. Each of data set was tested for normality and found to be normally distributed. Paired t-tests revealed that was no statistical difference between the two groups of subjects, indicating that there were no differences in the quality of the scans ($p = 0.67$).

The mean difference between the male and female facial templates was 1.28 ± 1.02 mm. The areas of greatest deviation were at the nasal, zygomatic area and lower jaw line. The template suggests that males had a more prominent and protruded brow area. Furthermore, the nasal region was broader and nasal bridge was longer vertically. The lips appeared thinker and fuller whilst the mandible and chin were more protruded. These areas are marked in red (Fig. 2b).

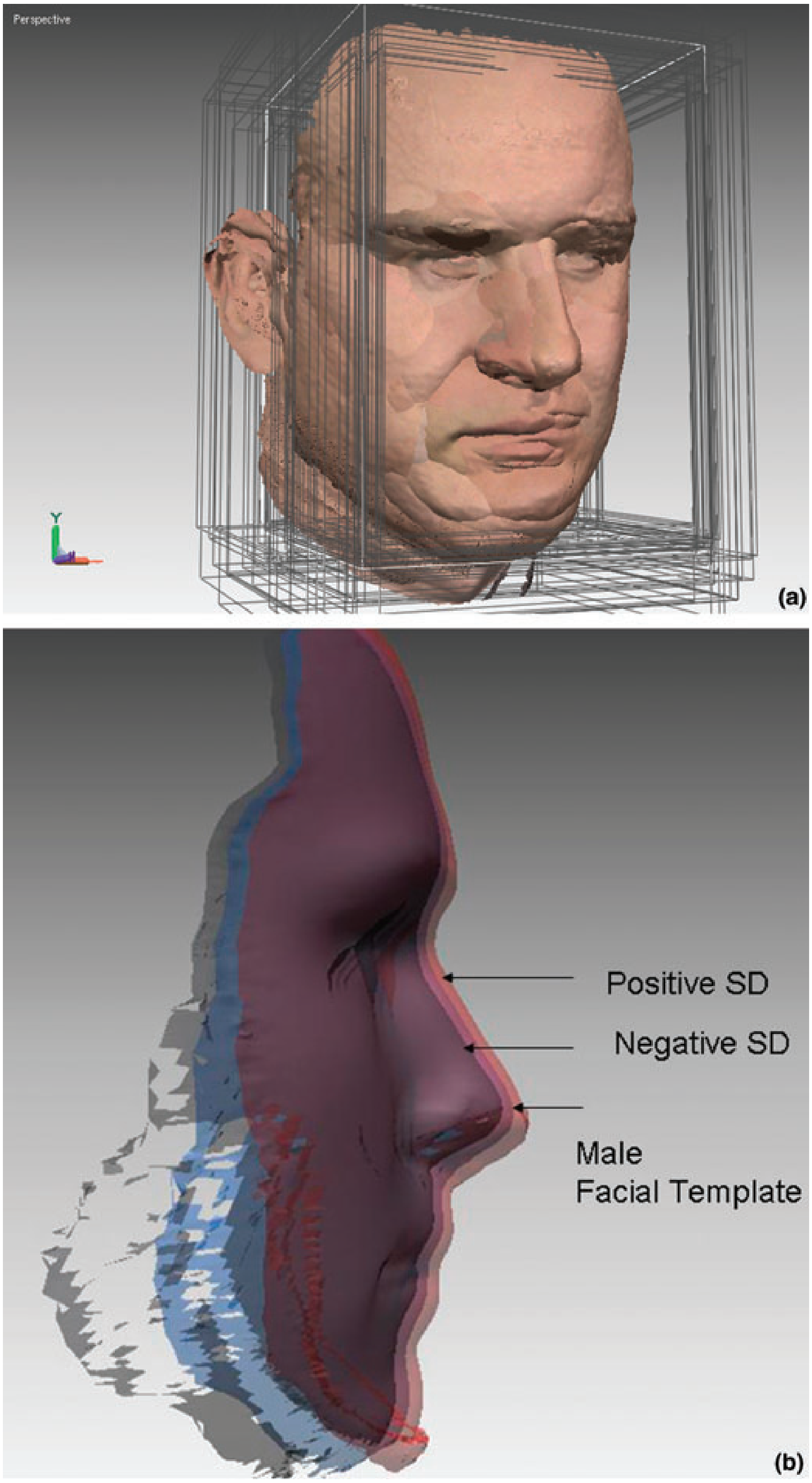

Fig. 1. (a) Facial template construction by pre-alignment of three-dimensional facial scans of 40 individuals. The pre-alignment of images was done by determining the principal axes of rotation (based on computing the tensor of inertia of each three-dimensional image). This was followed by manual positioning, when necessary, to improve the previous stage. Finally, the best-fit alignment was carried out using the built-in algorithm in RF4. (b) The male facial template when a transparent texture is applied. One positive and negative standard deviation shells have also been included to show the possible deviation range.

Clinical evaluation of patients with facial disproportions and treatment outcomes

Subject A was a female, aged 19.5 years and presented with a Class III facial skeletal disproportion and right-sided facial asymmetry. The mean difference between the subject and gender-specific facial template was 2.42 ± 2.28 mm. There was a 73.29% difference in the overlap of the facial shells between the subject and the facial template. Furthermore, there

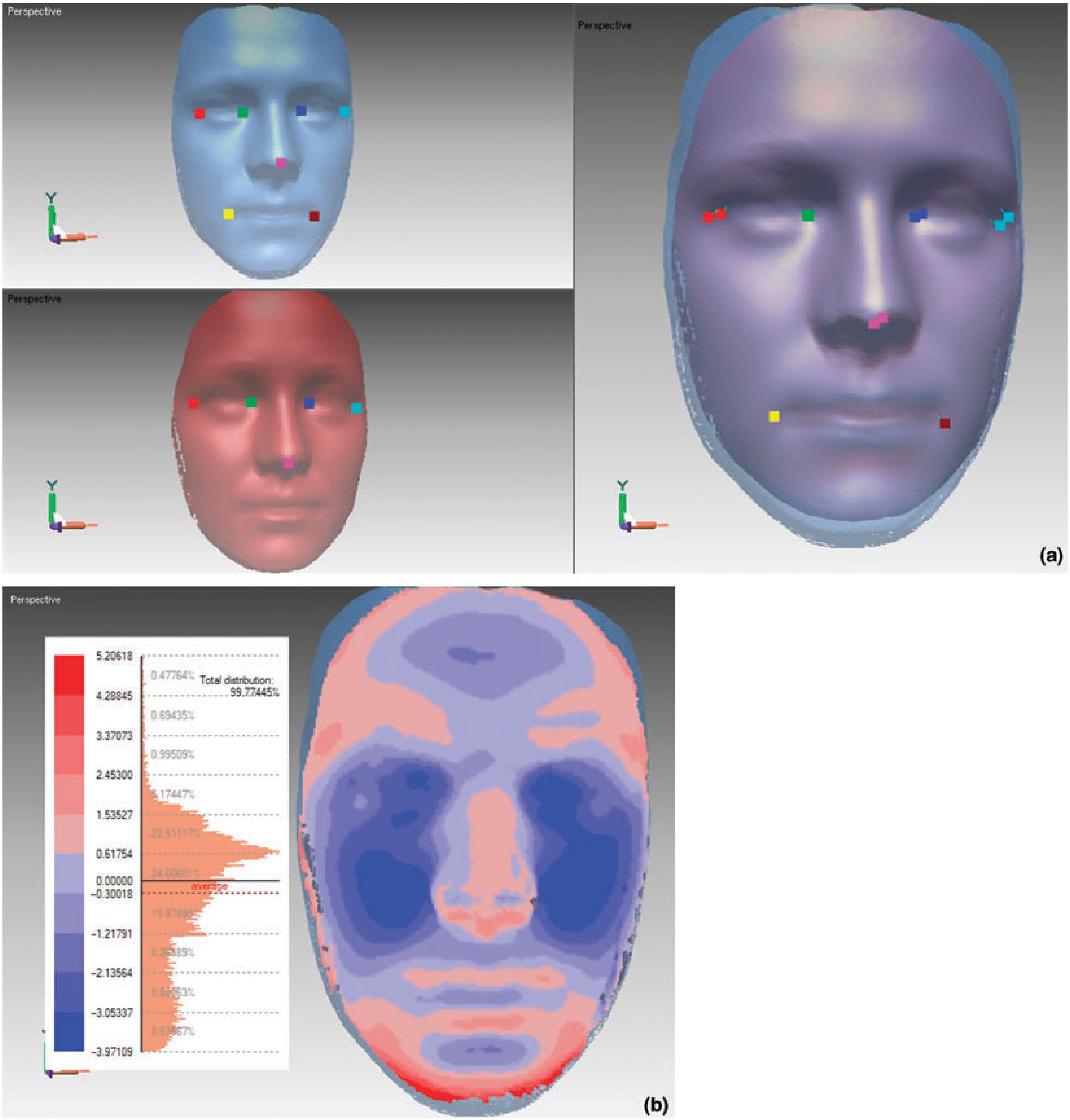

Fig. 2. (a) The pre-alignment sequence performed before alignment algorithm is applied. (b) Differences in facial morphology between males and females. The coloured areas depict positive facial differences. The nasal, zygomatic and lower mandibular areas show difference.

was an obvious asymmetrical deviation on the colour map for the subject to the female facial template (Fig. 3a–c).

Subject B was a female patient, aged 20.3 years, presenting with a Class III malocclusion that required orthognathic surgery. The first sequence of scans shows the patient superimposed onto the gender-specific facial template. The mean difference between the facial shells was 2.06 ± 1.33 mm. There was a 77.91% difference in overlap of the facial shells between the subject and the facial template. The areas of overlap are represented diagrammatically on the coloured facial maps (Fig. 4a–c). A two-jaw surgery was performed after orthodontic de-compensation and a set of three-

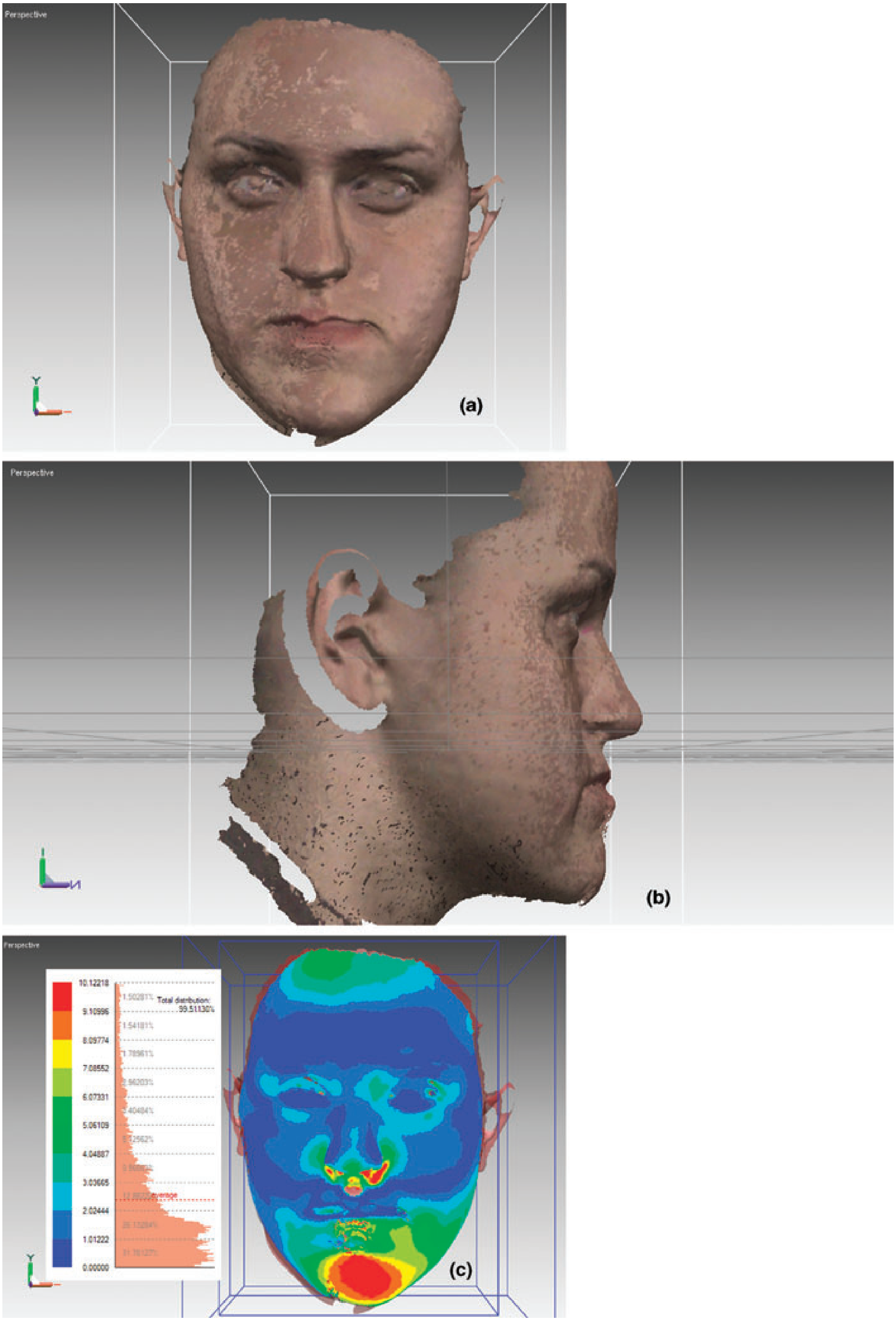

Fig. 3. (a, b) Subject A: Patient with a Class III skeletal disproportion and right-sided mandibular facial symmetry. (c) A colour deviation map showing the prominent asymmetry to the female facial template.

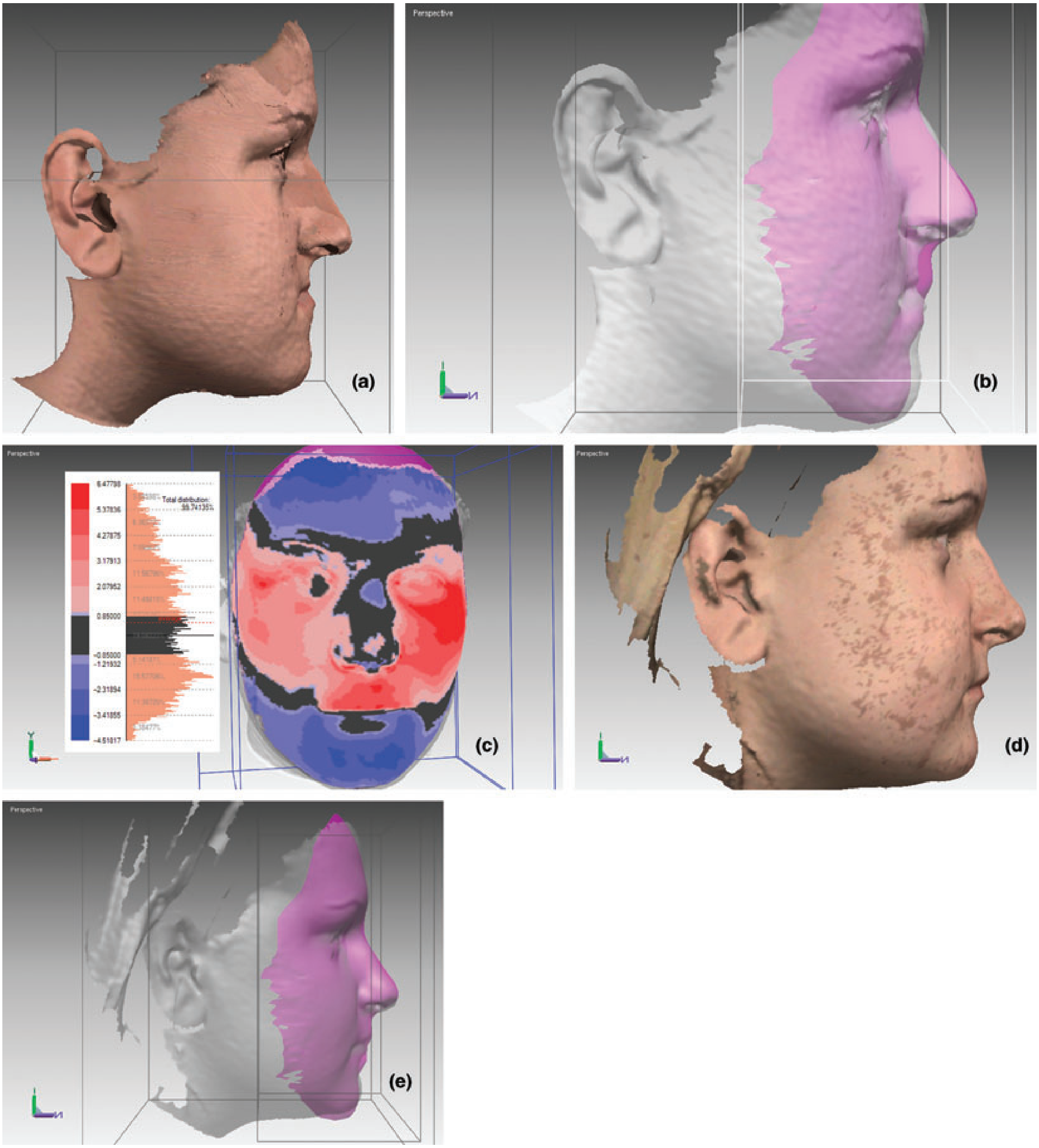

Fig. 4. (a, d) Three-dimensional facial scans of Subject B pre- and post-surgery. (b, d) The female template overlaid onto Subject B. (c) Coloured shell deviation map showing the differences in facial morphology between pre-surgical scans and facial template.

dimensional facial scans were taken 1 year later. The mean difference between the facial shells was 1.57 ± 1.38 mm. There was a 55.10% difference in overlap between the facial shells. There was a better harmonization of her facial features post-surgery (Fig. 4d,e).

Discussion and clinical applications

This paper describes the construction of three-dimensional facial templates and its clinical application in orthodontics. There have been brief descriptions of the use of three-dimensional average faces in the literature. In a recent report, 421 facial scans of subjects aged 1–80 years old were amalgamated to form dense surface models (20). The authors arbitrarily aligned 10 surface landmarks and applied a hybrid combination of algorithms to construct active facial models. These models were used to assist in the diagnosis of Noonan's syndrome (21). The average faces have also been described in early laser scanning articles and these were used to compare a variety of treatment changes in orthodontics (8,22). The processes of averaging the faces were, however, not mentioned in detail.

This paper describes the construction and use of three-dimensional facial templates and serves as a step forward in the applications of three-dimensional imaging in orthodontics. The facial templates used in this study seem to be successful in describing differences in facial morphology between gender groups and also in the descriptive analysis of skeletal disproportion. Further work is required to validate the templates for larger population groups and a wider range of facial anomalies. It is hoped that the facial template will be a useful tool in future orthodontic studies and analysis.

Conclusions

The following conclusions may be drawn from this study:

(1) The facial templates, specific to age and gender, can be efficiently and effectively created from a sample of three-dimensional faces.
(2) The facial templates may also be used to compare differences in facial morphologies for different gender groups.
(3) The facial templates may also be used to compare diagnose and analyse treatment outcomes in subjects who present with facial disproportion.

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