Snapshot MRI with volume reconstruction of the fetal brain

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Introduction: Fetal magnetic resonance imaging (MRI) is able to increase the detection of abnormalities within the fetal brain and to improve their characterisation when compared with antenatal ultrasound. The most frequent indications for referral for MRI include ventriculomegaly, abnormal appearance to the cerebellar vermis or suspected commissural agenesis. Fetal imaging provides information on both diagnosis and prognosis for the fetus which inform clinical management. This has enormous consequences for the family and for health and educational services. MRI 's role is complimentary to ultrasound, which remains the screening technique of choice, but in addition MR could play a valuable role in the objective assessment of the normally developing brain and the response of the immature brain to injury. Data obtained from normal fetuses would provide the ideal control for prematurity allowing comparisons to be made at different gestational ages. There have, however, been few advances in the field of fetal MR imaging since the introduction of fast single shot T2 weighted techniques. These enabled good quality individual image slices to be acquired without the use of either maternal or fetal sedation. Fetal motion still hampers data acquisition resulting in repeated attempts to obtain images across the brain that are within plane and so it has not been possible to obtain datasets suitable for quantification. Examination times may be prolonged whilst efforts are made to image specific brain structures at the right level e.g. midline sagittal views of the cerebellar vermis. We have recently developed a novel methodology, Snapshot MRI with Volume Reconstruction (SVR) using dynamic acquisition to densely sample space and a registration programme to produce high signal to noise, high resolution reformatable volumetric datasets of the fetal brain. (1)

The aims of this study were:

To assess the acceptability of this sequence in a clinical setting

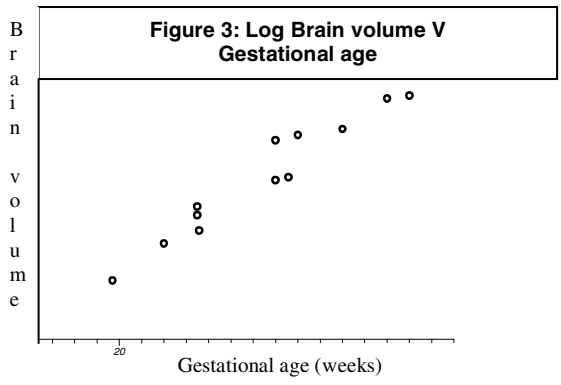
To compare the information available from the raw data and reformatted images with that obtained by conventional fetal examination

To use the SVR reconstructed datasets to measure brain volume in a cohort of fetuses at different gestations.

Methodology: The study was approved by the Hospital Ethics Committee. Informed consent was obtained form the mother prior to the examination All scans were performed on a Philips 1.5 T Achieva scanner (Best, The Netherlands). Mothers were usually imaged using either a 4 element phased array body coil or a phased array cardiac coil and placed in the lateral tilt position, to prevent compression of the vena cave by the gravid uterus. Following scout scans, the fetal brain was imaged with single shot turbo spin echo (ssTSE) sequences (TE 80ms T2100ms FOV 38cm slice thickness 4 mm, in plane acquired resolution 1.08mm×1.45 mm SENSE factor 2).). A set of parallel contiguous slices was then prescribed using the ssTSE sequence with the same parameters except that the slice thickness was reduced to 2.5-2.8 mm and the number of slices increased to maintain coverage. In contrast to a conventional exam, no attempt was made to align with specific fetal brain anatomy. These slice planes were acquired in a repeated loop consisting of two complete sets of slices one offset from the other by half a slice thickness. Four loops were obtained in the transverse plane and in some patients an additional two loops of data were collected in the sagittal and coronal planes. This resulted in up to 60 slices per loop. These images were first segmented to exclude maternal structures and then registered to one another using rigid body transformations before being combined into a single self consistent volume image (1).

Image analysis: All conventional fetal scans and the multiple thin slices obtained for SVR were assessed for normal anatomy and the presence of abnormalities (Fig1) specifically the ability to detect: the optic nerves, brainstem myelination, cortical subplate and the cerebellar vermis in the sagittal plane. Two dimensional measures of biparietal diameter (BPD), ventricular size, trans cerebellar diameter (TCD) and vermis height were made. The SVR images were also compared with the conventional examination. Brain volume was measured in a subset of fetuses from the SVR images by manual segmentation using ImageJ.

Results: **The sequence was well tolerated by the mothers, who were more comfortable doing acquisition of data for SVR. In addition no breath-hold was required. Also dispensing with the need for careful slice placement made the SVR scans more efficient even though the actual scan duration was longer. Datasets were obtained from 37 fetuses with a median gestational age of 27.6 weeks (range 18-35 weeks). Fifteen fetuses showed normal brain appearances, 6 had cerebellar abnormalities, 14 had unilateral or bilateral ventricular dilatation, one of whom also had a small cerebellum, two had absent septum pellucidum, one callosal agenesis and one a cortical abnormality. It was possible to identify all anatomical features of the brain on the raw scans acquired for SVR. In all but two cases where there was marked image artefact and severe fetal rotation it was possible to do a full clinical interpretation on the initially images prior to 3D reconstruction. The vermis of the cerebellum was well seen on both conventional and SVR input data but measurement was easier on the latter as the decreased slice thickness and increased number of slices meant a true midline image was invariably obtained. There were no significant differences in 2 D measures made of the BPD, ventricular size, TCD and vermis height.** The improved SNR and resolution of the reformatted images allowed excellent identification of anatomical features and structural abnormalities (Fig1). Additionally the 3D images were easier to assess because of their consistent orientation and the ability to reformat to obtain views of a structure in different planes (Fig 2). Brain volumes ranged from 35.7- 304 cm3 in the fetuses and showed, as expected, a significant relationship with gestational age (Fig 3)



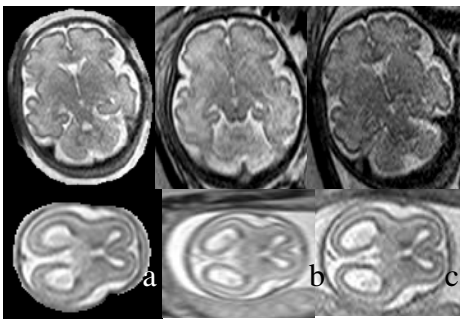


Figure 1 shows reformatted (a), single shot (b) and raw dynamic images(c) at 33 weeks (top) and 20 weeks (bottom)

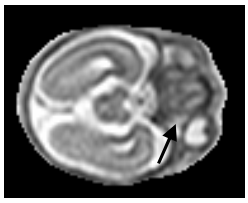


Figure 2: Reformatted image at 19+ weeks gestation, showing optic nerve (arrow) High SI subplate can be seen in both temporal poles. Low SI myelin is clearly seen within the brainstem.

Discussion

SVR is a novel technique that could transform fetal imaging practices. It allows a thorough realtime clinical appraisal of the fetal brain using thinner slices than is current practice and the added benefit of data suitable for processing into a 3D volumetric dataset. Quantification of these datasets will improve the identification and description of abnormal phenotypes, which is necessary to improve our predictions of outcome. Such volume dataset will allow, for the first time, analysis of fetal brain using a wide range of neuroscience tools that have already been developed fro adult and paediatric studies. Thereby providing detailed information on the growth and development of the brain in healthy fetuses and those with anomalies

Reference (1) Jiang et al, IEEE TMI 2006, in press. [3] Lee et al. IEEE TMI 1997 3(3) 228-243.