

WHITE PAPER

3D-ICRV: A Novel Ultrasound Technique for Fetal Brain Surface Imaging

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Introduction

The fetal cerebral cortex undergoes a highly ordered transformation throughout gestation, evolving from a smooth surface in the early second trimester into a complex arrangement of sulci and gyri¹. This sulcation process follows a reproducible timeline, beginning with the Sylvian fissure (SF) and advancing through structures such as the central sulcus (CS) and superior temporal sulcus (STS), serving as a key marker of cortical maturation and a diagnostic window into neurodevelopmental integrity^{2,3}. While magnetic resonance imaging (MRI) and two-dimensional ultrasound (2D-US) have contributed to cortical assessment, MRI is resource-intensive and often impractical for routine use, and 2D-US is limited in its ability to depict the convex brain surface due to acoustic shadowing and restricted imaging planes⁴⁻¹⁰. To address these limitations, we introduce 3D-ICRV (Inversion, CrystalVue™, RealisticVue™, SAMSUNG MEDISON Co., Ltd., Seoul, Korea), an advanced rendering method that enables intuitive, high-resolution visualization of cortical surface anatomy from 15 weeks onward. This white paper explores its clinical utility and assessment potential.

Materials and Methods

This retrospective imaging study was conducted at a tertiary maternity and child medical center between January 2020 and March 2022. A total of 3D fetal brain volumes were acquired from low-risk singleton pregnancies between 15+0 and 35+6 gestational weeks using the high-resolution ultrasound system WS80A and HERA W10 and transabdominal high-frequency 1-8 MHz volumetric transducers, CV1-8A (SAMSUNG MEDISON Co., Ltd., Seoul, Korea). Volume acquisition was standardized through a trans-thalamic axial approach, and only fetuses with normal anatomy and appropriate growth parameters were included. After the acquisition, post-processing utilized CrystalVue™, RealisticVue™, and invert mode to generate 3D-ICRV images. The sulci and gyri were analyzed by two experienced sonographers for display rate and morphological features. Follow-up included birth outcomes and postnatal developmental assessments, ensuring the exclusion of cases with confirmed anomalies.

As an example of the imaging output using the 3D-ICRV technique, Figure 1 presents a high-quality case (not included in the study sample), illustrating the sequential development of the cerebral convexity surface from 16 to 36 gestational weeks. The sulcal and gyral evolution is clearly visualized: the Sylvian fissure (SF) emerges and deepens progressively; by 27–30 weeks, most primary sulci become identifiable; and from 30 to 36 weeks, increasingly complex cortical folding and secondary sulci are apparent. This example demonstrates the technical capability of 3D-ICRV to depict surface brain maturation across a wide gestational range.

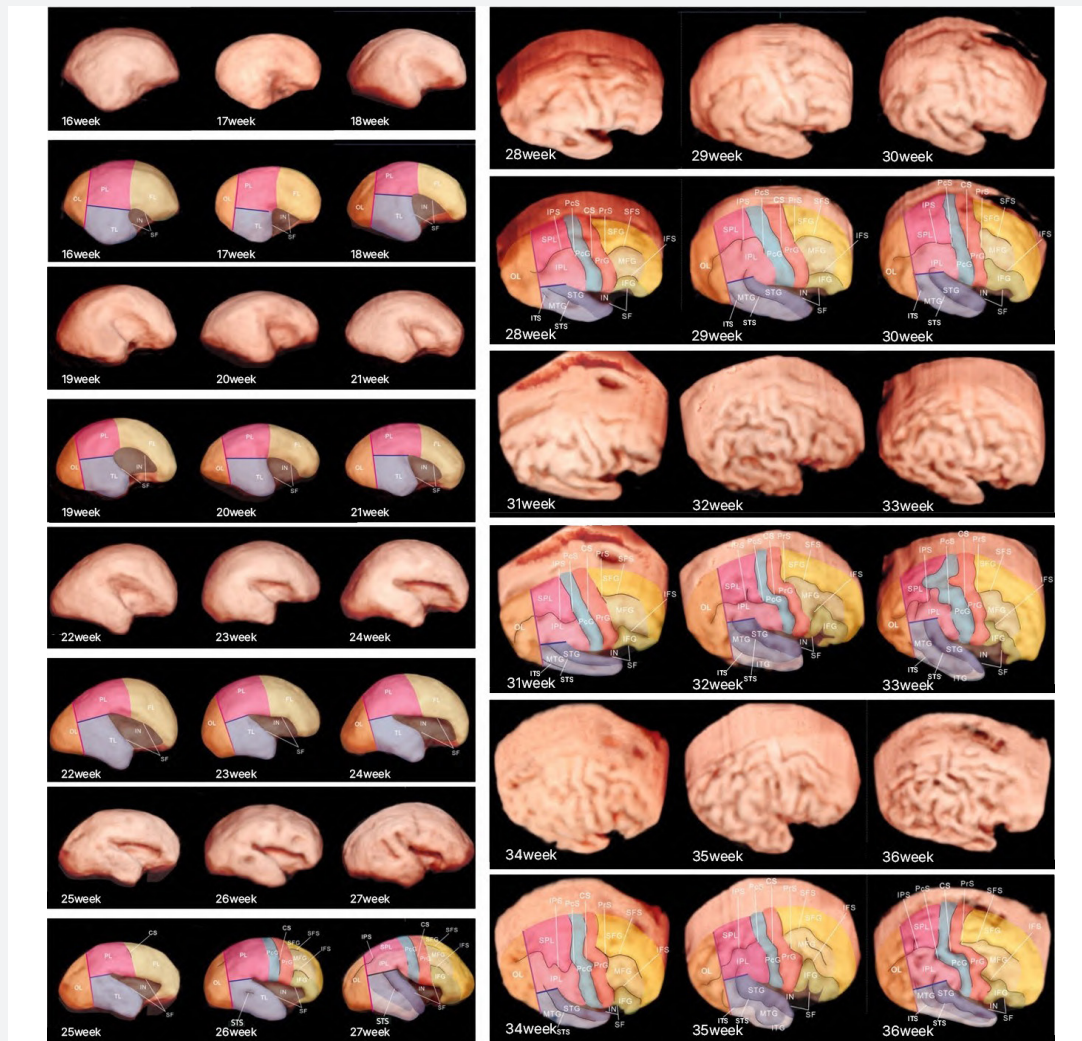


Figure 1. Representative 3D-ICRV images from a non-study case shows cerebral convexity development from 16 to 36 gestational weeks. Top: raw-rendered 3D surface images. Bottom: anatomical color mapping and sulcal labeling. 15w-16w: Surface of the brain is smooth, and the SF is flat and shallow. 17w-18w: SF deepened slightly and formed the insula circular sulcus. 23w-26w: Insula region gradually decreased, and the SF gradually narrowed. 27w-30w: The SF changes mainly from the posterior upper to the anterior and inferior. Most primary sulci begin to emerge around 27–28 weeks, and by 29–30 weeks, the major sulcal structures are largely identifiable.

Results and Discussion

Sulcal Development and Display Rates by Gestational Age

In 294 qualified fetal cases, 3D-ICRV successfully demonstrated the sequential appearance of sulci and gyri during gestation. The Sylvian fissure (SF) was the first to appear, consistently visualized from 15 weeks, and it serves as a stable anatomical landmark. From 25 to 35 gestational weeks, other convexity sulci—including the central sulcus (CS), superior temporal sulcus (STS), frontal sulci (SFS, IFS), and parietal sulci (PrS, PcS, IPS, ITS)—emerged in a temporally ordered pattern.

Sulcus display rates increased with gestational age, and by 30 weeks, most primary sulci were visualized in more than 95% of cases (Figure 2). While the SF, CS, and STS showed early and consistent visibility, sulci in the frontal and parietal regions exhibited slightly more variation. Compared to 2D ultrasound, 3D-ICRV provided enhanced visualization of the cortical surface, offering superior spatial resolution and developmental assessment. This method is especially valuable for early detection of cortical abnormalities.

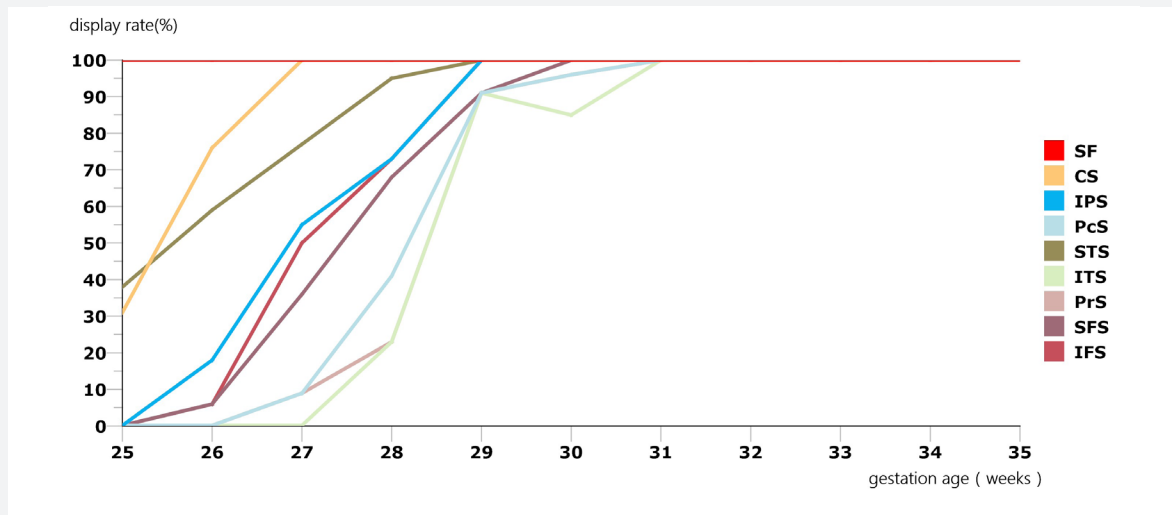


Figure 2. Sulcus display rates increased with gestational age.

Morphological Evolution of Sulci and Gyri

3D-ICRV imaging effectively captured the chronological development of cortical sulci and gyri. The Sylvian fissure (SF) appeared as a shallow groove around 15–16 weeks and progressively deepened with opercularization of the insula from 24 to 27 weeks, with near-complete coverage by 32 weeks (Figure 3–7). From 25 weeks onward, additional sulci became sequentially visible: the central sulcus (CS), superior temporal sulcus (STS), superior and inferior frontal sulci (SFS, IFS), pre- and postcentral sulci (PrS, PcS), intraparietal sulcus (IPS), and inferior temporal sulcus (ITS) (Figure 5–6). Sulcal maturation peaked between 26 and 30 weeks, after which secondary folds and increased tortuosity were observed. A notable feature was the evolving shape of the inferior frontal gyrus (IFG), which folded into an inverted “U” by 35 weeks, marking the early architecture of Broca’s area (Figure 7–8).

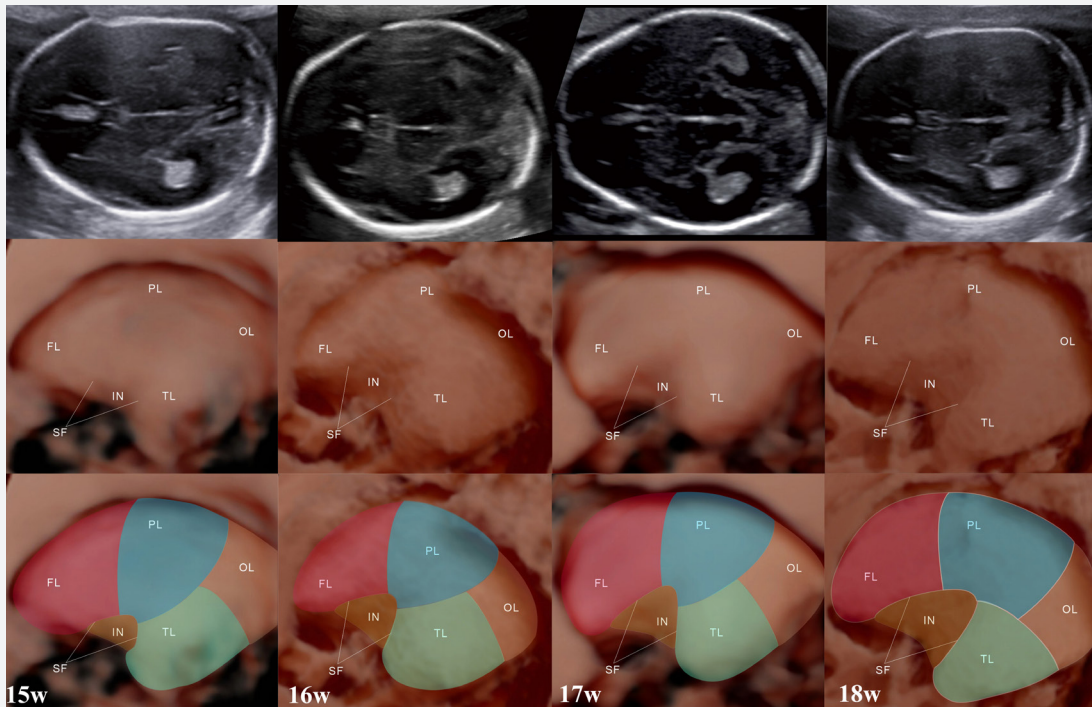


Figure 3. 3D-ICRV images of the convex surface of the cerebral hemisphere from 15–18 weeks of gestation. The fetal brain surface presents smoothly in the beginning. The Sylvian fissure (SF) is seen as a small triangular shallow indentation at 15 weeks. It deepens inwardly and expands at 17–18 weeks. IN: insula.

(Figures Note: Figure 3-7 The first line of the images is the 2D-US transthalamic planes of different normal cases that are arranged from small to large gestational age. The second line and the third line are the same group of 3D-ICRV images, corresponding to the cases in the first line. In the third line, cerebral lobes are partitioned into areas in colors based on the images in the second line. Abbreviations: SF: Sylvian fissure; FL: frontal lobe; PL: parietal lobe; TL: temporal lobe; OL: occipital lobe; IN: insula; CS: central sulcus; PrS: pre-central sulcus; PcS: post-central sulcus; IPS: intraparietal sulcus; STs: superior temporal sulcus; ITs: inferior temporal sulcus; SFS: superior frontal sulcus; IFS: inferior frontal sulcus; SFG: superior frontal gyrus; MFG: middle frontal gyrus; IFG: inferior frontal gyrus, PrG: pre-central gyrus; PcG: post-central gyrus; SPL: superior parietal lobe; IPL: inferior parietal lobe; STG: superior temporal gyrus; MTG: middle temporal gyrus; ITG: inferior temporal gyrus.)

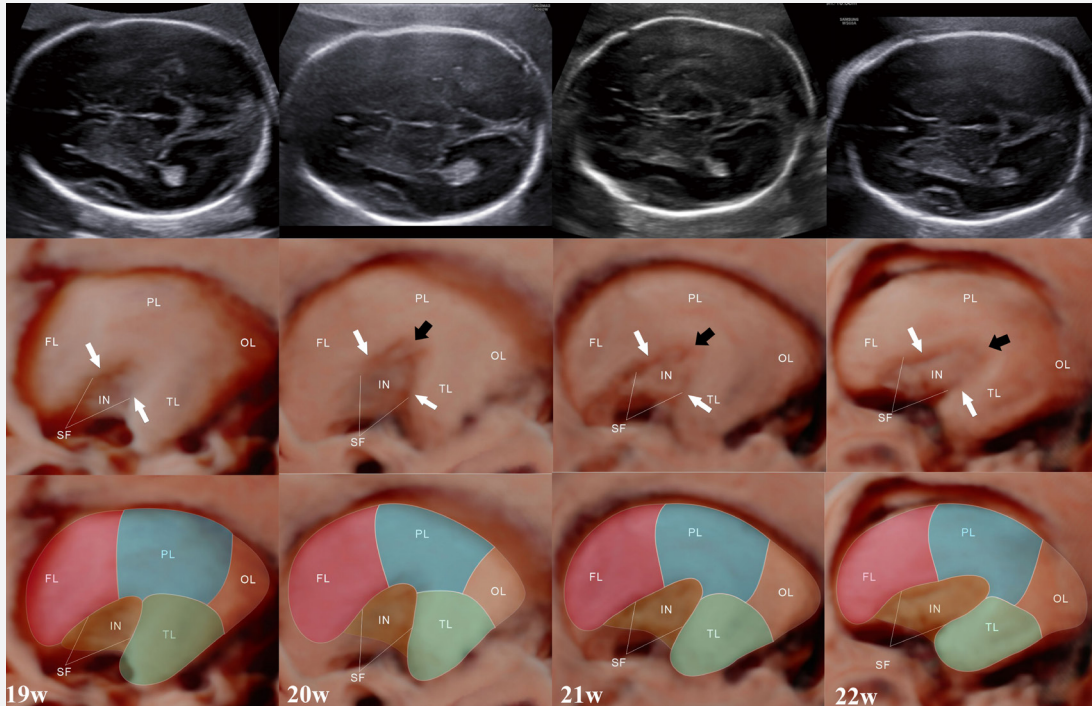


Figure 4. 3D-ICRV images of the convex surface of the cerebral hemisphere from 19–22 weeks of gestation. The fetal brain surface remains smooth except for the Sylvian fissure (SF) and insula (IN) area. The IN expands continually. The outline of the SF is further developed, turning out to be clearer. The apex of the triangle (black arrow) is round and blunt, and the linear shadow on two sides (white arrows) becomes clearer as gestational age increased.

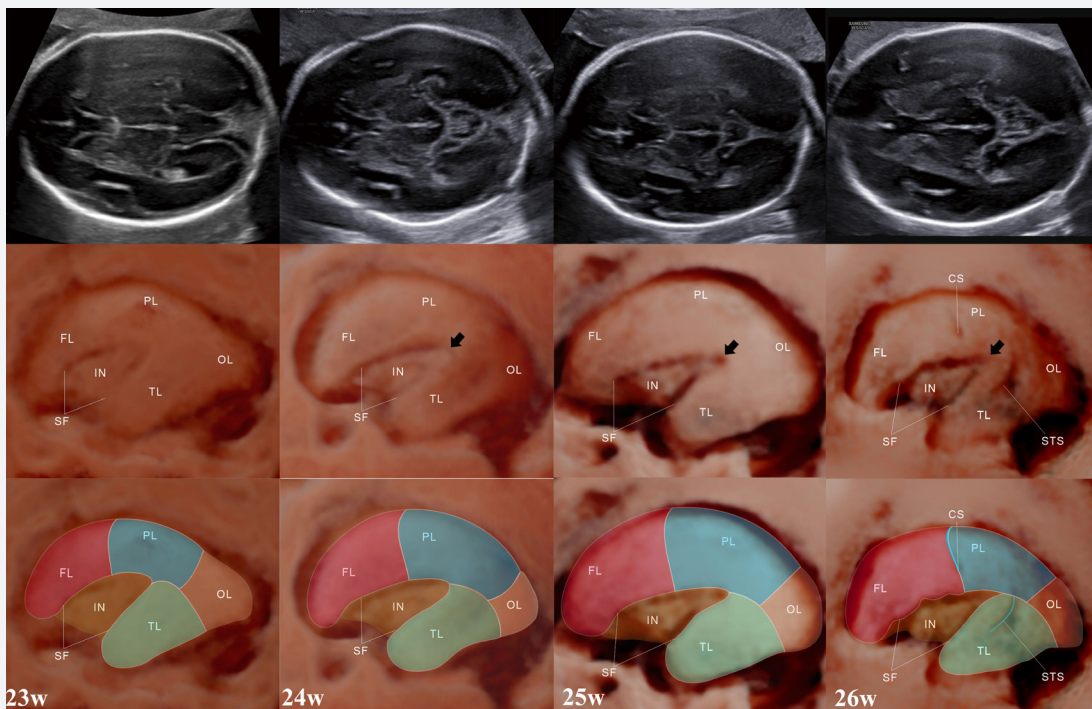


Figure 5. 3D-ICRV images of convex surface of cerebral hemisphere from 23–26 weeks of gestation. The shape of the Sylvian fissure (SF) triangle is more evident. The apex of the triangle becomes more acute (black arrow). The inner insula (IN) cortex under the apex is gradually becoming invisible. At 26 weeks, the central sulcus (CS) and the superior temporal sulcus (STS) emerge as a short linear shadow.

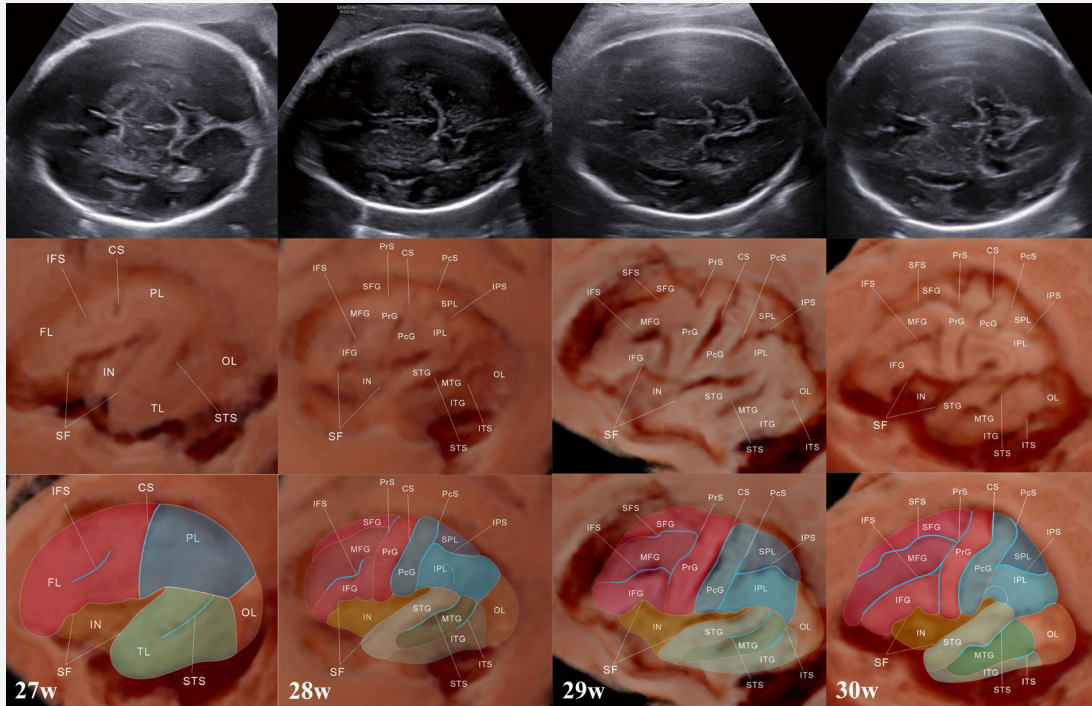


Figure 6. 3D-ICRV images of the convex surface of the cerebral hemisphere from 27-30 weeks of gestation. Starting from the apex to the base of the Sylvian fissure (SF) triangle, the two sides of the triangular SF gradually approach each other. As a result, the inner uncovered insula (IN) area is further reduced. Other sulci begin to appear at 27 weeks of gestation, and as gestation progresses, most of the sulci are identifiable by 30 weeks.

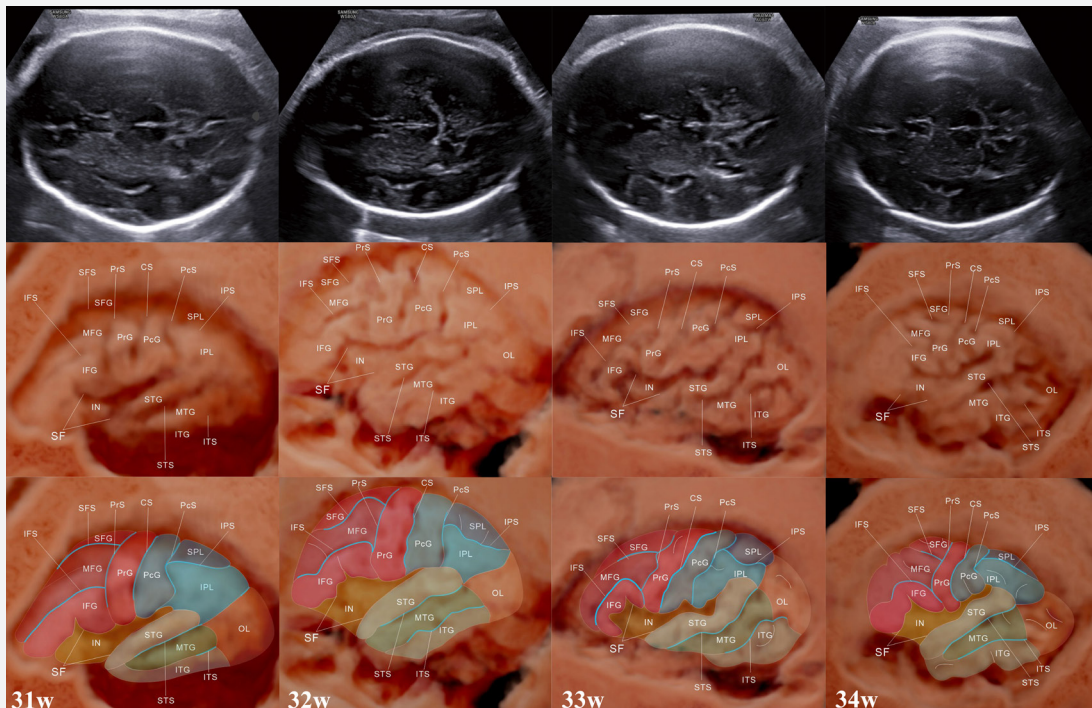


Figure 7. 3D-ICRV images of the convex surface of the cerebral hemisphere from 31-34 weeks of gestation. All primary sulci can be seen after 30 weeks of gestation. As gestational weeks increase, primary sulci form to be more tortuous and enfold more inward to the brain parenchyma leading to the dusky shadow, and the gyri are further clearly delineated. At 34 weeks, only base side of the Sylvian fissure (SF) triangle remains open, and the insula (IN) can be barely seen. Secondary sulci begin to be visible.

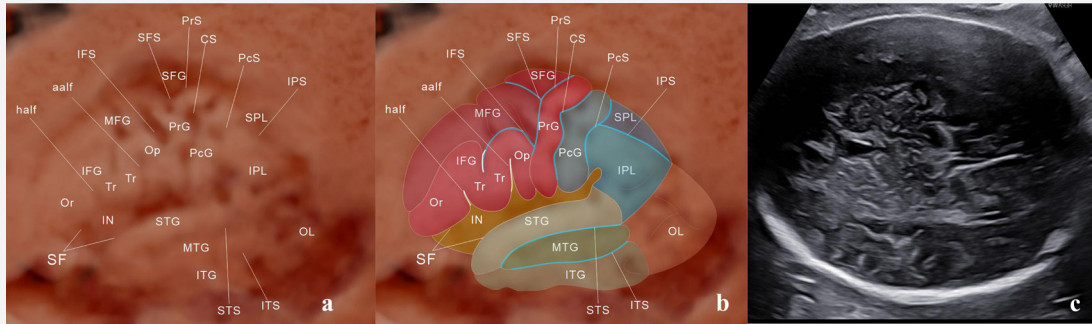


Figure 8. 3D-ICRV images a-b of the convex surface of the cerebral hemisphere and 2D-U's transthalamic axial plane c at 35 weeks of gestation. The operculum of insula (IN) attains maturity. The morphology of the sulci and gyri is similar to that in newborns. The inferior frontal gyrus (IFG) forms an inverted "U"-like structure and its subarea- triangular part (Tr) and opercular part (Op) constitute the Broca area.

These detailed surface renderings, enhanced by RealisticVue's lighting simulation, offer an intuitive, high-resolution view of cortical morphology that surpasses conventional 2D or standard 3D ultrasound in clarity and clinical utility. 3D-ICRV provides clear visualization of fetal brain surface but has limitations such as poor image quality in some cases, acoustic shadowing due to fetal position or skull ossification. Large-scale prospective clinical studies and quantitative indicators are needed to further validate its clinical utility.

Abnormal Case Comparisons

In three representative abnormal cases, 3D-ICRV imaging revealed distinct patterns suggestive of malformations of cortical development (MCD): Case 1: Dysgyria – Irregular sulcal orientation and indistinct gyral separation (confirmed by genetic testing for TUBB3 mutation) (Figure 9). Case 2: Lissencephaly – Smooth cortical surface with absence of normal sulcation at 28 weeks (confirmed by postnatal MRI) (Figure 10). Case 3: Polymicrogyria – Excessive small gyri with disrupted sulcal pattern (associated with confirmed CMV infection) (Figure 11).

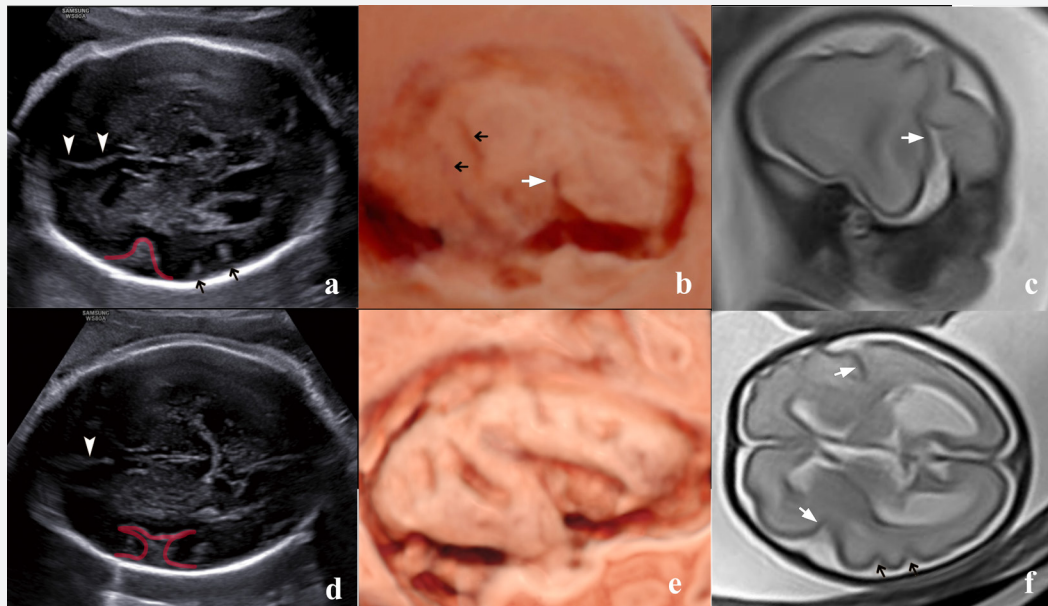


Figure 9. Case 1, at 28 weeks of gestational, was confirmed to have a TUBB3 mutation. The 2DUS transthalamic plane of case 1 a showed an abnormal short platform on the Sylvian fissure (SF) (red mark line) and the curved cerebral falx (white arrows head) compared with the large platform on SF (red mark line) and the straight cerebral falx (white arrowhead) in a normal fetus d at 28 gestational weeks. 3D-ICRV image of case 1 b showed vertically oriented SF (white arrow) and two long anomalous sulci (black arrows) compared with the SF and sulci and gyri of a normal fetus e at 28 gestational weeks. Sagittal T2-weighted section of case 1 c confirmed the abnormal SF morphology on 3D-ICRV image of case 1. Axial T2-weighted section of case 1 f showed bilateral abnormal SF (white arrows) and confirmed the two abnormal sulci (black arrows) on 2DUS a and 3D-ICRV b image of case 1.

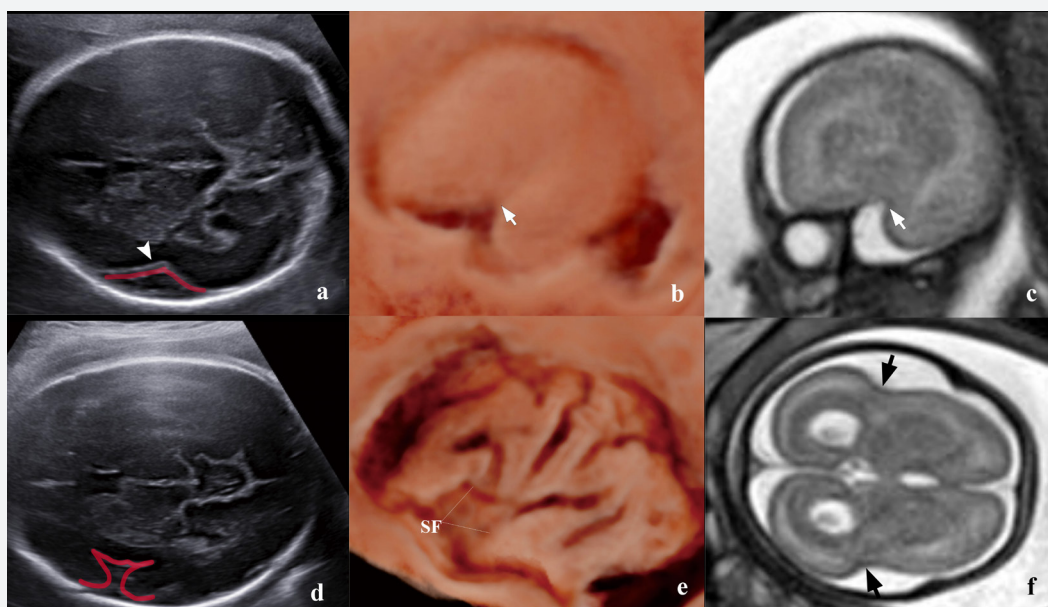


Figure 10. Case 2 at 29 gestational weeks confirmed the diagnosis of lissencephaly by MRI. The 2DUS transthalamic plane of case 2 a showed no plateau on the Sylvian fissure (SF) (red mark line) and complete absence of sulcation compared with the large platform on the SF (red mark line) in a normal fetus d at 29 gestational weeks. 3D-ICRV image of case 2 b showed a shallow and extremely small SF (white arrow) and the brain surface was smooth with no visible sulcus or gyrus compared with a normal fetus e at 29 gestational weeks. Sagittal T2-weighted section of case 2 c confirmed the findings of small SF (white arrow) on the 3D-ICRV image b and axial T2-weighted section of case 2 f showed bilateral shallow SF (black arrows) and typical manifestations of lissencephaly.

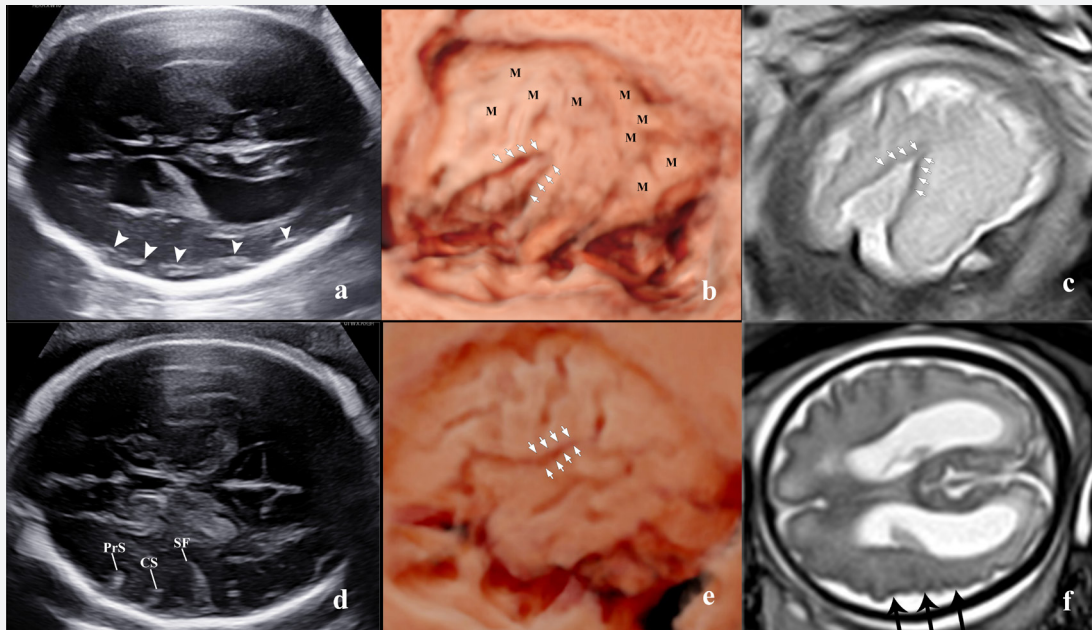


Figure 11. Case 3, at 32 weeks of gestational, was confirmed to have an intrauterine cytomegalovirus infection. The 2DUS transverse cavum septum pellucidum plane a of case 3 showed multiple micro-convolutions (white arrows head) along the outer edge compared with the primary sulci (SF, Sylvian fissure, CS, central sulcus; PrS, pre-central sulcus) on a similar plane d in a normal fetus at 32 gestational weeks. On the 3D-ICRV image of case 3 b the sulci and gyri pattern was inordinate with a number of abnormally shallow sulci and micro gyri (M) (black text) compared with the 3D-ICRV image of a normal fetus e at 32 gestational weeks. The SF apex (white arrows) remained open in case 3 b compared with the closed apex (white arrows) in e. Sagittal c and axial f T2-weighted sections of case 3 confirmed the open apex of the Sylvian fissure (white arrows) on the 3D-ICRV image of case 3 b and the cortical surface with wavy changes (white arrows head) on 2DUS transverse planes of case 3 a.

These findings underscore 3D-ICRV's capability to detect and differentiate subtle patterns of cortical malformation—particularly in settings where 2D imaging lacks spatial fidelity and MRI is not feasible. Its accessibility, real-time acquisition, and high-resolution surface rendering make it a compelling modality for early cortical surveillance and prenatal diagnosis of MCD.

Conclusion

3D-ICRV offers a reliable, non-invasive method for visualizing sulci and gyri on the fetal brain surface from 15 to 35 weeks. By enhancing contrast and spatial depth, it enables clear assessment of cortical maturation and early detection of malformations. With its accessibility, efficiency, and assessment precision, 3D-ICRV represents a valuable addition to prenatal neurosonography, supporting both routine monitoring and targeted evaluation of fetal brain development.

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