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Expert assessment of the fetal anatomy in Fetal Medicine: role of three-dimensional ultrasound, CrystalVue™ and MV-Flow™

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Introduction

Enhanced resolution of modern ultrasound (US) machines and probes, together with the development of novel three-dimensional (3D) rendering software and Doppler technologies highly sensitive towards low velocity flow, have improved the diagnostic potential of prenatal US in the evaluation of the normal fetal anatomy and in the characterization of fetal anomalies suspected on two-dimensional (2D) imaging during the second trimester of pregnancy.

Three-dimensional US consists of a tomographic technique of creating 3D images reconstructed from prenatally-acquired ultrasound volumes. Post-processing involves the use of rendering technologies such as RealisticVue™ and CrystalVue™, or the mere offline navigation of the acquired US volume. The formers may allow the vivid reconstruction of anatomical surface details, such as those that can be seen in the fetal face, head, or limbs. This type of detailed reconstruction plays a role in maternal bonding and parental counselling in the event of abnormal features[1,2]. It also complements 2D and multiplanar imaging by adding diagnostic information resulting from the enhanced contrast of structures and tissues, as is the case of using CrystalVue™ for imaging the fetal secondary palate[3].

The offline navigation of 3D US volumes acquired with high resolution probes can assist in the expert assessment of the fetal central nervous system (CNS) by allowing the visualization of midline structures and by allowing a comprehensive navigation of the posterior fossa and the cortical folding across gestation[4-7]. Rendering technologies have been proposed by neurosonologists for the expert assessment of dedicated structures of the fetal CNS such as the optic chiasm[8,9]. CrystalVue™ is a context-preserving, postprocessing technique for 3D volumes that allows easier differentiation between tissues with different echogenicity by enhancing contrast. Our group recently described the properties of CrystalVue™ in detailing cerebral structures and improving the visualization of sulci, gyri, as well as the wall of cystic structures[3]. With respect to the other clinical applications of 3D US imaging in fetal medicine, the fetal spine, ribs, secondary palate, and esophagus are among the structures which may also benefit from 3D imaging complementing 2D US[10-12].

Modern color and power Doppler technologies have enabled the clear depiction of small vessels and complex vascular architecture, such as intrahepatic circulation[13], and simplified the visualization of pulmonary veins in the context of the expert assessment of the fetal heart. Recent implementation of MV-Flow™ and LumiFlow™ technologies has enabled the demonstration of low velocity flow vessels such as the dural sinuses and the torcular Herophili[14].

Methods and results

In this work, we describe the imaging features obtained with 3D US RealisticVue™ and CrystalVue™ rendering, and high-resolution modern Doppler technologies including newly developed MV-Flow™ and LumiFlow™ algorithms in women referred for the advanced assessment of the fetal anatomy in the second trimester. RealisticVue™, CrystalVue™, MV-Flow™, and LumiFlow™ are built-in, commercially-available software installed on the high-resolution ultrasound system HERA W10 (SAMSUNG MEDISON, Co., Ltd, Seoul, Korea).

Advanced assessment of the fetal anatomy in the second trimester is performed upon clinical indication by means of 2D and 3D US and may benefit from a combination of transabdominal and transvaginal approaches. The transvaginal approach is acknowledged to aid in the expert evaluation of the CNS in the cephalic-presenting fetus. Volume acquisition can be performed in any scanning plane, axial, coronal or sagittal depending upon fetal lie, position and the anatomic area to be investigated. Following acquisition, the volume can be oriented to demonstrate the anatomic structures in a standardized way. Importantly, multiplanar imaging allows the real-time assessment of the position of the "dot" (point of intersetion of all 3 orthogonal planes) within the US volume. Modern, high-frequency transvaginal probes allow the clear depiction of the structures of the posterior fossa together with the brainstem and the proximal spinal cord by means of a midsagittal, suboccipital insonation. Such an approach, which may be limited with advancing gestation due to the ossification of the skull bones, enables the visualization of the cerebellum together with the pons lying anterior to the cerebellar vermis (Figure 1).

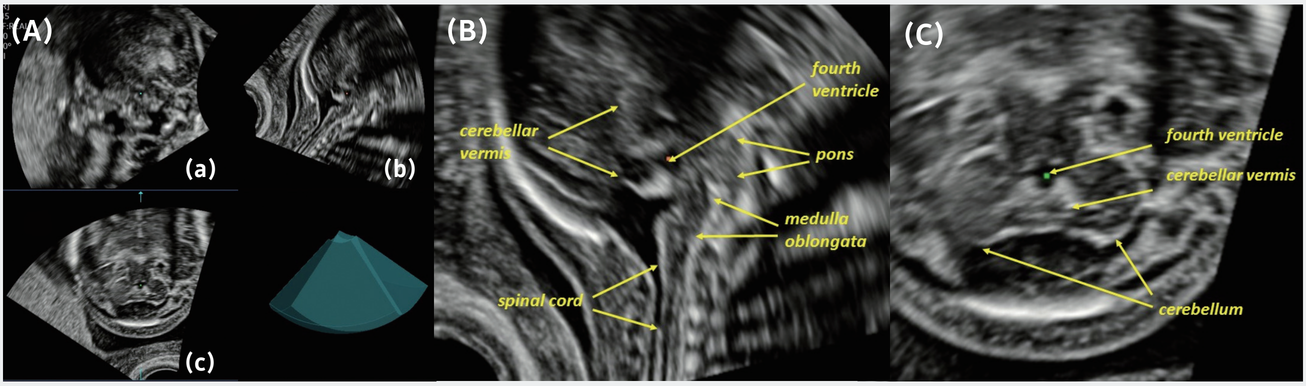

Figure 1. Three-dimensional, multiplanar imaging of the posterior fossa obtained by transvaginal ultrasound through suboccipital insonation on the midsagittal plane. (A) Grayscale, multiplanar view of the coronal (a), sagittal (b), and axial (c) views. (B) Midsagittal view showing highly-defined imaging of the cerebellar vermis, the fourth ventricle, the pons, the medulla oblongata and the proximal cervical spine. (C) Axial view showing the fourth ventricle, the cerebellar vermis, and hemispheres.

Different anatomical details can be demonstrated by insonating the fetal CNS on the mid-sagittal plane through the sagittal suture, which enables the visualization of the corpus callosum together with the cerebellar vermis and the tentorium cerebelli (Figure 2A). When MV-Flow™ and LumiFlow™ are applied on this scanning plane, the straight sinus and the other dural sinuses can be imaged (Figure 2B).

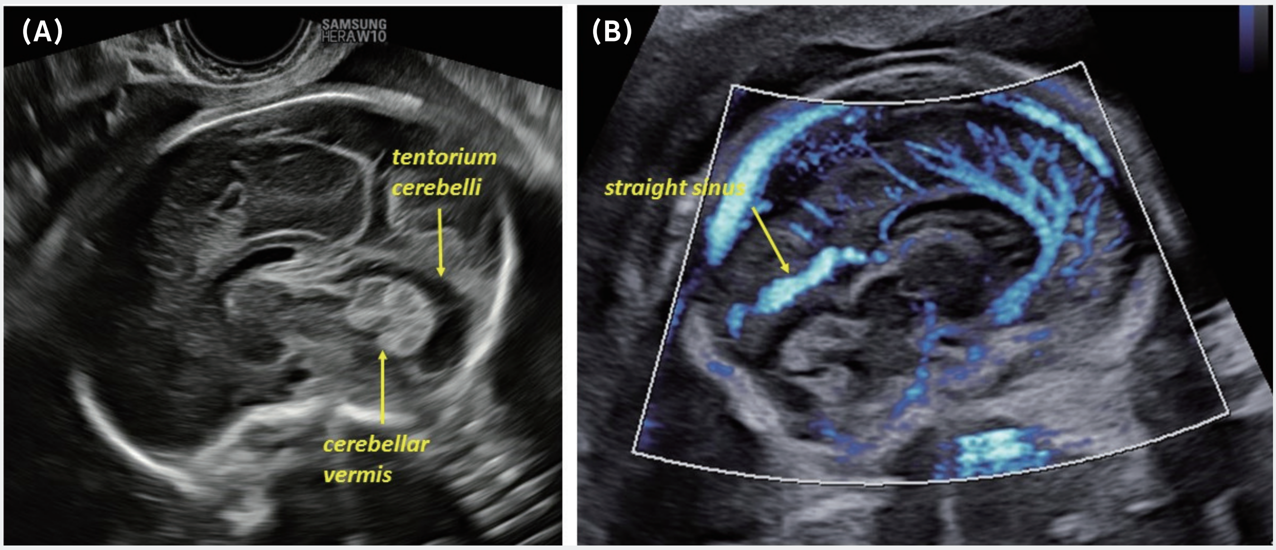

Figure 2. Ultrasound imaging of the fetal central nervous system on transvaginal ultrasound on the midsagittal plane through the sagittal suture. (A) Visualization of the cerebellar vermis and the tentorium cerebelli on two-dimensional ultrasound. (B) Visualization of the straight sinus with MV-Flow™ and LumiFlow™.

MV-Flow™ and LumiFlow™ also have the potential to clearly depict small vessels such as the middle suprarenal artery (Figure 3), whose visualization may be challenging with conventional Doppler techniques and very recently have been suggested to aid in the expert characterization of abnormal vascularization in the context of suspected placenta accreta spectrum (Figure 4).

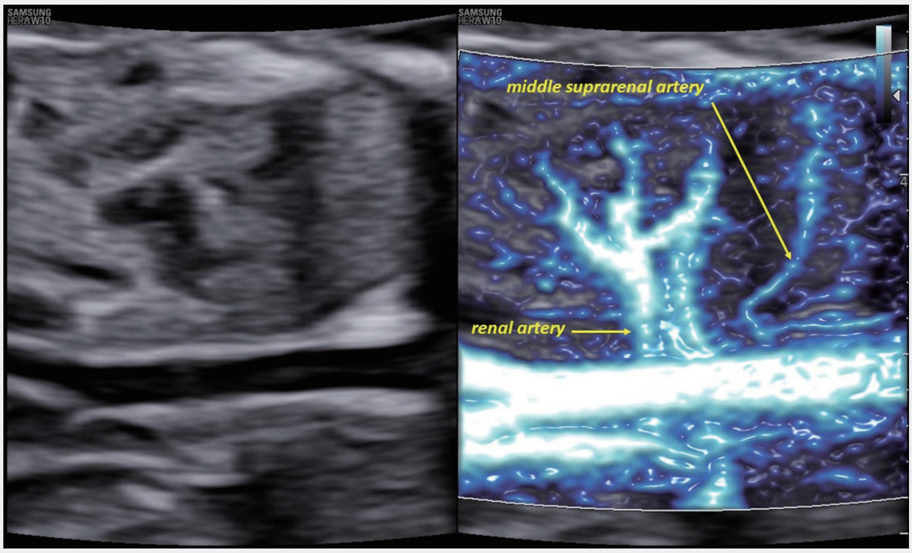

Figure 3. "Dual live" display of the coronal view of the fetal abdomen showing the high-quality depiction of the renal and the middle suprarenal artery with the adjunct of MV-Flow™ and LumiFlow™ technologies.

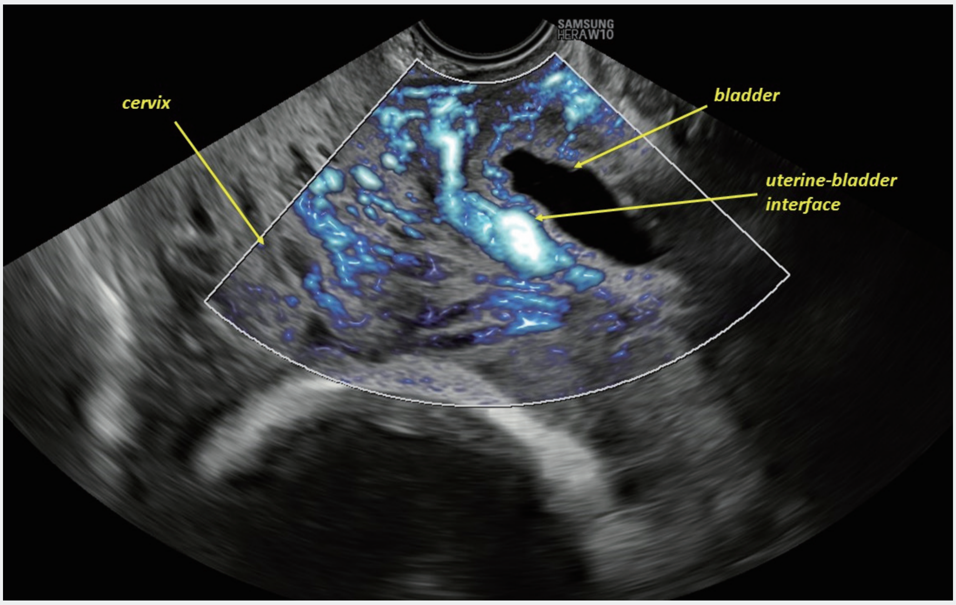

Figure 4. Transvaginal ultrasound image from a 34-week, para 3 woman referred due to suspected placenta accreta spectrum demonstrating the abnormal vascularization of the cervix and of the uterovesical interface with MV-Flow™ and LumiFlow™.

Other than these Doppler techniques, modern color and power Doppler technologies, like those available on the HERA W10 ultrasound system, allow a clear demonstration of small vessels, such as the pulmonary veins draining into the left atrium (Figure 5A), as well as demonstration of structural anomalies including muscular ventricular septal defects (Figure 5B). These technologies are available on transabdominal and transvaginal probes.

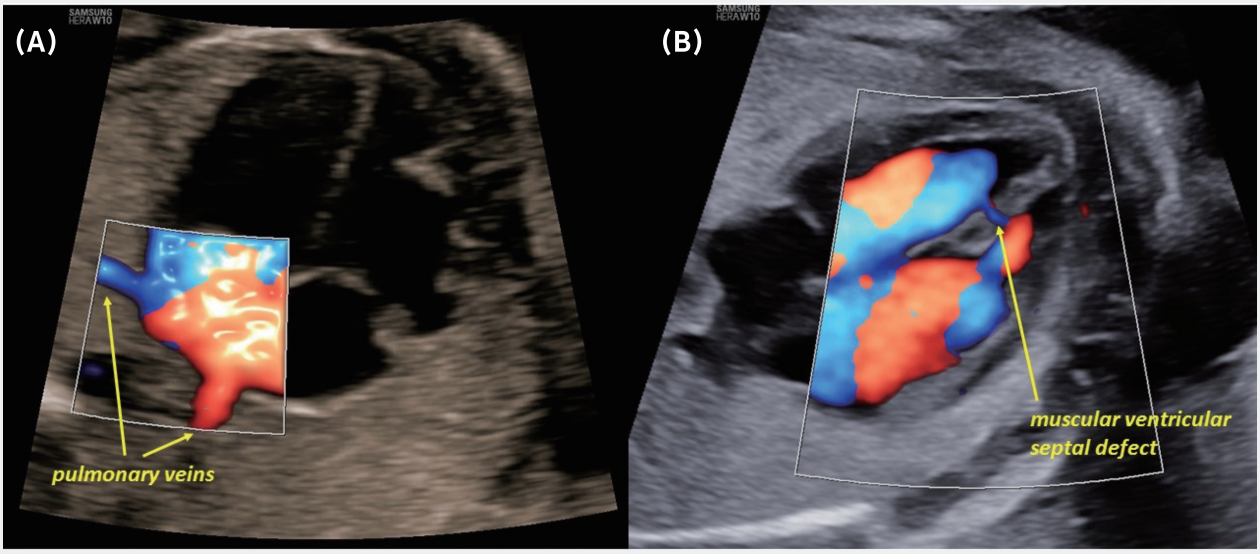

Figure 5. Imaging of the fetal heart with HERA W10 ultrasound system. (A) Demonstration of power Doppler imaging of the pulmonary veins draining into the left atrium in a normal case; (B) muscular ventricular septal defect imaged with power Doppler technology.

CrystalVue™ rendering enables the user to obtain the desired mixture of contrast, light, and transparency levels to retrieve additional information. The technique performs best when the quality of the volume acquisition is set to "extreme" and the angle of the volume sweep is adjusted to encompass the anatomy of interest. Following the acquisition, offline postprocessing is best performed by adjusting the region of interest (ROI) to obtain the thinnest slice, and then select the "CrystalVue™" and the "RealisticVue™" icons from the touch screen controls. In our experience, such steps have proven to aid in the expert assessment of cerebral (Figure 6) and facial structures, such as the secondary palate. The transabdominal, midsagittal view of a 32-week fetal brain shown in Figure 7, demonstrates that the enhanced contrast with CrystalVue™ allows visualization of sulci and gyri including the central and the cingulate sulcus. Of note, such structures cannot be demonstrated on multiplanar imaging.

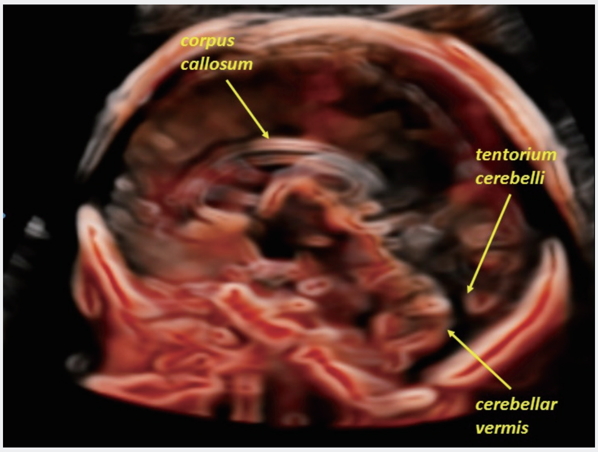

Figure 6. Midsagittal view of the fetal brain with CrystalVue™. Following acquisition, offline postprocessing is best performed by adjusting the region of interest (ROI) to obtain the thinnest region of interest (ROI) slice prior to selecting the "CrystalVue™" and the "RealisticVue™" icons. In the presented case, the techniques clearly allow the visualization of midline structures including the corpus callosum, the tentorium cerebelli, and the cerebellar vermis.

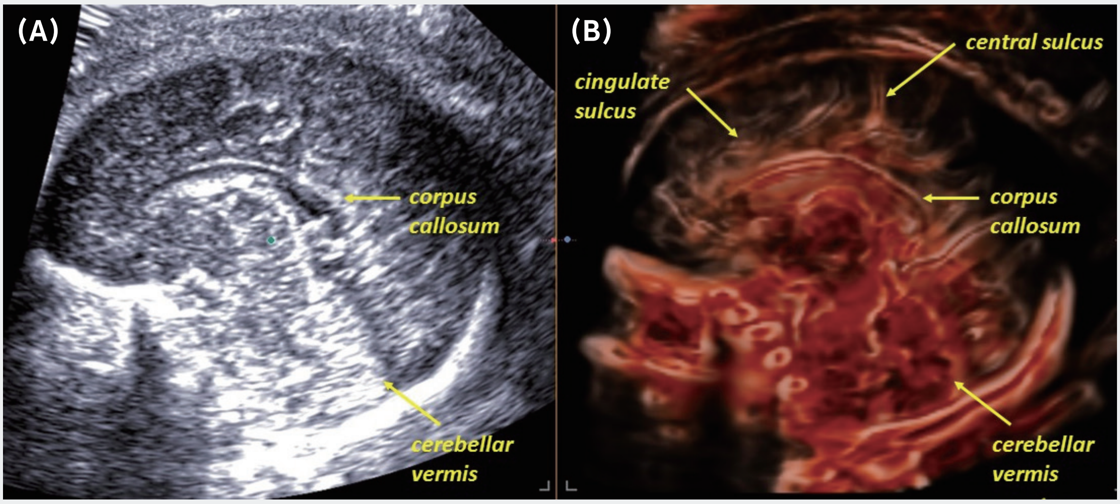

Figure 7. Transabdominal, midsagittal view of a 32-week fetal brain demonstrating enhanced contrast with CrystalVue™ and RealisticVue™, which allow the visualization of sulci and gyri including the central sulcus and the cingulate sulcus (B). Of note, such structures cannot be demonstrated on multiplanar imaging (A).

In the parasagittal view of a 29-week fetus shown in Figure 8, RealisticVue™ and CrystalVue™ allow a vivid depiction of the wall of the lateral ventricle and of the choroid plexus which is superior to that provided by multiplanar imaging.

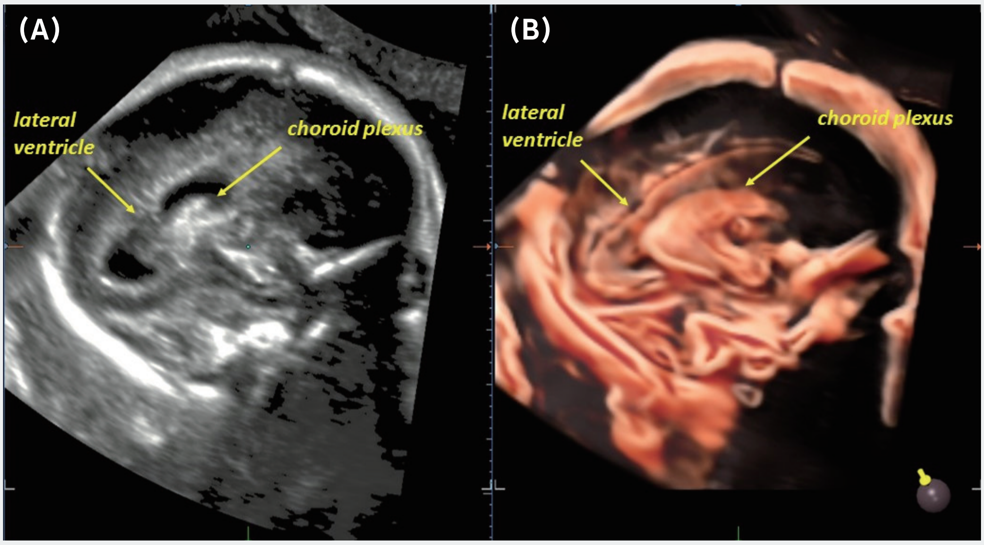

Figure 8. Parasagittal view from a 29-week fetus showing the vivid depiction of the wall of the lateral ventricle and of the choroid plexus with RealisticVue™ and CrystalVue™ (B) and comparison with multiplanar imaging (A).

3D US may also assist in the visualization of the secondary palate (Figure 9).

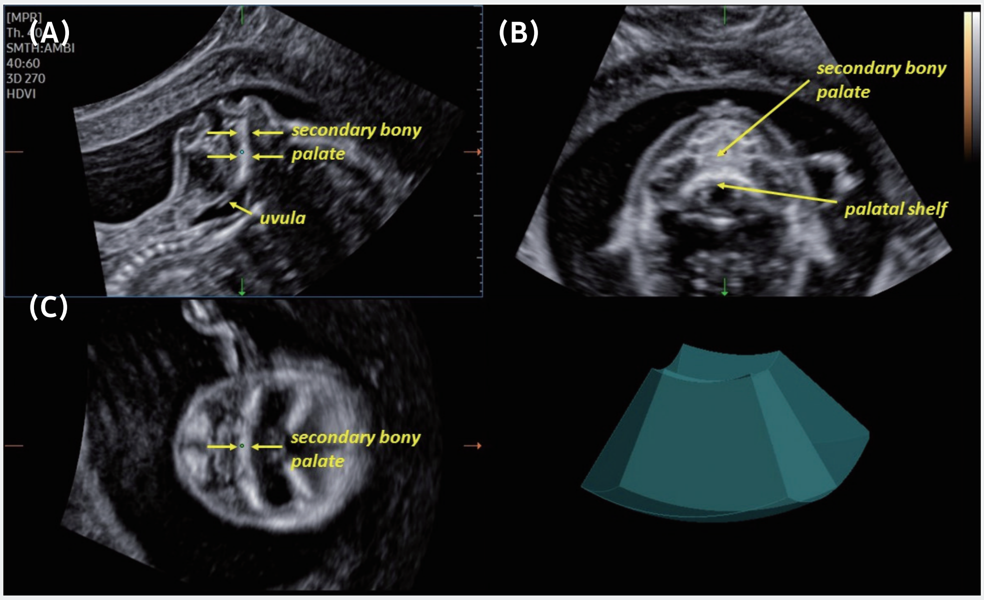

Figure 9. Three-dimensional, multiplanar imaging of the fetal face showing the secondary palate on the sagittal (A), axial (B), and coronal (C) planes (secondary bony palate pointed by arrows unless otherwise stated).

The combination of CrystalVue™, RealisticVue™ and a thin ROI enables the vivid demonstration of palatal defects on the axial and coronal planes. In Figures 10 and 11, we present the case of a 21-week fetus with cleft involving the alveolar ridge and secondary bony palate. On the axial plane, the tongue can be visualized caudally to the maxilla and the defect of the alveolar ridge. When imaging more cranially, a deviated nasal septum, which represents an indirect sign of cleft affecting the secondary bony palate, is demonstrated with multiplanar imaging and rendering technologies (Figure 10).

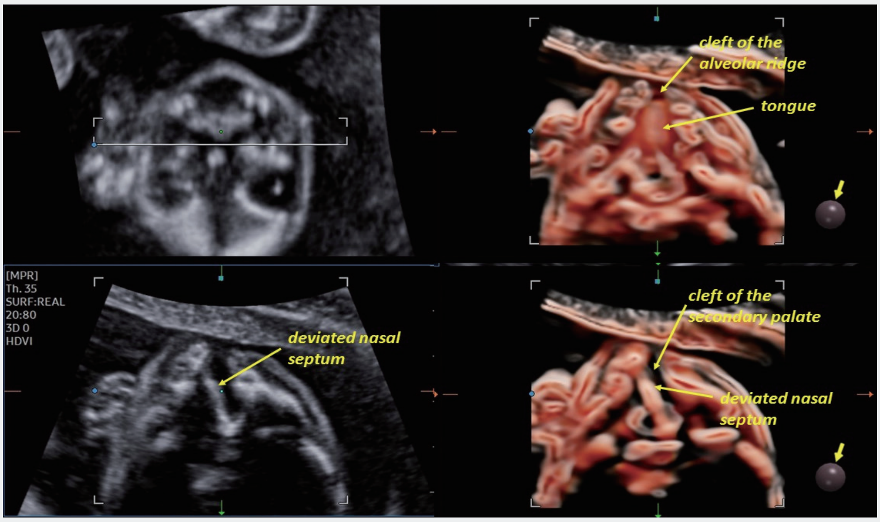

Figure 10. Imaging of a 21-week fetus with cleft involving the alveolar ridge and secondary bony palate on the axial plane with CrystalVue™ and RealisticVue™ rendering. The tongue can be visualized caudally to the maxilla and the defect of the alveolar ridge. Cranially a deviated nasal septum, which represents an indirect sign of cleft affecting the secondary bony palate, can be demonstrated.

On the coronal plane, CrystalVue™ and RealisticVue™ enable the soft tissues (i.e., the tongue) to be distinguished from the bony structures and the palatal defect to be demonstrated (Figure 11).

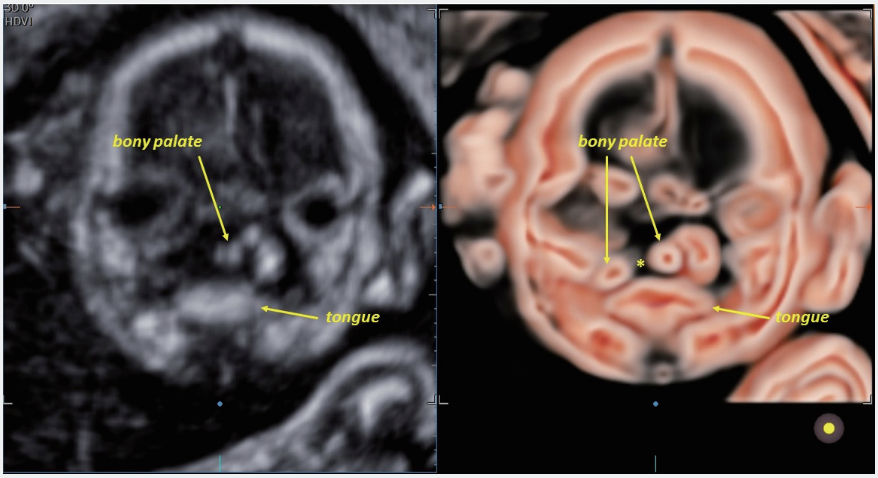

Figure 11. Imaging of a 21-week fetus with cleft involving the alveolar ridge and secondary bony palate on the coronal plane with CrystalVue™ and RealisticVue™ rendering. They enable a clear depiction of the borders of the tongue, the bony structures, and also demonstrate the palatal defect (*).

In Figure 12, the RealisticVue™ rendering, with different light sources, depicts a crisp definition of the facial defect. The light source tool also allows a vivid rendering of other craniofacial and limb structures such as ears (Figure 13), hands, and fingers (Figure 14).

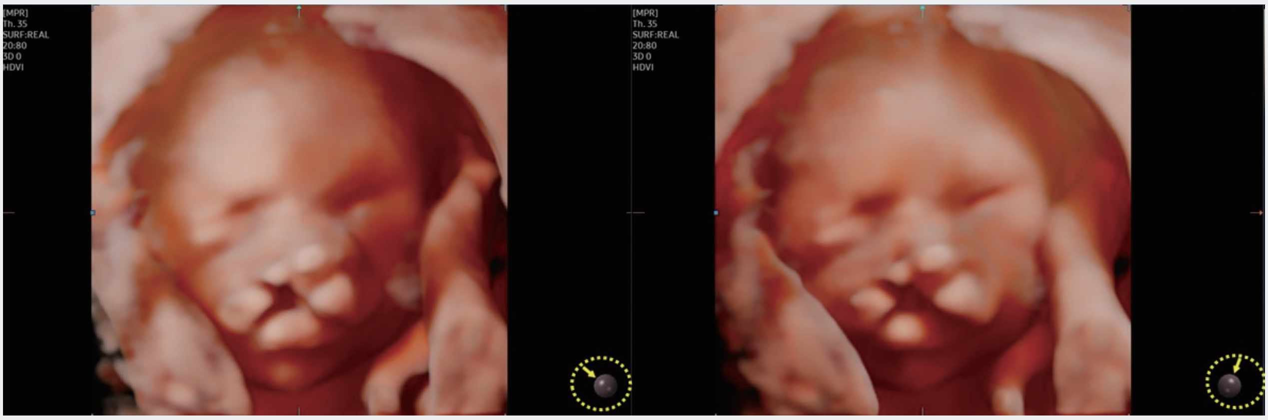

Figure 12. RealisticVue™ imaging of the fetal face in a 21-week fetus with a right, unilateral cleft of the lip, alveolar ridge, and palate showing a vivid view of the defect of the lip. The appearance may vary based on the direction of the light source (dotted circles).

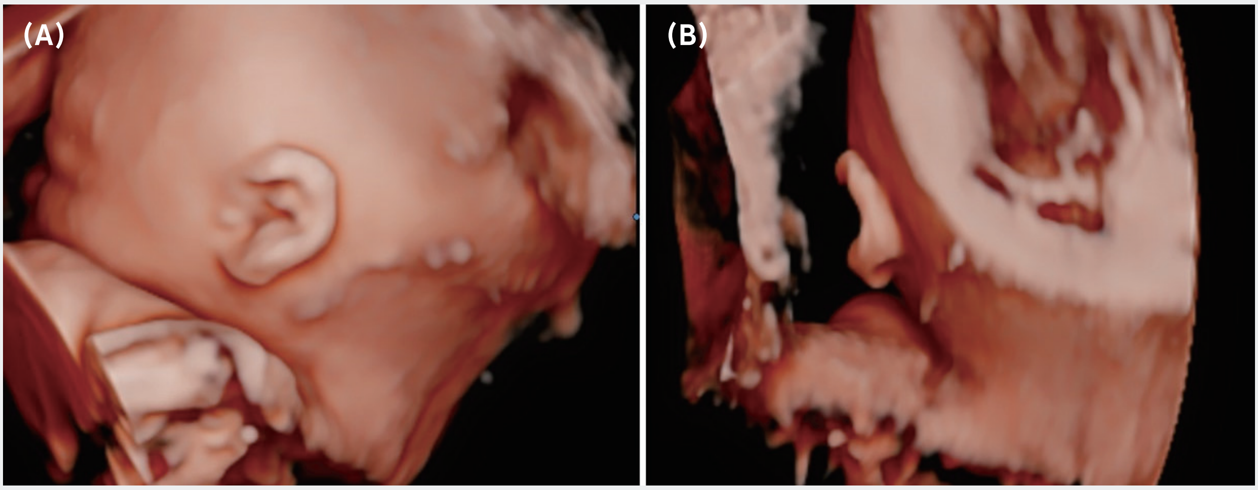

Figure 13. RealisticVue™ imaging of the fetal ear in a 20-week, normal fetus in a lateral (A) and in a posterior (B) view. The lateral view also demonstrates a normal insertion of the fetal ear lying at the same level as the fetal orbits.

Figure 14. RealisticVue™ imaging of the fetal left hand in a 20-week, normal fetus. The prominence of the head of the metacarpal bones and of the phalanges of the correspondent fingers is demonstrated. The overall appearance of the rendered view of the hand is vivid. (Reproduced from the UOG Art Gallery published in the 30th anniversary celebratory issue of Ultrasound in Obstetrics and Gynecology (UOG), 2021.

Conclusion

In conclusion, while 2D ultrasound together with 3D ultrasound and Doppler techniques can delineate normal and abnormal fetal anatomy in the second trimester of pregnancy, our experience has shown that the adjunct of 3D US rendering technologies including Crystal-Vue™ and RealisticVue™, and highly sensitive Doppler techniques such as MV-Flow™ and LumiFlow™, can add clinical information and have the potential to assist in the expert assessment of the fetal anatomy. Such easy-to-use, progressive tools complement standard 2D imaging of the second trimester fetus with suspected or confirmed structural anomalies.

Supported Systems

- HERA W10

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