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Objectification of cranial vault correction for craniosynostosis by three-dimensional photography☆

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Purpose: Correction of craniosynostosis is necessary in predominant cases. Surgical planning usually requires a preoperative CT to estimate the bony and intracerebral structures. A postoperative CT scan would involve a significant dose of radiation, which carries an elevated risk of malignant tumor development in later life. This study was performed to demonstrate the quality of three-dimensional (3D) photogrammetry when objectifying perioperative changes in craniofacial surgery.
Patients and methods: Twenty-eight patients with different premature craniosynostoses were analyzed photogrammetrically before and after surgical correction. 3D changes in cranial distances, symmetry and volumes were evaluated. A statistical covariance analysis excluded changes in cranial shape caused by physiological head growth.
Results: The Cephalic Index in Scaphocephaly changed from 75.1% to a median value of 77.4%. The anterior symmetry ratio for coronal synostoses improved from 0.943 to 0.949 (a value of 1.0 represents perfect symmetry). The posterior symmetry ratio improved from 0.733 to 0.808 postoperatively in one single lambdoidal synostosis. In trigonocephaly, the median anterior skull volume rose from 528 to 601 ml.
Conclusions: 3D photogrammetry has great potential to track and objectify the clinical course of surgical correction of craniosynostoses. Craniofacial changes become highly reproducible and demonstrate clinical utility based on this technology.

1. Introduction

Premature craniosynostosis mostly requires surgical correction to prevent sequelae in later life (Scott et al., 2009). Craniofacial correction is performed in various centers worldwide, using different techniques (Tessier, 1971, McCarthy, 1979, Jimenez and Barone 1995, Zöller et al., 2003, Toma et al., 2010). Anthropometric measurements are typically used for pre- and postoperative control (Farkas, 1994, Junger et al., 2001, Wilbrand et al., 2011). Other categorization patterns do exist (Whitaker et al., 1987, Sloan et al., 1997), but solely classify the postoperative results by the need for any further surgical intervention.

Usually, a three-dimensional (3D) computed tomography (CT) scan is performed preoperatively (Toma et al., 2010, McKay et al., 2010). This radiographic illustration of the craniofacial complex allows exact planning and early detection of anatomical characteristics. A postoperative control CT scan is performed by some centers (Surpure et al., 2001, Marcus et al., 2006, Toma et al., 2010, McKay et al., 2010), but it carries a risk of high radiation exposure to infant patients. The radiation dose of a CT scan increases the risk of malignancies in later life, especially if performed in children (Brody et al., 2007). Therefore, the estimation of the final postoperative result remains mainly subjective (Whitaker et al., 1987).

A new photographic technique has been developed lately. This 3D photogrammetric evaluation is suitable to map all kinds of craniofacial deformities (Wong et al., 2008). Accuracy of photogrammetry of the infant head is high, and the method is rapid, easy to apply, non-invasive, and independent of the examiner (Schaaf et al., 2010).

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This retrospective observational trial was implemented to monitor the feasibility of photogrammetry during the course of premature craniosynostosis correction.

2. Materials and methods

Sixty-five patients were operated on for premature craniosynostosis during 2006–2009 in the Department of Maxillofacial Surgery at the University Hospital in Giessen, Germany. Twenty-eight patients with differing premature craniosynostoses had adequate pre- and postoperative photogrammetric Scans and therefore were included in the present study. Eight children were diagnosed with premature closure of the sagittal suture; 12 had a premature synostosis of the metopic suture and seven were diagnosed with a premature synostosis of one coronal suture. Lambdoid synostosis was diagnosed in one case. Informed consent was obtained by the caregivers for fabrication of all imaging and its use for publication and approval of the local institutional review board was given.

Photographic scans were performed using a Canfield VECTRA-360-four-pod system and mirror software. 3D photographs were obtained between 1 day and 2 weeks (mean: 5.9 days) before surgery and at 10 days to 8 weeks (mean 39.4 days) after the corrective operation. All patients underwent operative cranial vault correction with or without fronto-orbial advancement between the 4th and 9th months of life (mean 7.8 months). The operative procedure was performed using standardized bilateral remodeling and fronto-orbital advancement (Zöller et al., 2003), using a tongue-in-groove technique. The bone flap junctions were assured by resorbable sutures (Fearon, 2003), in a modified cross-over suture technique.

Pre- and postoperative 3D photographs were matched using Cranioform Analytics 3.0® Software (Fig. 1). Exact overlay of pre- and postoperative scans was assured by marking the anthropometric landmarks nasion, subnasale, tragus right, and tragus left. These landmarks illustrated the mid-facial area and were estimated to exhibit the least amount of change during cranial vault correction and due to physiological growth of the infantile neurocranium.

The Cranioform Analytics 3.0® Software created a 3D coordinate system with the y axis through the midpoint between the tragus markers (Tr) and the subnasale marker (SN). The x axis was applied as a perpendicular plane through the midpoint. The z axis was an additional perpendicular plane to x and y through the vertex of the head.

The following parameters were subsequently analyzed at 11 parallel levels to the original plane (Tr–Tr–SN):

Cranial length: The length was measured in centimeters. For the middle plane (level 5), the particular length through the midpoint was determined.

Cranial width: The cranial width was the length of the x axis through the midpoint at level 5. The measure was in centimeters.

Diagonal A and Diagonal B: These parameters used the longest diagonal of the right side of the head versus the analogous diagonal on the left side. The appropriate measuring track was automatically explored in 5° steps from 15° to 80° from the x axis to find the longest diagonal.

Quadrant volume Q1, Q2, Q3, Q4: Q1 was the volume of the anterior left cranial quadrant; Q2 of the right anterior quadrant; Q3 of the posterior right quadrant; and Q4 of the posterior left quadrant. Volumes were estimated over all 11 planes. All volumes were measured in ml.

Anterior Asymmetry Ratio (ASR): This ratio is of major relevance for coronal synostosis. It illustrated the ratio of the higher anterior volume to the lower anterior volume ASR= Q_{max}/Q_{min}. This ratio showed a gain in symmetry for anterior synostotic plagiocephaly, independent of the affected side. Perfect symmetry would be calculated as 1.

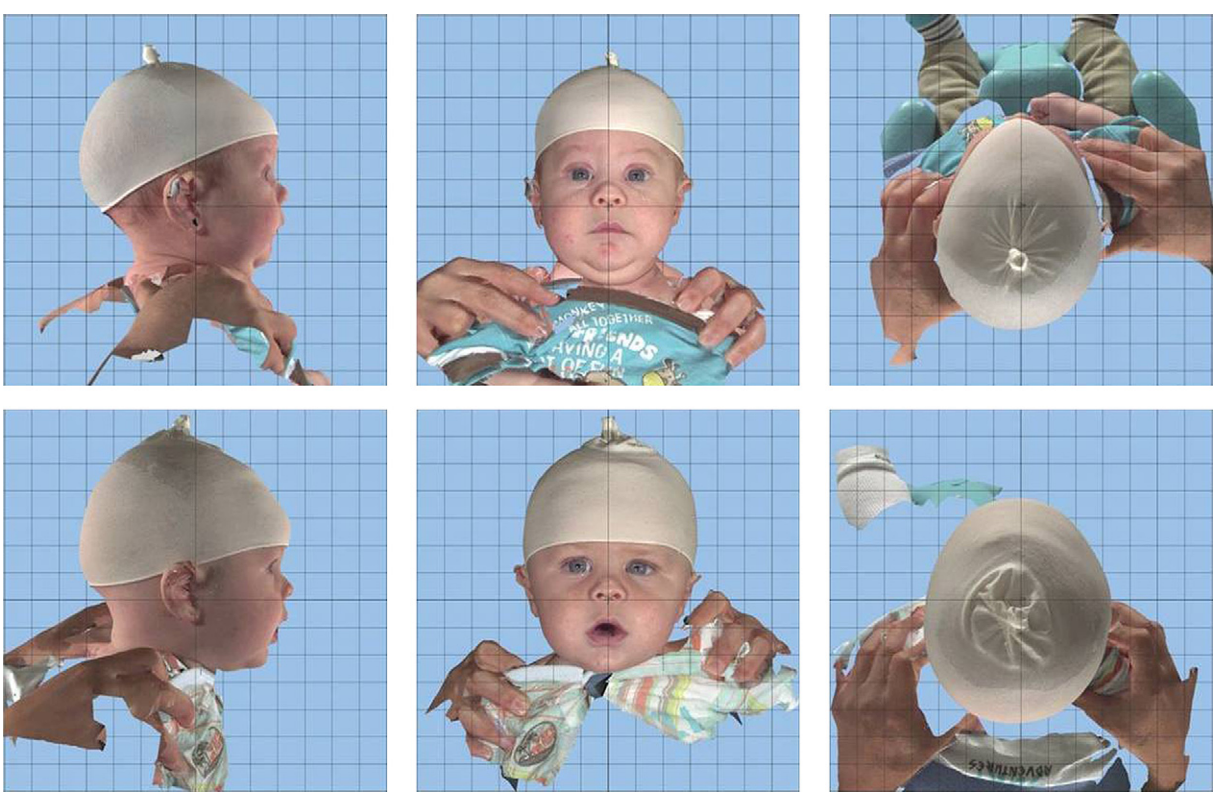

Fig. 1. Pre- and postoperative photogrammetric scans matched and compared with Cranioform Analytics® 3.0 Software.