Original Article

Measurement Methods of Head Circumference in Pediatric Brain Magnetic Resonance Imaging to Determine the Head Size

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Objective: To evaluate the most reliable measurement method of the head circumference (HC) in brain magnetic resonance imaging (MRI).

Material and Methods: The MR images of 84 pediatric brain protocols with both axial T2-weighted image (T2-WI) and sagittal T1-weighted image (T1-WI) were retrospectively reviewed. The HC was independently measured in axial T2-WI and sagittal T1-WI by two radiologists before the data analyses. The reference method was obtained by semi-automatic software from the reconstructive images.

Results: Eighty-four patients were included. Both measurement methods had a strong positive correlation (r=0.981, 0.984) with the reference method. The mean difference between all methods was lower than the accepted value of error (2 cm). The second method, called 2D-axial with sagittal measurement, was more accurate than the first method, called 2D-axial measurement, compared with the reference method with a mean difference of 1.52 in radiologist 1 and 1.24 in radiologist 2. The interobserver agreement was good for all measurement methods with ICC of first and second methods being 0.98 and 0.99, respectively.

Conclusion: The second method, called 2D-axial with sagittal measurement, is more reliable than the first method, named 2D-axial measurement, to determine the head size in MR images using a simple application formula. Moreover, both methods are reliable to determine the head size in MR images with no limitation of the software.

Keywords: Head circumference; Magnetic resonance imaging

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The measurement of head circumference (HC) is a standard method in the evaluation of head growth, disease pattern, and related neurodevelopment of children[(1,2)]. The HC-taped measurement is a simple, rapid, non-invasive, and cost-effective approach for normal practice[(3-5)]. According to Medicine plus of the US National Library of Medicine, the HC-taped measurement is made from the largest area of the head as well as from the most prominent part of the occiput to just above the supraorbital ridge[(5)]. After that, by plotting the HC-taped measurement data on the growth chart would show the percentile of the HC[(6-8)]. This is useful because there is no radiation and it is more beneficial for diagnosing brain disease. However, magnetic resonance imaging (MRI) is increasingly being used to examine and monitor brain lesions in children[(9-12)]. Although the tape measurement is the standard method, there are situations when this is not possible or was not done. In the previous studies[(2,4,9,12)], HC measurement in prenatal or postnatal MRI has been reported, but no one has explained the best method for HC assessment in MRI in children. Most previous studies[(13-20)] were conducted on the fetus and from sonography or computed tomography (CT), which the authors assumed that could be used for postnatal HC measurement in MRI. According to the study[(3)], the result revealed the normative model of HC development by applying non-linear correction factors to estimate HC, but their formulas were difficult to use. Therefore, the present study aimed to evaluate the most reliable measurement method of the HC in MR images using a simple application formula.

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Materials and Methods

Study design and target population

The presented retrospective review study of patients who had brain MRI studies between January 2017 and June 2018, was approved by the Institutional Review Board (REC 61-428-7-4). Patients more than five years of age who had undergone brain MRI with axial T2-weighted image (T2-WI) and sagittal T1-weighted image (T1-WI), on the same date were included. Patients with prior cranial surgery, abnormal head shape, scalp mass, and incomplete information were excluded.

Eighty-four patients were enrolled in the present study and included 51 males and 33 females with mean age of 24.2 months. They were divided into five groups according to their age with Group I at one year or younger, Group II at two years or younger, Group III at three years or younger, Group IV at four years or younger, and Group V at five years or younger. The patients were also categorized into normocephaly, macrocephaly, and microcephaly by the World Health Organization (WHO) HC guideline.

Image acquisition

The MRI studies were performed with either a 3.0-Tesla (T) (Achieva, Philips) or a 1.5T scanner (Ingenia, Philips) with a standard head coil. The protocol included whole brain axial fluid attenuation inversion recovery (FLAIR), diffusion weighted imaging (DWI), T1-WI, T2-WI, Gradient echo sequence (GRE), Susceptibility-weighted image (SWI). The axial spin echo T2 was performed with the following parameters: repetition time (TR)/echo time (TE) 3499 ms/80 ms, with 3 mm section thickness, NEX 2, Matrix 284×227. The sagittal spin echo T1 was obtained following the parameters: TR/TE 874 ms/10 ms, NEX 1, Matrix 164×162.

The semi-automatic software [MATLAB (Natick, MA)] was used for the measurement of the reference HC method. The software also reconstructed the image and selected the level of maximal frontal-occipital extension of the reference plane as glabella to opisthocranion, including the scalp area, and a post-reconstruction image was obtained (Figure 1). It was validated by phantom before use, ensuring that it was accurate enough to be used.

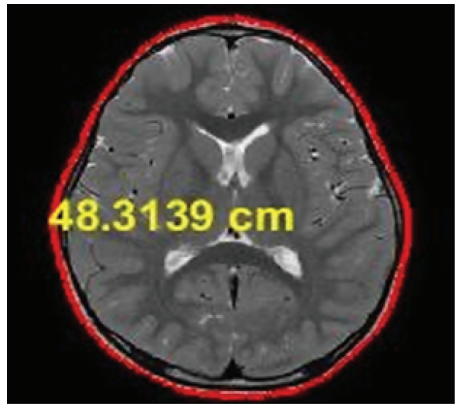

Figure 1. The reference method was the image from the semi-automatic post-reconstruction software.

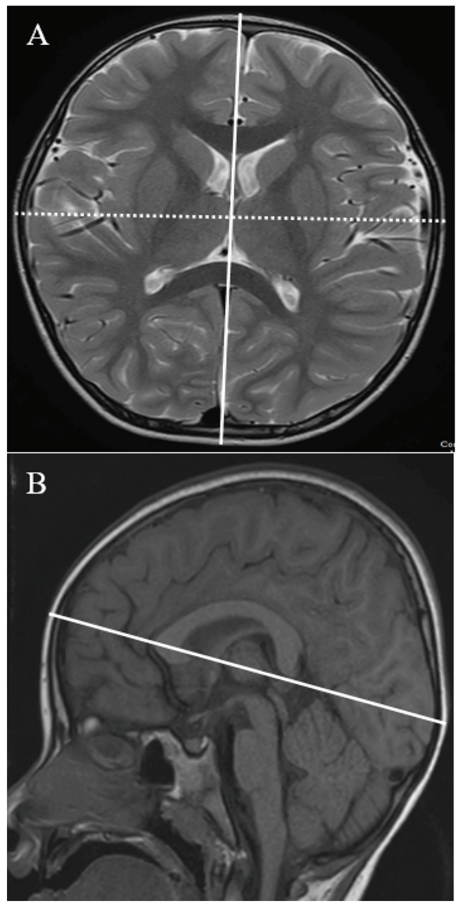

Figure 2. Two measurement methods with manually measured 2D parameters. Axial T2-weighted image (A) shows the biparietal diameter (BPD), in the dotted line, and the occipitofrontal diameter (OFD), in the solid line. Mid-sagittal T1-weighted image (B) shows the anteroposterior (AP) line.

Reader assessment method

Two radiologists with 11 and 4 years of experience, independently measured HC from MR images of the 84 patients. Axial T2-WI and sagittal T1-WI were used to assess the HC value by two methods (Figure 2). The first method, called 2D-axial measurement, measured the occipito-frontal diameter (OFD) and the biparietal diameter (BPD) in axial T2-WI, which showed the transthalamic plane with caudate, lentiform nuclei, and thalami maximally visible, including the outer border of the scalp. Then the HC was calculated by the formula[12]: HC = 1.57×(BPD+OFD). The second method, named 2D-axial with sagittal measurement, measured the BPD in axial T2-WI the same as the first method and measured the anteroposterior diameter (AP) in mid-sagittal T1-WI. The HC was calculated by the formula[12]: HC = 1.57×(BPD+AP).

Statistical analysis

The results of the two measurement methods compared with the reference method were statistically evaluated by one-sample t-test as the mean difference, constructing accepted value of error and standard deviation (SD). The data analysis was performed by using the R Statistic software version 3.6.2. A p-value of less than 0.05 was considered statistically significant. The interobserver agreement was also determined by intraclass correlation coefficient. The previous study revealed that the interobserver limits of agreement were between 19.9 and 20.3 mm for manual HC measurements by using clinicians' measurements as the gold standard compared with the ultrasound technologists. According to the prior data, the accepted value of error from HC measurement in the present study was determined as less than 2 cm.

Results

Eighty-four patients including 51 were males or 60.7% and 33 were females or 39.3% were included in this study (Table 1). A comparison between the reference method and the two measurement methods revealed that the mean difference between all methods was within the accepted value of error. The second method, called 2D-axial with sagittal measurement, was more accurate than the first method, called 2D-axial measurement, compared with the reference method with a mean difference of 1.52 in radiologist 1 and 1.24 in radiologist 2) (Table 2, Figure 3).

The statistical correlation was also highly significant for the HC, which was measured by reference methods compared with two measurement methods. (r=0.981, 0.984) (Figure 4). The interobserver agreement between the two radiologists evaluated by the intraclass correlation coefficient was good for all measurement methods with the ICC of the first and second methods as 0.98 and 0.99, respectively (Table 3).

Table 1. Demographic data

	n (%)
Total	84 (100)
Sex	
Male	51 (60.7)
Female	33 (39.3)
Age	
Mean	24.2 months
0 to 12 months	29 (34.5)
>12 to 24 months	17 (20.2)
>24 to 36 months	13 (15.5)
>36 to 48 months	17 (20.2)
>48 to 60 months	8 (9.5)
Normocephaly	58 (69.1)
Macrocephaly	10 (11.9)
Microcephaly	16 (19.0)

Table 2. Difference between the reference method and two measurement methods

Method	Radiologist 1			Radiologist 2		
	Diff (cm)	p-value	SD	Diff (cm)	p-value	SD
First	1.834	0.028	0.78	1.430	<0.001	0.84
Second	1.526	<0.001	0.76	1.244	<0.001	0.80

Diff=mean difference; SD=standard deviation

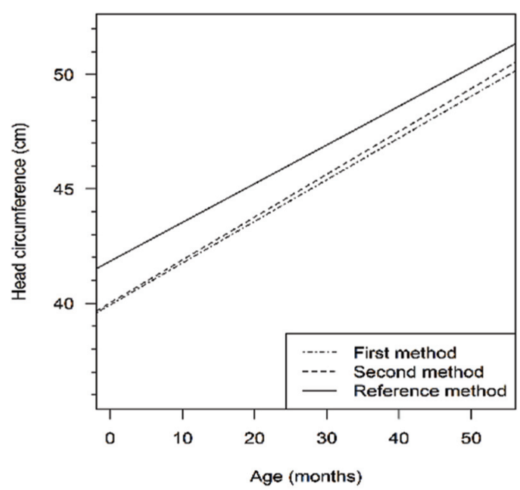

Figure 3. Comparison of the reference method and other two measurement methods.

Discussion

The HC measurement is a standard method in the evaluation of head growth, relating to neurodevelopment of children and helping differential diagnosis. Although the HC-taped measurement is non-invasive and easy to make, it is not always

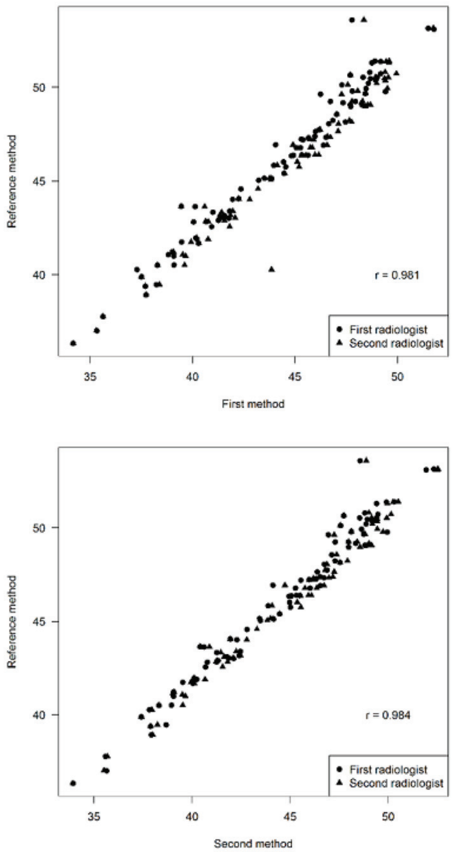

Figure 4. Correlation of the HC of two measurement methods compared with the reference method. All methods have a strong positive correlation.

Table 3. Inter-correlation between two radiologists

Method	ICC	95% CI
First	0.988	0.964 to 0.995
Second	0.998	0.983 to 0.999

ICC=intraclass correlation coefficient; CI=confidence interval

available retrospectively for medical purposes and operator dependent. The authors adapted and created the reference method from the previous studies, which described the indirect HC measurement method from MRI for minimizing the operator-dependent problem. Therefore, the purpose of the present study was to evaluate the most reliable measurement method of the HC in MR images using a simple application formula and no limitation of the software. In previous studies[2,4,9], the HC measurement from reconstructive 3D MRI showed a strong correlation between directed HC-taped measurement and indirect technique from MRI, but it is still not available in many places. Most of the studies mentioned digital HC measurement by using computer software. No one ever explained about the indirect HC measurement method, secured by the human on MRI in the child. Prior research[13-20] focused on the fetus and used sonography or fetal MRI, which the authors anticipated might be used to quantify postnatal HC in MRI. According to the study[3], the result revealed the normative model of HC development by applying non-linear correction factors to estimate HC, but the formulas were difficult to use. Reichel et al[12] studied biometry of the fetal head on MRI and ultrasound in fetuses with and without suspected central nervous system (CNS) abnormalities. The fetal HC formula was described as HC = (BPD+OFD)×1.57. They found a significant correlation between the HC measured by MRI and ultrasound in both groups. All of them showed a similar method by using the software for measurement of the HC from MRI, which secured the indirect HC from the glabella to opisthocranion plane. As a result, the authors established semi-automatic software for measuring the reference HC from MRI using a comparable plane from the reconstruction image and the authors adapted the fetal HC formulas to use in the postnatal MR study.

In the present study, the authors found that the second method was more accurate than the first method as compared with the reference method. In addition, both methods showed high accuracy and reliability for measurement HC from MR images. The authors also found an excellent correlation between the reference method and the two measurement methods as well as the interobserver agreement between the two radiologists being good in both measurement methods. Although, the present study showed that the second method was better than the first method, if the sagittal plane was not done, the first method could be used instead. Nevertheless, these two measurement methods might be inappropriate for use in the case of head-shaped deformity, post-cranial surgery, or scalp mass as they used the linear equation to get the result.

The present study had limitations. First, the authors used semi-automatic software to determine the reference method in the present study, despite the fact that tape measurement is the standard HC measurement. On the other hand, the program had been calibrated to ensure that the data was very close to the standard method and was not operator-dependent. Second, the authors' study did not exclude the groups of macrocephaly and microcephaly, so it could not demonstrate the mean HC of normal children in Songklanagarind Hospital.

Conclusion

The 2D-axial with sagittal measurement method is more reliable than the 2D-axial measurement method to determine the head size in MR images using a simple application formula and reproducible HC measurement. Both methods are reliable to determine the head size in MR images with no limitation of the software.

What is already known on this topic?

HC measurement in prenatal or postnatal imaging has been reported in a number of studies.

What this study adds?

The 2D-axial with sagittal measurement method is more reliable than the 2D-axial measurement method to determine the head size in MR images using a simple application formula. Both methods are reliable to determine the head size in MR images with no limitation of the software.

Conflicts of interest

The authors declare no conflict of interest.

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