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ORIGINAL ARTICLE

Facial morphology of Finnish children with and without developmental hip dysplasia using 3D facial templates

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Structured Abstract
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Background – Developmental dysplasia of the hip (DDH) is a condition that affects the femoral head and the acetabulum and leads to hip subluxation and dislocation. Infants with DDH are usually treated using splints that immobilize their hip joint and are forced on their back for long periods of time. The link between positioning and facial asymmetries is poorly understood.
Objective – To compare the facial morphologies of children with DDH to a group of healthy controls.
Subjects and methods – Fifty-six Finnish patients born with DDH were matched on the basis of gender and age to a control group. Three-dimensional surface images were captured using the 3dMDface system. Using RF6 PP2 software, anthropometric landmarks were plotted and used to calculate asymmetry based on 3D co-ordinates in a reference framework.
Results – There was statistically significant difference between all paired facial shells. Relative to the control group, DDH boys and girls presented a chin-point deviation to the right, a more prominent left orbital ridge, a more protrusive nose and upper lip. The gender-specific subgroups show a similarity of 66.54 and 65.22% in girls and boys, respectively.
Conclusions – Patients with DDH present a facial asymmetry when compared to healthy controls. Gender characteristics are marked whether subjects are affected with DDH or not. Three-dimensional surface imaging is a powerful diagnostic and research tool.

Key words: 3D analysis; asymmetry; face; hip

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Introduction

Developmental dysplasia of the hip (DDH) is a condition that affects the femoral head and the acetabulum and leads to hip subluxation and dislocation. It occurs one in 1000 births and affects more girls than boys (1, 2). The left hip is involved in the majority of cases (60%). This incidence is in relation to the most common intrauterine position, the left occiput anterior, which is believed to push the left hip against the mother's lumbosacral spine. The right hip is affected in 20% and both hips in 20% of cases (3). Infants with DDH are usually treated using splints that immobilize their hip joint. As a result, they are forced on their backs with limited head movement. The relationship between facial asymmetries and infant positioning is poorly reported in the literature. However, a supine sleep position for all children, as recommended by the American Academy of Pediatrics (4), has been associated with an increased incidence of deformational changes in the cranium and face (5–8). Previous literature also shows that children with either deformational plagiocephaly or torticollis have an increased incidence of craniofacial asymmetries, dental arch asymmetry, malocclusions, and need for orthodontic treatment than the general population (9). Moreover, studies linked congenital muscular torticollis with DDH in 14–20% of patients (10, 11). Tolleson et al. (12) determined that facial asymmetry existed in patients with DDH using three-dimensional surface imaging. However, they did not have a control group. Surface imaging acquisition generates a three-dimensional (3D) representation of a face in a non-invasive and non-ionizing manner (13). The accuracy and precision of anthropometric measures derived from 3D stereophotogrammetric images is well documented (14–16). We hypothesize that infants with DDH would also have a tendency toward asymmetry. To test the link between DDH and facial asymmetry, the aim of this study is to compare children with DDH to children with no DDH using 3D imaging.

Subjects and methods

Fifty-six Finnish patients born with developmental hip dysplasia in the Northern Ostrobothnia Hospital District between 1998 and 2002 were recruited. They were all treated using the Von Rosen splint method. None of the children was diagnosed with plagiocephaly or craniosynostosis at the initial clinical examination. This study group had been screened for facial asymmetries in an earlier study (12). All patients were matched for gender and age with healthy children born in the same hospital district and collected from a governmental database of Finnish children. Each group comprised 20 boys and 36 girls.

Image acquisition

All patients had their 3D pictures taken in Natural Head Posture with the 3dMD system (3dMDface, Atlanta, GA,, USA). Participants were seated on a chair at a standard distance so that their face was centered on a computer screen. They were asked to swallow hard and to keep their jaws in a relaxed position just before the images were taken. The 3dMDface™ system combines stereophotogrammetry and a structured light technique. It consists of two camera boxes each containing three lenses (one color and two infrared) working in stereopairs. This system is able to capture full facial images from ear to ear and under the chin in 1.5 ms at the highest resolution. The manufacturer accuracy is < 0.5 mm, and the quoted clinical accuracy is 1.5% of the total observed variance (15). Each image was captured in approximately 50 ms and immediately transferred to the 3dMDpatient™ Software Platform to verify its quality (Fig. 1).

Processing of facial shells and average face construction

All of the images acquired were processed using the RF6 PP2 software (Rapidform Technology Inc, Gangnam-gu, Seoul, Korea.). The data were processed before analysis to obtain an image that had a preserved shape, surface, and volume using custom macros for the RF6 as described previously (17). As a result of this

Fig. 1. Sample pictures generated by the 3dMD™ face system using the 3dMDpatient™ software platform. These views are only snapshots taken from the three-dimensional image, which can be rotated 360 degrees on any axis.

processing procedure, one facial model (or 'shell') was created for each subject.

The second step consisted of superimposing the obtained facial shells to create one average face for each group. The superimposition technique had been described previously and may be summarized as follows (18, 19):

- Images are pre-aligned by determining the principle axis of rotation (based on computing the tensor of inertia of each three-dimensional image).
- Manual positioning is performed, when necessary, to improve the previous stage.
- Best-fit alignment is achieved using the in-built algorithm in RF4.
- Co-ordinates of the images are averaged normally to a facial template.
- Point cloud is triangulated to obtain an average face.
- Areas with small holes are filled in.
- Color texture is applied.
- Standard deviation shells were created.

This procedure resulted in the creation of four composite average faces corresponding to the following subgroups:

- NDDH-M: non-developmental dysplasia of the hip-male
- NDDH-F: non-developmental dysplasia of the hip-female
- DDH-M: developmental dysplasia of the hip-male
- DDH-F: developmental dysplasia of the hip-female.

Subgroups were stratified on the basis of gender to explore the morphological differences between boys and girls.

Parameters measured

To be able to quantify the differences between the four groups, the average shells were again superimposed one over the other by selecting landmarks on each of the corresponding facial average images (endocathion left and right, exocanthion left and right, tip of nose). Subsequent fine registration is performed where the RF6 PP2 software determines the best-fit of the two average shells.

The following parameters were measured: linear measurements, color histograms, and surface areas and shapes.

Linear measurements

When two average shells are superimposed as described earlier, their topographies overlap. The amount of overlap can be quantified in millimeters. Linear measurements measure the mean differences between all points from one surface to another. This value indicates the extent of fit between the average composite faces and allows the quantification of their amount of deviation.

Color histograms

Color histograms are produced using the Rapidform 6 version PP2 software. They allow a visual evaluation of the variation between two superimposed shells. It is positive when the second shell topography is more prominent than the base shell, and negative in the opposite situation. The similarities between the shells are depicted in black. The differences are represented across a color spectrum with values associated with each color. The ends of the spectrum represent the most extreme situations: when comparing two shells, an excessive positive change (prominence) is coded in red, and a great deficiency is represented in blue.

Surface areas/shapes

Surface areas and shapes are automatically generated by the Rapidform 6 version PP2 software with a tolerance level of 0.425 mm applied to the paired surface shells. This value is derived from previous work that showed that 90% of created composite facial scans are within an error of 0.85 mm (20). Therefore, the chosen tolerance level of an average corresponds to 0.425 mm. Area variations within 0.425 mm were considered to be similar surfaces, while surface areas outside this tolerance showed as surface shapes and color deviations.

Analysis

To analyze the similarities and differences between male children and female children born with and without DDH, the following comparisons of average facial shells were made:

- NDDH-M vs. DDH-M
- NDDH-M vs. NDDH-F
- NDDH-M vs. DDH-F
- NDDH-F vs. DDH-M

Fig. 2. Average facial constructs for the developmental dysplasia of the hip (DDH) and non-DDH (NDDH) boys and girls. Blue = NDDH-male. Red = NDDH-female. Green = DDH-male. Yellow = NDDH-female.

- NDDH-F vs. DDH-F
- DDH-M vs. DDH-F

Paired *t*-tests (SPSS 17.0, Chicago, Ill, USA) were used to determine whether significant differences existed between the different subgroups.

Results

Average faces

Average faces constructed for each of the four subgroups: NDDH-M, NDDH-F, DDH-M, and DDH-F are shown in Fig. 2.

Table 1. Absolute linear measurements indicating differences between facial shells

	Max. distance (mm)	Avg. distance (mm)	Std. dev. (mm)
NDDH-M vs. DDH-M	4.68	0.446	0.532
NDDH-M vs. NDDH-F	4.77	0.504	0.623
NDDH-M vs. DDH-F	4.75	0.580	0.565
NDDH-F vs. DDH-M	4.44	0.570	0.744
NDDH-F vs. DDH-F	4.31	0.468	0.605
DDH-M vs. DDH-F	4.50	0.436	0.397

DDH, developmental dysplasia of the hip; DDH-F, DDH-female; DDH-M, DDH-male; NDDH, non-DDH.

Linear measurements

Table 1 shows the average absolute linear differences and their associated standard deviations. The largest absolute difference was observed between NDDH-F and NDDH-M (4.77 mm). Average gender difference between DDH and NDDH groups were 0.446 ± 0.532 mm for boys and 0.468 ± 0.605 mm for girls. The

Table 2. **Signed color map measurements indicating differences in facial shells**

	Max. distance (mm)	Avg. distance (mm)	Std. dev. (mm)	% Similarity
NDDH-M vs. DDH-M	2.00	−0.178	0.671	65.22
NDDH-M vs. NDDH-F	4.74	0.215	0.772	59.74
NDDH-M vs. DDH-F	3.93	−0.122	0.800	50.05
NDDH-F vs. DDH-M	2.32	−0.289	0.892	61.01
NDDH-F vs. DDH-F	2.34	−0.263	0.718	66.54
DDH-M vs. DDH-F	4.50	−0.021	0.589	60.70

DDH, developmental dysplasia of the hip; DDH-F, DDH-female; DDH-M, DDH-male; NDDH, non-DDH.

results indicated that there was statistically significant difference between all paired facial shells.

Color histograms

Table 2 shows the differences between the average facial shells of the four subgroups: NDDH-M, NDDH-F, DDH-M, and DDH-F. The color histograms demonstrate a range of similarity from 50.05% (*NDDH-M* vs. *DDH-F*) to 66.54% (*NDDH-F* vs. *DDH-F*). The gender-specific subgroups show a similarity of 66.54 and 65.22% in girls and boys, respectively. The average linear distance of the signed color histograms between subgroups ranged between −0.289 ± 0.892 mm (*NDDH-F* vs. *DDH-M*) and 0.215 ± 0.772 mm (*NDDH-M* vs. *NDDH-F*).

Figure 3 depicts gender overlay superimpositions: the male subgroup comparison (*NDDH-M* vs. *DDH-M*) showed that the DDH-M group has a chin-point deviation to the right, more prominent left orbital ridge and a more protrusive nose and upper lip when compared to the NDDH-M group. The same findings were reproduced in the female subgroup (*NDDH-F* vs. *DDH-F*): the DDH-F group had facial asymmetry with the chin point being deviated to the right and a more protrusive nose, upper lip, lower lip, and left superior orbital ridge when compared to the female controls.

Surface area⁄shape

The differences seen in the surface areas and shape of the facial shells are reported in Fig. 4 (absolute color) and Fig. 5 (signed color), as explained in the previous section. The similar areas among all subgroups are the forehead, bridge of nose, and perioral soft tissues. The primary differences were noted in the chin, lips, nose, and the right-side malar process and cheeks.

Discussion

This study was conducted to assess facial differences between a group of children with DDH and a control

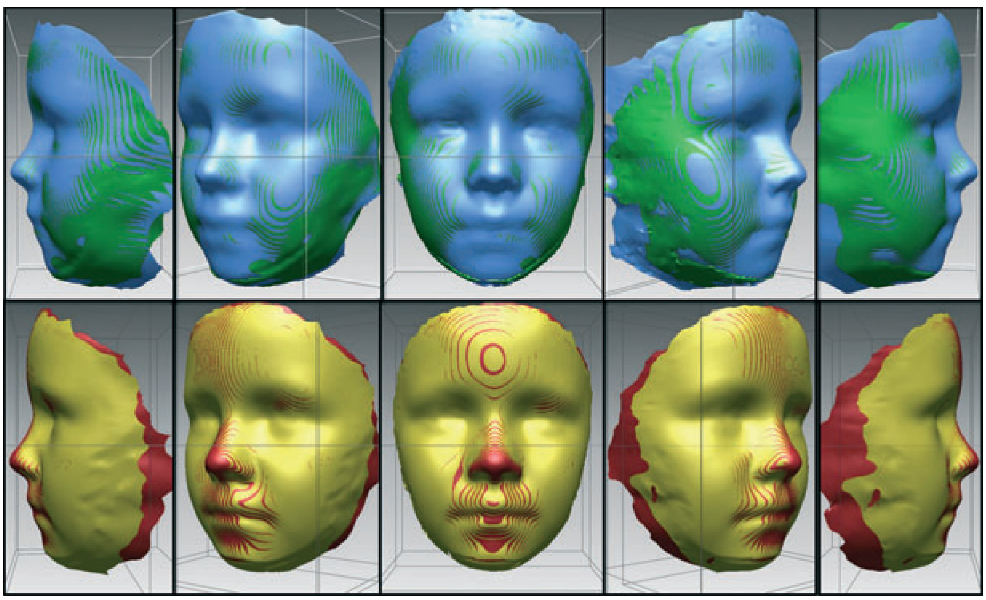

Fig. 3. Overlay superimpositions of gender-specific developmental dysplasia of the hip (DDH) and non-DDH (NDDH) subgroups. Upper row shows NDDH-male (blue) and DDH-male (green) superimpositions, lower row shows NDDH-female (red) and NDDH-female (yellow) superimpositions.

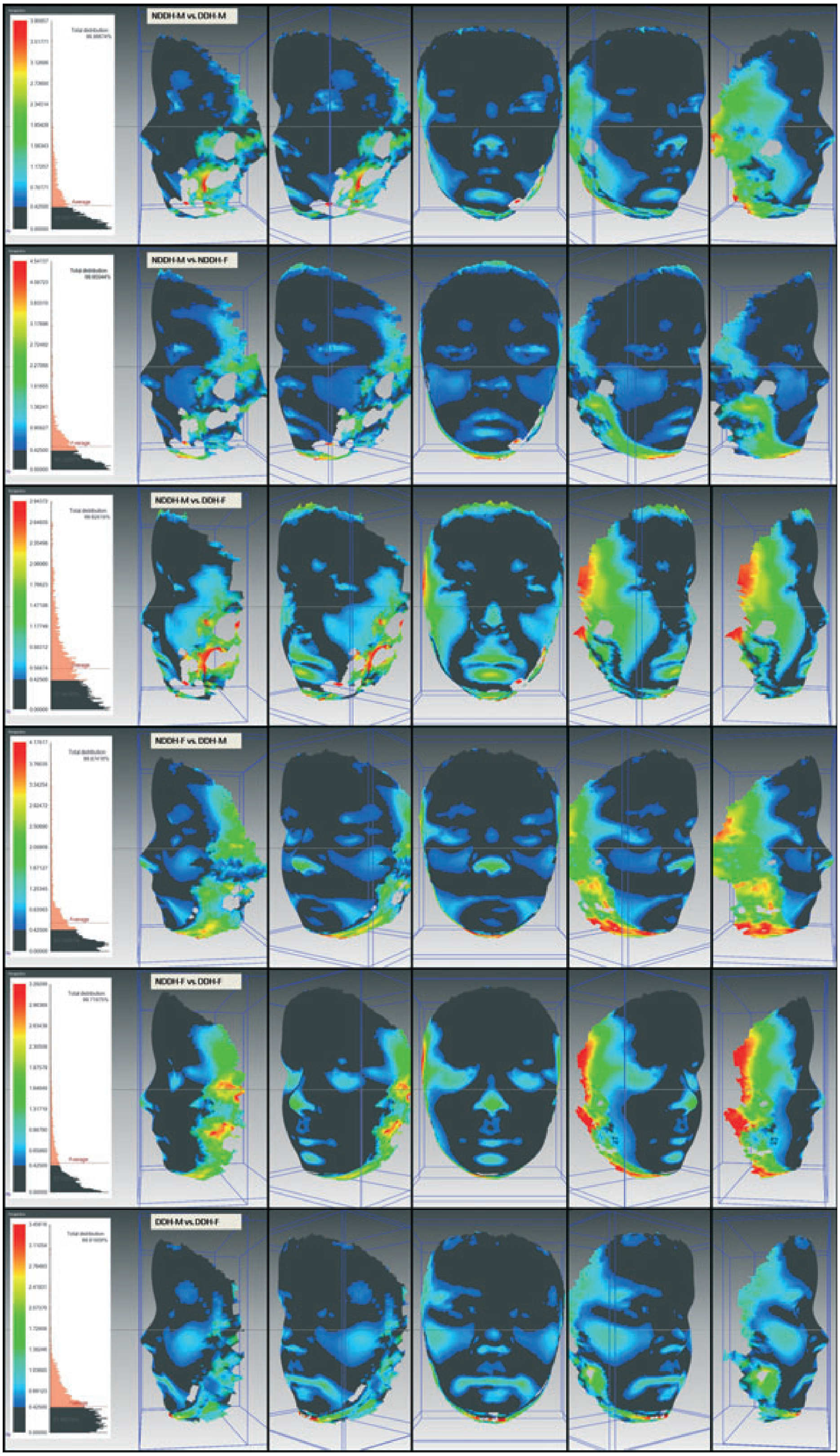

Fig. 4. Color histograms and facial mapping showing the absolute facial differences between average shells. All the possible comparisons between the four study groups are made. Rows 1, 3, 4, and 5 show intragender and intergender differences between developmental dysplasia of the hip (DDH) and non-DDH (NDDH) groups. Gender differences in the control group and the DDH group are shown in rows 2 and 6, respectively. Rows 3 and 4 confirm the expected differences between two totally unrelated groups.

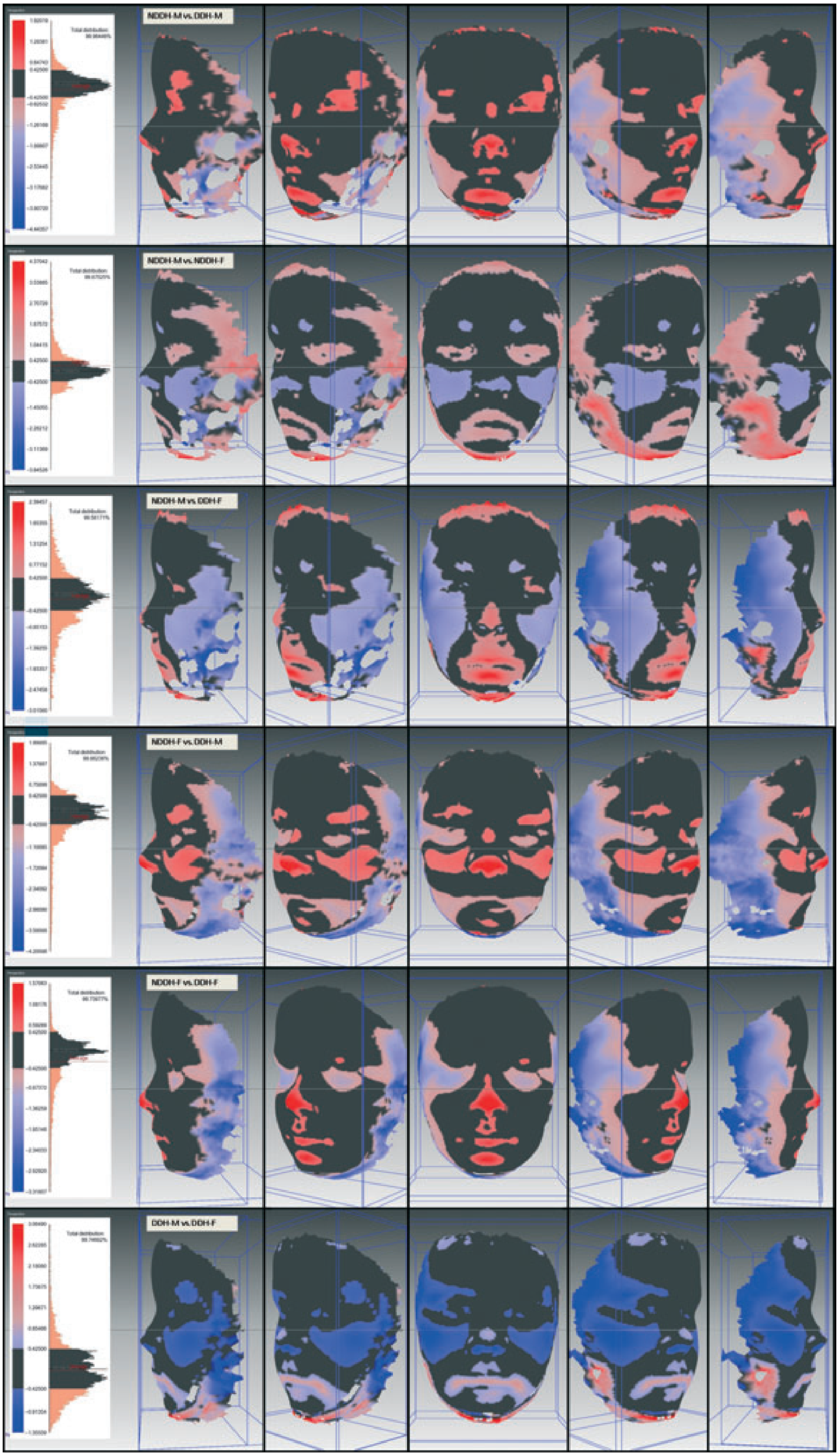

Fig. 5. Color histograms and facial mapping showing the facial differences between average shells. The red areas show ‘positive’ changes (prominence), whereas the blue areas show ‘negative’ changes (deficiency). All the possible comparisons between the four study groups are made. Rows 1, 3, 4, and 5 show intragender and intergender differences between developmental dysplasia of the hip (DDH) and non-DDH (NDDH) groups. Gender differences in the control group and the DDH group are shown in rows 2 and 6, respectively.

group matched for gender and age. The children we recruited for our study group had already been imaged in a previous study (12), but when invited to participate again, four children withdrew. In their original sample (N = 60), Tolleson et al. found that 45% of the examined children had significant upper face asymmetry and 40% had chin-point deviations. Both results were significant, showing more than 2- mm variation. When compared to a healthy control group, the same results were reproduced: regardless of gender, the DDH group showed facial asymmetry and chin-point deviation, thus validating the previous study results. Although the observed differences are statistically significant, the reported asymmetries are clinically mild. Therefore, it is important to screen more patients with DDH to establish the range of asymmetries they present and be able to gauge the need for future orthodontic/surgical corrections.

On the other hand, groups were compared on the basis of gender. Gender differences had been previously analyzed (21, 22). In an earlier study, we observed 59 faces of children aged 12–14 over a period of 2 years (22). The findings obtained from 3D surface imaging indicated that boys grow more than girls and at a later age. Moreover, the areas that grow the most are the nose, brows, lips, and vertical dimension of the face. In our study, gender difference is also very apparent: girls of both groups and boys of both groups show high similarity percentages (66.54 and 65.22%, respectively); yet, all of the comparisons between boys and girls show a lesser degree of similarity. These numbers implicate that gender differences are still very marked even when a systemic affection exists.

Three-dimensional models of the entire face as well as associated analyses have been described by numerous authors (23, 24). The method we present allows the creation of facial averages and volumetric and numerical comparison between different groups. Consequently, it can be used to study the variations in facial morphologies in individuals who present medical challenges and compare them to healthy controls, as well as to persons with the same clinical situation but from different ethnicities. Three-dimensional surface imaging can therefore be a central tool when used to identify variations from the norm as well as specific facial morphologies associated with a particular systemic situation.

Conclusion

- Patients with DDH present a facial asymmetry when compared to healthy controls.
- Gender characteristics are marked whether subjects are affected with DDH or not.
- Three-dimensional surface imaging is a powerful diagnostic and research tool.

Clinical relevance

Developmental hip dysplasia is a common condition that affects the femoral head and the acetabulum and leads to hip subluxation and dislocation. Boys and girls with hip dysplasia and treated with Von Rosen splint therapy present facial asymmetry when compared to healthy controls. Orthodontists should be aware of this associated phenomenon.

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