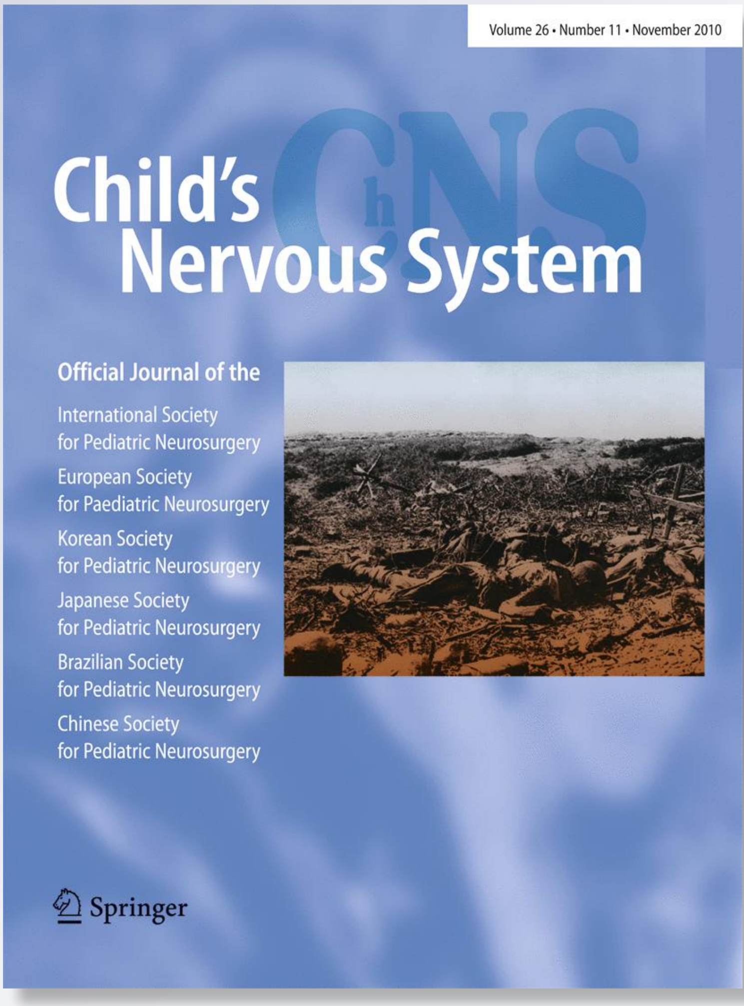
Study of brain growth in children?a new approach to volume measurements using MRI-reconstructed 3D neuroimaging

Child's Nervous System

ISSN 0256-7040
Volume 26
Number 11

Childs Nerv Syst (2010)
26:1619-1623
DOI 10.1007/
s00381-010-1280-1



Springer

Your article is protected by copyright and all rights are held exclusively by Springer-Verlag. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your work, please use the accepted author's version for posting to your own website or your institution's repository. You may further deposit the accepted author's version on a funder's repository at a funder's request, provided it is not made publicly available until 12 months after publication.

Springer

Author's personal copy

Childs Nerv Syst (2010) 26:1619–1623
DOI 10.1007/s00381-010-1280-1

ORIGINAL PAPER

Study of brain growth in children—a new approach to volume measurements using MRI-reconstructed 3D neuroimaging

Ein-Yiao Shen · Kuan-Hsun Wu · Ming-Fan Lin · Chia-Yuan Chen

Received: 26 February 2009 / Accepted: 8 September 2010 / Published online: 19 September 2010
© Springer-Verlag 2010

Abstract

Objective The three-dimensional (3D) reconstructed neuroimages are currently available to analyze brain structure. It provides a new tool for clinical evaluation and academic research on brain. However, there are several methods for processing 3D images. In this article, we present a technique that utilizes a work station and a software program to process reconstructed 3D neuroimages after magnetic resonance imaging (MRI) scanning.

Methods The brain volumes of 50 normal children aged between 3 months and 12 years and 11 months were measured by 3D neuroimages reconstructed from regular MRI scans. These results were then analyzed statistically against the growth curve.

Results The regression curve of cortical growth was $y=39.317Ln(x)+631.31$, $R^2=0.1318$. The regression curve of white matter growth was $y=81.754Ln(x)+186.07$, $R^2=0.5675$. The regression curve of whole brain growth was $y=121.07Ln(x)+817.738$, $R^2=0.4077$. Current studies show that at the postnatal stage, the cortex grows mainly between birth and 4 years of age. At the same time, the postnatal development of the brain depends mainly on the growth of white matter from birth through adolescence.

Conclusions This study presents the basic data from a study of children's brains using reconstructed 3D brain images. A 3D reconstructed neuroimage provides a new tool for neurological and psychological in vivo research of the brain. Based on the techniques we introduce here, the clinician may evaluate the growth of the brain in a more efficient and precise manner.

Keywords 3D neuroimaging · MRI reconstructed · Brain growth · Volume measurement

E.-Y. Shen
Graduate Institute of Acupuncture Science,
China Medical University,
Taichung, Taiwan, China

E.-Y. Shen · K.-H. Wu
Department of Pediatrics,
Taipei Medical University-Wan Fang Hospital,
Taipei, Taiwan, Republic of China

M.-F. Lin · C.-Y. Chen
Department of Radiology,
Taipei Medical University-Wan Fang Hospital,
Taipei, Taiwan, Republic of China

E.-Y. Shen (✉)
China Medical University,
No.91 Hsueh-Shih Road,
Taichung, Taiwan 40402, Republic of China
e-mail: einyiao@gmail.com

Introduction

The three-dimensional (3D) image processing technology is commonly used in scientific research as well as in movies, video games, and industrial applications. Since the late 1980s, 3D imaging technology has been applied to various fields for medicine. In particular, neuroscience and its related disciplines have employed 3D imaging technology for years to examine the brain and its pathology [1, 2].

The volume CT, or multi-detector (MD) CT scan, is a well-accepted technique for 3D images [3, 4], but it requires costly facilities and well-trained technicians, limiting its utility in clinical practice. This prompted scientists to be familiar with imaging technologies to develop various techniques for processing 3D images in

Author's personal copy

the laboratory. Here we present a new method for 3D image reconstruction in daily clinical practice with the use of a conventional magnetic resonance imaging (MRI) scanner connected to a workstation. When the parameters have been set up, the reconstruction process is managed by software based on the data extracted from the MRI scanner. With this technique, we are able to study brain growth in children with volume measurements of a reconstructed 3D image of the brain more efficiently, cost-effectively, and precisely.

Materials and methods

Subjects

During the period from June 1, 2005 to July 31, 2007, all brain MRI scans taken by the Department of Pediatrics at Wan Fan Hospital were delivered for 3D image construction after obtaining the consent of the parents' and the approval from the hospital's Ethics Committee. We examined a total of 165 cases during this period; 50 of them had functional disorders, such as headaches, migraines, seizures, breath-holding spells, and somnambulism. After the authoring physicians diagnosed these cases as benign from both clinical (author 1) and radiological (author 3) perspectives, the 3D reconstructed images were collected for brain volume measurement for analysis.

Technique for 3D reconstruction

The processes of this study begins with the setting of the MRI scan's specifications to a mode suitable for 3D image reconstruction. We used a G.E. 1.5 T Excite MRI machine at our hospital and scanned with the following parameters: (1) patient position, supine; (2) coil, head; (3) T1W, 3D SPGR; (4) repetition time, 33 ms; (5) echo time, 3.0 ms; (6) flip angle, 35°; (7) bandwidth, 15.63 kHz; (8) matrix, 256*192 Zip 512; (9) field of view, 22 cm; (10) slice thickness, 1.5 mm; (11) cover range, whole brain. The MRI unit database transmitted the scans to an established workstation for algorithmic 3D image reconstruction. We used the 3D Amira software system (version 3.1.1, Mercury Computer Systems, Inc., USA) for image processing. Its "brush" and "wrapper" tools enabled us to identify the regions of interest and remove the skull component of the brain with an arithmetic module that isolates the cerebrum component.

We limited the gray scale values to 110–155 of 1024 (2^{10}) scales in order to approximate the boundary of the grey matter. The software's "threshold" and "edge detection" tools allowed for a precise delineation of the grey matter.

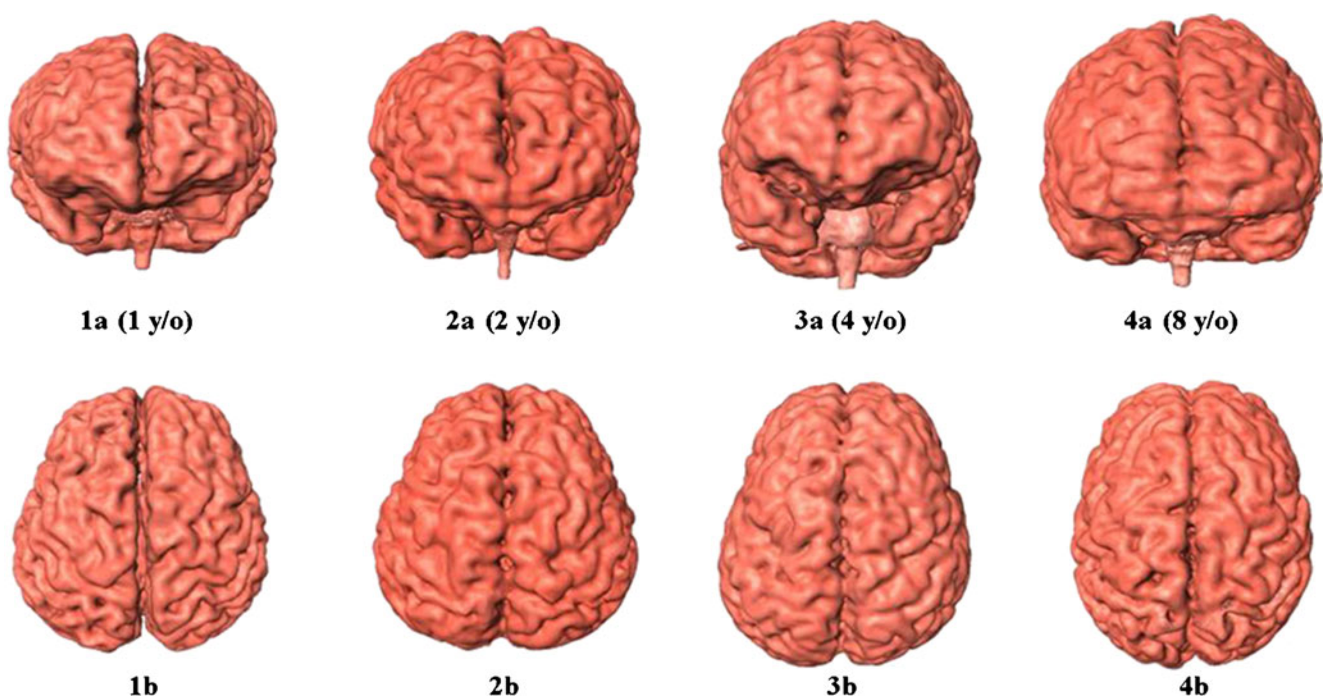


Fig. 1 Three-dimensional reconstruction neuroimages of brain cortex at different ages. *1a* Anterior view and *1b* vertical view of a child 1 year old (cortical volume, 611.3 cm^3). *2a* Anterior view and *2b* vertical view of a child 2 years old (cortical volume, 667.3 cm^3). *3a* Anterior view and *3b* vertical view of a child 4 years old (cortical volume, 769.4 cm^3). *4a* Anterior view and *4b* vertical view of a child 8 years old (cortical volume, 927.6 cm^3)

Author's personal copy

Table 1 The cortical volume, white matter volume, and whole brain volume by 50 aged patients

Group	Age	Number	Cortical volume (cm^3)		White matter volume (cm^3)		Whole brain volume (cm^3)	
			Range	Mean±SD	Range	Mean±SD	Range	Mean±SD
1	3 m~11 months	5	432.9–675.0	578.3±98.8	12.8–213.7	85.9±79.7	458.9–919.1	683.6±170.8
2	1~1.9 years	5	561.9–859.3	673.0±115.3	179.4–308.6	250.4±52.4	815.0–1193.3	952.0±156.7
3	2~3.9 years	4	633.2–753.2	691.4±63.1	198.8–442.8	290.6±108.7	863.8–1213.9	1005.4±161.1
4	4–5.9 years	18	602.7–830.8	691.5±63.4	253.4–479.8	352.8±65.4	889.2–1328.2	1058.9±117.1
5	6~8.9 years	9	613.8–966.4	766.1±123.6	302.7–393.2	337.1±33.8	928.2–1346.9	1127.0±140.7
6	9~12 years	9	565.8–833.1	673.8±94.1	275.1–422.5	335.9±46.3	874.4–1189.2	1030.9±103.9

SD standard deviation

Certain areas of less than 50 pixels (area <0.1 cm^2) were removed to eliminate erroneously identified grey matter. We then repeated the procedure for the white matter with gray scale values in the range of 75–95 of 1024. Subsequently, we computed volumetric measurements of the grey matter with the following formula: Volume of cortex = (number of voxels within cortex) × (volume per voxel). This formula can be modified to compute the white matter and whole brain volumes. Fifty normal children fit the study criteria and became the study's subjects. We sent their MRI scans for 3D image reconstruction (Fig. 1) and computed brain volume measurements. Results included age and brain volume, calculated by the following formula volume of cortex = (number of voxels within brain) × (volume per voxel), derived from Courchesne et al. [5].

Statistical analysis

We conducted statistical analyses of the data with Excel 2003 and SPSS version 11.5 and individually graphed the regression curves of the cortex, white matter, and whole brain. The whole brain, cortical, and white matter volumes were recorded by age. Our statistical probabilities and regression analysis used logarithmic functions.

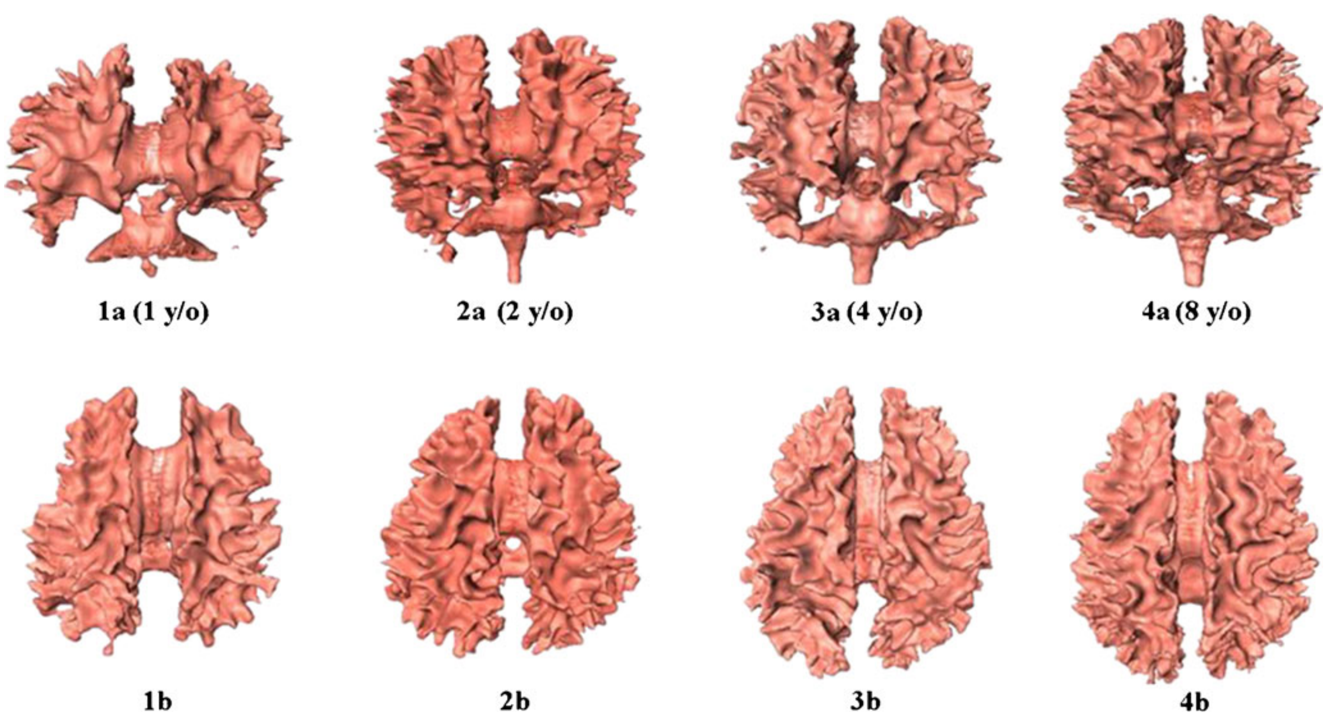


Fig. 2 Three-dimensional reconstruction neuroimages of brain white matter at different ages. *1a* Anterior view and *1b* vertical view of a child 1 year old (white matter volume, 179.4 cm^3). *2a* Anterior view and *2b* vertical view of a child 2 years old (white matter volume, 276.8 cm^3). *3a* Anterior view and *3b* vertical view of a child 4 years old (white matter volume, 315.6 cm^3). *4a* Anterior view and *4b* vertical view of a child 8 years old (white matter volume, 393.2 cm^3)

Author's personal copy

Results

We analyzed a total of 50 normal children aged from 3 months to 12 years and 11 months. Their age distribution and brain volume are listed as Table 1. The figures of cortical and white matter growth are in Figs. 1 and 2.

The regression curve of cortical growth is $y=39.317Ln(x)+631.31$, $R^2=0.1318$. The regression curve of white matter growth is $y=81.754Ln(x)+186.07$, $R^2=0.5675$, and the regression curve of whole brain growth is $y=121.07Ln(x)+817.738$, $R^2=0.4077$ (Fig. 3.). In the formula, y represents volume, and x represents age.

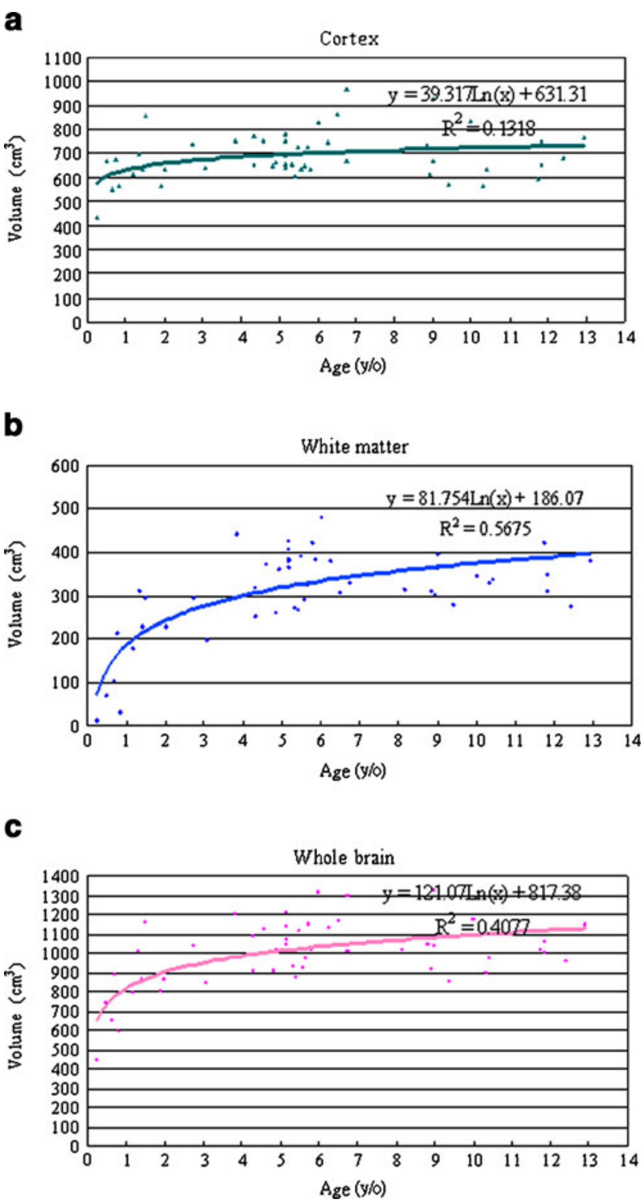


Fig. 3 Growth curve of the brain from 3 months to 12 years and 11 months of age. **a** Cortex, **b** white matter, and **c** whole brain

Data analysis from our study showed that postnatal cortical growth occurs primarily during the period between birth and 4 years of age (Fig. 3a), while brain growth from birth to adolescence is fueled primarily by white matter growth (Fig 3b, c).

Discussion

The development of digital image processing with algorithm makes it possible to demonstrate a 3D image practically, effectively, and efficiently. We used a high-resolution gray scale (1024) method to define the gray scale levels of different parts of the brain on a delicately sliced MRI scan (slice thickness 1.5 mm, approximately 80–120 slices in a normal brain). Then we set up a level threshold and processed the image with an algorithm computer program. With this procedure, we were able to display each component of the brain using 3D images, including the cortex, white matter, ventricles, vessels as well as pathological lesions. With delicately sliced MRI scans, this technology may provide a new tool for more precise demonstrating of both the normal anatomy and pathological lesions of the brain. This program can also be modified for volume arithmetic to enable the evaluation of brain volume.

Computation for volumetric measurements of the grey matter used the following formula: $\text{Volume of cortex} = (\text{number of voxels within cortex}) \times (\text{volume per voxel})$. Modifications to this formula can allow for the computation of the volume of white matter, entricles, whole brain, and even brain lesions [5].

Brain volume analysis in the developmental children with MRI image and segmentation technique has been reported previously [6–9]. The present study provides another methodology to calculate the brain volume. We started by processing the MRI 3D image, which is followed by voxel count of the region of interest after tissue differentiation by the light resolution gray scale (1024). This made the identification of the tissue or lesion for volume measurement possible.

Brain development in the early childhood is extremely dynamic and likely plays an important role in neuro-developmental disorders. Knowledge related to the growth during this period is currently quite limited [10]. However, the using of structural MRI studies of brain development and longitudinal volumetric MRI observations of the brain during prematurity [7, 11] were developed.

Our study result is consistent with the results from prior studies [6, 10]. A 3D reconstructed neuroimage with volume measurement allow physicians to follow the development of a normal brain through cross-sectional analyses. This study's novel approach can help clinicians

Author's personal copy

evaluate an under-developed brain or the long-term outcome of a damaged brain. The 3D neuroimages offer enhanced convenience and efficacy for the evaluation of structural or anatomical anomalies as well as the assessment of brain development in clinical practice.

Genetic factors, intrauterine factors, prenatal insults, as well as postnatal and nutritional effects may all influence the development of a child's brain. Therefore, a close tracking of the brain's longitudinal growth curve is necessary for the detection of brain disorders during childhood.

In Table 1, the cortical, white matter and whole brain volume of age group 6 is smaller than the antecedent group. This is likely due to one isolated case with a rather small brain (age 9.3 years old, cortex 571.6 cm^3, white matter 279.8 cm^3 and whole brain 851.4 cm^3). However, from the limited available data (Table 1), we noted gradual increases of the cortex, white matter, and whole brain from infancy through 12 years of age. The main events in human development include primary neurulation, prosencephalic development, neuronal proliferation, neuronal migration, organization, and myelination. Most of these events occur before birth. The peak time for development takes place between 5 months of gestation and 4 years of age, while myelination takes place between birth and the postnatal years [12]. Furthermore, both animal studies [13, 14] and functional MRI examinations of the infantile brain [15] demonstrate that myelination and synaptogenesis occur primarily during the postnatal stage. According to these studies, myelination and synapse formation account for brain and white matter growth during childhood. The brain volume decreases from adolescence onward [16]. As described by these studies, our 3D neuroimaging method provides clinicians with an efficient and cost-effective method to visually map and study the brain development in actual patients.

The evaluation of the brain growth is especially important for patients with developmental delays without obvious clinical etiology. Also, it is important to track the brain growth of children who have brain insults beyond the toddler ages.

Acknowledgments The authors wish to thank Gen-Jia Li and Yi-Lu Chien for technical assistance and Yun-Yin Chen for manuscript drafting.

References

1. Benveniste H, Blackband S (2002) MR microscopy and high resolution small animal MRI: applications in neuroscience research. Prog Neurobiol 67:393–420
2. Wong STC, Koslow SH (2001) Human Brain Program Research Progress in Biomedical Imaging/Neuroscience. J Am Med Inform Assoc 8:510–511
3. Flohr TG, Schaller S, Stierstorfer K, Bruder H, Ohnesorge BM, Schoepf UJ (2005) Multi-detector row CT systems and image-reconstruction techniques. Radiology 235:756–773
4. Mortele KJ, McTavish J, Ros PR (2002) Current techniques of computed tomography. Helical CT, multidetector CT, and 3D reconstruction. Clin Liver Dis 6:29–52
5. Courchesne E, Chisum HJ, Townsend J, Cowles A, Covington J, Egaas B, Harwood M, Hinds S, Press GA (2000) Normal brain development and aging: quantitative analysis at in vivo MR imaging in healthy volunteers. Radiology 216:672–682
6. Ment LR, Kesler S, Vohr B, Katz KH, Baumgartner H, Schneider KC, Delancy S, Silbereis J, Duncan CC, Constable RT, Makuch RW (2009) Longitudinal brain volume changes in preterm and term control subjects during late childhood and adolescence. Pediatrics 123:503–511
7. Knickmeyer RC, Gouttard S, Kang C, Evans D, Wilber K, Smith JK, Hamer RM, Lin W, Gerig G, Gilmore JH (2008) A structural MRI study of human brain development from birth to 2 years. J Neurosci 28:12176–12182
8. Matsuzawa J, Matsui M, Konishi T, Noguchi K, Gur RC, Bilker W, Miyawaki T (2001) Age-related volumetric changes of brain gray and white matter in healthy infants and children. Cereb Cortex 11:335–342
9. Rovaris M, Iannucci G, Cercignani M, Sormani MP, De Stefano N, Gerevini S, Comi G, Filippi M (2003) Age-related changes in conventional, magnetization transfer, and diffusion-tensor MR imaging findings: study with whole-brain tissue histogram analysis. Radiology 227:731–738
10. Benedetti B, Charil A, Rovaris M, Judica E, Valsasina P, Sormani MP, Filippi M (2006) Influence of aging on brain grey and white matter changes assessed by conventional, MT, and DT MRI. Neurology 66:535–539
11. Ge Y, Grossman RI, Babb JS, Rabin ML, Mannon LJ, Kolson DL (2002) Age-related total grey matter and white matter changes in normal adult brain. Part I: volumetric MR imaging analysis. Am J Neuroradiol 23:1327–1333
12. Volpe JJ (2001) Human brain development. In neurology of the newborn, 4th edn. Sounders, Philadelphia, pp 3–99
13. Moriizumi T, Sakashita H, Furukawa M, Kawano J, Okoyama S, Kitao Y, Kudo M (1995) Electron microscopic study of synaptogenesis and myelination of the olfactory centers in developing rats. Exp Brain Res 103:385–392
14. Levitt P (2003) Structural and functional maturation of the developing primate brain. J Pediatr 143:S35–S45
15. Yamada H, Sadato N, Konishi Y, Muramoto S, Kimura K, Tanaka M, Yonekura Y, Ishii Y, Itoh H (2000) A milestone for normal development of the infantile brain detected by functional MRI. Neurology 55:218–223
16. Bartholomeusz HH, Courchesne E, Karns CM (2002) Relationship between head circumference and brain volume in healthy normal toddlers, children, and adults. Neuropediatrics 33:239–241