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The fetal cerebellar vermis: anatomy and biometric assessment using volume contrast imaging in the C-plane (VCI-C)

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KEYWORDS: fetal brain; fetal cerebellum; VCI; vermis; volume contrast imaging; volume ultrasound

ABSTRACT

Objectives *To describe the normal appearance and study the biometry of the fetal cerebellar vermis by three-dimensional (3D) volume contrast imaging in the coronal (C-) plane (VCI-C).*

Methods *A total of 203 normally developed fetuses were examined prospectively at 18–33 weeks' gestation. At the level of the view used to measure the transverse cerebellar diameter (TCD), a VCI-C plane was displayed to examine, using a transabdominal probe, the fetal mid-saggital vermis. The volumes acquired were stored for later review and measurement of the anteroposterior (AP) diameter, craniocaudal (CC) diameter and surface area of the cerebellar vermis. Each dataset was evaluated by two independent observers. Measurements as a function of gestational age (GA), biparietal diameter (BPD), head circumference (HC) and TCD were expressed by regression equations. Interobserver variability was evaluated. Nomograms were produced. In order to validate the use of VCI in fetal biometry, datasets from 57 patients were selected arbitrarily for comparison of their VCI-C measurements with those from mid-sagittal sections of a stored 3D multiplanar examination. Intraclass correlation was used to evaluate the agreement between these measurements.*

Results *The mean maternal age was 32 years. We were able to measure mid-sagittal CC diameter, mid-sagittal AP diameter and cerebellar vermis surface area in all fetuses. Interobserver variability analysis showed no significant differences between the two observers ($P > 0.05$). Measurements of the cerebellar vermis (AP diameter, CC diameter and surface area) correlated linearly with GA, BPD, HC and TCD ($r \geq 0.82$, $P < 0.0001$). CC and AP diameters estimated from the mid-sagittal section of the multiplanar measurements were significantly correlated with VCI-C measurements ($r = 0.96$, $P < 0.00001$ and $r = 0.95$, $P < 0.00001$, respectively).*

Conclusions *VCI-C is a valuable tool, allowing intrauterine assessment of the normal appearance of the fetal cerebellar vermis. The nomograms developed in this study should enable accurate evaluation of the cerebellar vermis. Copyright © 2005 ISUOG. Published by John Wiley & Sons, Ltd.*

INTRODUCTION

Evaluation of the posterior fossa of the fetal cranium is performed routinely in obstetric ultrasound examinations[1,2]. Evaluation of the fetal cisterna magna and the cerebellar vermis is particularly useful in the detection of various abnormalities such as neural tube defects, Dandy–Walker complex and Joubert syndrome[3–8]. More subtle lesions of the cerebellar vermis are usually only diagnosed postnatally.

The axial sonographic planes are those used routinely for the evaluation of the fetal brain[2,9]. The depiction of the cerebellar vermis is based on the demonstration of serial axial planes with slight angulations between them, to demonstrate the portions of the cerebellar vermis[10]. The use of an oblique coronal plane may be helpful in some cases, but can cause the false appearance of an enlarged cisterna magna or even partial agenesis of the cerebellar vermis[11]. False-positive diagnosis of vermian pathology has been reported[12–15]. The excellent resolution in the sagittal planes made possible by magnetic resonance imaging (MRI) has led to demonstration of vermian dysgenesis as one of the anomalies included in the Dandy–Walker complex[16–18]. However, fetal MRI is not readily available in most countries, requires radiological

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expertise, and is more expensive and time-consuming compared with sonography[19]. Transvaginal sonography in sagittal planes with the fetus in a vertex presentation is essential for accurate visualization of the vermian anatomy[10]. However, technical inability to always depict the mid-sagittal plane precludes diagnosis of some forms of vermian pathology.

Volume contrast imaging (VCI) is a new approach that was developed to enhance contrast in B-mode sonography. It involves real-time volume acquisition and a very small elevation sweep angle. Within this volume there is a render box with a large surface area. The operator can select the thickness of the render box as 3, 5, 10 or 15 mm, but its thickness is kept at 3 mm. Hence the result of VCI is a surface-rendered image of a solid organ[20]. This may allow better assessment of sizes, margins, and internal aspects of structures and tissues. It can be applied in the A-plane, which is projected in the same image plane as that obtained by conventional two-dimensional (2D) ultrasound, or the coronal (C-) plane, consisting of a sagittal plane in relation to the original 2D image[20,21]. If this plane is projected in the suboccipitobregmatic view, orthogonal to the measurement of the transverse cerebellar diameter (TCD) and at the level of the cerebellar vermis, a mid-sagittal rendering vermian section is automatically displayed.

The purpose of this study was to describe the normal appearance and to study the size of the fetal cerebellar vermis by three-dimensional (3D) VCI in the C-plane (VCI-C).

METHODS

Volume contrast imaging in the C-plane (VCI-C) was performed in 203 normally developed fetuses to examine prospectively the fetal posterior fossa. The women had been referred for routine sonographic examination between 18 and 33 weeks' gestation (mean, 24 weeks); in our experience, the quality of image resolution of the volume acquired before 18 weeks and after 33 weeks of gestation is reduced. Informed consent to undergo VCI-C was given in all cases. Gestational age (GA) was determined on the basis of the last menstrual period and confirmed by at least one previous sonographic examination, performed during the first trimester. Only singleton pregnancies were included in the study and patients were excluded if (1) their GA, as predicted by the last menstrual period, could not be confirmed by early sonography (< 13 weeks), (2) a discrepancy of more than 4 days existed between the GA predicted by the last menstrual period and that estimated by the sonographic measurements, (3) evidence of impaired fetal growth or malformation was found, or (4) there were medical complications in the pregnancy. Normal cranial and fetal growth was confirmed by measuring the biparietal diameter (BPD), head circumference (HC), TCD, abdominal circumference and femur length. There were no specific considerations regarding fetal presentation. All patients studied were followed up until delivery.

Technique and measurements

All patients were examined by the same operator (F.V.), using a Voluson 730 Expert ultrasound machine (GE Medical systems, Kretz Ultrasound, Zipf, Austria). VCI scans were carried out immediately after conventional ultrasound, with a 4–8-MHz transabdominal transducer. The routine examination of the fetal brain in our center includes a transverse scan at the level of the cavum septi pellucidi, which demonstrates the lateral borders of the anterior, medial and posterior horns of the lateral ventricles, the choroid plexuses and the third ventricle. This view is also used for measurement of the posterior horns of the lateral ventricles, BPD and HC. A second transverse plane allows examination of the mid-brain and posterior fossa; this view is used for measurement of the TCD, cisterna magna and for demonstration of the cerebellar vermis. The magnification of the image was such that the resolution of the calipers was 0.1 mm. At this level, a VCI-C plane in relation to the original 2D image is projected with a high-quality scan density acquisition and 3-mm thickness of the render box (Figure 1). The volume sweep angle was standard, set at 40°. An average of 2–4 s of VCI-C volume acquisition was stored for later review and measurement. Extra time (average, 15 (range, 9–21) min) was allowed for the fetus to change to a more favorable position if necessary. Acquisition was performed in the absence of fetal movement. Patients were also asked to suspend breathing momentarily. The quality of the acquired volume was estimated by direct analysis of the real-time mid-sagittal plane. In order to obtain a precise mid-sagittal plane, the corpus callosum should be clearly visualized anteriorly. To avoid the variability of linear measurements, craniocaudal (CC) measurements were made parallel to the fetal spine. The correct plane of measurement is shown in Figure 2.

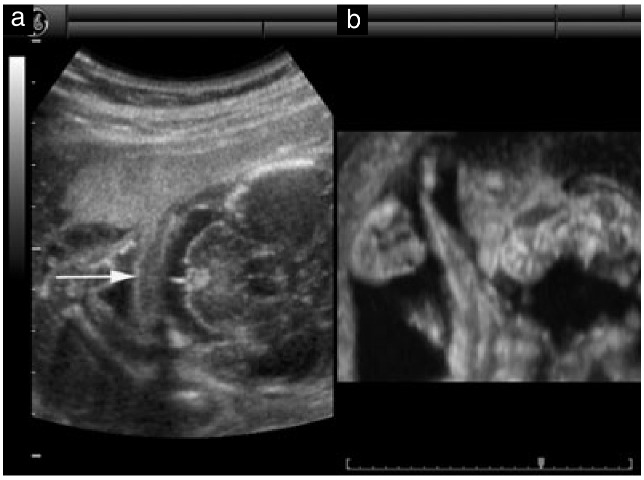

Figure 1 Two-dimensional image in a 26-week fetus (a) showing the projection (arrow) of the volume contrast image in the coronal plane (b).

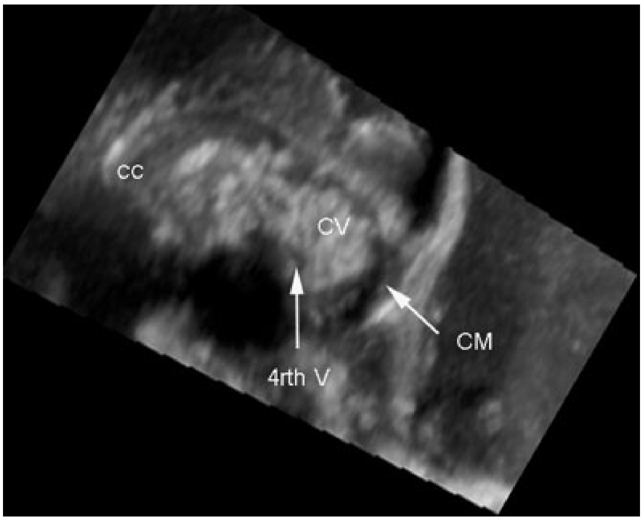

Figure 2 Precise mid-sagittal volume contrast image in the coronal plane at 25 weeks' gestation. 4rthV, fourth-ventricle; cc, corpus callosum; CM, cisterna magna; CV, cerebellar vermis.

Offline analysis and measurement of the stored VCI-C volume data was performed independently by two investigators (F.V. and M.M.) using the 4D View software version 1 (GE Medical systems, Kretz Ultrasound, Zipf, Austria). This software allows the user to zoom, slow or stop motion and also change obliquely the projection of the C-plane. The size of the cerebellar vermis was measured directly from a magnified view using the software's electronic calipers (0.1 mm resolution). As reported previously[10,22], the anteroposterior (AP) diameter was defined as the maximum distance between the most anterior portion of the central lobule and the most posterior portion of the tuber. The CC diameter was defined as the maximum distance between the most cranial portion of the culmen and the most caudal portion of the uvula (Figure 3). The surface area of the vermis was also measured in this plane using the same electronic calipers.

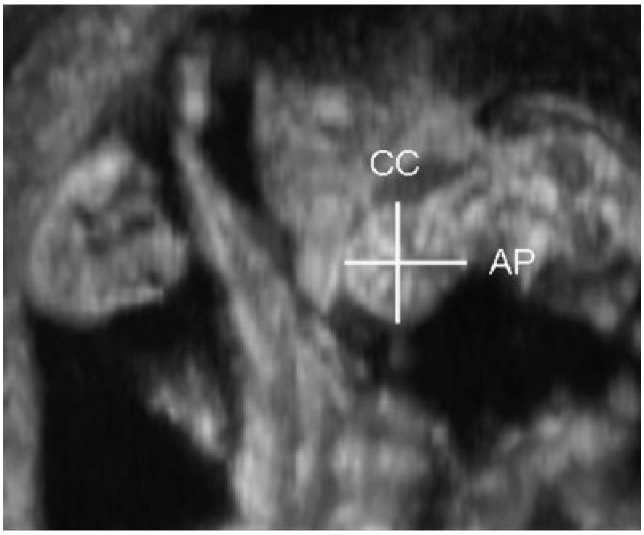

Figure 3 Measurement of the cerebellar vermis anteroposterior (AP) and craniocaudal (CC) diameters.

In order to validate the use of VCI in fetal biometry, 57 stored datasets were selected arbitrarily and both operators compared independently the VCI-C measurements with the measurements of the fetal mid-sagittal vermis obtained from the 3D stored multiplanar dataset.

Statistical analysis

Data were analyzed using the Statistica 5.5 statistical program (Kernel Release Statsoft, Inc., Tulsa, OK, USA). The *t*-test for dependent samples was used to assess the interobserver variation of the measurements of the cerebellar vermis and a Bland–Altman plot[23] was created for CC and AP diameters to assess interobserver reliability. Pearson's correlation coefficients were calculated to examine the strength of the linear relationship between each of the cerebellar vermis parameters and GA, BPD, HC and TCD. Regression analysis was used to calculate the equation of the linear fitted function with each cerebellar vermis parameter as a dependent variable, and GA, BPD, HC and TCD as the independent variables. A Bland–Altman plot was used for fetal cerebellar vermis diameters measured from the multiplanar stored dataset and VCI-C, using the 95% limits of agreement method for detecting possible discordant observations[23].

RESULTS

The mean maternal age was 32 (range, 15–41) years. We were able to measure mid-sagittal CC and mid-sagittal AP diameters in all fetuses. The interobserver variability analysis showed no significant differences between the two observers ($P > 0.05$) (Table 1). For CC diameter, the intraclass correlation coefficient between both operators was 0.97 (95% confidence interval (CI), 0.96–0.98) and for AP diameter it was 0.94 (95% CI, 0.92–0.95).

VCI-C cerebellar vermis measurements (CC and AP diameters and surface area are shown in Table 2). The VCI-C CC diameter of the cerebellar vermis correlated linearly with GA ($r = 0.91$; Figure 4), BPD ($r = 0.89$), HC ($r = 0.90$) and TCD ($r = 0.90$). The VCI-C AP diameter of the cerebellar vermis correlated linearly with GA ($r = 0.86$; Figure 5), BPD ($r = 0.82$), HC ($r = 0.83$) and TCD ($r = 0.83$). As there was no significant difference between the measurements of the two observers, the variables were correlated with the measurements from Operator A.

Table 1 Interobserver variability in cerebellar vermis measurements

	Operator A		*Operator B*		
Measurement	*Mean*	*SD*	*Mean*	*SD*	P
CC (mm)	16.648	3.686	16.739	3.715	0.108
AP (mm)	12.524	3.103	12.618	3.178	0.198
Surface area (cm^2)	1.602	0.735	1.579	0.728	0.788

AP, anteroposterior diameter; CC, craniocaudal diameter.

Table 2 Mean ± SD measurements obtained by volume contrast imaging in the coronal plane of the cerebellar vermis in 203 normal fetuses

Gestational age (weeks)	*Patients* (n)	*Craniocaudal diameter (mm)*	*Anteroposterior diameter (mm)*	*Surface area* (cm^2)
18–19	10	10.5 ± 1.3	8.3 ± 0.8	0.6 ± 0.05
20–21	19	12.7 ± 1.4	9.1 ± 1.6	0.7 ± 0.3
22–23	46	14.2 ± 1.6	10.5 ± 1.7	1.2 ± 0.2
24–25	45	15.8 ± 1.6	12 ± 1.4	1.5 ± 0.3
26–27	28	17.6 ± 1.7	13.5 ± 1.8	1.7 ± 0.3
28–29	19	19.6 ± 1.7	13.9 ± 1.1	2.1 ± 0.2
30–31	16	20.9 ± 1.5	15.5 ± 1.6	2.4 ± 0.06
32–33	20	22.8 ± 1.6	18.2 ± 1.7	3.4 ± 0.2

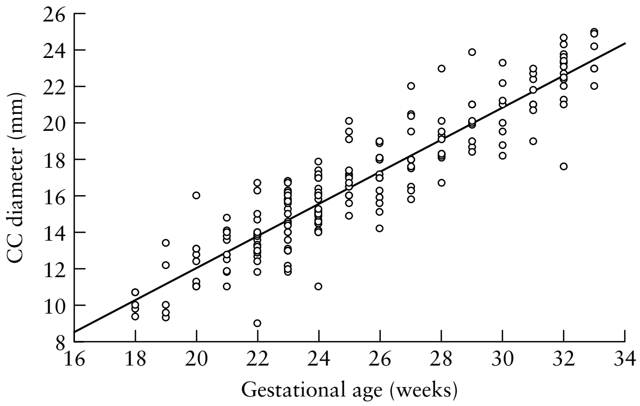

Figure 4 Correlation of cerebellar vermis craniocaudal (CC) diameter with gestational age (GA). CC diameter = (0.86 × GA) − 5.532 ($r = 0.912$).

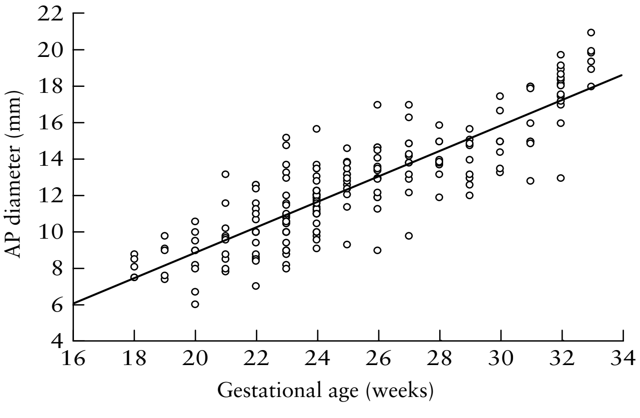

Figure 5 Correlation of cerebellar vermis anteroposterior (AP) diameter with gestational age (GA). AP diameter = (0.698 × GA) − 5.108 ($r = 0.861$).

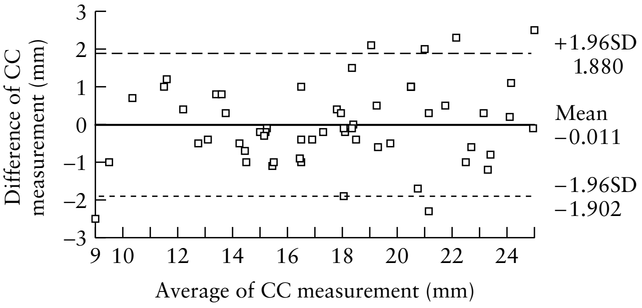

Figure 6 Plot of the difference against mean for craniocaudal (CC) diameter estimated by measurements using two-dimensional ultrasound and volume contrast imaging in the coronal plane, with mean difference and 95% limits of agreement indicated.

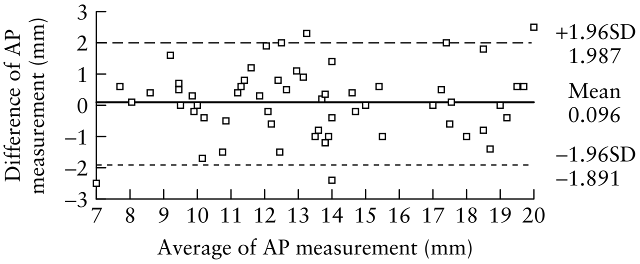

Figure 7 Plot of the difference against mean for anteroposterior (AP) diameter estimated by measurements using two-dimensional ultrasound and volume contrast imaging in the coronal plane, with mean difference and 95% limits of agreement indicated.

CC diameter estimated by measurements from the multiplanar stored dataset was significantly correlated with VCI-C measurements ($r = 0.96$; $P < 0.00001$); the intraclass correlation coefficient was 0.94 (95% CI, 0.94–0.98). AP diameter estimated by 3D multiplanar dataset was significantly correlated with VCI-C measurements ($r = 0.95$; $P < 0.00001$); the intraclass correlation coefficient was 0.95 (95% CI, 0.92–0.97). The differences were plotted against the mean of the two readings using the 3D multiplanar stored dataset (Figures 6 and 7).

DISCUSSION

The formation of the vermis predates that of the cerebellar hemispheres by 30–60 days, and the entire vermis and cerebellum are fully formed by the end of the 15th week[24]. However, it has been reported that the GA at which each aspect of this growth can be appreciated sonographically is much later than the age at which it occurs anatomically[24–26]. Until the vermis has developed fully, the caudal portions of the fourth ventricle remain covered only by the fourth ventricle roof. This roof is sufficiently thin that, before 16 weeks, separation between the fourth ventricle and the cisterna magna can be difficult to appreciate sonographically[27]. Bromley *et al.*[26] described the vermis as being open posteroinferiorly until 17.5 weeks' GA and the fourth ventricle and the cisterna magna communicating in most fetuses until 13.5–14 weeks' GA. This study was reinforced by Ben-Ami *et al.*[28] who demonstrated, using transvaginal sonography, that the inferior vermis is still open and communication between the fourth ventricle and the cisterna magna is visible in all normal fetuses at 14–16 weeks of gestation. A recent study to evaluate sonographically visible fetal cerebellar development using MRI and anatomical correlations indicated that although the fourth ventricle and the cisterna magna appear to communicate early in gestation, they are, in fact, separated by the thin fourth ventricular roof, and it is the limited resolving power of imaging that creates this impression[29]. Before 18 weeks, the posterior fossa does not demonstrate the familiar mature relationships among the fourth ventricle, cisterna magna, cerebellar vermis and cerebellar hemispheres. Therefore, the diagnosis of vermian agenesis, especially partial agenesis, is typically not made with confidence prior to 18 weeks of gestation; this is why we obtained our measurements of the vermis with VCI-C ultrasound from 18 weeks of gestation onwards[10,15].

VCI was developed by the manufacturer to increase resolution and to reduce noise, enhancing the contrast between tissues or organs that would appear similar on conventional 2D ultrasound. It is a real-time procedure that involves the display of a rendering volume as a 2D image[20]. Although it is based on complex technology, VCI is as easy to perform as is conventional 2D ultrasound and it can be applied easily to fetal sonography, as has recently been demonstrated in fetal chest assessment[21]. Besides artifacts typical of 3D volume acquisition, such as those resulting from fetal or maternal movements, we found that there were also limitations in the quality of the volume acquired when the head was overextended or an appropriate acoustic window could not be identified. However, if extra time was allowed for the fetus to change to a more favorable position, these limitations were avoided. VCI allows images to be measured on frozen frames. It is important to remember that the normal dimensions of the fetal cerebellar vermis are important in evaluating abnormalities of the posterior fossa since the key feature of these malformations is a vermian defect[10,24]. We have found that the quality of the volume acquired before 18 weeks and after 33 weeks of gestation is reduced. It is likely that some of these limitations will be resolved in the future with technological improvements in 3D acquisition.

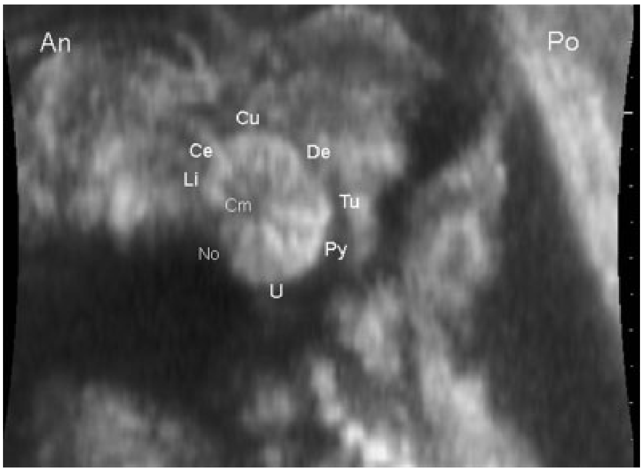

Figure 8 Principal fetal cerebellar vermian lobule in a standardized view of the volume contrast image in the coronal plane at 24 weeks' gestation. An, anterior; Ce, centralis; Cm, corpus medullare; Cu, culmen; De, declive; Li, lingula; No, nodulus; Po, posterior; Py, pyramis; Tu, tuber vermis; U, uvula.

In the past, limitations to the prenatal sonographic diagnosis of fetal anomalies were predominantly related to poor technical resolution. With the proposed use of VCI-C to evaluate the posterior fossa, exquisite anatomical detail can now be visualized (Figure 8). Moreover, the nomograms developed in this study should enable accurate evaluation of the cerebellar vermis from the second trimester as they provide normative data for the size of the fetal cerebellar vermis throughout gestation. Our results also suggest that CC and AP diameters can be estimated either by multiplanar 3D or by VCI-C imaging because these methods showed good agreement. Although this new technique's real potential for routine fetal sonography cannot be determined at this stage, its simplicity and the quality of the images it yields are promising. Further studies are necessary to demonstrate exactly how early diagnosis of vermian anomalies can be made and when they can confidently be excluded.

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