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Research article

Measurement of normal fetal cerebellar vermis at 24–32 weeks of gestation by transabdominal ultrasound and magnetic resonance imaging: A prospective comparative study

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ABSTRACT

Objectives: Fetal cerebellar vermis may be assessed by ultrasound (US) or magnetic resonance imaging (MRI), and median-plane views are best for evaluation. The purpose of this study was to compare measurements of normal fetal vermis at 24–32 weeks of gestation obtained in median plane by transabdominal 2D-US, 3D-US, and MRI.

Methods: A prospective study was conducted, examining normal singleton fetuses between 24 and 32 weeks of gestation. Within a 24-h period, median-plane views of posterior fossa were generated using 2D-US, 3D-US, and MRI. Measurements of anteroposterior (AP) diameter, craniocaudal (CC) diameter, mid-sagittal surface area, brainstem-vermis (BV) angle and brainstem-tentorium (BT) angle were obtained to compare these imaging modalities.

Results: A total of 180 fetuses were studied. Correlation among imaging methods was good, marked by the following intraclass correlation coefficients: AP diameter, 0.955; CC diameter, 0.956; mid-sagittal surface area, 0.982; BV angle, 0.810; and BT angle, 0.865 ($p < 0.001$).

Conclusions: Visualization rates of MRI, 3D-US, and transabdominal 2D-US were decremental, MRI being superior in this regard. However, these three imaging modalities correlated well in measuring cerebellar vermis and its surroundings.

1. Introduction

Development of cerebellar vermis begins at 9 weeks of gestation, proceeding rostrally through fusion of the rhombic lips and reaching completion by end of the 15th week [1]. However, agenesis or hypoplasia may occur for a variety of reasons. Such defects are among the more common central nervous system (CNS) malformations that typically present in evaluating posterior fossa (PF) [2].

Ultrasound (US) is the preferred approach for examining fetal structures, because this method is safe and cost-effective, and it allows real-time fetal assessment [3,4]. In mid-gestational transabdominal scans during pregnancy, the axial plane of fetal brain is easier to visualize, based on fetal orientation. Vermis is thus routinely evaluated in transcerebellar axial view, displaying its hallmark features (two hypoechoic cerebellar hemispheres connected by hyperechoic vermis). These findings may be altered in various abnormal states—for example, cystic lesions of Dandy-Walker malformation (DWM) or fissures (vermian hypoplasia or Blake's pouch cyst) situated between dilated fourth ventricle and PF (the latter enlarged in DWM). However, such changes in axial plane are not definitive, given the inherently insufficient detail of vermis and its surroundings. A median-plane view is essential for proper assessment, which then requires time and effort, whether transabdominal or transvaginal approach is taken.

Despite the capacity of 3D-US to reconstruct median planes rapidly and simply [5], there are fundamental technical impediments (e.g., maternal size, fetal position, and amniotic fluid volume) that render the quality of reconstructed images unsatisfactory. MRI is of greater benefit under these circumstances, affording clearer visualization of vermis and structures nearby to investigate potential vermian abnormalities. In MRI studies, the contrast between simple fluid and solid neural elements is exceptional, readily delineating vermis, bony PF, and precise location of tentorium cerebelli [6–8]. Despite the high contrast

Abbreviations: 2D-US, 2D ultrasound; 3D-US, 3D ultrasound; AP, anteroposterior; BT, brainstem-tentorium; BV, brainstem-vermis; CC, craniocaudal; CNS, central nervous system; DWM, Dandy-Walker malformation; GA, gestational age; ICC, intraclass correlation coefficient; MRI, magnetic resonance imaging; PF, posterior fossa; VCI, volume contrast imaging

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resolution, MRI has a limited spatial/tissue resolution limiting the PF evaluation in early pregnancy [9].

Various nomograms have been devised to establish normal biometry of the fetal vermis through US or MRI. The most commonly used indices (anteroposterior [AP] diameter, craniocaudal [CC] diameter, and median surface area) are measured in median plane. In addition, the brainstem-vermis (BV) angle is typically checked as a measure of vermian rotation, and the brainstem-tentorium (BT) angle provides a gauge of tentorial position. To our knowledge, there have been no comparisons of US and MRI involving all five parameters.

The objective of our study was to compare measurements of fetal vermis at 24–32 weeks of gestation obtained in median plane by 2D-US, 3D-US, and MRI.

2. Materials and methods

2.1. Patients

This prospective study was approved by the institutional review board, with written informed consent granted by each patient prior to study onset. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. From January 2014 to December 2016, we evaluated singleton fetuses between 24 and 32 weeks with presumed normally formed PF's scanned for many different clinical indications. Gestational age (GA) was based on date of last menses and was confirmed by US examinations done in early pregnancy. Fetal MRI were performed due to suspected extracranial defects or increased risk of suspected CNS abnormalities. Both studies were conducted within a 24-h time frame, and each fetus was included only once in the study. Inclusion criteria were singleton pregnancy and no intracranial abnormalities found by US and MRI, this includes cases of spinal bifida occulta that showed a normal brain on US and MRI. The numbers of fetuses at each gestational age were equivalent. Fetuses inappropriate for gestational age, or those with oligohydramnios, and pregnancies in which maternal weight exceeded 90 kg at time of testing were excluded from study.

2.2. Prenatal ultrasonography

A Voluson E8 US system (GE Healthcare, Chicago, IL, USA), equipped with transabdominal transducer (4–8 MHz), was used by a single examiner (D.Z.) to perform all studies. In each patient, transabdominal imaging was attempted to acquire median-plane views of fetal brain. Thereafter, 3D assessment of fetal head volume was conducted in transcerebellar axial plane during fetal rest periods (maternal apnea), using volume contrast imaging (VCI) at 2-mm slice thickness to improve contrast resolution. The A plane was set to transcerebellar axial plane, with vermis as reference point, until corpus callosum and cerebellar vermis were fully visualized in C plane. When 2D and 3D median planes were impossible, extra time (30–45 min, at most 3 times in the same day) was allowed for the fetus to change to a more favorable position. Measurement of fetal vermis was enabled by proprietary software (4D View; GE Healthcare).

2.3. Fetal MRI studies

MRI studies were undertaken using a 1.5-T Unit (Intera; Philips, Amsterdam, The Netherlands). No maternal sedation was administered. The examination should be performed during fetal rest periods(maternal eupnoea). As part of a whole body examination, the fetal brain was examined using single-shot fast spin-echo T2-weighted sequences in three orthogonal planes relative to fetal lie: section thickness, 3–4 mm; no gap; flexible coil (8-channel cardiac coil); matrix, 320 × 224; TE, 90 ms; and TR, 1298 ms. The FOV was determined by size of fetal head (smaller, 24 cm; larger, 30 cm). The cases with distorted images because of fetal motion were re-examined until the images met our requirement for diagnosis. Measurements of fetal vermis were obtained on a mid-sagittal plane T2-weighted sequences on a picture archiving and communication system (PACS).

2.4. Measurements of variables

To be eligible for quantitative measurements, the images had to be in the mid-sagittal plane and display the clear contour of the vermis and its surroundings. Images were magnified to maximal level, until caliper resolution was 0.1 mm. AP diameter, CC diameter, and median surface area of vermis were measured in median planes, as were BV and BT angles. Each measurement was performed in triplicate on the same image, recording the mean value in each fetus. AP diameter was defined as the distance between anterior and posterior extremes of cerebellar vermis. Likewise, CC diameter constituted the distance between cranial and caudal extremes of cerebellar vermis. Surface area was calculated using manually assigned vermian contours. To determine BV and BT angles, one line was drawn tangentially to dorsal aspect of brain stem, drawing a second line tangential to ventral curvature of cerebellar vermis and a third line tangential to tentorium cerebelli. Intersection of the first and second lines (BV angle) and the first and third lines (BT angle) defined the respective angles. To avoid disparities in measurements, CC diameter was measured parallel to the second line; and AP diameter was measured perpendicular to CC diameter (Fig. 1).

2.5. Professional experience and intra-/inter-observer variability

All sonographic examinations and measurements were performed by the same sonographer (DZ), highly qualified (> 10 years of experience) in prenatal ultrasonography and skilled in 3D-US reconstruction. All fetal MRI examinations were performed by one dedicated MR technician (> 10 years of experience) and the measurements were performed by the same radiologist with > 5 years of experience in fetal MRI (YW). A subgroup of 60 fetuses was selected at random, serving to test data reproducibility. The chief sonographer (DZ) measured same-image parameters twice to address intra-observer variability, whereas another equally experienced counterpart (BW) repeated these measurements to gauge inter-observer variability. Two radiologists (YW and JZ) used a similar procedure to determine intra- and inter-observer variability.

2.6. Statistical analysis

Means and standard deviations of vermian parameters were calculated, using linear regression to assess their correlation with GA. All tests were two-tailed, setting statistical significance at $p \leq 0.05$. Intraclass correlation coefficients (ICCs) were calculated for the three imaging modalities used in measuring each fetal vermis and for the various observers to determine consistency. All computations relied on standard software (SPSS Statistics v22.0; IBM, Chicago, IL, USA).

3. Results

3.1. Visualization rates of 2D-US, 3D-US, and MRI

A total of 180 fetuses were studied (20 per week of gestation), as summarized in Table 1. Representative images, with landmarks indicated, are shown in Fig. 2(A–F). Using 2D-US, median-plane views were generated transabdominally in 124 pregnancies (68.9%), each yielding values for AP diameter, CC diameter, and median surface area. However, determination of BV and BT angles was limited to 88 (71%). Using 3D-US, median-plane views were acquired in all 180 pregnancies, documenting AP diameter, CC diameter, and median surface area in each fetus. Again, determinations of BV (172/180, 95.6%) and BT (169/180, 93.9%) angles fell short. In failed attempts, acoustic shadowing from base of skull obscured the brain stem or tentorium,