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Original paper

Morphological analysis of the skull shape in craniosynostosis

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Craniosynostosis represents premature suture fusion of the fetal and neonatal skull. Pathogenesis of craniosynostosis is complex and probably multifactorial. Growth of skull bones is strictly connected with the expanding growth of the brain and cranial malformations or prematurely fused sutures cause abnormal head shape. In order to diagnose the craniosynostosis, physical examination, plain radiography, and computed tomography with 3D reconstructions are indispensable. Engineering software such as Mimics v.13.1 and 3-matic v.5.0 enables a 3-dimensional model of head to be generated, based on the pictures obtained from CT. It is also possible to indicate the distances between the characteristic anatomical points. These measures are helpful during planning the neurosurgical correction of the skull, because the possibility of strictly specifing incisions before surgery, which is very important to provide the maximal safety of a child.

Key words: *craniosynostosis, preoperative planning, skull surgery, children, 3D modelling*

1. Introduction

Craniosynostosis represents premature suture fusion of the fetal and neonatal skull. It occurs in approximately 1 per 2,000 live births. Most forms of craniosynostosis are isolated and not associated with any other conditions, and are therefore nonsyndromic. On the other hand, the pathogenesis of craniosynostosis is complex and probably multifactorial. The cause of craniosynostosis may lie either in primary suture abnormalities, sufficient extremes of forces that overcome the underlying expansive forces of the brain, inadequate intrinsic growth forces of the brain, or in various genetic and environmental factors [4]–[6]. Craniofacial skeleton is composed of bones, cranial sutures and connective tissues. Because the growth of skull bones is strictly connected with the expanding growth of the brain, an abnormal head shape resulting from cranial malformations or prematurely fused sutures (craniosynostosis) in infants is a diagnostic and therapeutic challenge [3]. It is important make an objective evaluation of deformity as soon as possible, because untreated progressive craniosynostosis can stunt to brain growth and can increase intracranial and intraorbital pressure [2], [3], [5].

2. Methods

The diagnosis of craniosynostosis is based on physical examination, plain radiography, and computed tomography with 3D reconstructions. The classification of craniosynostosis depends on the

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shape of the skull, which usually reflects the underlying prematurely fused suture or sutures. There are a few types of deformations [1] according to which sutures have fused. They are presented in figure 1.

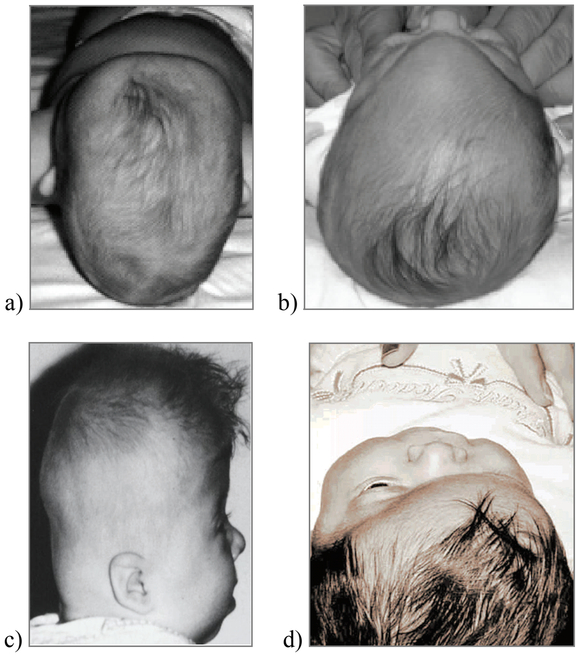

Fig. 1. Types of nonsyndromic craniosynosostosis:
a) scaphocephaly, b) trigonocephaly,
c) brachycephaly, d) anterior plagiocephaly [1]

The radiodiagnosis of craniosynostosis is used to define quantitatively anatomic anomalies, to plan surgical procedures, and, first of all, to demonstrate the difference between stenosed and nonstenosed sutures to parents. Engineering software such as Mimics v.13.1and 3-matic v.5.0 can generate a 3-dimensional model of head, based on the pictures obtained from CT (figure 3). It is also possible to indicate the distances between the characteristic anatomical points. These measures are helpful during planning the neurosurgical correction of the skull, because of the possibility of strictly specifying incisions before surgery, which is very important to provide the maximal safety of a child.

The proposed procedure of preoperative planning in craniosynostosis surgery is presented in figure 2.

3. Results

In the first step of analysis, we obtained two 3D geometrical models of the skull, before and after the surgery. These models allowed us to perform the simulations of bone thickness (figure 4) and also to generate the characteristic cross-sections based on the parallel planes crossing the points of nasal bone and occipital bone (N–P in the figures 5, 6).

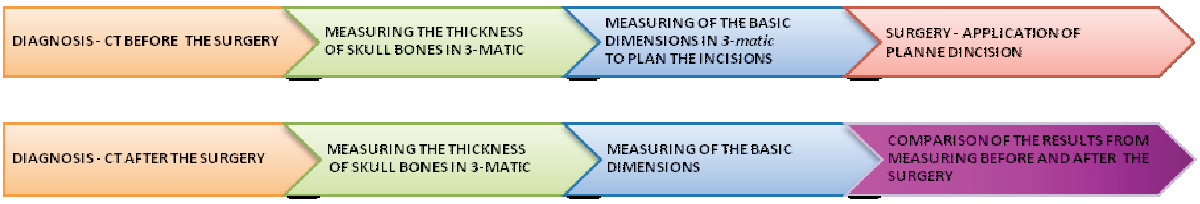

Fig. 2. Schema of the process examining patient with scaphocephaly

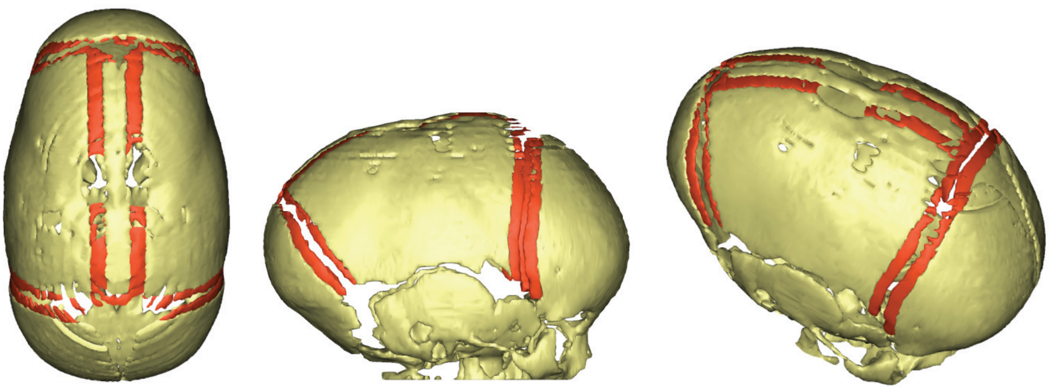

Fig. 3. Preoperative neurosurgical planning of the whole calvaria correction
in case of premature closure of sagittal suture

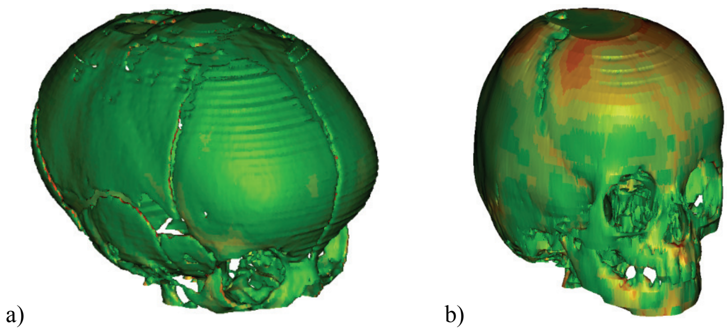

Fig. 4. Simulations of the skull thickness in 3-matic: a) before surgery, b) after surgery

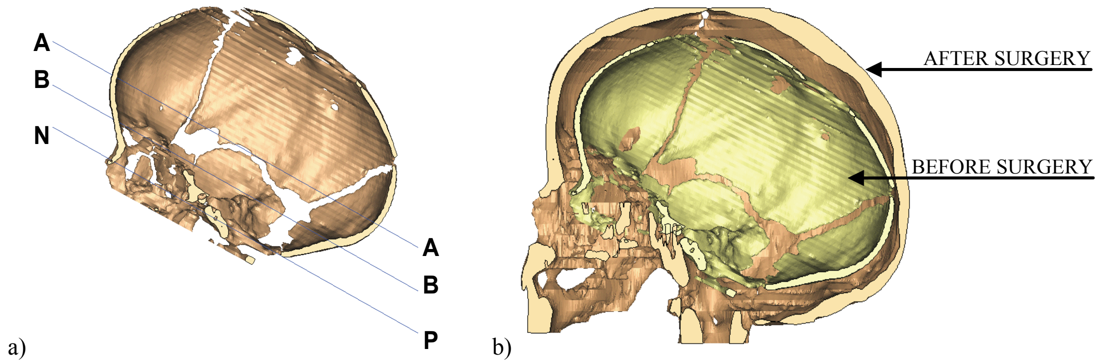

Fig. 5. Cross-sections of skull before the surgery (a),
models of head before (inside) and after (outside) the surgery (b)

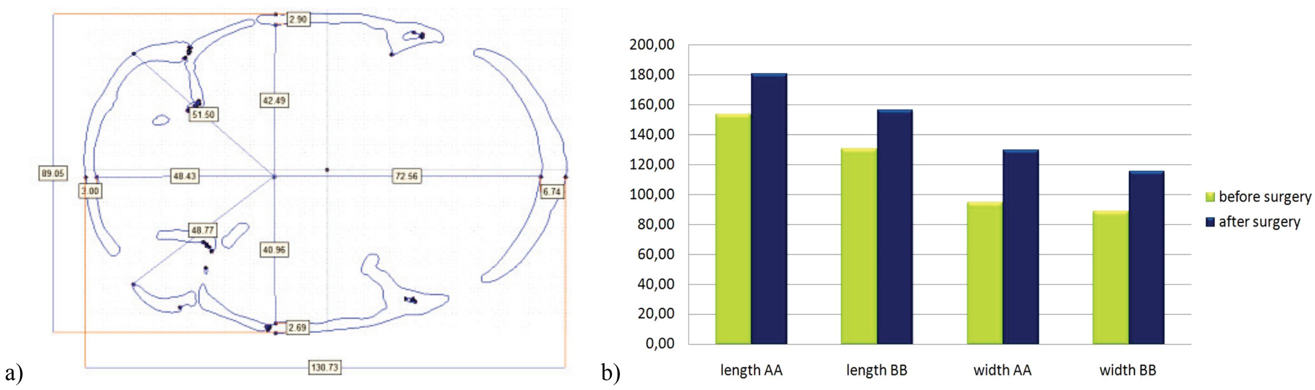

Fig. 6. Cross-section B–B before the surgery (a),
selected results of measurement in 3-matic software (b)

In these plans, many measurements were carried out to evaluate abnormal head shape based on the distance (in mm) from one point on the skull to another (figure 7, table 1).Comparison of the anthropometric data on the right and left sides was presented in figure 6 and in table 2. The most significant measures used in this initial evaluation are: skullbase asymmetry, cranial vault asymmetry, orbitotragial depth, and cephalic index. The values of indices for the skull before and after surgery were calculated as follows:

$$\text{Cephalic index} = \frac{\text{skull width (eu.r} - \text{eu.l)}}{\text{skull length (g} - \text{op)}}. \quad (1)$$

The scaphocephalic indices obtained for the skull before and after surgery were presented in table 3 and in figure 8.

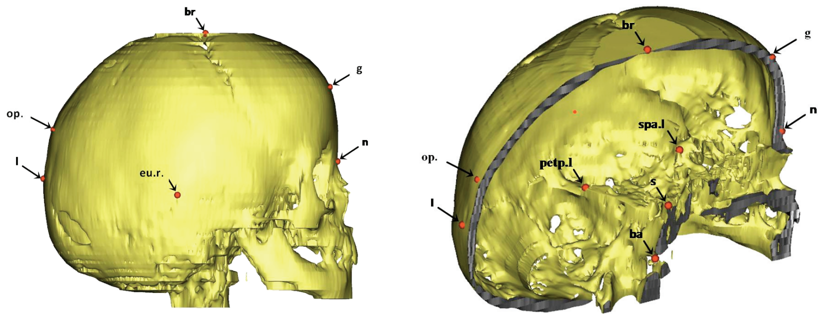

Fig. 7. Skull landmarks

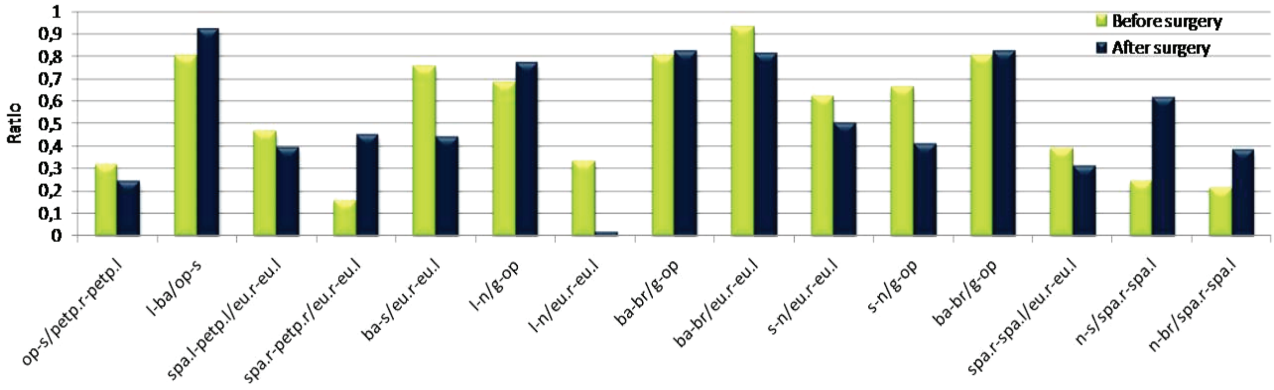

Fig. 8. Values of skull indices before and after surgery

Table 1. Description of skull landmarks

Landmarks	Description
ba	basion
br	bregma
l	lambda
n	nasion
s	sella
eu.l *eu.r*	euryon left euryon right
g	glabella
op	opisthocranion
petp.l *petp.r*	petrous posterius left petrous posterius right
spa.l *spa.r*	sphenoidale anterior left sphenoidale anterior right

Table 2. Measurements for the skull shape

Measurement	Description	Before the surgery (mm)	After the surgery (mm)
eu.l-eu.r	maximum cranial width	85.8	128.3
g-s	posterior cranial base length	21.3	111.3
petp.l-petp.r	posterior cranial fossa width	67.4	89.4
l-ba	posterior cranial valut height	87.2	120.6
spa.l-petp.l	left lateral middle cranial fossa length	39.9	50.7
spa.r-petp.r	right lateral middle cranial fossa length	13.8	58.1
s-ba	posterior cranial base length	65.1	56.5
br-ba	cranial height	68.8	155.1
g-op	maximum cranial length	91.7	157.8
l-n	cranial valut length	58.7	166.3
s-n	anterior cranial base length	137.8	64.7
spa.l-spa.r	anterior cranial base width	33.7	40.1
br-n	anterior cranial valut height	155.5	103.8

Table 3. Values of indices for the skull

Indices/ratio		Description	Before surgery	After surgery
Posterior cranial fossa	*op-s* / *petp.r-petp.l*	index of length and width	0.317	0.245
	l-ba / *op-s*	index of height and length	0.804	0.923
Middle cranial fossa	*spa.l-petp.l* / *eu.r-eu.l*	index of left length and width	0.466	0.396
	spa.r-petp.r / *eu.r-eu.l*	index of right length and width	0.161	0.453
	ba-s / *eu.r-eu.l*	index of height and width	0.758	0.440
	l-n / *g-op*	index of length and width maximum cranial length	0.685	0.771
	l-n / *eu.r-eu.l*	index of length and width	0.640	0.685
	ba-br / *g-op*	index of height and length	0.333	0.018
	ba-br / *eu.r-eu.l*	index of height and width	0.802	0.827
	eu.r-eu.l / *g-op*	cephalic index	0.935	0.813
Anterior cranial fossa	*s-n* / *eu.r-eu.l*	index of height and width	0.623	0.504
	s-n / *g-op*	index of height and length	0.666	0.410
	ba-br / *eu.r-eu.l*	index of height and width	0.802	0.827
	spa.r-spa.l / *eu.r-eu.l*	index of width	0.393	0.312
	n-s / *spa.r-spa.l*	index of inferior height and width	0.245	0.618
	n-br / *spa.r-spa.l*	index of superior height and width	0.217	0.385

4. Discussion

In this paper, their authors wanted to show the possibility of carrying out anatomical, pathomorfological, preoperative and postoperative analyses with the application of modern 3D modelling methods. We present the aforementioned analyses in the child with scaphocephaly. Until now, more than 60 children with single suture and complex craniosynostoses were provided with neurosurgical planning and treatment with the application of engineer support, especially the children with premature closure of sagittal or metopic sutures. In all cases, we obtained informed consent from parents. The aim of this paper was to show and explain the methods applied in case of *scaphocephaly*. The analysis of surgical results of the whole group of operated children will be the topic of the next paper after collecting whole data with an appropriate follow-up.

The main purpose of the skull correction in craniosynostosis cases is to reopen the cranial suture in order to free the growing skull. Closed sutures not only provoke deformation of the skull calvaria and skull base, but also can bring about local intracranial hypertension. This means that after a successful surgery the skull grows and can expand sufficiently under the sustained stress generated by brain [2]–[5].

For a proper skull reconstruction the sequence of bone osteotomies and repositioning are required. During the surgery, the pieces of bone that have been taken out of the skull need to be often bent before they can actually be used in its reconstruction, especially in most reconstructions of the orbital rim. Because of the complexity of the surgery as a whole, preoperative planning is unavoidable [2], [3], [5]. Up to now, neurosurgeons during preoperative planning of bones' correction based on their own knowledge and experience. The measurements performed complement full neurological and neurosurgical diagnosis in children with craniosynostosis. By measuring the parameters specified in the paper, surgeons are able to estimate cranial malformations better than in a conventional way. This is very important regarding the etiopathogenesis of possible neurological consequences in case of high intracranial pressure. The results obtained are helpful in the context of making decision about the method of cranioplasty of the cranial vault. Virtual models can help in the better imagination of the skull shape and its crucial details such as sutures and foramina. The models play an important role in preoperative planning of neurosurgical cranial reconstruction, especially in terms of ranges, angles and proper contours of osteotomies.

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