Title:

Determination of Reference Values for Normal Cranial Morphology by using Mid-Sagittal Vector Analysis in Japanese Children

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Summary

Mid-Sagittal Vector Analysis (MSVA) is a method of measuring the distance from a defined central point on the skull surface in the entire mid-sagittal plane and provides a clear description of the lateral view of the skull. We used a series of images of normal skulls of Japanese children to determine normal MSVA values. For this cross-sectional study, we first constructed a database of head CT and MRI images of children aged 0–6 years (41.5±24.9 month (mean±SD)) who showed no abnormality of cranial development and growth at the time of imaging. Measurement errors due to lateral shifting of the sagittal plane during MSVA were examined, CT and MRI images taken in the same patients at the same time were compared, and measurement differences were examined. Finally, MSVA was carried out, and the mean of the measured values was calculated according to age group.

Two hundred ninety-five images were included in the database. When the lateral shifting of the sagittal plane was within 4 mm from the true midsagittal plane, the mean errors were less than 1 mm at all measurement points. Between the CT and MRI images from the same patients, most differences in MSVA values were within ± 1 mm. These differences were thus acceptable for use in clinical settings.

After the above verifications, 220 images were extracted for determination of normal MSVA values. We established a normal dataset of MSVA for Japanese children that can be used effectively for preoperative diagnosis, surgery planning, and postoperative assessment of cranial deformities.

Introduction

Normalization of cranial morphology is an important goal in the surgical treatment of craniosynostosis.[1,2] To achieve this goal, establishing an evaluation method and a normal dataset of cranial morphology is necessary for comparisons during preoperative assessments, surgery planning, and evaluation of therapeutic efficacy. In addition, the evaluation method should allow for detailed description of morphology, and measurements should be easy to perform.

The cephalic index (CI) is an example of a widely used index, describing the percentage of the ratio of the maximum width of the skull to the occipitofrontal length; normal ranges of CI values have been established for different ethnicities.[3] The CI has been used in a number of publications for the evaluation of therapeutic efficacy in the treatment of cranial deformities.[2,4,5] It can however not be used for complex morphological abnormalities, and only allows for assessment of one horizontal plane; therefore, the CI alone is not enough to evaluate cranial morphology.[6,7]

In contrast, several morphological evaluation methods using measurements conducted on three-dimensional images have recently been reported, and have made it possible to examine cranial morphology in a highly

detailed manner.[7-12]

Three-dimensional image analysis provides a detailed and accurate description of cranial morphology, but because it requires the use of expensive dedicated software and a specific workstation, it may take a long time for this method to be widely used.

A method evaluating cranial morphology in detail without an expensive workstation is thus needed. In this article, we focused on the Mid-Sagittal Vector Analysis (MSVA) that Marcus et al. have previously reported.[6] MSVA is a two-dimensional morphological analysis for the mid-sagittal plane, and was developed to address inadequacies of CI while maintaining clinical applicability. This is performed by measuring each distance from the top of the dorsum sella summit to the skull surface, on radial lines in 10-degree increments, originated from the top of the dorsum sella summit on the mid-sagittal plane. MSVA can clearly represent the lateral morphology of the skull, and can be performed relatively easily without an expensive device.

Few reports have examined normal reference data on cranial morphology in Japanese children,[3,13] and particularly the normal morphology of the lateral view remains unknown. The main purpose of our study was therefore to determine

normal MSVA values in Japanese children.

Additionally, we included cases with not only CT but also MRI scans available for analysis, in order to collect as many images as possible. We therefore provide auxiliary verification of the hypothesis that MSVA can achieve clinically acceptable results on the mid-sagittal plane, even when shifted, and in the sagittal plane on MRI images.

Materials and Methods

We first evaluated errors that may occur during MSVA conducted on CT and MRI images and then determined normal MSVA values in Japanese children. We adhered to STARD guidelines.

After obtaining approval from the Okayama University Hospital ethics review committee (research no. 1702-006), CT and MRI scans of children between the age of 0 and 6 years (0 to 83 months) taken at Okayama University Hospital between January 2012 and December 2016 were collected. All charts were retrospectively reviewed, and we extracted those that had shown no cranial growth abnormality, and whose images of the axial, sagittal, and coronal plane had been taken adequately, and created a database.

The exclusion criteria were as follows: history of low birth weight (<2500g), low or high growth rate (<-2 SD or >2 SD from the Japanese standard growth curve), developmental retardation (<70 at the developmental quotient test, the *Kyoto Scale of Psychological Development 2001*), severe epilepsy (in need of permanent medication), craniosynostosis, intracranial tumor or mass lesion, intracranial arachnoid cyst, hydrocephalus, underlying diseases that can cause low growth (such as cardiovascular malformations or hypothyroidism), chromosomal abnormalities, and fractures in the measurement area. Patients with benign epilepsy, with normal intellectual development, and with disorders that were predicted to have virtually no effect on cranial morphology at the time of the scan (such as acute encephalopathy shortly after its onset) were included in the study.

The scan parameters for CT and MRI are shown in Table 1; the measurement of distances was carried out using SYNAPSE® (FUJIFILM, Tokyo, Japan), which is an image viewing system running on electronic medical chart devices, and AZE Virtual Place® (AZE, Tokyo, Japan), a DICOM workstation for data analysis.

As a guide for the angle, a digital protractor was displayed on the

measurement screen using the free software protractor.exe (Daigo, http://hp.vector.co.jp/authors/VA034718) (Fig. 1).

Sequential analysis was carried out as follows. Statistical calculations were performed using EZR (Version 1.35, Saitama Medical Center, Jichi Medical University, Saitama, Japan)[14], a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria), and radar charts were created using Excel® 2013 (Microsoft, Redmond, United States).

MSVA measurement

The sagittal plane was selected by defining the plane that traverses the central vertex, the midpoint of the sella, and the midpoint of the nasofrontal suture. On the resultant mid-sagittal image, the digital protractor was placed so that its center coincided with the apex of the dorsum sella summit and the angle-0 line (baseline) passed the front end of the nasofrontal suture. Guided by the protractor, vectors were described from the center to the skull surface in 10-degree increments, beginning at the baseline, then rotating dorsally to the opisthion, and named after their rotation angle. The length of each vector was also measured (Fig1).[6]

MSVA was carried out within the range from vector 0 to 21 (in the majority

of cases, vector 22 reached the foramen magnum, making it impossible to conduct measurements). Missing values were not included in statistical analyses.

Verification of MSVA errors caused by misalignments of the sagittal plane

We searched the database for cases with data suitable for three-dimensional reconstruction (CT volume data with a cross-section thickness of 1.25 mm or less) and extracted five cases that were distributed evenly among the age groups targeted in this study. The CT volume data of the five cases were reconstructed three-dimensionally, and from the resulting image, we created a true mid-sagittal plane and a para mid-sagittal plane shifted by 1 mm towards the left side, respectively (1-10 mm). In each plane, MSVA was performed, the differences in MSVA values between true and para mid-sagittal planes were measured, and the mean and maximum error were calculated.

Then, the acceptable range of the misalignment sagittal plane in which the average error in all vectors was within 1 mm was determined (Fig 3), and the database was updated by re-extraction of images whose mid-sagittal section was suitable for MSVA.

Verification of MSVA differences in modalities

From the updated database, we extracted cases in which both CT and MRI had been performed in the same patient and within the same time period of 7 days. MSVA was performed on each image, and values were compared. To evaluate the inter-method reliability of MSVA values, the intraclass correlation coefficient (ICC(2,1)) was calculated. To evaluate agreement between MSVA values of CT and MRI scans, the 95% limits of agreement (LOA) and the systematic bias were expressed by Bland-Altman plotting.

Determination of normal MSVA values in Japanese children

The database was divided into nine age groups (0-2, 3-5, and 6-11 months, 1, 2, 3, 4, 5, and 6 years). MSVA was performed for all images, and the mean and standard deviation of each measured value were calculated for each age group. When a series of several scan data of the same patient was available for the same age group, the mean age at the time of the scan and the mean of the measured values were used for one case. Similarly, for patients who had been subjected to both CT and MRI at the same time, the mean values were used.

Results

First, 2140 CT and MRI images were collected, and we constructed a database of 295 images extracted after chart review. As described in the following section, 64 images were excluded from the database due to misalignment, and, after optimization of overlapping samples, 220 images (123 males, 97 females) were finally analyzed for the determination of normal MSVA values. The subject flow chart is presented in Figure 2, and details of population characteristics are shown in Table 2.

MSVA errors caused by misalignments

In the database, 60 cases with data suitable for three-dimensional reconstruction were detected. From these, five cases of an approximately equal age distribution (patients aged 15, 24, 41, 52, and 71 months) were extracted. Differences from the true MSVA values with no missing data are shown in Table 3.

When the shift from the true midline was 4 mm or less, the average measurement error at all measurement points was 1 mm or less. In addition, at

the vectors 3-19, the average measurement error was 1 mm or less when the shift was 9 mm or less.

We then excluded 64 images due to misalignment of the mid-sagittal section.

MSVA differences in modalities

Seven cases had both CT and MRI scan data taken within the same time period and suitable for MSVA. Table 4 shows the mean and maximum of the absolute value of differences between CT and MRI at each measurement point with no missing data.

Throughout the entire measurement, the mean of the absolute value of differences was 0.42 mm (0.54%), and the maximum was 2.6 mm (3.78%). ICC (2,1) was 0.999 and the Bland-Altman plot showed a systematic bias of -0.127 mm (95% CI: -0.218-0.035). The LOA (mean ± 1.96*SD) was -1.25 mm to 0.999 mm (Fig. 4).

Normal MSVA values in Japanese children

The mean and standard deviation of the measured MSVA values in each

age group are shown in Table 5. In addition, the mean MSVA values in each age group are shown in radar chart format to make it easier to depict the morphology (Fig. 5). There were some missing data in vector 20 and 21 because of a variation in the angle from the baseline to the opisthion. The number of missing data is also shown in Table 5.

Discussion

Various evaluation methods have been reported to conduct a precise and effective analysis of cranial deformity.[15-18] Recently, with the development of more advanced equipment, cranial morphology can be measured more accurately and more detailed in all three dimensions. [7-12]

Marcus et al. proposed the three-dimensional vector analysis (3DVA), which has allowed for a more ultimate evaluation of morphology.[7,8] Because the three-dimensional coordinates of cranial CT images are used directly for morphological evaluation, 3DVA allows for near-perfect expression of cranial morphology, and this method allows for evaluation of all kinds of cranial deformities. However, carrying out three-dimensional analysis requires expensive

computers and software as well as the ability to operate them. Therefore, it may still take some time until three-dimensional analysis will be widely and universally used in routine medical care.

Before 3DVA, Marcus et al. (2006) proposed MSVA as a method supplementing the CI in the morphological evaluation of the sagittal plane.[6] Because absolute values are measured instead of ratios, this method can specifically determine how much deformity is occurring at which sites on the sagittal plane. One single mid-sagittal plane image is sufficient to conduct measurements, which simply consist of measuring linear distances; therefore, measurements can be carried out on conventional PC terminals.

For this reason, we used MSVA to widely disseminate the normal range of cranial dimensions in Japanese children.

Measurement errors occur in all imaging tests. According to a report published by Richtsmeier et al., errors in distance measurements with an average range of 0.5 mm or less may occur even when CT scans are carried out twice in the same sample.[19] Furthermore, according to a report published by Waitzman et al., the errors in some measurements on axial slices due to head tilting were within clinically acceptable limits (less than 5%) if the angle was no more than ±

4 degrees from baseline.[20] In the present study, we also considered that a measurement error of approximately 1 mm was acceptable in clinical settings when cranial morphology was assessed on an image; we therefore carried out the following verifications.

First, we examined whether evaluations of MSVA were still appropriate if the measured sagittal section had shifted from the true midline. This examination was necessary for the survey on the range of normal values using previous data, as in our study, and also for the use of MSVA in the sagittal section, which will be encountered in routine medical care (during routine tests in daily clinical practice) in the future. The results described in Table 2 show that if the sagittal section subjected to MSVA passes through the area shown in Figure 3, measurement accuracy with a mean error of 1 mm or less can be achieved. The error tended to be greater around degree 0-2 and degree 20-21, presumably due to the tight curvature of the cranial surface around the glabella and the external occipital protuberance.

The second verification consisted of a confirmation of the accuracy of MSVA in MRI. In recent years, to avoid the potential risk of ionizing radiation exposure, several reports have examined the issue of bone measurements using

MRI, and findings have shown the accuracy of MRI measurements to be nearly the same as that of CT.[21-25] Therefore, we examined whether MSVA using MRI images could be used in clinical settings. As shown in Table 3 and Figure 4-2, the MSVA values in CT and those in MRI showed high agreement. In addition, in this verification, the sagittal planes of CT and MRI may be slightly misaligned with each other (i.e., errors by misalignment may occur), but more than that, they showed a high agreement, suggesting that MSVA using MRI might be sufficiently accurate. Therefore, a calculation of the range of normal values by combining CT and MRI data might be acceptable for use in clinical settings.

Following the verifications described above, the mean MSVA values in 220 images of Japanese children with normal cranial development were finally calculated per age group. The results are shown in Table 4, and drawing a radar chart may allow for the silhouette to be easily displayed on paper. The Japanese MSVA charts depicted in Figure 4 show that cranial growth was rapid one year after birth. The findings also show that in all age groups, the cranial surface tended to be markedly curved around vectors 3, 12, and 17. These features become clearer with age.

In terms of clinical applications, MSVA proved very useful during surgery

planning, in making decisions regarding the amount and directions of movements of skull bones. The following is an illustration, describing one clinical case (a female pediatric patient with Crouzon syndrome, oxycephaly accompanied by a premature fusion of all cranial sutures) (Fig. 6-1).

First, the normal MSVA values in the corresponding age group were determined and used as treatment goals in terms of morphology (in consideration of the treatment period, the age group included individuals of the same age and up to 6 months older). In the surgical plan, comparison with the normal MSVA values allowed to determine the necessary amount and the direction of bone movement. Especially in this case, a substantial amount of bone movement had to be estimated across the entire skull; we therefore chose the Multidirectional Cranial Distraction Osteogenesis (MCDO).[26-27] In addition, postoperatively, the clinical course of bone distraction was evaluated by CT imaging and MSVA, and we were able to adjust the amount and direction of distraction in mid-course (MCDO is a device that allows for bones to distract multi-directionally).

Finally, the patients' MSVA curves improved and nearly matched the normal curve for people of the same age (Fig. 6-2).

To summarize, MSVA is an evaluation tool that greatly affects our

decisions regarding treatment strategies throughout the entire preoperative planning as well as intraoperative and postoperative management, and it can lead to favorable treatment results. Besides, the measurement procedure is inexpensive and easy to perform, as it only requires one sagittal image. In this study, we have defined the normal values in the cranial morphology of Japanese children. We hope that MSVA will be more widely used, and will help to achieve further developments in the treatment of morphological abnormalities of the skull.

One limitation of this study is that we could not clarify the difference in MSVA values between male and female subjects. A higher number of subjects would allow to evaluate the potential sex difference and to create more accurate normal MSVA values in narrower age groups.

Conclusion

Mid-sagittal Vector Analysis is a tool that clearly describes the lateral profile of the cranium without any expensive workstation. We verified that clinically acceptable accuracy of MSVA can be obtained even in the sagittal plane containing some misalignment and in the sagittal plane in MRI.

We further established the normal MSVA values of Japanese children up to 6

years of age. By establishing the normal range, this method became a useful guide for diagnosis, operation planning, surgical correction, and postoperative management. The collection of more subjects will lead to more accurate and more detailed normal values.

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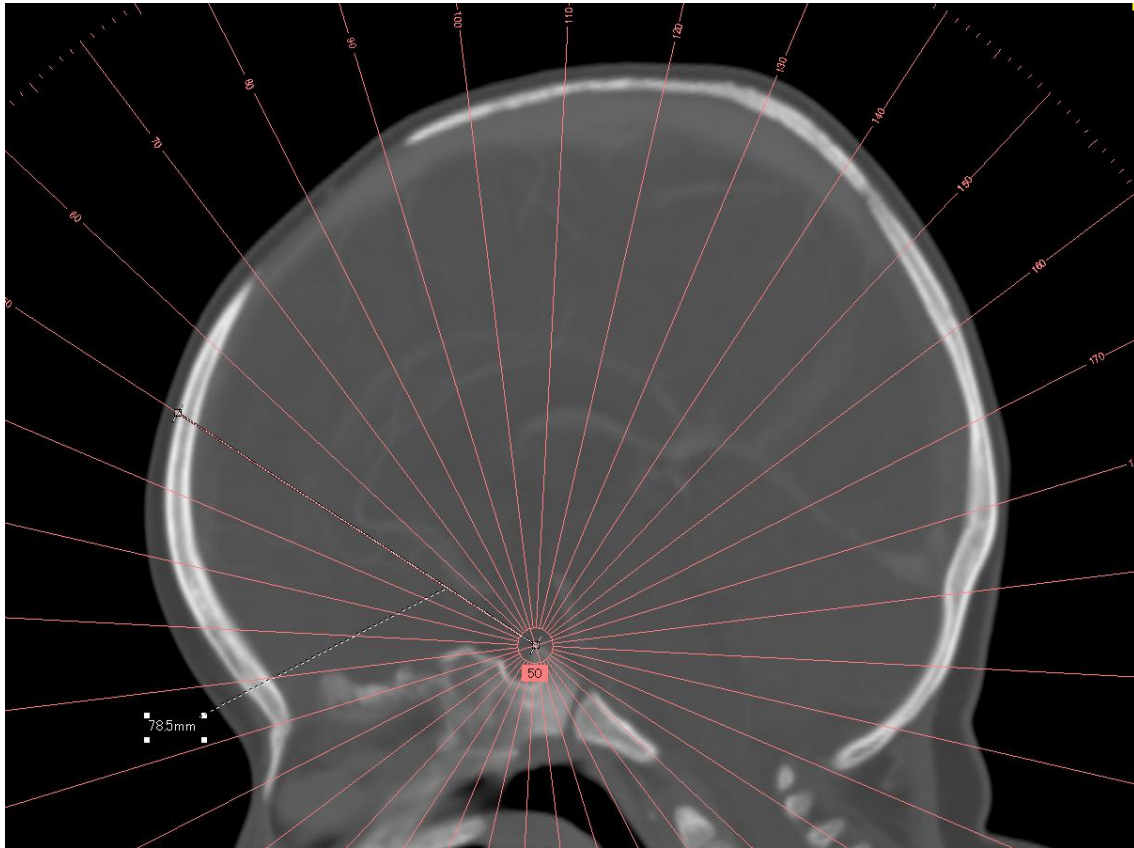
Figure 1-1

Image of a MSVA measurement screen displaying a digital protractor (pink 10-

degree incremental radial lines) in front of a SYNAPSE window.

The protractor center was located at the top of the dorsum sella summit, and the 0-degree line passed the front end of the nasofrontal suture. Each distance from the center to the skull surface on the protractor lines was measured.
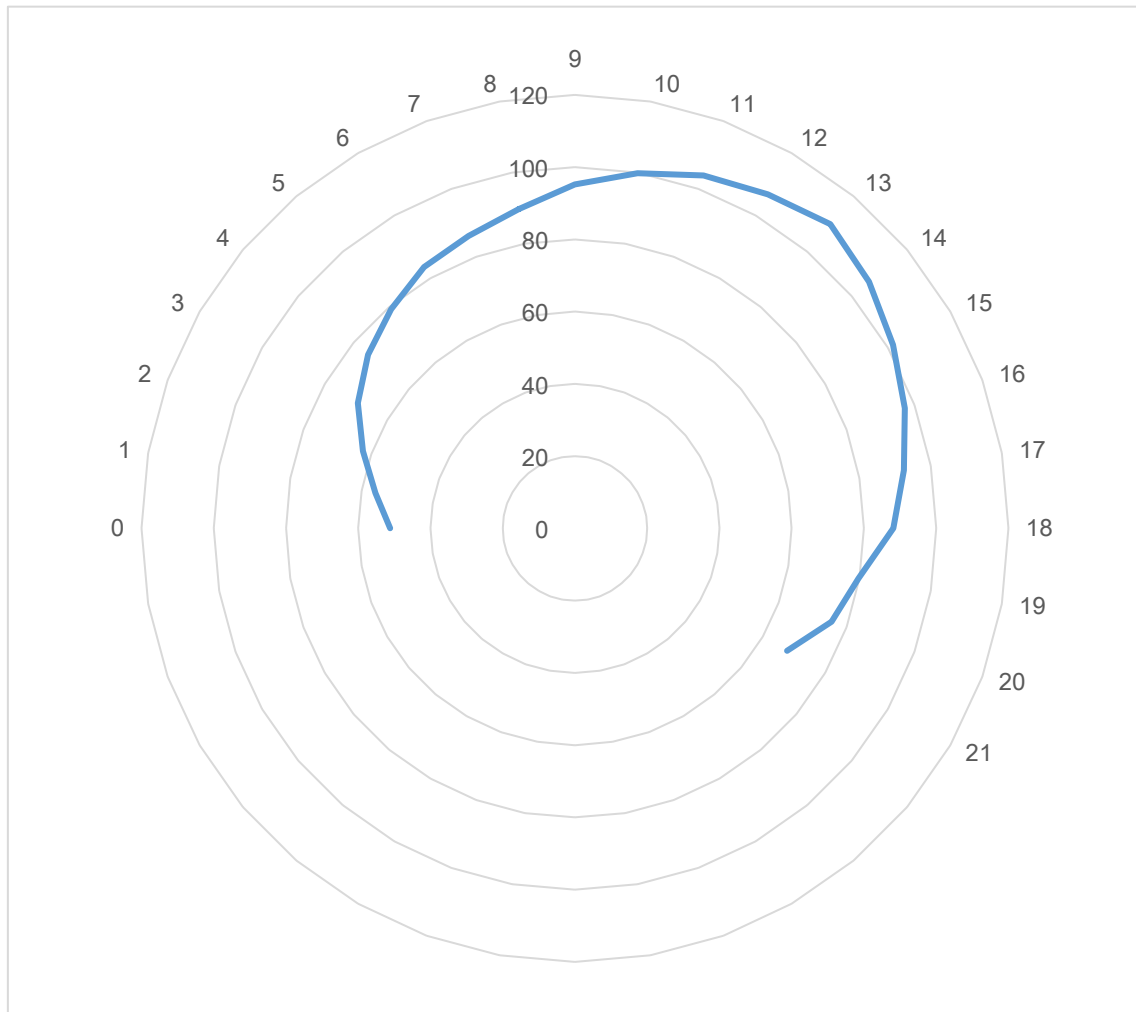
Figure 1-2

MSVA radar chart of the same patient.

The radar chart curve clearly describes the original skull shape.
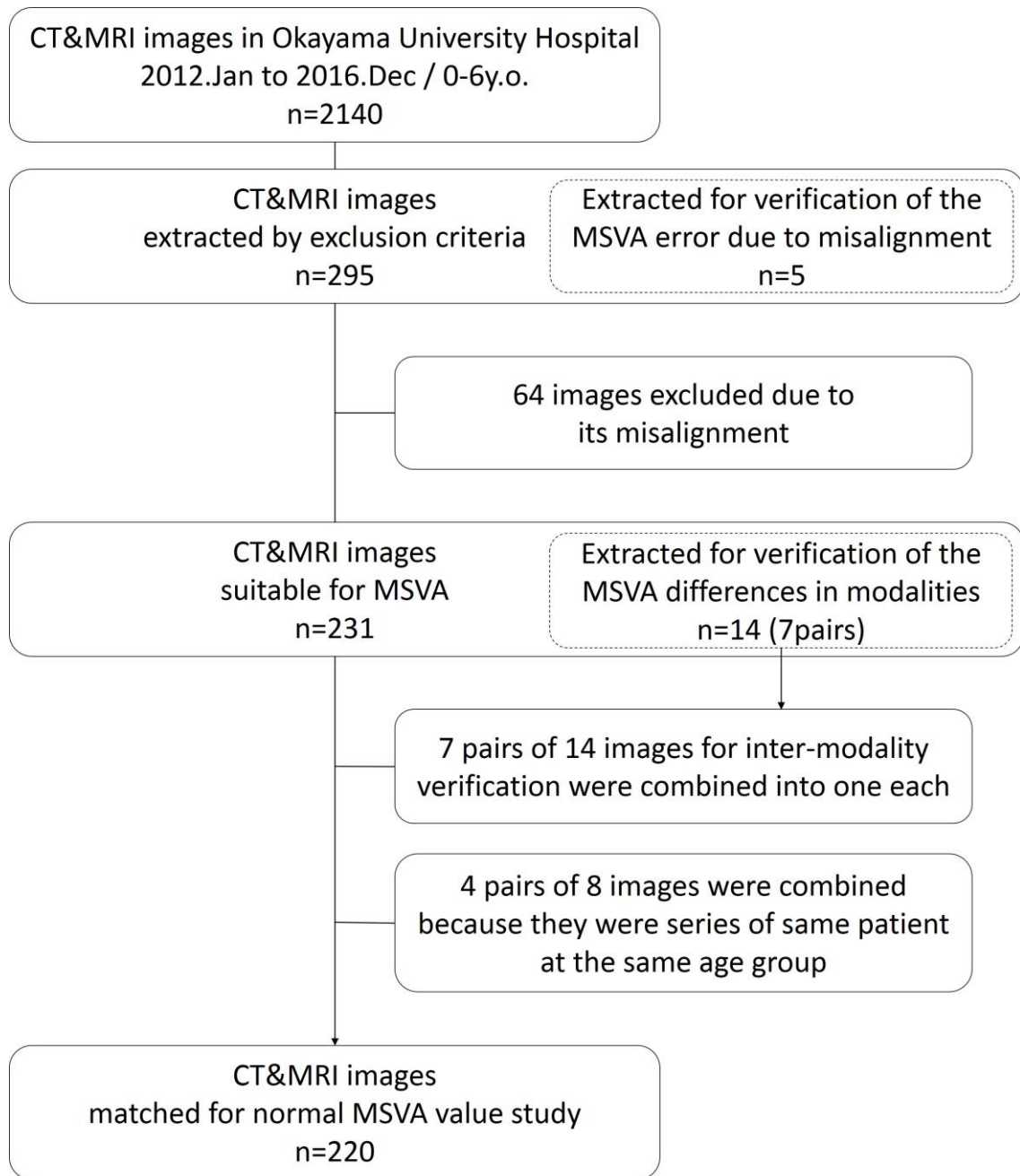
Figure 2

Study subject flow chart.
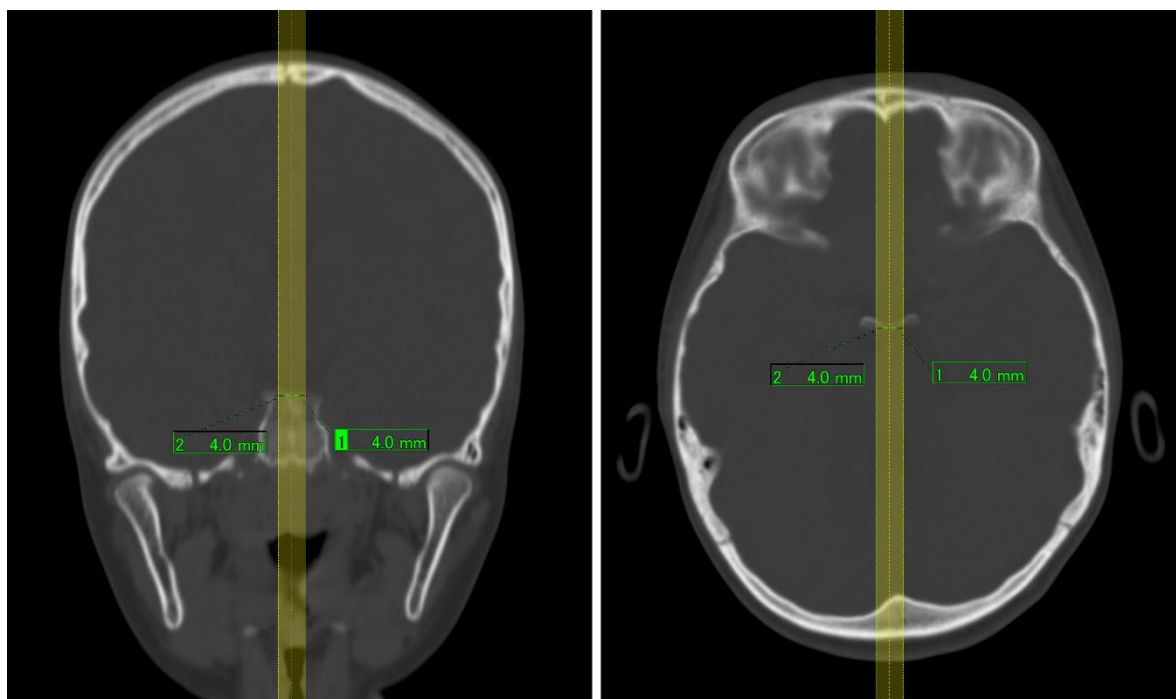
Figure 3

Image of the passing area for sagittal section within a 1-mm average error in

MSVA values.

In routine examination, sagittal sections may occasionally be provided at some offset. However, if the target sagittal section is within the area shown in the picture, the measurement error for true MSVA is less than 1 mm on average.
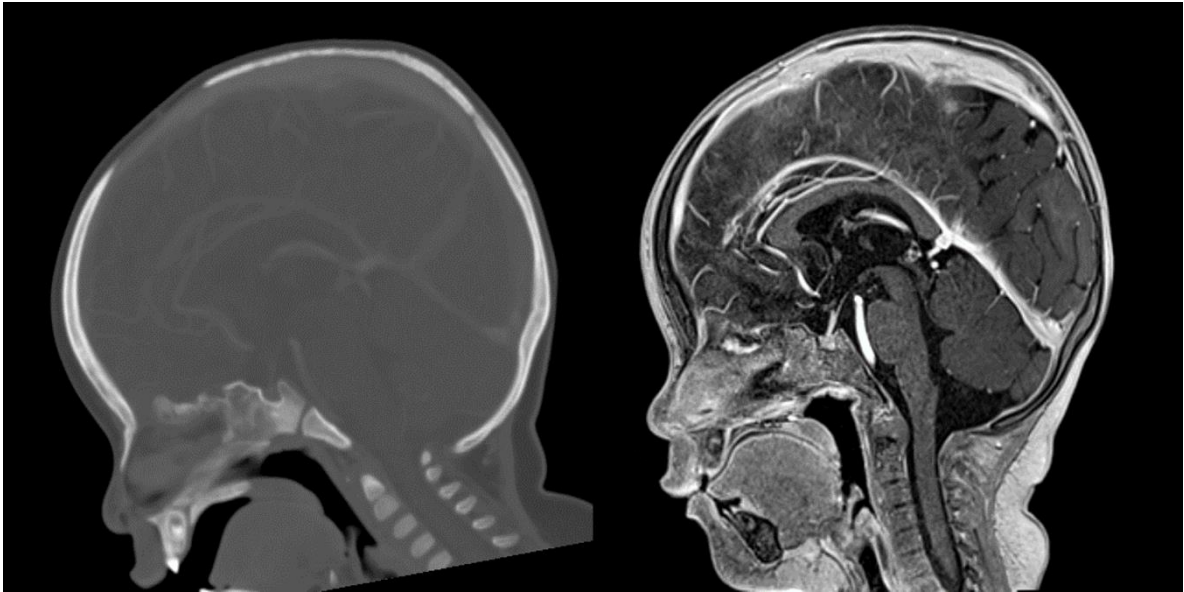
Figure 4-1

Comparative images of CT and MRI taken on the same day in the same patient.

Bones are displayed as white (high absorption region) in CT and black (no signal

region) in MRI. Both provide sufficient contrast and resolution for measurement.
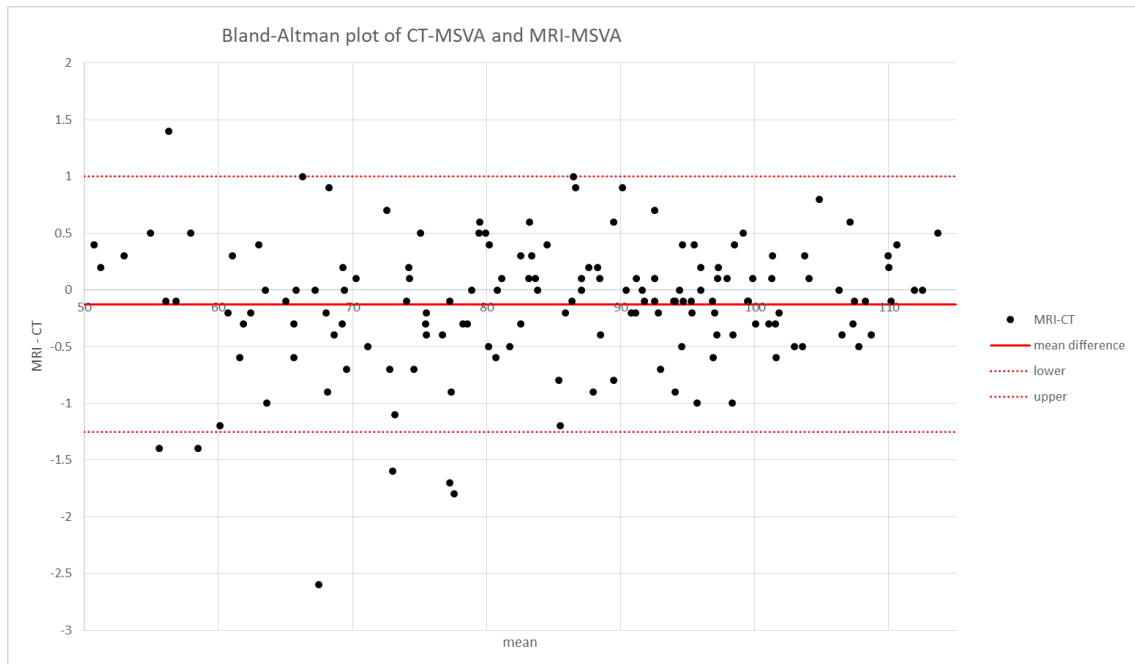
Figure 4-2

Bland-Altman plot of CT and MRI for MSVA measurement. The solid red line shows the mean difference between MRI and CT, with a value of -0.127 mm. The dashed red line shows the 95% confidence interval of the difference, with a value range from -1.25 to 1.00 mm.
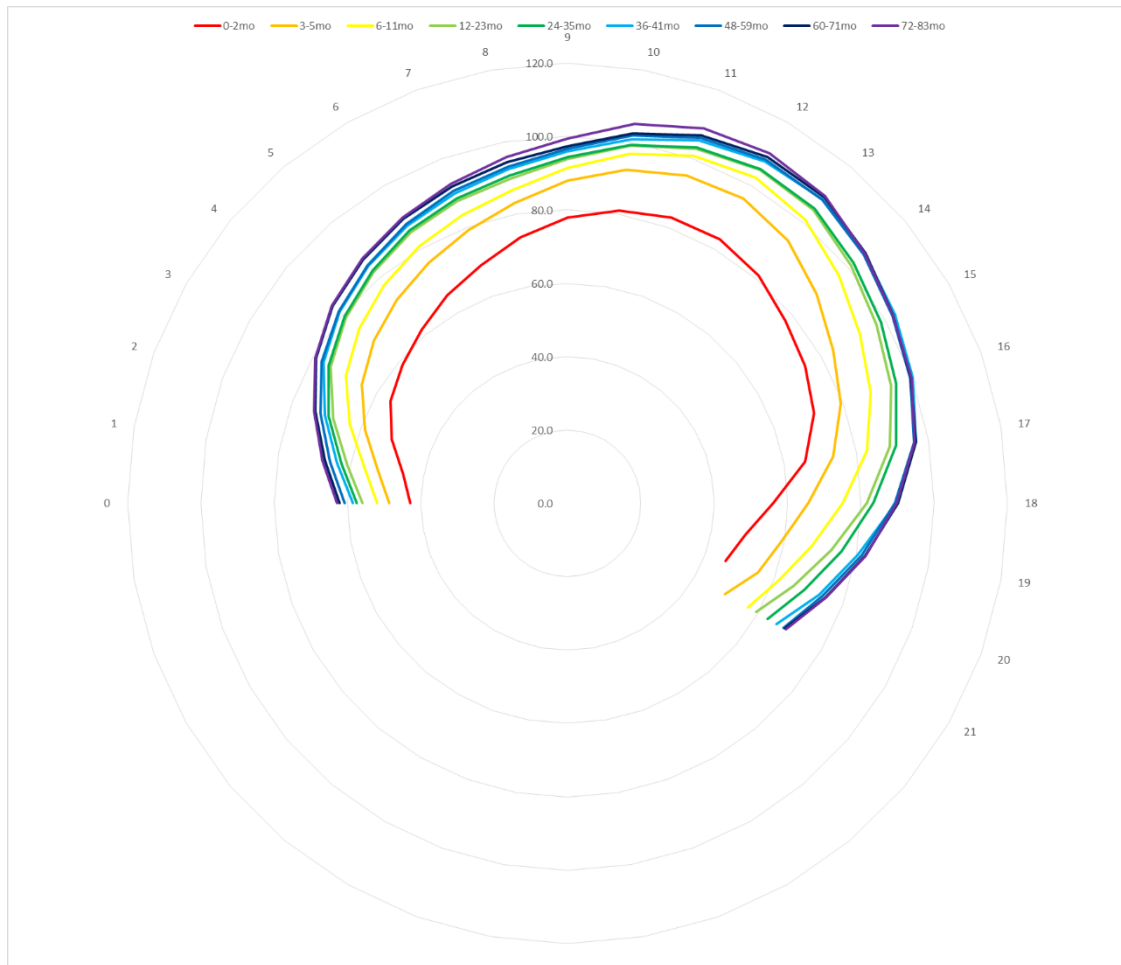
Figure 5

MSVA radar chart of mean values for each age group.

These curve shows that cranial growth is rapid one year after birth, and the cranial

surface tended to be markedly curved around vectors 3, 12, and 17.
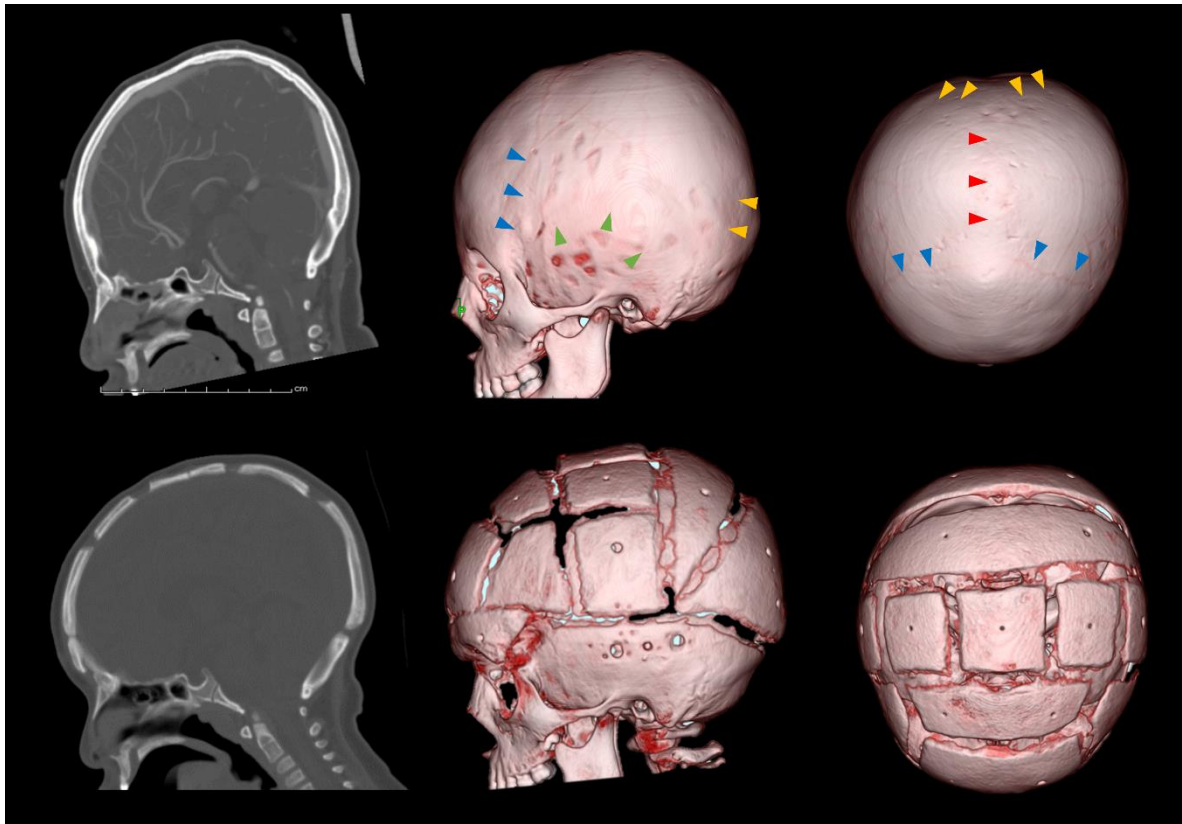
Figure 6-1

Comparison between preoperative CT (above) and 2-month postoperative CT (below) in clinical application. In each group, the side view (center) and the top view (right) of the 3D reconstructive image, and the mid-sagittal section (left) are shown. At the preoperative CT, no cranial suture was seen (arrows indicate the fused cranial sutures: coronal (blue), sagittal (red), lambdoid (yellow) and squamosal (green) suture), and all fontanels were closed. After the operation, the skull was completely expanded to a nearly natural form.
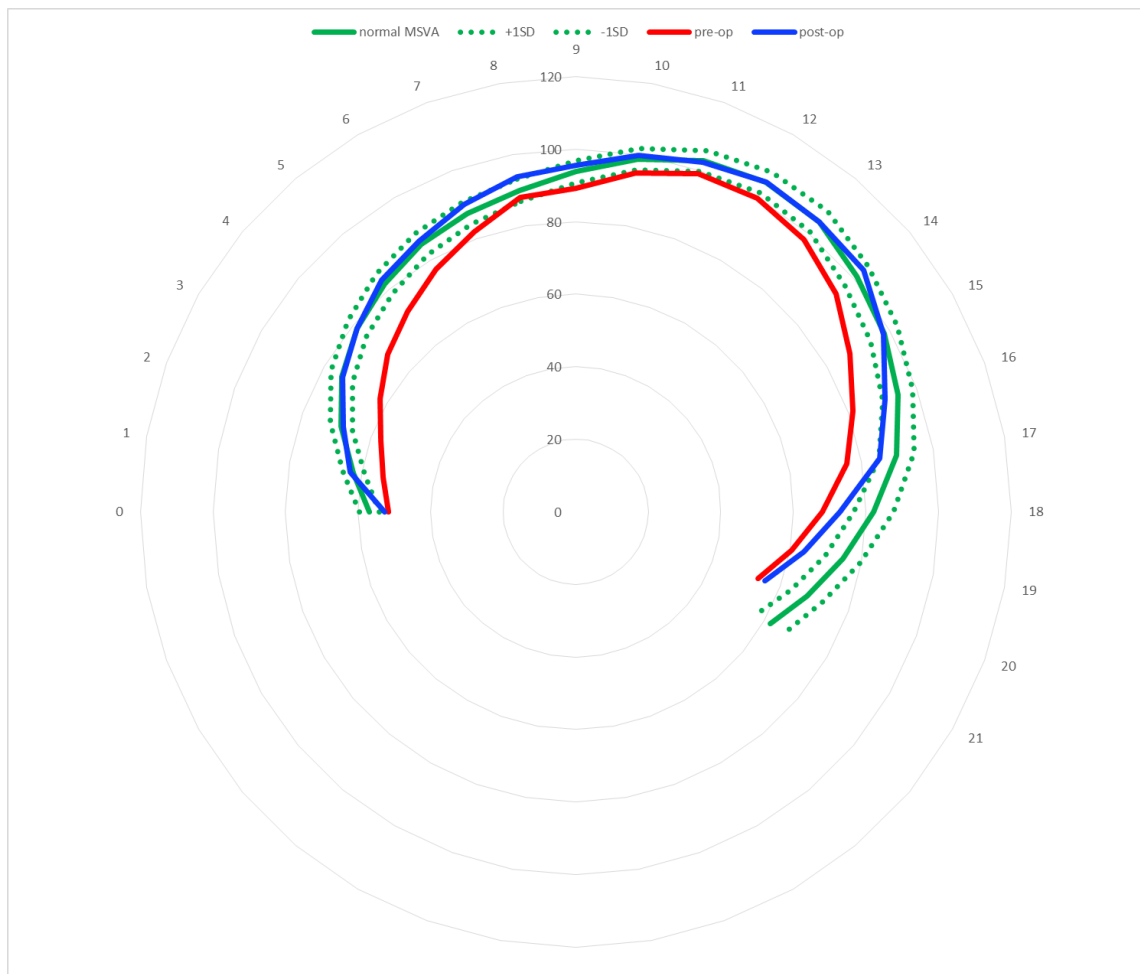
Figure 6-2

Comparison of MSVA before and after treatment on a radar chart. The red line shows preoperative MSVA, and the blue line shows MSVA at 2 months after surgery. The entire preoperative red line curve is below the normal values of the same age group; the green solid line shows the mean, the green dotted line indicates +or- 1SD. The postoperative blue line curve almost matches the green line.

scanning parameters of CT and MRI		
helical CT	Aquilion ONE ViSION (TOSHIBA)	
tube voltage	120	kV
tube current	300	mA
PF	0.637	
slice thickness	4	mm
	(0.5mm×80slice)	
FOV	200	mm
MRI	Skyra (SIEMENS)	
TR	4.30	ms
TE	1.82	ms
FA	10	degree
Slice thickness	1	mm
Gap	0	mm
FOV	200	mm
Phase encode	265	
Frequency encode	288	
Reeive bandwidth	290	

Table 1. CT and MRI scanning parameters

Summary of study population					
			male	female	total
Age Group	(range,mo)	mean(SD)			
0mo	(0–2)	0.75(0.87)	7	5	12
3mo	(3–5)	4.2(0.86)	7	11	18
6mo	(6–11)	8.8(1.7)	13	7	20
1yr	(12–23)	16.6(3.2)	26	22	48
2yr	(24–35)	28.3(3.6)	14	14	28
3yr	(36–47)	42.7(2.9)	10	13	23
4yr	(48–59)	54.1(3.4)	18	7	25
5yr	(60–71)	65.5(3.9)	16	9	25
6yr	(72–83)	77.7(3.5)	12	9	21
	Total		123	97	220
examination					
	CT		57	50	107
	MRI		68	52	120
	Total		125	102	227
	*7cases ware examined both CT and MRI				
reason for examination					
trauma & accident					52
seisure & epilepsy					55
acute inflammation					25
developmental screening					30
screening for latent spina bifida					9
superficial mass of face					7
neurofibromatosis without intracranial lesion					6
retinoblastoma (early screening after onset)					3
blood desease (early screening after onset					19
other tumor (early screening after onset)					1
headache & dizziness					3
other					10
				Total	220

Table 2. Characteristics of the study population

distance from true mid sagittal		Vector 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
									Difference from True MSVA （mm）															
1	mean	0.10	0.08	0.18	0.08	0.12	0.10	0.06	0.12	0.12	0.28	0.14	0.12	0.18	0.02	0.12	0.10	0.10	0.16	0.16	0.06	0.20	0.24
	(max)	(0.3)	(0.2)	(0.3)	(0.3)	(0.2)	(0.2)	(0.1)	(0.4)	(0.3)	(0.6)	(0.2)	(0.3)	(0.3)	(0.1)	(0.2)	(0.2)	(0.2)	(0.4)	(0.2)	(0.1)	(0.6)	(0.3)
2		0.20	0.08	0.32	0.12	0.12	0.12	0.08	0.10	0.14	0.30	0.22	0.18	0.22	0.22	0.10	0.12	0.04	0.26	0.24	0.28	0.44	0.16
		(0.5)	(0.2)	(0.5)	(0.3)	(0.3)	(0.2)	(0.2)	(0.3)	(0.3)	(0.6)	(0.4)	(0.4)	(0.4)	(0.4)	(0.2)	(0.2)	(0.1)	(0.6)	(0.4)	(0.5)	(1.4)	(0.6)
3		0.44	0.28	0.54	0.12	0.14	0.12	0.20	0.18	0.18	0.34	0.24	0.28	0.32	0.24	0.08	0.18	0.16	0.28	0.22	0.24	0.62	0.40
		(0.8)	(0.4)	(0.8)	(0.2)	(0.2)	(0.3)	(0.4)	(0.4)	(0.3)	(0.6)	(0.4)	(0.5)	(0.6)	(0.5)	(0.1)	(0.4)	(0.4)	(0.7)	(0.3)	(0.5)	(1.9)	(0.6)
4		0.76	0.32	0.62	0.20	0.26	0.20	0.24	0.20	0.24	0.38	0.28	0.28	0.42	0.24	0.14	0.24	0.16	0.30	0.30	0.26	0.76	0.46
		(1.1)	(0.4)	(0.8)	(0.4)	(0.6)	(0.3)	(0.5)	(0.4)	(0.6)	(0.8)	(0.5)	(0.5)	(0.6)	(0.6)	(0.2)	(0.4)	(0.3)	(0.7)	(0.5)	(0.5)	(2.5)	(0.6)
5		1.04	0.62	0.78	0.20	0.36	0.34	0.42	0.46	0.32	0.52	0.46	0.42	0.40	0.18	0.22	0.34	0.22	0.40	0.42	0.36	0.96	0.60
		(1.6)	(0.8)	(1.0)	(0.5)	(0.6)	(0.4)	(0.6)	(0.6)	(0.9)	(0.9)	(0.8)	(0.8)	(0.7)	(0.4)	(0.4)	(0.5)	(0.4)	(0.9)	(0.5)	(0.6)	(3.1)	(0.8)
6		1.50	0.80	1.00	0.32	0.46	0.46	0.54	0.50	0.42	0.54	0.64	0.54	0.46	0.26	0.18	0.40	0.24	0.50	0.42	0.40	0.88	0.66
		(2.1)	(0.9)	(1.2)	(0.6)	(0.7)	(0.5)	(0.7)	(0.7)	(1.1)	(1.1)	(0.9)	(1.2)	(0.7)	(0.6)	(0.5)	(0.6)	(0.5)	(0.8)	(0.7)	(0.7)	(3.0)	(0.8)
7		2.02	1.06	1.08	0.40	0.52	0.62	0.64	0.60	0.48	0.60	0.68	0.60	0.48	0.32	0.34	0.46	0.32	0.46	0.46	0.44	0.88	0.74
		(3.1)	(1.2)	(1.3)	(0.7)	(0.8)	(0.7)	(1.0)	(0.8)	(1.1)	(1.2)	(1.1)	(1.0)	(0.6)	(0.6)	(0.6)	(0.8)	(0.7)	(1.1)	(0.9)	(0.7)	(2.6)	(1.0)
8		2.64	1.28	1.28	0.57	0.70	0.78	0.72	0.74	0.62	0.64	0.80	0.76	0.48	0.38	0.38	0.46	0.32	0.50	0.54	0.60	0.92	0.78
		(4.1)	(1.5)	(1.7)	(1.1)	(1.0)	(1.0)	(1.0)	(1.0)	(1.3)	(1.2)	(1.0)	(1.3)	(0.9)	(0.8)	(0.9)	(0.8)	(0.6)	(1.2)	(1.0)	(1.1)	(2.2)	(1.3)
9		3.56	1.64	1.52	0.64	0.86	0.92	0.86	0.92	0.80	0.74	0.92	0.86	0.48	0.42	0.44	0.56	0.30	0.54	0.58	0.58	0.94	0.78
		(5.2)	(2.0)	(1.9)	(1.1)	(1.1)	(1.2)	(1.3)	(1.2)	(1.5)	(1.6)	(1.6)	(1.6)	(1.0)	(0.9)	(0.9)	(0.9)	(0.7)	(1.4)	(1.1)	(1.1)	(2.2)	(1.8)
10		4.10	2.00	1.68	0.74	1.00	1.10	1.12	1.08	0.94	0.88	0.96	0.92	0.52	0.48	0.50	0.60	0.40	0.66	0.50	0.64	0.92	0.86
		(4.4)	(2.4)	(2.1)	(1.2)	(1.2)	(1.3)	(1.5)	(1.5)	(1.7)	(1.7)	(1.4)	(1.5)	(1.2)	(0.9)	(1.2)	(1.0)	(0.9)	(1.6)	(0.9)	(1.1)	(2.0)	(2.1)

n=5 ，Broad ≥1　　Broad & Gray Marker ≥3

Table 3. Difference from true MSVA values (mm)

	MSVA difference between CT and MRI(mm)																					
	Vector 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
mean	0.47	0.54	0.43	0.36	0.39	0.34	0.27	0.49	0.61	0.37	0.21	0.24	0.24	0.19	0.26	0.23	0.29	0.34	0.67	0.87	0.86	0.54
(max)	**(1.4)**	**(1.2)**	(0.7)	(0.6)	(0.8)	(0.8)	(0.7)	**(1.0)**	**(1.0)**	(0.8)	(0.4)	(0.5)	(0.6)	(0.5)	(0.5)	(0.4)	(0.7)	(0.9)	**(1.2)**	**(1.8)**	**(2.6)**	**(1.4)**
																	n=7 , Broad >1					

Table 4. MSVA difference between CT and MRI (mm)

Age(mo)		Normal MSVA of Japanese children (mm)																						
		Vector0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0–2	Mean	42.9	45.4	51.1	55.6	58.8	61.8	65.4	69.1	73.6	77.9	81.0	82.8	83.1	81.1	77.5	74.8	71.6	65.8	56.1	49.2	45.9	
	(SD)	(2.3)	(2.7)	(3.4)	(4.4)	(5.0)	(5.5)	(6.2)	(6.8)	(7.4)	(8.0)	(8.3)	(8.2)	(7.1)	(5.7)	(5.4)	(5.5)	(5.7)	(6.2)	(5.5)	(4.6)	(3.7)	
																						*5	*12
3–5		48.6	52.5	58.8	64.8	69.0	72.3	75.7	79.3	83.1	88.0	92.3	95.2	95.9	93.6	88.6	83.6	79.2	73.7	65.6	59.3	55.2	49.6
		(2.3)	(3.1)	(4.5)	(5.0)	(5.5)	(5.6)	(5.7)	(5.8)	(6.4)	(6.5)	(6.4)	(6.0)	(5.3)	(5.1)	(5.3)	(5.2)	(5.3)	(6.4)	(6.5)	(4.4)	(3.5)	(2.9)
																						*1	*4
6–11		52.0	56.2	63.1	69.7	74.2	77.7	80.8	83.7	86.7	91.5	96.8	100.8	102.5	101.0	96.7	92.2	88.1	82.9	75.1	67.5	61.4	56.9
		(2.3)	(2.7)	(3.3)	(3.6)	(4.0)	(4.2)	(4.2)	(4.4)	(5.0)	(5.6)	(5.2)	(5.1)	(4.9)	(4.7)	(4.3)	(4.5)	(4.9)	(5.5)	(6.5)	(5.2)	(4.6)	(4.2)
																							*10
12–23		55.9	61.0	68.0	74.5	78.9	82.3	85.3	87.6	89.9	93.9	99.0	102.9	105.0	104.5	100.9	97.3	93.9	89.3	81.6	73.1	65.7	59.4
		(2.6)	(3.1)	(3.9)	(4.2)	(4.3)	(4.4)	(4.5)	(4.6)	(4.8)	(5.3)	(5.1)	(4.6)	(4.2)	(4.0)	(4.4)	(4.7)	(4.8)	(4.9)	(5.5)	(5.1)	(4.6)	(4.7)
																							*11
24–35		57.4	62.7	69.3	75.1	79.4	82.8	86.0	88.4	90.8	94.4	99.2	103.3	105.3	104.9	101.9	98.8	95.5	91.1	83.4	75.8	68.7	63.1
		(2.6)	(2.9)	(3.0)	(3.2)	(3.3)	(3.4)	(3.4)	(3.3)	(3.1)	(3.0)	(3.0)	(3.3)	(3.7)	(4.4)	(4.8)	(5.0)	(5.4)	(6.1)	(7.1)	(6.4)	(5.6)	(5.5)
																							*7
36–47		58.6	63.9	70.5	76.8	81.1	84.4	87.4	89.9	92.5	96.0	100.8	105.2	107.6	108.2	105.9	103.1	100.2	96.6	89.7	80.4	73.0	65.7
		(3.6)	(4.1)	(4.5)	(4.6)	(4.3)	(4.2)	(4.1)	(3.9)	(3.8)	(4.3)	(4.7)	(4.3)	(3.8)	(3.6)	(3.9)	(3.8)	(4.2)	(4.6)	(5.6)	(5.5)	(5.5)	(5.7)
																							*4
48–59		60.8	65.7	71.7	77.4	81.4	84.8	88.0	90.7	93.3	96.7	101.9	106.0	108.2	108.0	105.6	102.3	99.6	95.9	89.3	81.5	74.1	68.0
		(2.4)	(2.8)	(3.3)	(3.2)	(3.2)	(3.1)	(3.0)	(3.0)	(3.1)	(3.3)	(3.6)	(3.9)	(4.0)	(4.0)	(4.2)	(4.3)	(4.5)	(5.0)	(6.2)	(5.7)	(5.5)	(4.8)
																							*5
60–71		62.2	67.1	73.2	79.1	83.5	86.7	89.5	91.9	94.4	97.4	102.4	106.8	109.1	108.9	106.1	102.6	99.7	96.6	90.2	82.5	74.9	68.3
		(2.9)	(3.2)	(3.8)	(3.8)	(3.9)	(4.1)	(4.2)	(4.0)	(3.6)	(3.7)	(4.0)	(3.9)	(3.7)	(3.7)	(4.3)	(4.6)	(4.7)	(5.3)	(6.4)	(5.8)	(5.4)	(3.9)
																							*6
72–83		62.8	67.9	73.5	79.5	83.8	87.1	90.0	92.7	95.9	99.5	105.0	108.8	110.3	109.3	105.9	102.5	99.8	96.2	89.9	82.5	75.1	68.8
		(3.2)	(3.9)	(4.6)	(5.1)	(5.2)	(5.1)	(5.0)	(4.8)	(4.5)	(4.5)	(4.6)	(5.0)	(5.2)	(5.6)	(6.4)	(6.8)	(7.2)	(7.8)	(8.4)	(6.6)	(5.9)	(3.5)
																							*5
																						*number of missing values	

Table 5. Normal MSVA values of Japanese children (mm)