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Assessment of facial asymmetry in growing subjects with a three-dimensional laser scanning system

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Structured Abstract

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Objectives – To evaluate facial asymmetry in growing subjects with no malocclusion on three-dimensional laser facial scans.

Setting and Sample Population – Twenty-seven healthy Caucasian children (15 boys and 12 girls, aged 5.4 ± 0.3 years) in the primary dentition without malocclusion were randomly selected from a local kindergarten in Slovenia.

Material and Methods – Surface facial images were obtained using a three-dimensional laser scanning system at baseline and at 18, 30, 42 and 54 months of follow-up. Facial asymmetry was assessed quantitatively by measuring the average distance between facial image and mirrored image. Further, the percentage of asymmetry was calculated as the percentage of image to mirrored image not coinciding within 0.5 mm. Qualitative assessment was performed on colour deviation maps by recording the predominant side of the face for the upper, middle and lower parts of the face separately. Nonparametric tests were used for data analysis.

Results – No face was perfectly symmetric. The average distance between the mirrored images for the whole face ranged 0.22–0.85 mm and the percentage of asymmetry 7.8–66.9. There were no significant gender differences ($p > 0.05$), and no significant change was found over the observed period. The upper part of the face was the least asymmetric, while the lower and middle parts showed similar degrees of asymmetry.

Conclusion – Facial asymmetry is already present at an early developmental stage and does not show any tendency to increase or decrease with growth in the pre-pubertal period.

Key words: facial asymmetry; three-dimensional laser scanning

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Introduction

Asymmetry in craniofacial areas can be recognized as differences in the size or relationship between the two sides of the face. This may be the result of either discrepancies in the form of individual bones or a malposition of one or more bones in the craniofacial complex. The asymmetry may also be limited to the overlying soft tissues (1). Although perfect facial symmetry does not exist in nature, asymmetry ranges from clinically undetectable to a gross abnormality (2–6).

The organism does not favour identical growth of homologous bilateral structures (7). The difference in the degree of growth between the right and left sides may be caused by genetic factors, environmental factors or a combination of both (8, 9). The expression of the craniofacial asymmetry can be related to heredity as well as to the functional activity of the skeletal muscular system, especially of the masticatory apparatus (10, 11).

Orthodontists routinely evaluate facial asymmetry on photographs (Fig. 1A) or on postero-anterior (PA) cephalograms. However, both these techniques represent a three-dimensional (3D) subject in two dimensions (2D), which is their primary limitation. A 2D assessment of a 3D facial change provides incomplete data and does not account for differences in facial depth and shape (12).

Another problem in assessing asymmetry on photographs and PA cephalograms is landmark identification of hard and soft tissues. It has been claimed that at this stage, the major source of errors occurs (13) as it has been reported that the use of landmarks increases the degree of bias (13, 14). Further, the main disadvantage of evaluating facial asymmetry with any of these methods is also that the criteria for determining the facial midline need to be defined, despite the fact that it has been reported that there is no absolute facial midline (15). The reference points used to determine the facial midline, such as the glabella, nasion, pronasale, subnasale, labrale superious, labrale inferious and pogonion, are often not exactly in the middle of the face, which calls into question the precision of the symmetry plane measurement. Therefore, a landmark-independent method has to be used for analysing facial asymmetry (16).

Recently, several methods of analysing facial changes in three dimensions have been developed (17–21), including surface laser scanning. Images have been created to establish databases for normative populations (22–24) and cross-sectional growth changes (25) and also to assess clinical outcomes in surgical (26) and non-surgical treatments (21, 27, 28) in the head and neck regions.

In recent studies, facial asymmetry has also been quantified by means of landmark-independent methods, which take into account all available facial points and allow a full face analysis (5, 27, 29). However, most of these studies were mainly applied for the analysis of facial

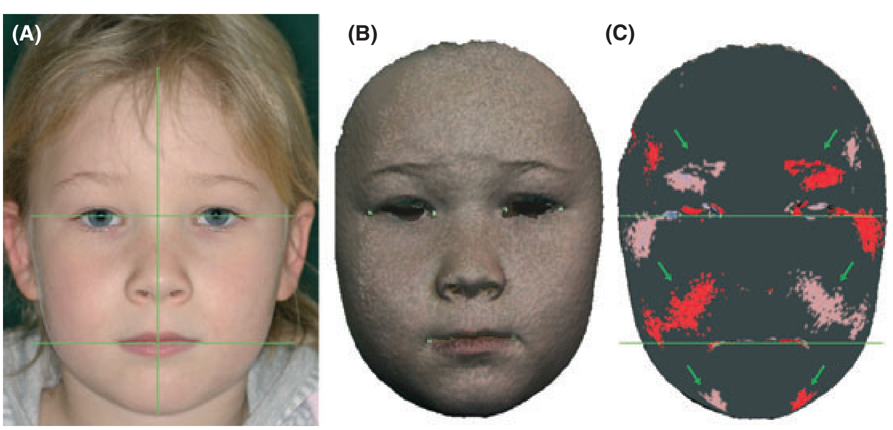

Fig. 1. Assessment of facial asymmetry on frontal photographs (A) and on 3D facial images (B) using a colour deviation map of the mirrored images (C). Black colour indicates image–image deviations within 0.5 mm that we considered symmetric; red colour indicates the positive, while blue colour the negative differences. The lines through the endocanthions and outer commissures of the lips were used to divide the face into the upper, middle and lower parts. Areas of asymmetry are indicated with green arrows.

asymmetry in orthodontic patients (6, 21), including cleft lip and palate patients (11, 16). Although some studies report the degree of symmetry in healthy pubertal and post-pubertal subjects (5, 30), there is little knowledge on the amount of three-dimensional facial symmetry in healthy pre-pubertal subjects and on changes in facial symmetry during the growth period.

The aim of the present longitudinal study was to assess facial asymmetry in growing subjects without malocclusion using a landmark-independent three-dimensional method.

Material and methods

Subjects and study design

A group of 27 Caucasian children (15 boys and 12 girls) aged 5.4 ± 0.3 years (4.9–6.2 years) were randomly selected from a local kindergarten. Only children in the primary dentition without malocclusion and having a good general health with no respiratory, deglutition or mastication problems were included. Ethical approval for this study was gained from the Slovenian Ethical Committee of the Medical University in Ljubljana (Ref. KME 80-81/04/06), Slovenia, and informed consent was obtained from the parents of all subjects.

The 3D surface facial images were obtained at baseline with all the children in the primary dentition, at 18 months (eruption of the first permanent molars and central incisors), 30 (first permanent molars in occlusion, eruption of permanent lateral incisors), 42 (complete mixed dentition) and 54 (complete mixed dentition) months of follow-ups.

Surface facial images were obtained using two Konica/Minolta Vivid 910 laser scanners angled to capture left and right sides of the face with significant overlap in the anterior part of the face to facilitate registration and merging of the two images to produce one facial image (31). These devices are eye-safe and have scanning time of about 2.5 s with a reported manufacturing accuracy of 0.3 mm (http://www.konicaminolta.com). Natural head posture (NHP) was adopted for this study as this has been shown to be clinically reproducible (32). The technique for positioning the patient and image capture has been validated and described elsewhere (31), and their use in growing children has been previously validated (31).

Assessment of facial asymmetry

The 3D data were imported to a reverse-modelling software package, Rapidform™ 2006 (INUS Technology Inc, Seoul, Korea). Each scan of the face (left and right images) was processed to remove unwanted data, registered and merged to produce a complete facial image (Fig. 1b). Left and right scans were merged only if there was at least 70% matching between them in the overlap area with ±0.5 mm tolerance (4, 33).

The facial image was aligned to the mid-sagittal (Y–Z) and transverse planes through the endocanthions of the eyes (X–Z). This procedure has been fully automated through a set of in-house VBA (Visual Basic Applications) subroutines for Rapidform; it requires only three landmarks to be set manually: left and right endocanthions (used to calculate the mid-endocanthion) and pogonion (used to identify the natural facial orientation), and it has been reported elsewhere (34).

The facial image was divided into three functional parts: 1) the upper part, defined as the part of the face above the endocanthion plane (forehead), 2) the middle part, from the endocanthion plane to the plane through the outer commissures of the lips (i.e. maxilla), and 3) the lower part, below this plane (i.e. mandible) (Fig. 1c). To check for left/right symmetry, the face was mirrored across the Y–Z plane and the mirrored images were superimposed using the automatic best-fit procedure of the mirrored facial image surfaces. The symmetry plane of this best-fitted facial images (original and mirrored) structure has been regarded as the sagittal plane of the original face (34).

Facial asymmetry was evaluated both quantitatively and qualitatively. Asymmetry was assessed quantitatively as the average distances (in millimetres) between the mirrored images and as the percentage of mirrored images not coinciding within 0.5 mm (percentage of asymmetry). The greater the average distance between the mirrored images and the greater the percentage of asymmetry, the greater the asymmetry of the face. The parameters were calculated for the whole face and for each part of the face separately.

Qualitatively, the predominance of either the left or right side of the face was assessed for each part of the face separately on colour deviation maps (Fig. 1c). The assessment was performed by an experienced operator (JP). Changes in the predominant side over the observed period of time were also recorded. The frequencies of left-/right-side predominance were calculated.

Statistical analysis

The Statistical Package for Social Sciences Software release 13.0 (SPSS Inc., Chicago, IL, USA) was used for data analysis. The balancing of the mean ages between the sexes was tested with a Student's t-test. After testing the normality of the data with the Shapiro–Wilk test and Q-Q normality plots, and the equality of variance among the data sets using a Levene's test, nonparametric methods were used for data analysis. Nevertheless, the mean and standard deviations are reported for descriptive purposes.

The average distance and percentage of facial asymmetry parameters for the whole face have been processed according to the gender groups. A Friedman's test was used to assess the significance of the differences in both parameters over the time points within each gender group. A Mann–Whitney U-test was used to assess the significance of the differences in both parameters between the two gender groups within each time point.

The average distance and percentage of facial asymmetry parameters were further clustered according to the different parts of the face (upper, middle and lower) and analysed separately. A Friedman's test was used to assess the significance of the differences in both the average distance and percentage of facial asymmetry parameters over the time points, within each part of the face recording, and among the parts of the face recordings within each time point. When significant interactions were seen, a Bonferroni-corrected Wilcoxon's test was used for pairwise comparisons. Similarly, a Cochran's test followed by a McNemar's test was employed to evaluate the significance of the difference in the frequencies of the predominant sides, that is, right or left.

The results were considered to be significant at p-values below 0.05. Method error was calculated using the intraclass correlation coefficients, which ranged from 0.67 to 0.97.

Results

The mean age was similar between the sexes at baseline and at each following time point, irrespective of the dropouts (Table 1).

No face was perfectly symmetric. In the whole group and over time, the average distance between the mirrored images for the whole face ranged 0.22–0.85 mm and the percentage of asymmetry 7.8–66.9. The mean values and

Table 1. **Sex distribution and ages of the subjects (according to sexes) at the different time points**

	Time point				
Parameter	Baseline (n = 27)	18 months (n = 24)	30 months (n = 27)	42 months (n = 21)	54 months (n = 26)
Sex (n)					
Males	15	14	15	11	14
Females	12	10	12	10	12
Age (years)					
Males	5.5 ± 0.4	7.0 ± 0.4	8.0 ± 0.4	9.0 ± 0.5	10.0 ± 0.4
Females	5.3 ± 0.2	6.9 ± 0.2	7.8 ± 0.2	8.8 ± 0.3	9.8 ± 0.2
Diff.	NS	NS	NS	NS	NS

Diff., significance of the differences between the sexes. NS, not statistically significant.

standard deviations for the facial asymmetry parameters (average distance and percentage of asymmetry) for the whole face over time separately for males and females are shown in Table 2. As there were no significant differences for the facial asymmetry parameters between the sexes ($p > 0.05$), the parameters for each part of the face are shown for the whole group in Table 3. The upper part of the face was the least asymmetric throughout the study, while the middle and lower parts showed mostly similar values of average distances and asymmetry with the

Table 2. **Mean values and standard deviations for the facial asymmetry parameters (average distance and percentage of asymmetry) for the whole face over time according to sexes**

Parameter/ Sex	Time point: Baseline (n = 27)	18 months (n = 24)	30 months (n = 27)	42 months (n = 21)	54 months (n = 26)	Diff.
Average distance (mm)						
Males	0.44 ± 0.12	0.46 ± 0.14	0.45 ± 0.08	0.47 ± 0.08	0.43 ± 0.08	NS
Females	0.43 ± 0.12	0.40 ± 0.08	0.42 ± 0.07	0.40 ± 0.08	0.38 ± 0.09	NS
Diff.	NS	NS	NS	NS	NS	
Asymmetry (%)						
Males	31.7 ± 10.6	34.5 ± 12.1	33.4 ± 8.5	35.8 ± 9.2	32.0 ± 8.1	NS
Females	29.3 ± 10.6	28.6 ± 9.3	30.5 ± 6.7	29.2 ± 9.2	27.4 ± 11.5	NS
Diff.	NS	NS	NS	NS	NS	

Diff., significance of the differences over time point or between the sexes. NS, not statistically significant.

Table 3. **The mean values and standard deviations for the facial asymmetry parameters (average distance and percentage of asymmetry) and the frequencies of the predominant side of the face over time according to each part of the face**

Parameter/Part of the face	Time point: Baseline (n = 27)	18 months (n = 24)	30 months (n = 27)	42 months (n = 21)	54 months (n = 26)	Diff.
Average distance (mm)						
Upper	0.39 ± 0.10	0.40 ± 0.13	0.41 ± 0.08	0.40 ± 0.09	0.37 ± 0.10	$p < 0.05$
Middle	0.44 ± 0.16	0.44 ± 0.14	0.45 ± 0.12	0.45 ± 0.13	0.43 ± 0.13	NS
Lower	0.52 ± 0.25	0.48 ± 0.27	0.45 ± 0.14	0.47 ± 0.15	0.42 ± 0.16	NS
Diff.	NS	NS	NS	NS	NS	
Asymmetry (%)						
Upper	27.1 ± 11.0	27.4 ± 12.6	28.6 ± 8.4	26.9 ± 7.5	24.9 ± 10.7	NS
Middle	30.8 ± 14.5	34.1 ± 14.4	33.8 ± 13.3	33.2 ± 11.8	32.2 ± 13.9	NS
Lower	36.9 ± 18.2	34.5 ± 21.7	34.5 ± 13.3	35.5 ± 15.4	31.6 ± 14.6	NS
Diff.	$p < 0.05$	$p < 0.05$	NS	NS	NS	
Predominant side (left/right frequencies as %)						
Upper	22.2/77.8	25.9/63.0	29.6/70.4	29.6/48.1	22.2/74.1	NS
Middle	63.0/37.0*	40.7/48.1	44.4/55.6	40.7/37.0	40.7/55.6	NS
Lower	51.9/48.1	40.7/48.1	37.0/63.0	40.7/37.0	33.3/63.0	NS
Diff.	$p < 0.01$	NS	NS	NS	NS	

Diff., significance of the differences over time point or among the parts of the face. *Statistically significantly different as compared to the corresponding value of the upper part of the face. NS, not statistically significant.

exception for the baseline values. The differences were statistically significant for the percentage of asymmetry at baseline ($p = 0.03$) and at 18 months ($p = 0.03$) of follow-up. At the pairwise comparisons, no significant differences between the parts of the face were found.

The frequencies of side predominance of each part of the face are shown in Table 3. In the upper part of the face, right-side predominance was more frequent, while in the middle and lower parts, although not statistically significant, there was more variability in the side predominance throughout the study. However, no significant difference for side predominance was found between the three parts, except at baseline, when, at the pairwise comparison, the middle part showed a significantly more frequent left predominance ($p = 0.021$) compared to the upper part.

Discussion

Symmetry and balance refer to the state of facial equilibrium, the correspondence in size, shape and arrangement of facial features on opposite sides of the median sagittal plane, while asymmetry means imbalance (35). However, as no human face is perfectly symmetric, minor, non-pathologic facial asymmetry or normal asymmetry is relatively common (36). In fact, in this study, no face was found to be perfectly symmetric.

Using the different evaluation methods of craniofacial asymmetry, various conclusions were proposed by researchers. Previous studies have shown that sex and age do not have an effect on facial asymmetry (5, 30, 37). On the other hand, there is evidence in favour of sexual dimorphism in the amount of facial asymmetry (35).

In the present longitudinal study, facial asymmetry was assessed in growing subjects over a period of 54 months, and no significant differences were seen between the sexes, in accordance with a previous study performed with the same methodology on an older population (5).

Furthermore, no significant changes in the facial asymmetry were seen up to 54 months of follow-up (Table 1). However, dropouts encountered herein may have been responsible for a partial lack of statistical power, thus covering possible differences over time or between the sexes.

Farkas and Cheung (38) reported that the upper part of the face is the most asymmetric, while other authors reported that the greatest asymmetry is detected either in the middle (35) or in lower part (15, 39–42) of the face. Although not statistically significant, according to the average distance parameter between the mirrored images and the percentage of asymmetry, the upper and lower parts of the face were the less and most asymmetric, respectively. However, the middle part of the face showed similar degree of asymmetry as compared to the lower part with the exception for the baseline values.

Further, it should be stated that in the present study, the face was divided into three functional parts, dividing the maxillary part from the movable mandibular part, in contrast to other studies (35, 38, 39) where part of the maxilla below the subnasale point was included in the lower facial third.

Therefore, the differences seen in previous studies (35, 38, 39) could be due to the different methodological approaches, either two- or three-dimensional recordings, used and due to the different subjects monitored. For instance, patients with malocclusion (6, 21) or those randomly selected from general population (5, 30) were examined.

It has been reported that the mandibular region has shown a larger degree of asymmetry (36, 43) because several factors related to dental arches were assumed as causes of craniofacial asymmetries, including asymmetric mastication, loss of deciduous and permanent teeth, loss of contacts and skeletal dysgnathia (8). Therefore, facial asymmetry has been associated with functional activities of the masticatory musculoskeletal system (10, 44). Craniofacial asymmetries are more evident when the functional dentition is established, at least in the literature, because the studies are scarce in early stages of development. This study was performed at an early developmental stage, and children were observed from the primary to the establishment of the mixed dentition. Although no significant differences were found over the observed period of time, at the establishment of a complete mixed dentition, less asymmetry of the lower part of the face was observed.

Several studies of normal asymmetry have reported that the right hemiface is wider than the left one (36, 38, 45), some have found the left hemiface to be wider (42, 43, 46), while others report no significant difference between the right and left hemiface sizes (47). In this study, predominance of one side was assessed for the upper, middle and lower parts of the face separately. Right predominance was found more frequently (77.8% at baseline) in the upper part, while in the middle part, left predominance was more frequent (63.0% at baseline). In the lower part of the face, almost half of the subjects showed a right (48.1% at baseline) and half (50.1% at baseline) a left predominance of the hemiface. Of note, in the present study, a landmark-independent method was used, and asymmetry of the face was assessed in 3D on a younger population than in the reported studies.

Conclusions

The results of this study show that facial asymmetry is already present at an early developmental stage and does not show any tendency to increase or decrease with growth in the pre-pubertal period. No significant gender differences were observed. Although different parts of the face (upper, middle, lower) showed either a left- or right-side predominance, no significant differences were found in the frequencies of side predominance between the three parts.

Clinical relevance

A symmetric face is a central clue for attractiveness, which has a high impact on psychosocial benefit, most probably even in small growing children. However, perfect facial symmetry does not exist in nature, and asymmetry ranges from clinically undetectable to a gross abnormality. Therefore, it is very important to distinguish normal asymmetry from a more pronounced pathological asymmetry for early diagnosis and treatment planning to prevent adverse skeletal growth. This longitudinal study aims to assess facial asymmetry in growing subjects without malocclusion in the pre-pubertal period using a landmark-independent three-dimensional method.

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