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Three-dimensional quantification of facial symmetry in adolescents using laser surface scanning

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SUMMARY Laser scanning is a non-invasive method for three-dimensional assessment of facial morphology and symmetry. The aim of this study was to quantify facial symmetry in healthy adolescents and explore if there is any gender difference. Facial scans of 270 subjects, 123 males and 147 females (aged 15.3 ± 0.1 years, range 14.6–15.6), were randomly selected from the Avon Longitudinal Study of Parents and Children. Facial scans were processed and analysed using in-house developed subroutines for commercial software. The surface matching between the original face and its mirror image was measured for the whole face, upper, middle, and lower facial thirds. In addition, 3 angular and 14 linear parameters were measured. The percentage of symmetry of the whole face was significantly lower in males (53.49 ± 10.73 per cent) than in females (58.50 ± 10.27 per cent; $P < 0.01$). There was no statistically significant difference in the amount of symmetry among facial thirds within each gender ($P > 0.05$). Average values of linear parameters were less than 1 mm and did not differ significantly between genders ($P > 0.05$). One angular parameter showed slight lip line asymmetry in both genders. Faces of male 15-year-old adolescents were less symmetric than those of females, but the difference in the amount of symmetry, albeit statistically significant, may not be clinically relevant. Upper, middle, and lower thirds of the face did not differ in the amount of three-dimensional symmetry. Angular and linear parameters of facial symmetry did not show any gender difference.

Introduction

A desire to improve facial aesthetics is very often the reason for seeking orthodontic treatment (Kiyak 2000, 2008; Miguel *et al.*, 2010). Recent papers in evolutionary psychology suggest that the perception of facial attractiveness is, among other factors, influenced by facial symmetry (Zaidel and Cohen, 2005; Rhodes, 2006; Komori *et al.*, 2009). With increased concern about facial appearance, more patients complain of even slight asymmetry (Hwang *et al.*, 2007), which justifies an inclusion of objective and thorough facial symmetry analysis in routine orthodontic examination. However, the problem arises when the boundaries of normal facial asymmetry are to be defined (Rossi *et al.*, 2003; Liukkonen *et al.*, 2005).

Albeit the need for three-dimensional assessment of facial symmetry was recognized more than six decades ago (Fischer, 1954), until the early nineties available methods were time consuming and not fully automated (Moss *et al.*, 1991). O'Grady and Antonyshyn (1999) evaluated six different techniques for quantitative analysis of facial symmetry in three dimensions. Two of these techniques relied on the identification of anthropometric landmarks (asymmetry in the location of anthropometric landmarks and Euclidean distance matrix analysis), two relied on interactive identification of anatomic features or boundaries (e.g. scalar measurements of the lower ciliary margin and palpebral fissure area), and two described the differences in whole surfaces (clearance vector mapping and determination of the volume of asymmetry). Landmark-dependent methods in facial symmetry analysis have dominated orthodontic literature (Ferrario *et al.*, 1994, 1995, 2001, 2003; Ras *et al.*, 1994a,b, 1995). However, these methods have been criticized due to unreliable identification of landmarks, questionable validity of the symmetry plane, and incapability of depicting asymmetries in regions where landmarks are few and far between (Hartmann *et al.*, 2007; Stauber *et al.*, 2008). In recent studies, facial symmetry has been quantified by means of landmark-independent methods, which take into account all available facial points and allow a full face analysis (Nkenke *et al.*, 2006; Hartmann *et al.*, 2007; Primožič *et al.*, 2009, 2011; Meyer-Marcotty *et al.*, 2010; Djordjevic *et al.*, 2011).

In orthodontic literature, the majority of research on facial symmetry of normal individuals has been conducted using two-dimensional methods. Hard tissue asymmetry has been analysed on panoramic (Kambylafkas *et al.*, 2006; Kurt *et al.*, 2008) and postero-anterior radiographs (Peck *et al.*, 1991; Haraguchi *et al.*, 2002; Rossi *et al.*, 2003;

Hwang *et al.*, 2007), whereas soft tissue asymmetry has been evaluated using anthropometry (Farkas and Cheung, 1981; Skvarilova, 1993; Farkas, 1994) and photography (Ercan *et al.*, 2008; Haraguchi *et al.*, 2008). With the exception of a few studies, three-dimensional imaging methods were mainly applied in the analysis of facial asymmetry in cleft lip and palate patients (Ras *et al.*, 1994a,b, 1995; Ferrario *et al.*, 2003; Nkenke *et al.*, 2006; Stauber *et al.*, 2008; Meyer-Marcotty *et al.*, 2010). There is a knowledge gap on the amount of three-dimensional facial symmetry in healthy individuals.

Previous studies have shown that age and gender do not have an effect on facial asymmetry (Burke and Healy, 1993; Skvarilova, 1993; Ferrario *et al.*, 2001). On the other hand, there are authors who demonstrated sexual dimorphism in the amount (Ercan *et al.*, 2008) and direction of facial asymmetry (Smith, 2000; Hardie *et al.*, 2005). Furthermore, it has been reported that different regions of the face have different degree of asymmetry (Farkas and Cheung, 1981; Severt and Proffit, 1997; Ferrario *et al.*, 1994, 2001; Shaner, 2000; Haraguchi *et al.*, 2002; Ercan *et al.*, 2008). The present study aimed to quantify facial symmetry and investigate gender differences in a cohort of 15-year-old British adolescents, using relatively novel method of three-dimensional assessment.

Subjects and methods

Sample

The study population comprised adolescents participating in the Avon Longitudinal Study of Parents and Children (ALSPAC), which is an ongoing research project based at the University of Bristol, UK. The study was designed to understand the ways in which the physical and social environment interact, over time, with the genotype to affect health, behaviour, and development (Golding and ALSPAC study team, 2004). The 14 541 enrolled pregnancies (expected date of delivery 1 April 1991 to 31 December 1992) represented about 85 per cent of the eligible population in the region of Avon, England, UK. Up to date information on this study and abstracts of publications can be found on the ALSPAC website (http://www.bristol.ac.uk/alspac).

During one of the follow-ups in 2006/2007, 4747 participants, 2233 males (average age 15.4 ± 0.3 years, range 14.5–17.0) and 2514 females (average age 15.4 ± 0.3 years, range 14.3–16.9), provided consent for facial laser scanning, which was organized in collaboration with Cardiff University. Only healthy normal growing individuals of Caucasian origin, without history of trauma, and operation in the maxillofacial region were included. Relevant ethics committees approved the protocol for laser scanning. For the purpose of this cross-sectional study, participants were randomly selected from the ALSPAC database. Sample size calculation was carried out using computer software G*Power 3 (Faul *et al.*, 2007). One hundred thirty-three males and 133 females were required for the unpaired *t*-test to have a 90 per cent chance of detecting a 5 per cent difference in three-dimensional facial symmetry, at the 5 per cent level of significance. An estimate of the variation (SD 12 per cent) was based on the pilot study. The number of participants was rounded up from 266 to 270 in the protocol.

Image acquisition and processing

Laser scanning protocol has been described previously (Kau *et al.*, 2005a). In this paper, a summary is provided. Two Minolta Vivid 900 laser scanners (Konica Minolta, Tokyo, Japan) were used to scan subjects in natural head position, which has proven to be reliable (Kau *et al.*, 2005b). After calibration, scanning was performed with medium range lenses (focal length 14.5 mm), at a distance of 135 cm from the subjects, and controlled with multi-scan software (Cebas Computer; GmBH, Eppelheim, Germany). The system acquired more than 307 000 points of the facial surface in approximately 8 seconds. The procedure was repeated if the subject moved, opened mouth, or changed facial expression during the scanning. Left and right halves of the face were scanned simultaneously for each subject and saved in the computer memory in a vivid file format (VVD). In-house developed subroutines for reverse engineering software Rapidform 2006® (INUS Technology, Seoul, Korea) were used for image processing and facial symmetry analysis. Image processing comprised removal of extraneous data, smoothing of the shells, filling small holes, registering, and merging (Zhurov *et al.*, 2005). Before merging, scan quality was assessed. Left and right scans were merged only if there was at least 70 per cent match between them in the overlap area, within 0.5 mm of tolerance (Toma *et al.*, 2008; Djordjevic *et al.*, 2011; Figure 1).

Three-dimensional facial symmetry parameters

Facial symmetry was quantified by means of the mirroring approach (Figure 2). For each subject, a mirror facial shell was created in Rapidform 2006 (INUS Technology, Seoul, Korea) using internally developed set of subroutines. The original facial shell was divided into the upper, middle, and lower thirds in order to compare facial symmetry in different regions of the face (Primožič *et al.*, 2009, 2011; Djordjevic *et al.*, 2011). The upper third was defined as the part of the face above the inner canthus plane, the middle ranged from the inner canthus plane to the plane through the outer commissures of the lips, and the lower was below this plane (Figure 3). The surface matching between the original and the mirror facial shells was assessed by the best-fit superimposition method for the whole face, upper, middle and lower thirds, within 0.5 mm of tolerance, and expressed as percentages. The lower the percentage, the lower facial symmetry, i.e. higher facial asymmetry. Average and maximum distances between the two shells were also

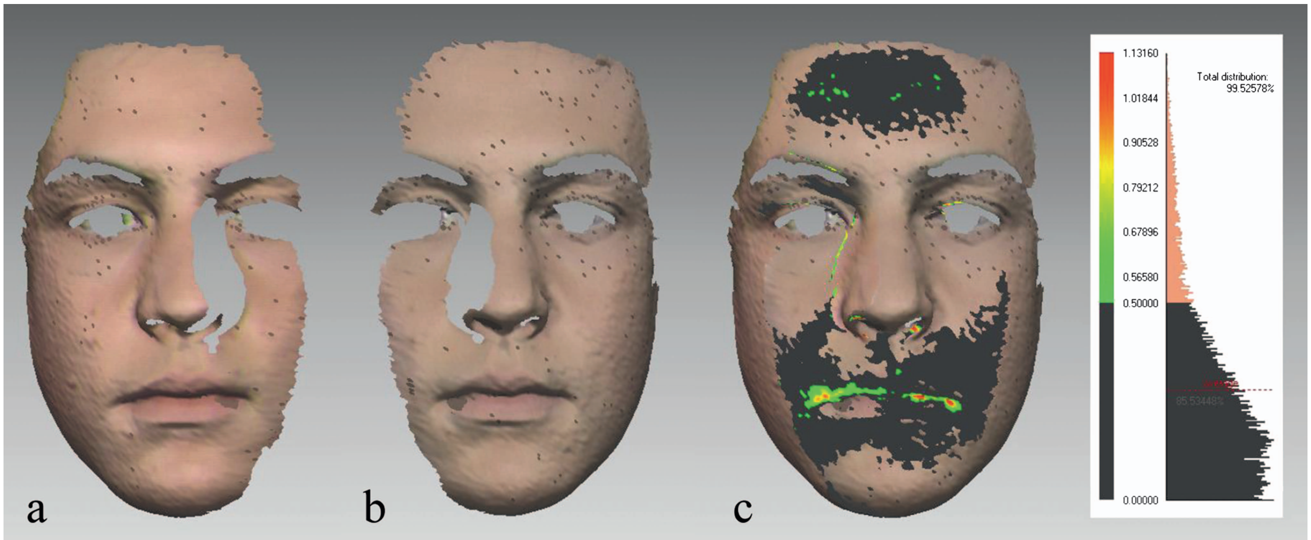

Figure 1 Evaluation of laser scan's quality. (a and b) Right and left facial halves (facial shells) in Rapidform 2006® (INUS Technology, Seoul, Korea) after four-stage processing. (c) Absolute colour map and the histogram were used to evaluate scan quality before merging. Surface matching of the two shells in the overlap area was 85.53 per cent. Deviations less than 0.5 mm are presented in dark grey, 0.51–0.79 mm in light green, 0.80–0.90 mm in yellow, and 0.91–1.13 mm in red. Internally developed subroutine automatically determined average distance between the facial shells in the overlap area: 0.28 mm (SD 0.24 mm). Therefore, laser scans were suitable for merging.

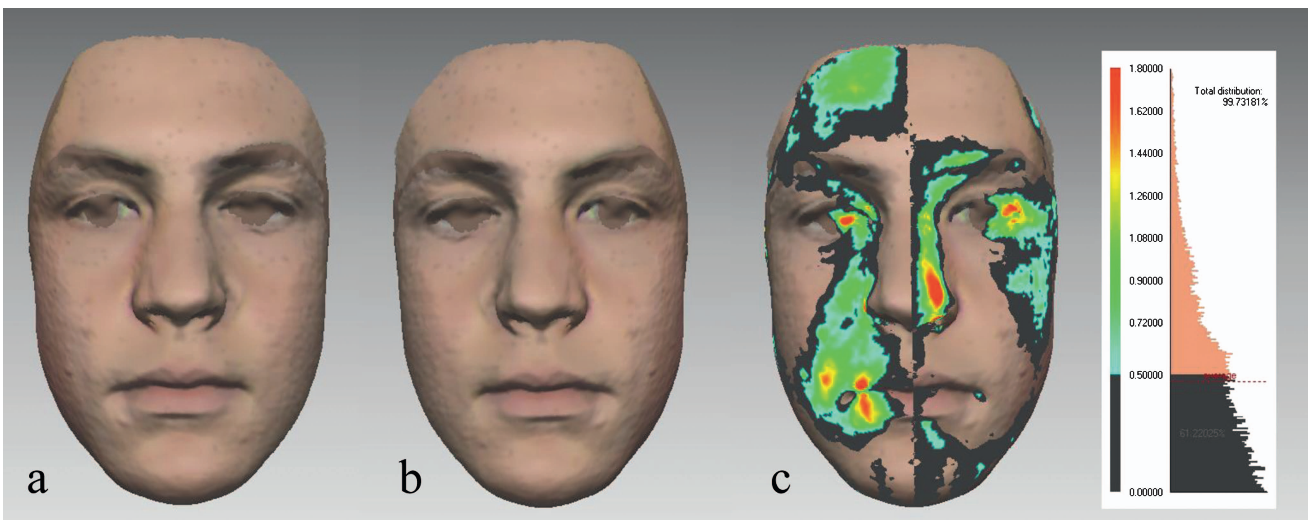

Figure 2 Three-dimensional facial symmetry analysis in a 15-year-old male (same as in Figure 1): (a) the original facial shell, (b) the mirror facial shell, and (c) the colour map and the histogram. Symmetric areas of the face (within tolerance level 0.5 mm) are presented in dark grey. The colours indicate the range of deviations between the original and the mirror facial shells: 0.50–0.72 mm in turquoise, 0.73–1.26 mm in light green, 1.27–1.44 mm in yellow, and 1.45–1.80 mm in red. The percentage of symmetry of the whole face read from the histogram is 61.22 per cent.

computed. Shell-to-shell deviations were presented graphically as colour maps and quantitatively on histograms.

Linear and angular facial symmetry parameters

Twenty-one reliable facial landmarks (Toma *et al.*, 2009; Djordjevic *et al.*, 2011) were manually identified on each facial scan by one operator. Based on these landmarks, 3 angular and 14 linear measurements were made in order to assess facial symmetry, as previously reported (Djordjevic *et al.*, 2011; Figure 4). The midsagittal plane of the structure created by the superimposition of the original and mirror facial shells (Zhurov *et al.*, 2010) was adopted as the symmetry plane for linear measurements.

Statistical analysis

All statistical analyses were performed using the Statistical Package for Social Sciences Software version 17.0 (SPSS Inc., Chicago, Illinois, USA). Descriptive statistics was

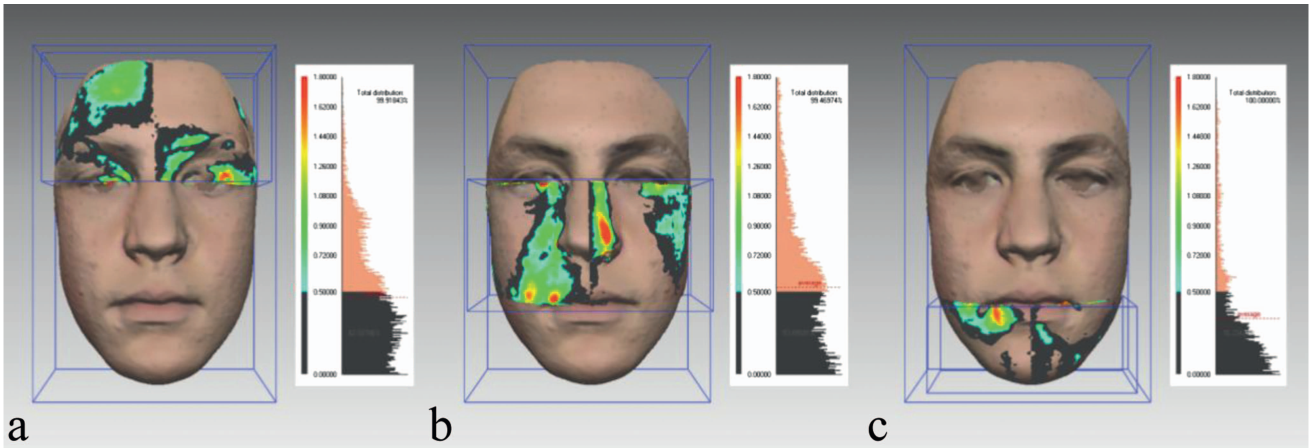

Figure 3 The original facial shell was divided into the upper, middle, and lower thirds. The upper third (a) was defined as the part of the face above the inner canthus plane, the middle third (b) ranged from the inner canthus plane to the plane through the outer commissures of the lips, and the lower third (c) was below this plane. The percentage of symmetry for the upper, middle, and lower thirds in this male subject (same as in Figures 1 and 2) was 62.03, 53.66, and 78.23 per cent, respectively. The colours indicate the same range of deviations as in Figure 2.

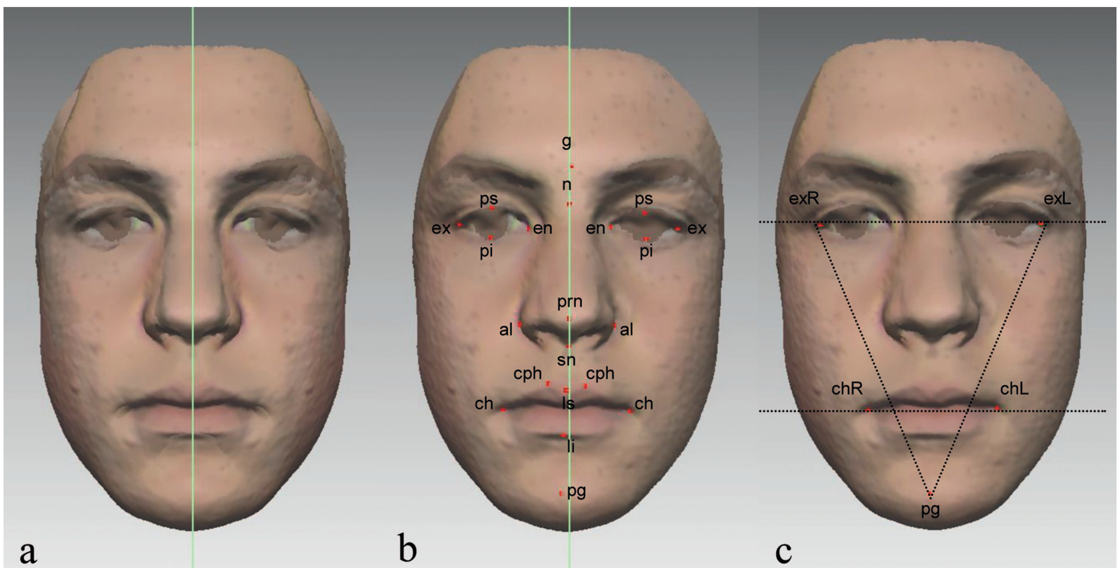

Figure 4 (a) The symmetry plane adopted for the study was the midsagittal plane of the structure created by the superimposition (best-fit registration) of the original and mirror facial shells. (b) For median landmarks [glabella (g), nasion (n), pronasale (prn), subnasale (sn), labiale superius (ls), labiale inferius (li), and pogonion (pg)], the distance from the symmetry plane was calculated. For bilateral landmarks [palpebrale superius (ps), palpebrale inferius (pi), exocanthion (ex), endocanthion (en), alare (aal), crista philtri (cph), and cheilion (ch)), the midpoint between two corresponding landmarks was first determined and then its deviation from the symmetry plane was measured. (c) Three angular parameters were measured: the exR–exL–pg, exL–exR–pg, and exRexL–chRchL. 'R' and 'L' denote 'right' and 'left'. These angles were projections of spatial angles onto the frontal plane.

used to assess the scan quality. The assumption of normality was checked by Shapiro–Wilk test, frequency histograms, and normal probability plots, and homogeneity of variances by Levene's test. The data for the three-dimensional symmetry (whole face, upper, middle, and lower facial thirds) and angular parameters were normally distributed. The data for linear parameters of facial symmetry were positively skewed and square root transformed in order to obtain normal distribution. Therefore, mean, standard deviation, and range (minimum and maximum) were presented. The data for the average and maximum distances between the original and the mirror facial shells were positively skewed. After logarithmic transformation, normal distribution was obtained and results presented as geometric mean, geometric standard deviation, and range (minimum and maximum). Unpaired *t*-test was performed to compare all facial symmetry parameters between genders. One-way analysis of variance (ANOVA) was used to compare three-dimensional symmetry of the upper, middle, and lower facial thirds in each gender. *P* values of 0.05 or less were considered statistically significant, with the exception of comparisons of facial thirds ($P < 0.017$) and linear parameters ($P < 0.004$), for which Bonferroni correction was applied.

Results

Facial symmetry analysis was performed on facial scans of 270 adolescents, 123 males (average age 15.3 ± 0.1 years, range 15.0–15.6) and 147 females (average age 15.3 ± 0.1 years, range 14.6–15.6). Although the sample size was calculated for equally sized groups of males and females, the power of the study was not affected by the change in the proportion.

All facial scans fulfilled predefined criteria. On average, surface matching of facial halves in the overlap area before merging was 87.5 ± 6.8 per cent and the average distance between them 0.3 ± 0.1 mm.

The results of quantitative analysis of facial symmetry for both genders are presented in Table 1. On average, the percentage of symmetry of the whole face in males was 53.49 ± 10.73 per cent and in females 58.50 ± 10.27 per cent. Unpaired *t*-test revealed that the difference of 5.01 per cent was statistically significant. Upper and middle thirds of male faces had significantly lower symmetry than those of female faces ($P < 0.01$). There was no statistically significant gender difference in the amount of symmetry of the lower third of the face ($P > 0.05$). Average distance between the original and the mirror facial shells was generally higher in males than in females, and the difference was statistically significant ($P < 0.01$). There was no statistically significant difference in the amount of maximum asymmetry between genders ($P > 0.05$). The ANOVA did not reveal any statistically significant difference in three-dimensional facial symmetry among the upper, middle, and lower facial thirds within each gender ($P > 0.05$; Table 2).

Table 1 Descriptive statistics and comparison of facial symmetry parameters between genders (independent samples *t*-test). OS, original facial shell; MS, mirror facial shell; Max., maximum; exR-exocanthion right; exL-exocanthion left; chR-cheilion right; chL-cheilion left; msp, midsagittal plane; mid (subscripted), the middle of the distance between bilateral landmarks; g, glabella; n, nasion; prn, pronasale; sn, subnasale; ls, labiale superius; li, labiale inferius; pg, pogonion; ps, palpebrale superius; pi, palpebrale inferius; ex, exocanthion; en, endocanthion; al, alare; cph, crista philtri; ch, cheilion; SD, standard deviation; range, minimum to maximum; diff., difference; CI, confidence interval; n.s., not significant.

Parameters	Males (*n* = 123)		Females (*n* = 147)		Mean difference/ ratio (95% CI)	*P* value
	Mean (SD)	Range	Mean (SD)	Range		
Three-dimensional facial symmetry						
Whole face (%)	53.49 (10.73)	31.01–79.55	58.50 (10.27)	31.99–83.14	−5.01 (−7.54 to −2.48)	<0.001*
Upper third (%)	53.41 (13.03)	22.23–83.50	59.84 (14.52)	24.17–91.34	−6.43 (−9.78 to −3.08)	<0.001*
Middle third (%)	54.07 (13.53)	18.14–84.43	58.87 (12.07)	30.49–85.10	−4.80 (−7.88 to −1.72)	0.002*
Lower third (%)	54.69 (21.92)	10.34–98.10	57.26 (18.25)	10.26–99.10	−2.57 (−7.39 to 2.24)	0.294 (n.s.)
Mean OS–MS (mm)	0.61 (1.28)**	0.33–1.14	0.54 (1.27)**	0.28–1.05	1.14 (1.07 to 1.20)	<0.001*
Max. OS–MS (mm)	2.85 (1.35)**	1.46–4.98	2.67 (1.37)**	1.34–4.92	1.07 (0.99 to 1.14)	0.084 (n.s.)
Angular parameters						
1. exR–exL–pg (°)	65.32 (1.35)	62.15–68.73	64.59 (1.51)	61.32–68.98	0.73 (0.38 to 1.08)	<0.001*
2. exL–exR–pg (°)	65.85 (1.44)	62.26–69.68	64.97 (1.49)	61.41–69.32	0.88 (0.53 to 1.23)	<0.001*
Difference 1−2 (°)	1.31 (1.12)	0.01–5.47	1.34 (0.93)	0.01–5.53	−0.03 (−0.27 to 0.22)	0.840 (n.s.)
exRexL–chRchL (°)	2.07 (1.18)	0.14–6.23	2.34 (1.29)	0.24–7.32	−0.27 (−0.57 to 0.03)	0.080 (n.s.)
Linear parameters						
g–msp (mm)	0.81 (0.35)***	0.01–3.01	0.77 (0.33)***	0.00–2.27	0.04 (−0.04 to 0.13)	0.286 (n.s.)
n–msp (mm)	0.73 (0.29)***	0.04–2.23	0.67 (0.30)***	0.00–1.74	0.06 (−0.02 to 0.13)	0.135 (n.s.)
prn–msp (mm)	0.78 (0.35)***	0.01–4.44	0.74 (0.33)***	0.00–2.94	0.04 (−0.04 to 0.13)	0.296 (n.s.)
sn–msp (mm)	0.67 (0.32)***	0.00–3.42	0.62 (0.30)***	0.01–2.03	0.05 (−0.02 to 0.13)	0.181 (n.s.)
ls–msp (mm)	0.76 (0.34)***	0.00–4.06	0.74 (0.33)***	0.00–2.70	0.02 (−0.06 to 0.10)	0.557 (n.s.)
li–msp (mm)	0.81 (0.36)***	0.00–3.14	0.80 (0.36)***	0.00–3.25	0.01 (−0.07 to 0.10)	0.816 (n.s.)
pg–msp (mm)	0.94 (0.42)***	0.00–6.14	0.88 (0.39)***	0.00–4.40	0.06 (−0.05 to 0.15)	0.312 (n.s.)
ps_{mid}–msp (mm)	0.67 (0.29)***	0.00–2.37	0.68 (0.31)***	0.02–1.95	−0.01 (−0.08 to 0.06)	0.827 (n.s.)
pi_{mid}–msp (mm)	0.67 (0.30)***	0.00–1.98	0.71 (0.29)***	0.01–1.80	−0.04 (−0.11 to 0.03)	0.273 (n.s.)
ex_{mid}–msp (mm)	0.68 (0.30)***	0.01–1.84	0.73 (0.29)***	0.00–1.79	−0.05 (−0.12 to 0.02)	0.160 (n.s.)
en_{mid}–msp (mm)	0.67 (0.30)***	0.00–1.91	0.63 (0.30)***	0.00–2.83	0.04 (−0.03 to 0.11)	0.274 (n.s.)
al_{mid}–msp (mm)	0.52 (0.27)***	0.01–3.48	0.54 (0.27)***	0.00–1.75	−0.02 (−0.08 to 0.05)	0.540 (n.s.)
cph_{mid}–msp (mm)	0.83 (0.36)***	0.01–4.07	0.78 (0.32)***	0.00–2.69	0.05 (−0.03 to 0.14)	0.175 (n.s.)
ch_{mid}–msp (mm)	0.81 (0.31)***	0.00–2.80	0.77 (0.34)***	0.01–3.19	0.04 (−0.03 to 0.13)	0.227 (n.s.)

*Statistically significant.
**Geometric mean and geometric standard deviation.
***Square root transformed.

Table 2 Comparison of facial thirds in the amount of symmetry. n.s., not significant.

	Upper third (%)	Middle third (%)	Lower third (%)	ANOVA	
	Mean (SD)	Mean (SD)	Mean (SD)	*F*	*P*
Males	53.41 (13.03)	54.07 (13.53)	54.69 (21.92)	0.175	0.839 (n.s.)
Females	59.84 (14.52)	58.87 (12.07)	57.26 (18.25)	0.885	0.414 (n.s.)

The average difference between the exR–exL–pg and the exL–exR–pg angles (Figure 4) was 1.31 ± 1.12 degrees in males and 1.34 ± 0.93 degrees in females. The third angle, exRexL–chRchL, showed slight lip line asymmetry of 2.07 ± 1.18 degrees in males and 2.34 ± 1.29 degrees in females. There was no statistically significant gender difference in angular parameters of facial symmetry ($P > 0.05$).

Average values of linear parameters of facial symmetry were less than 1 mm. In general, 'alare' was the least asymmetric and 'pogonio' the most asymmetric landmark. Maximum horizontal asymmetry ranged from 1.84 mm ('exocanthion') to 6.14 mm ('pogonion') in males and from 1.74 mm ('nasion') to 4.40 mm ('pogonion') in females. The amount of horizontal asymmetry of the landmarks did not differ significantly between genders ($P > 0.05$).

Discussion

Facial symmetry has been attracting attention of orthodontists and maxillofacial surgeons for decades. Progress of science and technology enables accurate and meticulous analysis of facial soft tissue anatomy, which was not feasible previously. In order to further improve diagnosis of facial symmetry, it is important to analyse faces objectively in three dimensions. Laser surface scanning provides such analysis in an accurate, reliable, and non-invasive manner (Kau *et al.*, 2004, 2005a,b; Zhurov *et al.*, 2005).

Different methods for three-dimensional analysis of facial symmetry have been suggested, but none of them is universally accepted. In this study, the focus was on the surface matching of the original and the mirror facial shells obtained by laser surface scanning. Once an image of a subject has been captured and processed, a mirror image can be generated and superimposed on the original one using iterative closest point algorithm. Theoretically, a face is perfectly symmetric if it is identical to its mirror image. Similar concept has been applied in two-dimensions, using composite photographs consisting of left–left and right–right facial halves, in order to investigate the effects of asymmetry on human perception (Penton-Voak *et al.*, 2001; Zaidel and Cohen, 2005).

The absolute distances between all pairs of points on the surfaces of the original and mirror facial shells have been automatically calculated and the average and maximum distances used in the subsequent analysis. The percentage of surface matching between the two shells was also measured. Deviations up to 0.5 mm were considered insignificant. This tolerance level was chosen according to the results of previous investigation, which showed that the accuracy of Minolta Vivid laser scanner is 0.56 ± 0.25 mm (Kau *et al.*, 2004). This method is independent of any symmetry plane and not influenced by the size of the face. One of the potential limits is the absence of the overlap between the original face and the mirror face in the marginal areas. Special consideration should be given to the image processing stages. Furthermore, laser scanning quality should be consistently checked prior to merging facial halves captured by two devices.

The results for three-dimensional parameters of facial symmetry showed that, on average, slightly more than half of the male face was symmetric. Mean symmetry of female faces was significantly higher, but the difference of 5 per cent, albeit statistically significant, may not be clinically relevant (95 per cent confidence interval between 2.5 and 7.5 per cent). Statistically significant gender difference was found for the upper and middle thirds of the face but not for the lower third. When facial thirds were compared within each gender, no statistically significant differences were revealed. Slight lip line asymmetry was revealed by measuring the exRexL–chRchL angle. On average, linear parameters did not exceed 1 mm and 'pogonion' was the most asymmetric landmark on the face. Angular and linear parameters of facial symmetry did not show any significant gender difference.

These findings can be directly compared to our recent prospective study on facial symmetry in Finnish adolescents (Djordjevic *et al.*, 2011). The results generally coincide, except that the gender difference in three-dimensional symmetry was not found in the later study. One of the explanations for this might be that the sample size was small and non-parametric tests not sensitive enough to reveal subtle difference, which was detected in the present study. Lip line asymmetry in general population has been previously analysed using the same angle on frontal facial photographs in 1282 Korean young adults, 18–29 years of age (Song *et al.*, 2007). The average values of the angle (0.2 ± 1.4 degrees in males and 0.3 ± 1.3 degrees in females) were less than in this study

There is no consensus in the published literature on the most asymmetric part of the face. Some authors stated that the upper third is the most asymmetric (Farkas and Cheung, 1981; Farkas, 1994), whereas others found the middle (Ercan *et al.*, 2008) and the lower third (Ferrario *et al.*, 1994; Severt and Proffit, 1997; Shaner *et al.*, 2000; Haraguchi *et al.*, 2002) to be the most asymmetric. The differences can be explained by different methodological approaches (two-dimensional or three-dimensional) and selection of participants (in some studies orthodontic patients), contrary to the random sampling from general population performed in this study.

The finding that the upper, middle, and lower parts of the face do not differ significantly in terms of the amount of facial symmetry may have important clinical implications.

An orthodontist should bear in mind that patients' perceptions of facial attractiveness may depend on the appearance/symmetry of features in the upper and middle thirds of the face, which are out of reach of orthodontic treatment. As patients' expectations might be high, good communication prior to undertaking treatment is essential. Colour maps can enhance patient's understanding of the problem and possibly impede unrealistic expectations.

When facial symmetry of a particular patient is to be compared with the average values, obtained from this or any other study, the difference must be cautiously interpreted. For example, a face with a visible deviation of the nose or chin may have the same degree of three-dimensional symmetry as a face with a barely noticeable asymmetry in the cheeks or forehead or a face with asymmetry scattered around the whole surface. It underlines the importance of further research to investigate the relationship between objective measurement and individual perception of facial symmetry. In the last few years, such research has been conducted mainly on photographs (van Keulen, *et al.*, 2004; Evans *et al.*, 2005; Chatrath *et al.*, 2007) and in a recent study on the three-dimensional images obtained by optical sensor (Meyer-Marcotty *et al.*, 2011). Facial laser scans could be applied in a similar manner in future studies.

To our knowledge, this is the first study to analyse facial symmetry in a large cohort of healthy adolescents using laser surface scanning. We believe that it is important to establish age- and gender-specific three-dimensional norms for facial morphology and symmetry in a given population. Therefore, it is hoped that this research would initiate further investigation in other populations and among different age groups in order to create databases, which will be applied clinically.

Conclusions

Faces of male 15-year-old adolescents were less symmetric than those of females, but the difference in the amount of symmetry, albeit statistically significant, may not be clinically relevant. Upper, middle, and lower thirds of the face did not differ in the amount of three-dimensional symmetry. Angular and linear parameters of facial symmetry did not show any gender difference.

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References

Burke P H, Healy M J 1993 A serial study of normal facial asymmetry in monozygotic twins. Annals of Human Biology 20: 527–534

Chatrath P, De Cordova J, Nouraei S A, Ahmed J, Saleh H A 2007 Objective assessment of facial asymmetry in rhinoplasty patients. Archives of Facial Plastic Surgery 9: 184–187

Djordjevic J *et al.* 2011 Three-dimensional longitudinal assessment of facial symmetry in adolescents. European Journal of Orthodontics 35: 143–151

Ercan I *et al.* 2008 Facial asymmetry in young healthy subjects evaluated by statistical shape analysis. Journal of Anatomy 213: 663–669

Evans C A, Viana G, Anderson N K, Giddon D B 2005 Tolerance of deviations in eye and mouth position. Orthodontics and Craniofacial Research 8: 75–84

Farkas L G (ed.) 1994 Anthropometry of the head and face. Raven Press, New York, pp. 20–25. 103–111

Farkas L G, Cheung G 1981 Facial asymmetry in healthy North American Caucasians. An anthropometrical study. Angle Orthodontist 51: 70–77

Faul F, Erdfelder E, Lang A G, Buchner A 2007 G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods 39: 175–191

Ferrario V F, Sforza C, Ciusa V, Dellavia C, Tartaglia G M 2001 The effect of sex and age on facial asymmetry in healthy subjects: a cross-sectional study from adolescence to mid-adulthood. Journal of Oral and Maxillofacial Surgery 59: 382–388

Ferrario V F, Sforza C, Dellavia C, Tartaglia G, Colombo A, Carù A 2003 A quantitative three-dimensional assessment of soft tissue facial asymmetry of cleft lip and palate adult patients. Journal of Craniofacial Surgery 14: 739–746

Ferrario V F, Sforza C, Poggio C E, Tartaglia G 1994 Distance from symmetry: a three-dimensional evaluation of facial asymmetry. Journal of Oral and Maxillofacial Surgery 52: 1126–1132

Ferrario V F, Sforza C, Miani A Jr, Serrao G 1995 A three-dimensional evaluation of human facial asymmetry. Journal of Anatomy 186: 103–110

Fischer B 1954 Asymmetry of the dentofacial complex. Angle Orthodontist 24: 179–192

Golding J, ALSPAC Study Team 2004 The Avon Longitudinal Study of Parents and Children (ALSPAC)—study design and collaborative opportunities. European Journal of Endocrinology 151: U119–U123

Haraguchi S, Iguchi Y, Takada K 2008 Asymmetry of the face in orthodontic patients. Angle Orthodontist 78: 421–426

Haraguchi S, Takada K, Yasuda Y 2002 Facial asymmetry in subjects with skeletal Class III deformity. Angle Orthodontist 72: 28–35

Hardie S, Hancock P, Rodway P, Penton-Voak I, Carson D, Wright L 2005 The enigma of facial asymmetry: is there a gender-specific pattern of facedness? Laterality 10: 295–304

Hartmann J, Meyer-Marcotty P, Benz M, Häusler G, Stellzig-Eisenhauer A 2007 Reliability of a method for computing facial symmetry plane and degree of asymmetry based on 3D-data. Journal of Orofacial Orthopedics 68: 477–49

Hwang H S, Youn I S, Lee K H, Lim H J 2007 Classification of facial asymmetry by cluster analysis. American Journal of Orthodontics and Dentofacial Orthopedics 132: 279.e1–e6

Kambylafkas P, Murdock E, Gilda E, Tallents R H, Kyrkanides S 2006 Validity of panoramic radiographs for measuring mandibular asymmetry. Angle Orthodontist 76: 388–393

Kau C H, Knox J, Zhurov A I, Richmond S 2004 Validation of a portable 3D optical scanning device for field studies. Proceedings of the 7th

European Craniofacial Congress, Bologna, Italy, Monduzzi Editore, International Proceedings Division, pp. 41–45

Kau C H *et al.* 2005a Natural head posture for measuring three-dimensional soft tissue morphology. In: Middleton J, Shrive M G, Jones M L (eds). Computer methods in biomechanics and biomedical engineering—5 FIRST Numerics Ltd, Cardiff

Kau C H *et al.* 2005b Reliability of measuring facial morphology with a 3-dimensional laser scanning system. American Journal of Orthodontics and Dentofacial Orthopedics 128: 424–430

Kiyak H A 2000 Cultural and psychologic influences on treatment demand. Seminars in Orthodontics 6: 242–248

Kiyak H A 2008 Does orthodontic treatment affect patients' quality of life? Journal of Dental Education 72: 886–894

Komori M, Kawamura S, Ishihara S 2009 Averageness or symmetry: which is more important for facial attractiveness? Acta Psychologica 131: 136–142

Kurt G, Uysal T, Sisman Y, Ramoglu S I 2008 Mandibular asymmetry in Class II subdivision malocclusion. Angle Orthodontist 78: 32–37

Liukkonen M, Sillanmäki L, Peltomäki T 2005 Mandibular asymmetry in healthy children. Acta Odontologica Scandinavica 63: 168–172

Meyer-Marcotty P, Alpers G W, Gerdes A B, Stellzig-Eisenhauer A 2010 Impact of facial asymmetry in visual perception: a 3-dimensional data analysis. American Journal of Orthodontics and Dentofacial Orthopedics 137: 168.e1–e.8

Meyer-Marcotty P, Stellzig-Eisenhauer A, Bareis U, Hartmann J, Kochel J 2011 Three-dimensional perception of facial asymmetry. European Journal of Orthodontics 33: 647–653

Miguel J A, Sales H X, Quintão C C, Oliveira B H, Feu D 2010 Factors associated with orthodontic treatment seeking by 12–15-year-old children at a state university-funded clinic. Journal of Orthodontics 37: 100–106

Moss J P, Coombes A M, Linney A D, Campos J 1991 Methods of three dimensional analysis of patients with asymmetry of the face. Proceedings of the Finnish Dental Society 87: 139–149

Nkenke E *et al.* 2006 Determination of facial symmetry in unilateral cleft lip and palate patients from three-dimensional data: technical report and assessment of measurement errors. Cleft Palate-Craniofacial Journal 43: 129–137

O'Grady K F, Antonyshyn O M 1999 Facial asymmetry: three-dimensional analysis using laser surface scanning. Plastic and Reconstructive Surgery 104: 928–937

Peck S, Peck L, Kataja M 1991 Skeletal asymmetry in esthetically pleasing faces. Angle Orthodontist 61: 43–48

Penton-Voak I S *et al.* 2001 Symmetry, sexual dimorphism in facial proportions and male facial attractiveness. Proceedings of the Royal Society B Biological Sciences 268: 1617–1623

Primožič J, Ovsenik M, Richmond S, Kau C H, Zhurov A 2009 Early crossbite correction: a three-dimensional evaluation. European Journal of Orthodontics 31: 352–356

Primožič J, Richmond S, Kau C H, Zhurov A, Ovsenik M 2011 Three-dimensional evaluation of early crossbite correction: a longitudinal study. European Journal of Orthodontics 35: 7–13

Ras F, Habets L L, Van Ginkel F C, Prahl-Andersen B 1994a Facial left-right dominance in cleft lip and palate: three-dimensional evaluation. Cleft Palate-Craniofacial Journal 31: 461–465

Ras F, Habets L L, Van Ginkel F C, Prahl-Andersen B 1994b Three-dimensional evaluation of facial asymmetry in cleft lip and palate. Cleft Palate-Craniofacial Journal 31: 116–121

Ras F, Habets L L, Van Ginkel F C, Prahl-Andersen B 1995 Logitudinal study on three-dimensional changes of facial asymmetry in children between 4 to 12 years of age with unilateral cleft lip and palate. Cleft Palate-Craniofacial Journal 32: 463–468

Rhodes G 2006 The evolutionary psychology of facial beauty. Annual Review of Psychology 57: 199–226

Rossi M, Ribeiro E, Smith R 2003 Craniofacial asymmetry in development: an anatomical study. Angle Orthodontist 73: 381–385

Severt T R, Proffit W R 1997 The prevalence of facial asymmetry in the dentofacial deformities population at the University of North Carolina. International Journal of Adult Orthodontics and Orthognathic Surgery 12: 171–176

Shaner D J, Peterson A E, Beattie O B, Bamforth J S 2000 Assessment of soft tissue facial asymmetry in medically normal and syndrome-affected individuals by analysis of landmarks and measurements. American Journal of Medical Genetics 93: 143–154

Skvarilova B 1993 Facial asymmetry: type, extent and range of normal values. Acta Chirurgia Plastica 35: 173–180

Smith W M 2000 Hemispheric and facial asymmetry: gender differences. Laterality 5: 251–258

Song W C *et al.* 2007 Horizontal angular asymmetry of the face in Korean young adults with reference to the eye and mouth. Journal of Oral and Maxillofacial Surgery 65: 2164–2168

Stauber I *et al.* 2008 Three-dimensional analysis of facial symmetry in cleft lip and palate patients using optical surface data. Journal of Orofacial Orthopedics 69: 268–282

Toma A M, Zhurov A, Playle R, Richmond S 2008 A three-dimensional look for facial differences between males and females in a British-Caucasian sample aged 15 ½ years old. Orthodontics and Craniofacial Research 11: 180–185

Toma A M, Zhurov A, Playle R, Ong E, Richmond S 2009 Reproducibility of facial soft tissue landmarks on 3D laser-scanned facial images. Orthodontics and Craniofacial Research 12: 33–42

van Keulen C, Martens G, Dermaut L 2004 Unilateral posterior cross-bite and chin deviation: is there a correlation? European Journal of Orthodontics 26: 283–288

Zaidel D W, Cohen J A 2005 The face, beauty, and symmetry: perceiving asymmetry in beautiful faces. International Journal of Neuroscience 115: 1165–1173

Zhurov A I, Kau C H, Richmond S 2005 Computer methods for measuring 3D facial morphology. In: Middleton J, Shrive M G, Jones M L (eds). Computer methods in biomechanics and biomedical engineering—5 First Numerics Ltd, Cardiff, ISBN 0-9549670-0-3

Zhurov A I, Richmond S, Kau C H, Toma A M 2010 Averaging facial images. In: Kau C H, Richmond S (eds). Three-dimensional imaging for orthodontics and maxillofacial surgery, Wiley-Blackwell, London, ISBN 978–1405162401