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THREE-DIMENSIONAL VISUALIZATION AND MORPHOMETRIC ANALYSIS OF THE DEVELOPING FETAL BRAIN USING MRI AND DIGITAL RECONSTRUCTION

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Abstract: *Advancements in magnetic resonance imaging (MRI) and digital reconstruction have revolutionized fetal neuroimaging by providing high-resolution, non-invasive insights into the developing brain. This study aimed to analyze the morphometric growth patterns and structural organization of the fetal brain in different gestational stages through three-dimensional (3D) visualization and measurement using MRI and digital modeling. A cohort of 50 fetuses between 18 to 36 weeks of gestation was studied. T2-weighted MRI sequences were acquired, segmented, and reconstructed using digital software for volumetric and surface analysis. Significant trends in brain volume, cortical folding, and structural asymmetry were observed across gestational weeks. The findings underscore the utility of 3D morphometric analysis in understanding fetal neurodevelopment and detecting early anomalies.*

1. Introduction

The human brain undergoes rapid morphological changes during fetal development, forming the foundation for postnatal neurological function. Traditional ultrasound, though widely used, has limitations in detailing intricate brain structures. Magnetic resonance imaging (MRI), due to its superior soft-tissue contrast and non-invasive nature, has emerged as a powerful modality for fetal brain imaging. The integration of digital reconstruction with MRI data enables the generation of accurate three-dimensional (3D) models for morphometric analysis, allowing for precise quantification of brain growth and shape alterations.

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Numerous studies have described fetal brain development using linear or volumetric measurements, but few have utilized full 3D reconstructions to evaluate developmental trajectories in detail. This study aims to fill that gap by providing a comprehensive 3D morphometric analysis of the developing fetal brain from the second to third trimesters, highlighting key anatomical transformations.

2. Materials and Methods

2.1 Study Population

This cross-sectional study included 50 pregnant women undergoing clinically indicated fetal MRI at 18–36 weeks of gestation. Inclusion criteria included singleton pregnancy, no evidence of fetal anomalies, and informed consent. The study protocol was approved by the institutional ethics committee.

2.2 MRI Acquisition

MRI scans were performed on a 1.5T Siemens Avanto system using a body coil. T2-weighted single-shot fast spin-echo sequences were obtained in axial, coronal, and sagittal planes. Parameters included: TR/TE = 1600/90 ms, slice thickness = 3 mm, field of view = 240 mm, matrix = 256 × 256.

2.3 Image Processing and 3D Reconstruction

MR images were imported into ITK-SNAP for manual segmentation of brain structures. The brain was segmented into major components: cerebral hemispheres, cerebellum, ventricles, and brainstem. Reconstructed 3D models were generated using 3D Slicer. Morphometric data (volume, surface area, sulcal depth) were extracted and analyzed using MATLAB.

2.4 Morphometric Analysis

Gestational age-specific morphometric parameters were analyzed using regression models. Brain growth curves were generated, and developmental asymmetries were assessed by comparing left and right hemisphere measurements. Cortical folding was evaluated by calculating gyrification indices and sulcal depth maps.

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3. Results

3.1 Brain Volume Growth

Total brain volume showed a non-linear exponential increase with gestational age ($R^2 = 0.92$). Mean cerebral volume increased from 45 cm^3 at 18 weeks to 310 cm^3 by 36 weeks. The cerebellum and brainstem also demonstrated significant volume expansion, though at a lower rate compared to the cerebrum.

3.2 Cortical Maturation and Folding

Surface-based analysis revealed the initial appearance of major sulci (e.g., Sylvian fissure, central sulcus) between 22–24 weeks. By 28–30 weeks, cortical folding became more complex, with increasing gyrification index values, indicating progressive maturation. The sulcal depth reached a mean of 6.5 mm by 36 weeks, compared to 2.1 mm at 20 weeks.

3.3 Hemispheric Asymmetries

A statistically significant asymmetry in hemispheric development was observed, with the right hemisphere showing greater volume and earlier sulcation in 60% of cases from 24 weeks onward ($p < 0.05$). The temporal lobe showed the most consistent asymmetry.

3.4 Ventricular and Midline Structure Development

The lateral ventricles decreased in relative volume with advancing gestation, while midline structures such as the corpus callosum became more defined and measurable by 24 weeks. The corpus callosum length increased from 12 mm (at 20 weeks) to 36 mm (at 36 weeks).

4. Discussion

This study provides detailed 3D visualization and morphometric analysis of fetal brain development, validating MRI and digital reconstruction as reliable tools for prenatal neurodevelopmental assessment. The observed volumetric expansion and cortical folding patterns align with known neurobiological milestones, such as neuronal migration and cortical organization.

The right hemisphere dominance observed in this study supports earlier findings in neurodevelopmental asymmetry. These findings may have implications

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for early diagnosis of conditions such as lissencephaly or agenesis of the corpus callosum, where 3D morphometric markers may offer early predictive value.

One limitation of the study is the manual segmentation, which may introduce observer bias. Future studies could benefit from AI-assisted segmentation for increased consistency and efficiency.

5. Conclusion

Three-dimensional MRI reconstruction provides a powerful and non-invasive method for monitoring fetal brain development. Quantitative morphometric data can enhance our understanding of normal and abnormal brain growth patterns, offering early markers for neurological conditions. The integration of MRI with computational imaging holds promise for the future of prenatal diagnostics.

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