Magnetic Resonance Imaging of the fetus

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The Moonbeam Trust
Overview

- Practicalities and Sequences
- Clinical applications
  - Non Central Nervous System
  - Central Nervous System (CNS)

- Research and development: studies in IUGR pregnancies
Fetal MR imaging

- Relatively new technique
- Complimentary to ultrasound

- Main application for CNS
- Motion is a major problem
  
  Initially paralysed fetus (French studies)
  Sedation mother in some units (non UK)
Philips 1.5 Tesla magnet

Pregnant patient in left lateral tilt
Ear protection
Fan on to keep cool

Cardiac coil- 5 channels
Around abdomen

We will use a new cardiac coil with 32 channels. Gives better coverage and higher signal to noise.
The fetus is often in continual motion which can be captured using a fetal cine sequence (Hayat et al AJNR 2011)
Fetal MR sequences

- Fast single shot T2 weighted image acquisition
- Image slice in less than 1 second
T1 weighted imaging

Previous T1W spin echo acquired with breathhold

Recently developed SNAPIR*

* Malamateniou et al Radiology 2011
Clinical non CNS imaging

- Chest
- Abdomen
  - Renal
  - Liver
- Skeletal
- Cardiac
Possible to image the entire fetus, even at late gestations
Diagnosis: Diaphragmatic hernia (bowel in chest - arrow)
Diaphragmatic hernia

- Assess contents of chest
  - Stomach (arrowhead)
  - liver
- Assess lung signal intensity and volume
  - Visually (arrows)
  - Objectively
- Use to predict respiratory outcome
Fetal hydrops

- Pleural effusion
- Compressed lung
- Ascites
- Subcutaneous oedema
Abdominal Imaging

- Ultrasound: Renal pelvis dilatation (A)

- Posterior urethral valves (B) in male fetus (C)
CNS imaging

Common indications

- Ventriculomegaly
- Agenesis of the corpus callosum
- Cerebellar anomalies
- Congenital infection

- Complications of twin pregnancies
- Acute hypoxic event
Ventriculomegaly

- Most common reason for MRI referral
- Detect any obvious cause for ventriculomegaly e.g. haemorrhage /obstruction
- Identify additional anomalies
- Predict outcome to counsel parents
Ventricular dilation with evidence of germinal matrix haemorrhage
Haemorrhage involves basal ganglia (arrow)

- Ventricular dilation with evidence of germinal matrix haemorrhage
Posterior limb of internal capsule (PLIC) may be spared (arrow)

- Motor outcome likely to be normal

Ventricular dilation with evidence of germinal matrix haemorrhage
Agenesis of the corpus callosum

- May be referred with ventriculomegaly
- Occasionally as a parenchymal cyst
Agenesis corpus callosum (A) with interhemispheric cyst (B) (arrow)
Agenesis with interhemispheric cyst

Postnatal imaging T1 weighted showing cyst (arrow)
Postnatal diffusion tensor imaging (DTI) Showing white matter tracts circumventing cyst
Postnatal diffusion tensor imaging (DTI)

Showing white matter tracts circumventing cyst

Normal PLIC may Predict normal gross motor function
Cerebellar anomalies

- Large cisterna magna
- Cerebellar hypoplasia
- Cerebellar haemorrhage
26+3 weeks. Large cisterna magna >10mm (A,B)

- Bilateral irregular germinal matrix arrows (C)

Diagnosis: subependymal heterotopia

Female fetus

Repeat at 32 weeks GA

Not visible on sagittal or coronal images
Mother asymptomatic
Maternal grandmother epileptic

- Enlarged cisterna magna

Diagnosis:
X linked subependymal heterotopia with enlarged cisterna magna
Research and development

- Improving image quality
Fetal motion

- Single slices fast acquisition - not artefacted

- But fetus moves in and out of plane during acquisition

Rotation of fetal head between slices
Aim

- Provide high signal to noise, high resolution 3-Dimensional volumetric datasets of the brain in presence of fetal motion

* Jiang et al 2007
Registered 3D fetal data
Ex utero data
3 Tesla Dynamic scan
Single shot 1 loop

Dynamic scan
Single shot 1 loop
Registered 3D fetal data

Dynamic scan
Single shot 1 loop

Combined loops
Dynamic scan
Single shot 1 loop

Combined loops

Registered
3D fetal data
(a) (b) (c)
(d) (e) (f)
(g) (h) (i)
(j) (k) (l)

Registered 3D fetal data

Dynamic scan
Single shot 1 loop

Combined loops

Registered 3D fetal data

Ex utero data
3 Tesla
Quantifying normal brain development

20 weeks 32 weeks
Manual Segmentation of normal fetal brain n=18

Hayat 2007
Cerebral Parenchyma Volume and Log Volume against gestational age

Gestational Age (weeks)

$r = 0.99 \ p < 0.05$

Gestational Age (weeks)

$r = 0.99 \ p < 0.05$

Hayat 2007
The fetus with intrauterine growth restriction (IUGR)

- Brain images may look normal

- High risk of mortality and short term morbidity

- Longer term
  - neurodevelopmental impairments
  - adult onset hypertension, diabetes.
The fetus with IUGR

- Cohort of IUGR fetuses = 40
  - Estimated fetal weight < 5\textsuperscript{th} centile.

- Graded by Doppler studies
  - Umbilical artery (UA) pulsatility index >95\textsuperscript{th} C
  - As above with PI <5\textsuperscript{th} centile in middle cerebral artery
  - Absent end diastolic flow (EDF) in UA
  - Reversed EDF in UA
  - Absent or reversed “a” wave in ductus venosus and/or pulsatility in the umbilical vein

Damodaram (in prep.)
Growth parameters (ultrasound) in IUGR
Umbilical Artery Doppler

positive end diastolic flow (normal pregnancy)

absent end diastolic flow (growth restricted pregnancy)
The Placenta in IUGR

Reduced volume in IUGR

Placental volume and fetal weight

Damodaram et al 2012
Body volume in IUGR

IUGR = 20
Normal = 19

Damodaram (2012)
The fetus with IUGR

Is there any evidence of organ “sparing”?
The fetus with IUGR: liver volume

- Decreased glucose transfer and hepatic storage
- Decreased IGF-1 production
- Link to later adult disease; type 2 diabetes

Damodaram (2012.)
An increase in the brain:liver ratio predicted perinatal mortality with an AUC of 0.89 (p =0.001, 95 CI = 0.78 – 1.0)

A brain:liver ratio above 3.0 was associated with a 3.3 fold increase in relative risk of perinatal mortality (95% CI = 1.68 – 6.47).
The fetus with IUGR: renal volume

- Decreased nephron number
- Inappropriate activation of renin-angiotensin
- Adult onset hypertension

Damodaram (2012)
The fetus with IUGR: lung volume

- Lung volume predicted need for CPAP (p=0.03)
- IUGR fetal sheep decreased alveoli and increased septal thickness
- Lung function relates to birthweight
- Additional problems from prematurity

Damodaram (2012)
The fetus with IUGR: cardiac volume

- Doppler studies show impaired cardiac function in human fetal IUGR
- Rat model shows increased apoptosis and decreased cardiomyocytes
- ? Predisposition to cardiac ischaemia in adult life

Damodaram (2012)
The fetus with IUGR: thymus volume

- Stress mediated thymic involution via hypothalamic-pituitary-adrenal axis

Mattodaram (2012)
The Fetus with IUGR: brain volume

- Increased reduction with increased severity of IUGR $p<0.001$

Damodaram (2012)
The fetus with IUGR: ventricular volume

Damodaram (in prep.)
Extracerebral space/brain volume

- Measures of BPD will overestimate brain size

Damodaram (in prep.)
The fetus with IUGR

Is there any evidence of organ “sparing”? NO
The fetus with IUGR: cortical folding

- Is there evidence of abnormal maturation of the cortex?
- Assessed cortical folding visually with 8 point score
The fetus with IUGR: cortical folding

- No difference in cortical folding

Damodaram
Automatic cortical segmentation

Optimisation of an automatic segmentation technique would allow quicker analysis of group data for research or individual data for clinical practice

Courtesy of Paul Aljabar
Fetal MR proton spectroscopy

- Metabolic information
  - Obtain chemical peaks Choline, Creatine, N Acetyl Aspartate, Lactate, *Myo*-inositol

- Technical difficulties
  - Motion
  - Small region of interest
  - Not possible to differentiate tissue types reliably—use large region of interest
MR spectroscopy

- In vivo assessment of brain metabolism in normal and IUGR fetuses n=28 (controls 46)
- Large voxel 2x2x2 cm³
- 70% success rate

Story et al 2011
24 week normal fetal control.

- Spectrum obtained with TE= 144 ms
- Spectrum obtained with (TE) 36 ms.
- A large bifid lactate peak is present at 1.3 ppm
- No NAA visible at 2ppm
NAA reduced in IUGR

Story et al. 2012
Reduced NAA in brain of IUGR fetus

- NAA is synthesised in neuronal mitochondria, then transported to oligodendrocytes
- Reduced NAA may be sign of immaturity but may also reflect mitochondrial dysfunction
- Rat models of IUGR demonstrate mitochondrial dysfunction in brain other organs e.g pancreas
- Use MRS to quantify NAA in rat IUGR model and then assess mitochondria phenotypes and function.
Overview

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- Clinical applications
  - Non CNS
  - CNS
- Research and development in IUGR pregnancies
To all the staff in the Robert Steiner MR Unit and the Centre for Fetal Care, Queen Charlotte’s Hospital.

Shuzhou Jiang  Joanna Allsop
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