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Early development of the fetal central sulcus on 7.0T magnetic resonance imaging

Haidong Zhang[a,b], Zhonghe Zhang[c], Xuntao Yin[a,d], Jinfeng Zhan[a], Zhenmei Zhao[b], Yuchun Tang[a], Chao Liu[e], Shuwei Liu[a,*], Shizhen Zhong[a,f,*]

[a] Research Center for Sectional and Imaging Anatomy, Shandong University School of Medicine, Jinan, Shandong 250012, China
[b] Department of Anatomy, Taishan Medical University, Taian, Shandong 271016, China
[c] Department of Medical Imaging, Shandong Provincial Hospital Affiliated to Shandong University, Jinan, Shandong 250021, China
[d] Department of Radiology, Southwest Hospital, Third Military Medical University, Chongqing 400038, China
[e] Department of Anatomy, Jining Medical University, Jining, Shandong 272067, China
[f] Research Institute of Clinical Anatomy of Southern Medical University, Guangzhou, Guangdong 510515, China

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ABSTRACT

In the previous studies, the criterion for deciding the occurrence time of the fetal central sulcus (CS) on magnetic resonance imaging (MRI) is based on the observation by the eyes. There have been no existing quantitative standards or numerical criteria in this field. In this study, we reconstructed the three-dimension (3D) images of the fetal brain based on the 7.0T MR images of 45 Chinese fetal specimens from the 11 to 22 weeks of gestational age (GA). Then we obtained data by measuring the maximum depth and length of the CS so as to analyze the early developmental pattern of it. These measures, especially CS depth, can be used to quantitatively determine the time of emergence of the fetal CS during the development. Statistics show that there are no gender or interhemispheric asymmetries of the CS from GA of 11 to 22 weeks.

1. Introduction

The central sulcus (CS) is one of the earliest sulci in the development of human brain (Chi et al., 1977; Welker, 1990). As an important structural and functional landmark in the lateral brain, CS is considered as a key region in studying the development of human brain (Cykowski et al., 2008; Hopkins et al., 2010). Traditionally, postmortem specimens have been used to study the cerebral cortex (Broca, 1888; Campbell, 1905; Cunningham, 1905; Nishikuni and Ribas, 2013; White et al., 1997). But the initial study methods affect the location and shape of the cerebral sulcus. Application of ultrasonic technology in medicine becomes the first noninvasive method in the study of the fetal brain (Cohen-Sacher et al., 2006; Ijaiya et al., 2002; Monteagudo and Timor-Tritsch, 1997; Toi et al., 2004). Magnetic resonance imaging (MRI) technology comes next, which can provide more abundant and clearer images than ultrasound, with more and more advanced methods and high-field density (Choe et al., 2013; Verhoye et al., 2013; Woodward et al., 1997; Zhan et al., 2013; Zhang et al., 2011).

Despite all the above research, there is no concurrent conclusion on the time when the fetal CS appears. No quantitative standards, or numerical criteria, can be used to define the appearance of the fetal CS (Dubois et al., 2008; Garel et al., 2001).

The aim of this study is to find out a quantitative standard to decide the time when the CS appears in the fetus by analyzing the early developmental pattern of the CS based on 7.0T MR images. The gender dimorphism and interhemispheric asymmetries in the 11–22 weeks of GA were also studied.

2. Materials and methods

2.1. Subjects

Sixty-five Chinese fetal specimens from the 11 to 22 weeks of GA were available for this study. They were collected from medically indicated or spontaneous abortions, fetal deaths caused by

Abbreviations: GA, gestational age; CS, central sulcus; MRI, magnetic resonance imaging; 3D, three-dimension; SAS, statistics analysis system.

* Corresponding authors at: Research Center for Sectional and Imaging Anatomy, Shandong University School of Medicine, 44 Wen-hua Xi Road, Jinan, Shandong Province 250012, China.
E-mail addresses: liusw@sdu.edu.cn (S. Liu), zhszh@fimu.com (S. Zhong).

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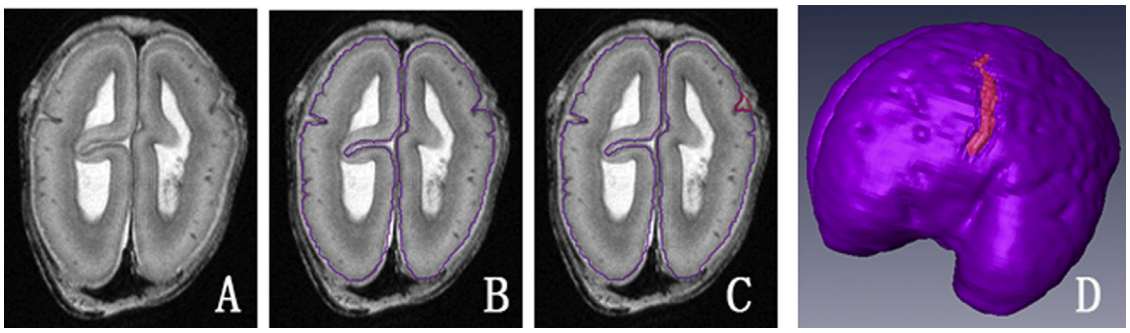

Fig. 1. The technical method of reconstructing the brain shape based on MRI. (A) The original scanned image of the head. (B) Continuous outline of the cerebral cortex. (C) Outline of CS. (D) Reconstruction of the brain shape and CS.

Table 1
Numbers of choosen specimens of different GA and sex ($n = 45$).

Weeks of gestational age (GA)	Sex and number
11	Male 1
	Female 1
12	Male 1
	Female 1
13	Male 2
	Female 2
14	Male 2
	Female 2
15	Male 2
	Female 2
16	Male 2
	Female 2
17	Male 2
	Female 2
18	Male 2
	Female 2
19	Male 2
	Female 2
20	Male 2
	Female 2
21	Male 2
	Female 2
22	Male 2
	Female 3

maternal diseases, stillbirths during abnormal labor, and premature deaths attributed to diseases outside of the brain (such as respiratory disease) in hospitals of Shandong Province, China. The GA of the fetuses was estimated on the basis of crown-rump length, head circumference, foot length and/or pregnancy records and was expressed in weeks from the last menstrual period (Guihard-Costa et al., 2002).

Forty-five specimens were selected for inclusion into this study. The selected criteria were as follows: the maternal pregnancy records with no documented fetal chromosomal abnormality, stressful intrauterine conditions, maternal genetic disease in their families, or records of seizures in the case of eclampsia; results of Ultrasonography (US) examination for the fetus during pregnancy and results of the US and post-mortem 3.0T MR pre-scanning for the specimen indicating an anatomically normal and developmentally appropriate fetal central nervous system (CNS); further validated detailed autopsy combined with neuro-pathological examinations also showed no detectable CNS malformations for those specimens without a definite conclusion, or with any additional diagnosis (such as air in the lateral ventricle, ecchymoma, intracranial hemorrhage, or any detectable neuro-pathological changes or abnormalities outside the brain) based on the above 2 selected criteria (Meng et al., 2012; Zhang et al., 2010, 2011a,b). The demographic distributions of the specimens are listed in Table 1.

All the specimens were preserved in 10% formalin, and scanned by MRI scanner within one week after the abortion. The study was approved by the Human Research Ethics Committees of the School of Medicine of Shandong University. The parents' consent to donate the fetal cadaver was obtained before specimen preparation and imaging. This study was conducted upon the approval of the Ethical Committee at Shandong University.

2.2. Image acquisition

Fetal imaging is performed in a 7.0T Micro-MRI (70/16 PharmaScan, Bruker Biospin GmbH, Germany), which can provide more clear images than 3.0T. Each fetal brain was scanned in situ and was fit into a small-animal-size body coil with an inner diameter of 60 mm. 2D T2-weighted slice images (field of view = 6 cm × 6 cm, slice thickness = 0.5 mm) were acquired in the axial plane. The acquisition parameters were as follows: TR/TE = 17,000/50 ms, matrix = 256 × 256, and NEX = 4 (Zhang et al., 2011b, 2013).

2.3. Image processing

The slice with the clearest image was selected from the three planes (horizontal, sagittal and coronal planes) after importing the MRI of each fetus into the Amira4.1 software (Fig. 1). The boundary between the cerebral cortex and cerebrospinal fluid was carefully distinguished, which was used as the basis for continuous description of the intact contour of cerebral cortex. The work to describe the boundary was manually done by two professionals who are familiar with the brain structures. The complete 3D shape of the brain was then reconstructed in the software (Zhang et al., 2011b, 2013).

2.4. Location of central sulcus

Used as a location symbol of CS, a line was drawn between the midpoint of the sagittal line and the lateral sulcus at the lateral surface of cerebral cortex in reconstructed image of the fetal brain (Fig. 2). The cerebral cortex hollow was judged as central sulcus which was adjacent to the line and stably existed in brain images from the 11 to 22 weeks of GA.

2.5. Data measurement

The maximum value on both hemispheres was determined as the maximum depth of CS of the fetus based on continual measurement at multiple sections. The length of CS was measured on the surface of the reconstructed 3D brain image. The length of each concave was summed when the CS was not continuous, and the total value was used as the length of this CS. Each value was measured by