In-utero three-dimensional magnetic resonance imaging of fetal brains

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We assessed ten prenatal magnetic resonance imaging (MRI) scans for fetal brain anomalies, and identified eight that were suitable for post-processing. Anatomical abnormalities were assessed on the three-dimensional (3D) models and compared with two-dimensional (2D) imaging findings. We calculated the volume of the intracranial ventricles and a periventricular haemorrhage. In three cases additional clinical information was obtained. 3D modelling of the brain in-utero is possible and can be used to plan treatment. Additional information provided by in-utero MRI facilitated postnatal management of a vein of Galen malformation.

Two-dimensional ultrasound (US) is the standard obstetrical imaging technique, used for the prenatal diagnosis of suspected fetal abnormalities. Other techniques augment the diagnostic power and accuracy of US - eg, pulse-, color-, and power Doppler. Three-dimensional (3D) US is used to image fetal facial and spinal cord abnormalities.
Many study results show successful use of magnetic resonance imaging (MRI) as a complementary to ultrasound for the assessment of fetal anomalies [McCarthy, 1985 #109] and assessment of fetal organ volumes. Development of fast MRI techniques has achieved high resolution images of the fetus in-utero with short acquisition times. By overcoming prior limitations of fetal MRI secondary to motion, greater use of the technique in obstetrics is now justified. [Quinn,1998 #135] We report the application of 3D reconstruction, from 2D MRI, of the fetal brain in-utero.

Ten patients underwent a total of 14 MRI examinations of the fetal brain between December 1998 and December 1999. Review of results revealed: six normal examinations, two periventricular haemorrhages, three hydrocephalus, and one each of Dandy-Walker variant, complex pathology with encephalocele, and vein of Galen malformation. Eight examinations were suitable for 3D reconstruction by following inclusion criteria: fetal gestation >20 weeks, singleton pregnancy and that the images were suitable for post data acquisition processing.

We used a 1.5-T MRI system (General Electric Medical Systems, Milwaukee, WI) to obtain multiplanar, single-shot, fast-spin echo, T2-weighted (repetition time/excitation time = 60000/99 ms) images were obtained in supine position in three planes (sagittal, coronal and axial) with the following parameters: 20 cm field of view, 256 x 256 matrix, 4mm slice thickness with a 1mm gap, bandwidth of 31.3 MHz, 90° flip angle and 1 to 0.5 NEX. Acquisition time ranged from 20 to 60 seconds per series.

We electronically transferred 2D images to a workstation (Sun Microsystems, Mountain View, CA) for post-processing. We reviewed all original images and chose those that best displayed the anatomy of interest for post-processing. Selection of pixels on the boundary of the structures of interest was done manually, slice by slice. We allocated different pixel values to skin, cerebral hemispheres, cerebellum, ventricles, eyes and pathological findings - eg. haemorrhage, encephalocele. We generated 3D surface models from the outlined structures by use of a weak gaussian smoothing followed by a pipeline, which consisted of the marching cube algorithm, a triangle reduction algorithm and a triangle smoothing algorithm (Figure 1).

We viewed final results with graphics acceleration and the 3D Slicer software (www.slicer.org). We obtained the volumes of the brain parts by addition of the number of the voxels in every model and conversion of these to volume in ml. Assessment of the ventricular volumes included the choroid plexuses. Time needed to complete image analysis and post-processing was 1 to 3 hours.

We selected four cases to show our technique; a normal fetus, hydrocephalus at 37 weeks gestation, periventricular haemorrhage and a vein of Galen aneurysmal malformation and did volume measurements in the first three cases. The ventricular volumes in the normal fetus were 4 ml at 24 weeks and 9.7ml at 28 weeks gestation. In the fetus with hydrocephalus at 37 weeks gestation, enlarged lateral ventricles measured 21mm in the transverse diameter. The ventricular system was visualized in 3D, and the total volume of the intraventricular cerebrospinal fluid measured 98.5ml. Postnatal assessment showed a
spontaneous reduction in volume by 35ml. In the fetus with periventricular haemorrhage, the volume of the haemorrhage showed a decrease over time, being 2.0ml at 28 weeks and 0.8ml at 33 weeks.

The vein of Galen aneurysm was assessed at 37 weeks after diagnosis by ultrasound, which only identified one feeding vessel. On 2D MRI two feeding vessels were seen. 3D reconstruction showed the dilated vein of Galen with unobstructed falcine sinus draining to the torcular. Four inferior feeding vessels (choroidal branches of the posterior cerebral arteries) were identified. Clinical evaluation after birth showed the predicted high output congestive cardiac failure, and postnatal MRI with MR angiography added no further information. Although the interventional radiologist was prepared for urgent embolisation, cardiac failure improved with medical management, and definitive treatment was deferred until 5 months of age. Catheter angiography, at the time of intervention, verified the accuracy of the 3D model at 37 weeks gestation. The shunt was cured by embolisation, and the infant developed normally since.

In the remaining two cases, one fetus was diagnosed with a Dandy-Walker-variant and the other with an encephalocele-meningocele, arachnoid cyst and absence of falx and corpus callosum. 3D models demonstrated the anatomical details of both abnormalities but added no further clinical information.

Our technique enables 2D images of the fetal brain to be reconstructed in 3D in-utero. The 3D model derived from MRI can show all anatomical structure separately or relations to others. This ability improves visualization from 2D images since 3D shape and location of normal and pathological structures can be appreciated. Better visualization enhances the assessment of the fetal brain and facilitates prenatal diagnosis.

Serial assessments can monitor the progression of diseases like hydrocephalus and haemorrhage, and the success of any postpartum intervention such as shunting. Here, an in-utero reduction in volume was shown in the fetus with periventricular haemorrhage. The fetus with hydrocephalus was examined before and after birth, showing the reduced ventricular volume. This reduction could be caused by changes associated with extra-uterine life or spontaneous regression of the hydrocephalus postpartum.

In malformation of the vein of Galen, the 3D model gave more information than 2D MRI and US by showing the vascular anatomy, which could not otherwise be accurately identified. Because decisions about treatment are based largely on imaging data, prospective identification of the number and size of arterial feeding vessels, venous drainage and venous anomalies is essential in the planning of endovascular intervention or surgery. The preferred method of assessment is postnatal MRI and MR angiography, reserving catheter angiography for the time of the intervention.

Our 3D technique provides additional diagnostic information in a non-invasive manner prior to delivery.
Is fetal MRI safe? There have been no reports of adverse effects to the developing human fetus. To avoid any unknown adverse effects due to MR imaging though, use of the technique is limited to gestation greater than 12 weeks. [Kanal, 1994 #83] The protocol in use for fetal 2D MRI can be further improved for 3D post-processing, with attention to details like isotropic voxels and high signal to noise resolution with thinner slices.

3D fetal reconstruction could be used in surgical simulation and treatment planning before birth. This technique has been successful in the assessment of conjoined twins intra-uterine in preparation for surgical separation. [Norwitz, 2000 #898] 3D reconstruction might also be relevant in the planning and undertaking of fetal surgery for selected life-threatening birth defects.

Rapid improvements in MRI and computer technology could soon make post-processing of 3D models faster, more reliable and cost effective. If this happens, such image-based instruments could provide information to allow earlier and more precise prenatal diagnosis and treatment.

References:


Figure Legends:

**Figure 1:** Post-processing of the original MRI gray scale from left to right: A) original gray scale image, B) manual segmentation, C) 3D model of the brain superimposed on the gray scale, D) 3D model of the skin superimposed on the gray scale.
Figure 2: 3D model of fetal skin (pink), brain (white) and the vein of Galen aneurysmal malformation (arterial feeding vessels in red and venous drainage in blue).