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The quantitative assessment of the pre- and postoperative craniosynostosis using the methods of image analysis

Anna Fabijańska*, Tomasz Węgliński

Lodz University of Technology, Institute of Applied Computer Science, 18/22 Stefanowskiego Str., 90-924 Łodz, Poland

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ABSTRACT

This paper considers the problem of the CT based quantitative assessment of the craniosynostosis before and after the surgery. First, fast and efficient brain segmentation approach is proposed. The algorithm is robust to discontinuity of skull. As a result it can be applied both in pre- and post-operative cases. Additionally, image processing and analysis algorithms are proposed for describing the disease based on CT scans. The proposed algorithms automate determination of the standard linear indices used for assessment of the craniosynostosis (i.e. cephalic index CI and head circumference HC) and allow for planar and volumetric analysis which so far have not been reported. Results of applying the introduced methods to sample craniosynostotic cases before and after the surgery are presented and discussed. The results show that the proposed brain segmentation algorithm is characterized by high accuracy when applied both in the pre- and postoperative craniosynostosis, while the introduced planar and volumetric indices for the disease description may be helpful to distinguish between the types of the disease.

1. Introduction

Craniosynostosis is a common condition which affects infants. The disease is caused by the premature fusion of one or more cranial sutures which changes the growth pattern of the skull [1,2]. Skull shape deformations and the resulting increased intracranial brain pressure may in turn cause a noticeable disorder in the neuropsychological development of a child.

The fusion of sutures in the craniosynostosis is usually confirmed by the fast, low-dose computed tomography (CT) imaging. A CT scan is also used to plan the corrective surgery (which is the only way of the disease treatment). However, although the rapid development of CT imaging devices is constantly observed, the preoperative assessment of craniosynostosis is still mainly qualitative and bases on the visual analysis of the consecutive slices. The supporting quantitative analysis is based on manual measurements of the characteristic dimensions of the skull. These are performed on the most representative CT slice. Hence, the existing methods are subjective as may depend on personal skills and experience. These two factors may affect both—the selection of the slice and the selection of characteristic dimensions. As a result, repeatability of the measurements may be limited. Another limitation of the manual measurements is that it considers only a small piece of information contained in the representative slice but ignores the significant information contained within a whole scan. Using the existing tools and methods dedicated to assessment of the craniosynostosis, the physicians are not able to take advantage of volumetric information contained within a scan. Visual and manual methods are not sufficient to analyze or measure planar and volumetric indices that could provide additional and useful information about the disease.

It should be also noticed that the existing methods for assessment of craniosynostosis are dedicated mainly to the preoperative cases. Since they are based on the analysis of skull dimensions, they cannot be used in the postoperative cases, where significant parts of skull are missing due to the corrective surgery.

The computer-aided diagnosis of brain diseases benefits over traditional methods by the ability to perform automatic and reliable measurements. Therefore, this paper proposes a set of image processing and analysis algorithms dedicated to the assessment of the pre- and postoperative craniosynostosis based on CT scans by means of linear, planar and volumetric measures.

The following part of this paper is organized as follows. First, basic information about the craniosynostosis types, diagnosis and treatment methods is given in Section 2. This is followed in Section 3 by the description of various problems, which need to be solved during segmentation of brain in the pre- and postoperative craniosynostosis. The related works in the field of brain segmentation

* Corresponding author. Tel.: +48 42 631 27 50x316.
E-mail addresses: anna.fabijanska@p.lodz.pl (A. Fabijańska), tomasz.weglinski@p.lodz.pl (T. Węgliński).

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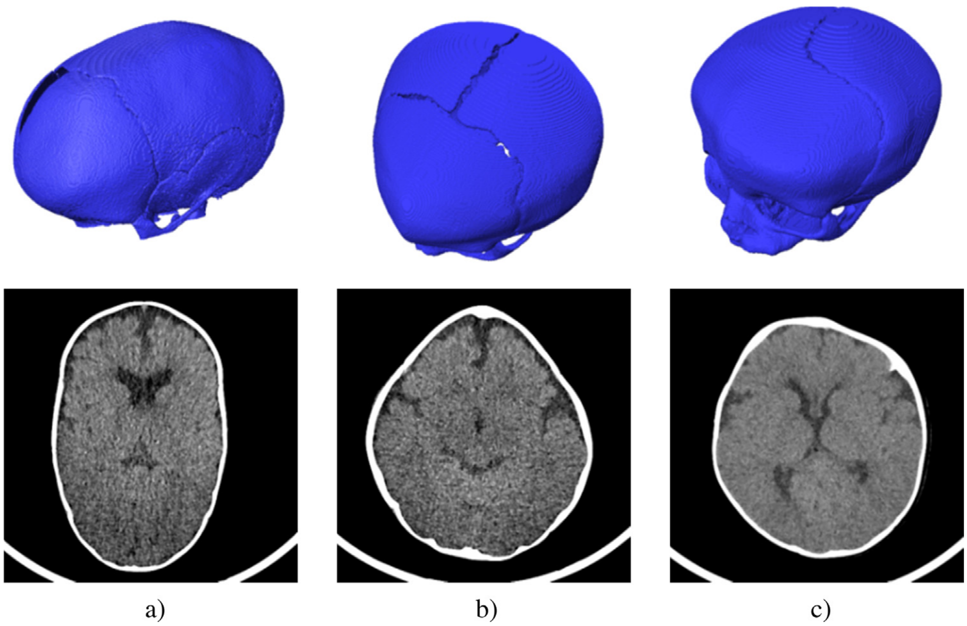

Fig. 1. The most common types of craniosynostosis; (a) scaphocephaly; (b) trigonocephaly; (c) plagiocephaly.

and image based assessment of the craniosynostosis are reviewed in Section 4. Section 5 describes the introduced algorithms and methods dedicated to linear, planar and volumetric description of the disease. Results provided by the proposed approaches are presented and discussed in Section 6. Finally, Section 7 concludes the paper.

2. Medical background

Craniosynostosis manifests itself as a serious malformation of a skull. It is caused by a premature fusion of one or more cranial sutures. If two or more sutures fuse, the growth of a skull in fusion direction is stopped, but the compensatory growth in other directions is observed. Most commonly, the following types of craniosynostosis can be observed [1]:

- scaphocephaly (*long head*) when the head is disproportionately long and narrow;
- trigonocephaly (*triangular head*) when the head has triangular shaped forehead;
- plagiocephaly (*flat head*) when there is a flat spot on the back or one side of the head.

The examples of skull shapes in the regarded types of craniosynostosis and the corresponding sample CT slices are shown in Fig. 1.

The only way of craniosynostosis treatment is the cranial vault remodeling, i.e. the corrective surgery which restores the normal spatial relationship between the skull and the contained neural and vascular structures and re-orientates the deviated growth vectors of the skull base and vault [3]. The corrective surgery always removes the deformed fragments of skull. A sample skull before and after surgery is shown in Fig. 2.

Although the craniosynostosis is quite a common disease (it appears about 1 in 2500 individuals [4,5]) there are only two parameters used for the preoperative assessment of the disease. These are cephalic index (CI) and head circumference (HC) [6]. Cephalic index is a ratio of the maximum length and the maximum width of a head (see Fig. 3a). Head circumference is a measurement taken around the largest part of the head, above the eyebrows, above the ears and the most back part of head (see Fig. 3b).

However, usage of these indices is limited. Neither HC nor CI can be used to unambiguously distinguish between different types of craniosynostosis. It is possible for example to distinguish scaphocephaly from other types based on the cephalic index, but this index for trigonocephaly and plagiocephaly exhibits similar values.

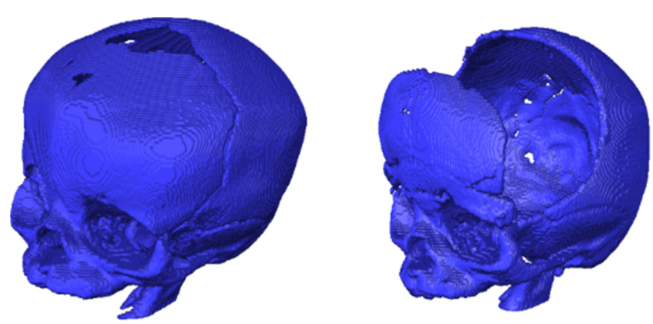

Fig. 2. Sample skull before and after the corrective surgery.

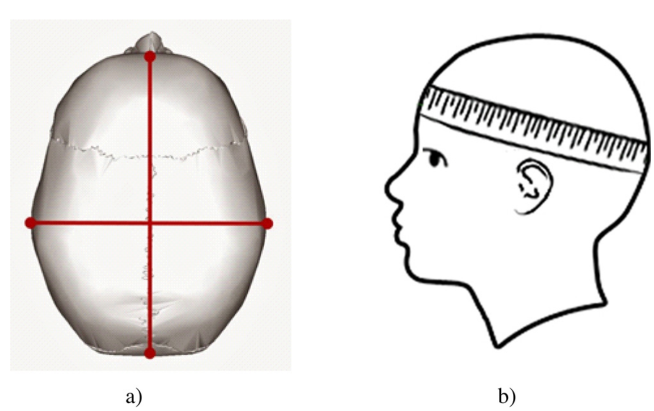

Fig. 3. Measurements used for assessment of craniosynostosis; (a) cephalic index—ratio of the maximal length to the maximal width of skull; (b) head circumference.