Optimising MR Imaging protocols

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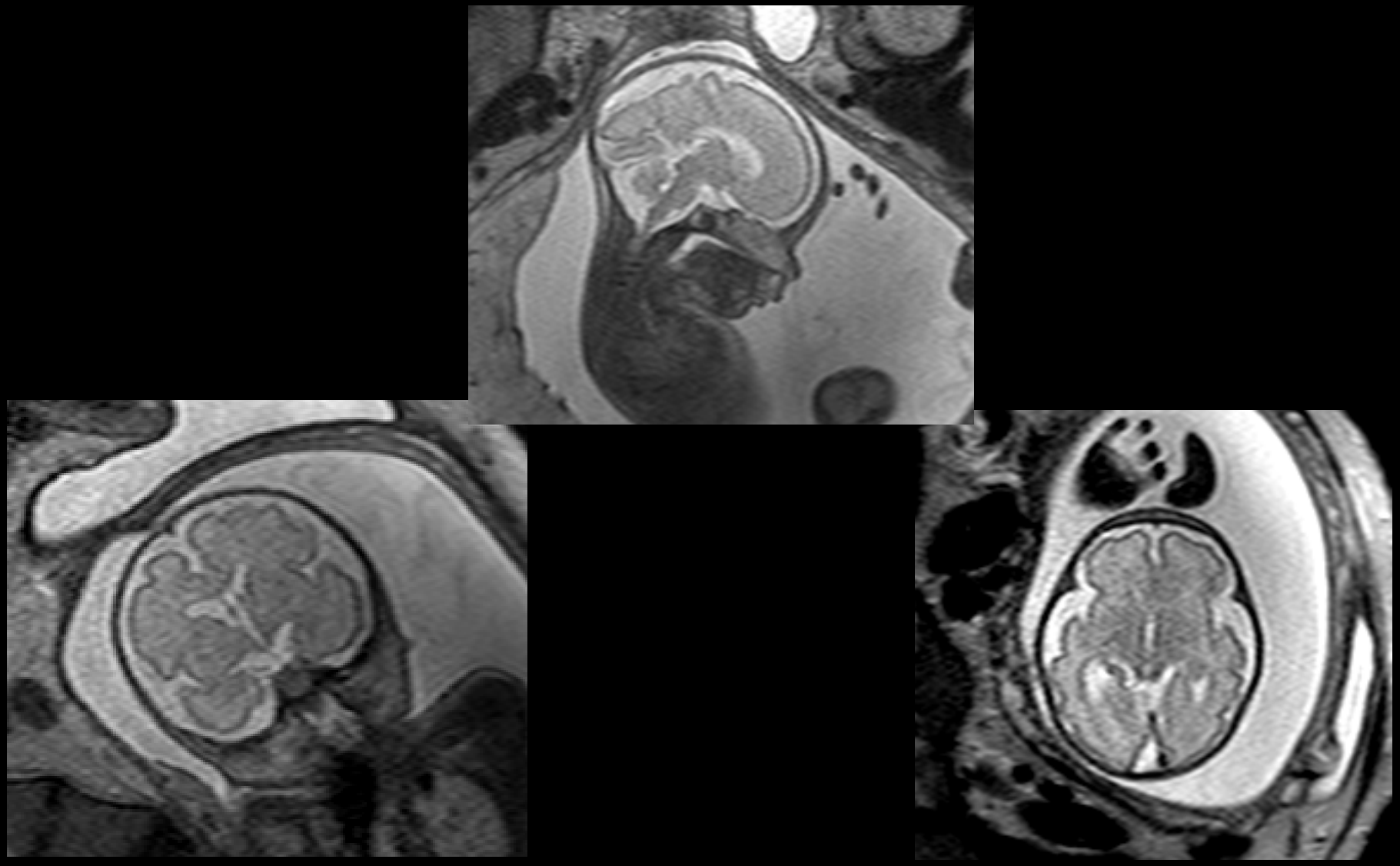
Study group: fetal patients

- Lies at the extreme of any other paediatric population
- It is perhaps the most difficult case to optimise MRI for.
- Fetal neuro focus

Fetal MRI

- Fetal MRI introduced in 1983 (Smith FH et al, Lancet)
- A useful diagnostic tool, complimentary to obstetric ultrasound (Whitby et al., 2001; Levine et al., 2003; Coackley et al, 2004, Dietrich et al., 2006)
- Structural MRI for congenital abnormalities (T1w, T2w)
- Functional MRI for brain connectivity (DTI, Kasprian G et al, 2008, fMRI, Fulford J et al, 2009, Jardri R et al, 2011)
- Quality of fetal MRI scans is vital for diagnosis

T2-weighted as the mainstay fetal brain MRI tool



Learning objectives

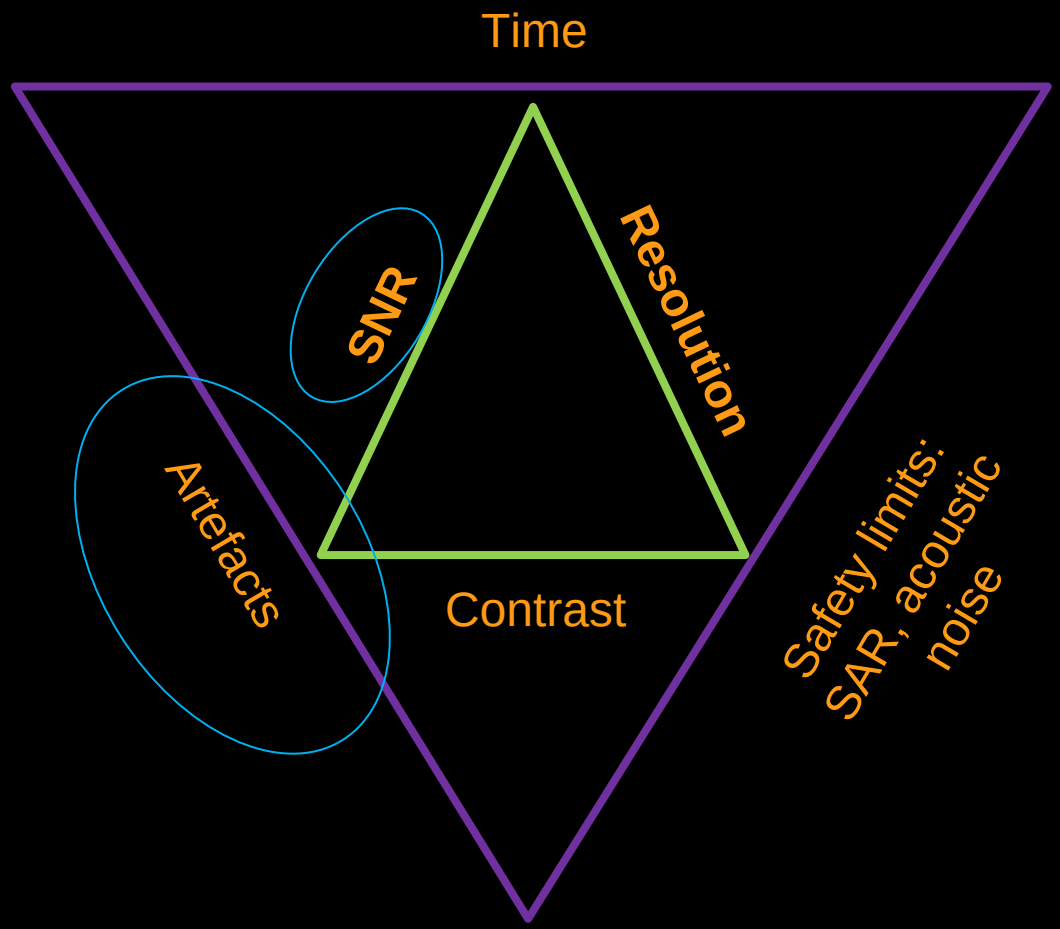
- 1. What makes these patients a unique population?
- 2. Which are the challenges associated with fetal MRI optimisation?
- 3. Which are the remedies?
- 4. An example of optimising fetal brain MRI.

Why is this population unique?

- Anatomy of interest is very small
- Fast developing
- Motion in unpredictable and uncontrollable
- Inside maternal body →in-homogeneity of surrounding tissues including maternal fat, amniotic fluid, maternal soft tissue

Fetal MRI challenges

Image quality optimisation process in MRI



Challenges

- Poor Signal to Noise Ratio
  - Minute fetal anatomy in coils designed for adult anatomy
  - Coil positioning relative to position of the anatomy of interest (often uncertain and variable)
- Motion artefacts
  - Maternal motion
  - Fetal motion

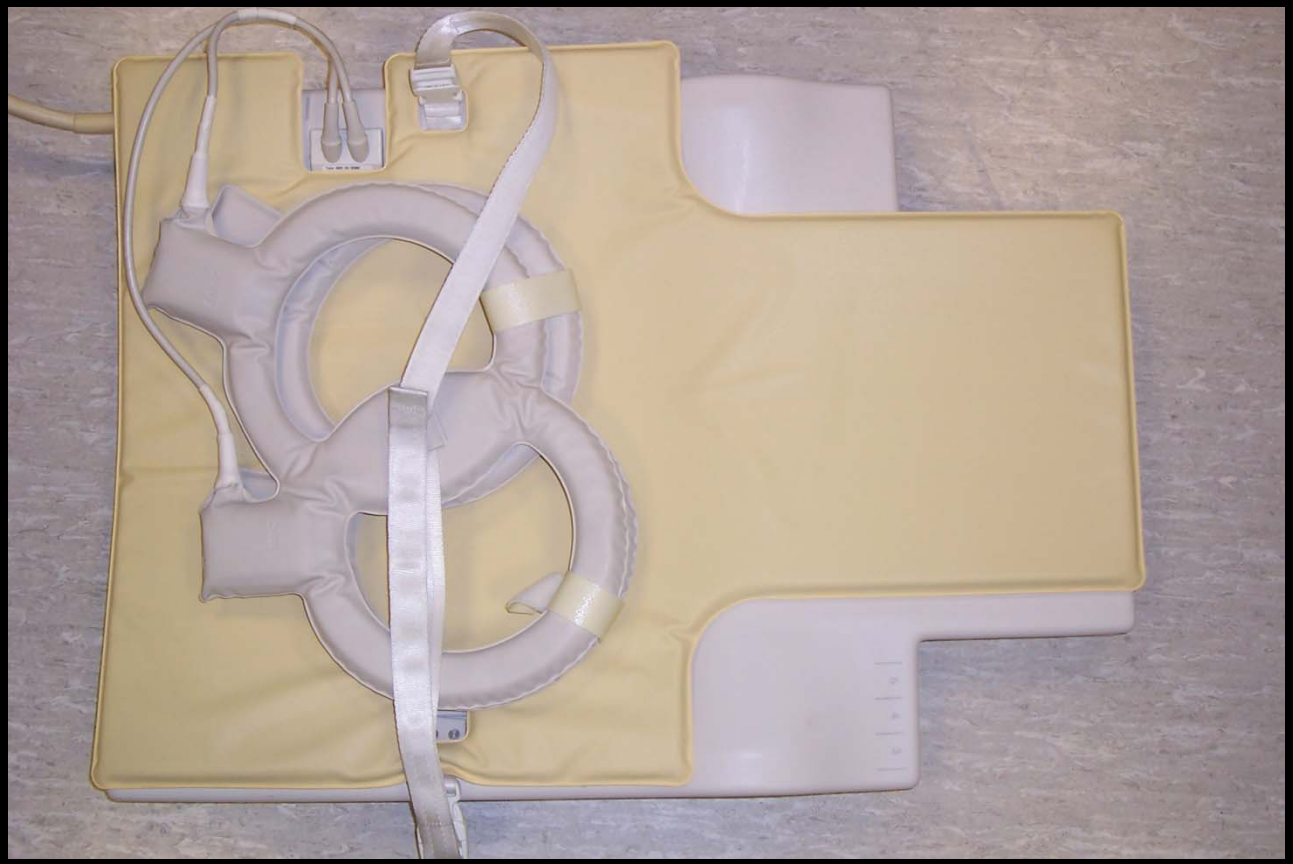
Signal to Noise Ratio (SNR) issues

Signal to noise ratio considerations

- For a given field strength
  - Receiver coil type
  - Coil positioning
  - Maternal size and distance from brain
  - Fetal presentation and positioning
  - Scan parameters

Coils used

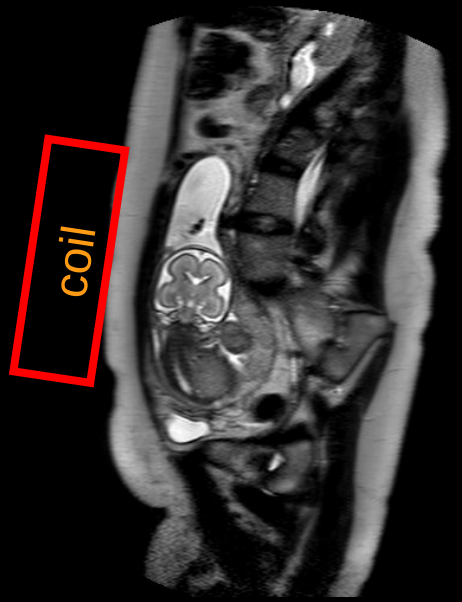
Multi-channel phased array or cardiac surface coils



Sense Cardiac Coil with five elements

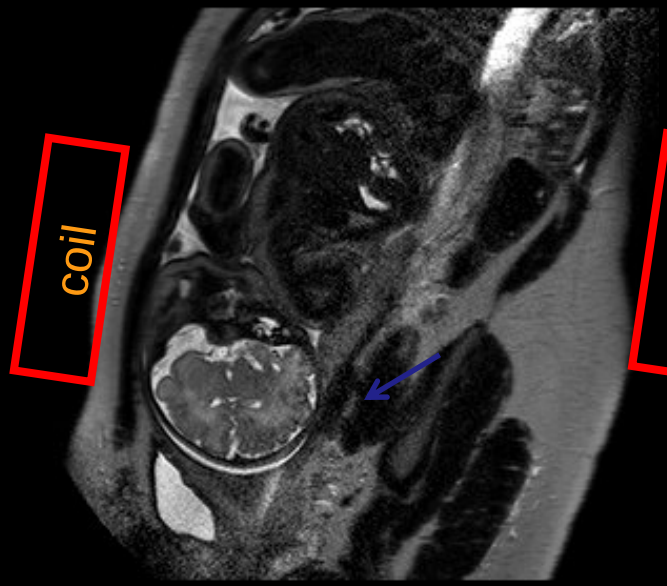
Signal-to-noise in fetal MR

Good SNR



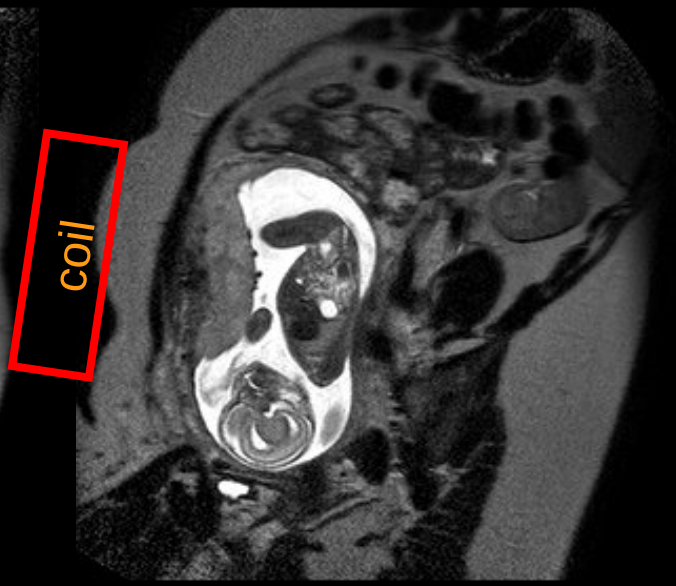
T2 weighted images

Poor SNR



1. Patient presentation
2. Head deep in pelvis

Poor SNR

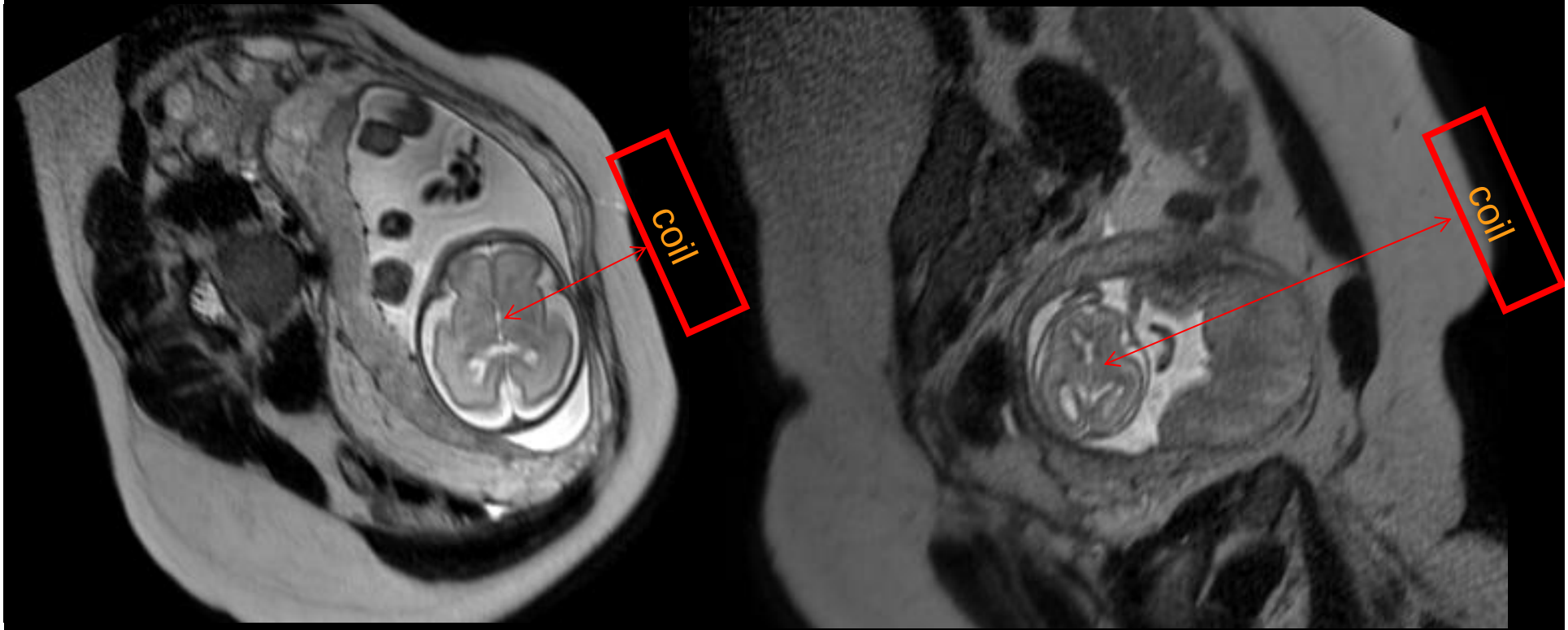


3. Maternal BMI > 40

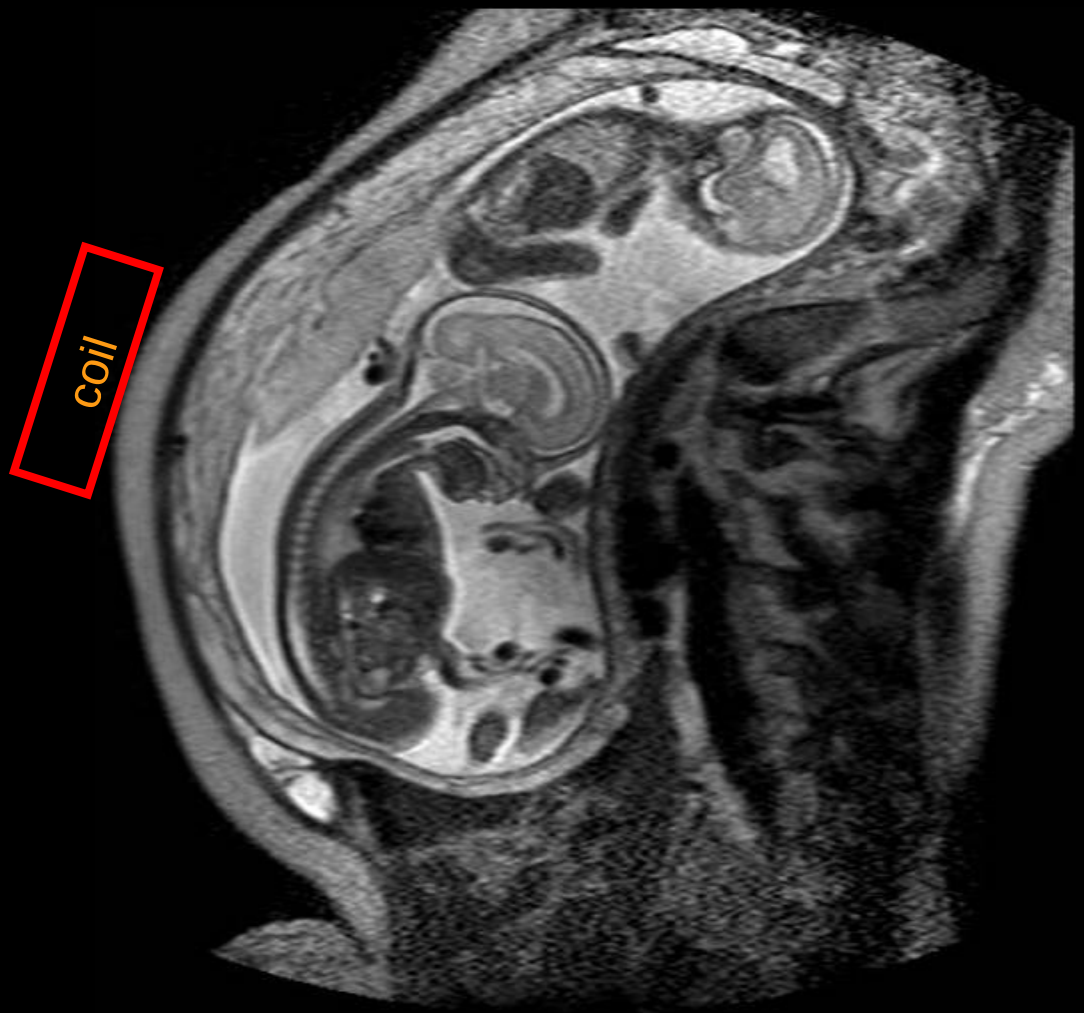
c/o Georgia Lockwood-Estrin, PhD student

Coil Placement, maternal anatomy, fetal size

AIM: To have good signal to noise ratio (SNR)



Coil Placement



c/o Amy Mc Guinness, Research Radiographer

Maximising SNR

- Optimal coil positioning
- Reposition coil after first scan, if required

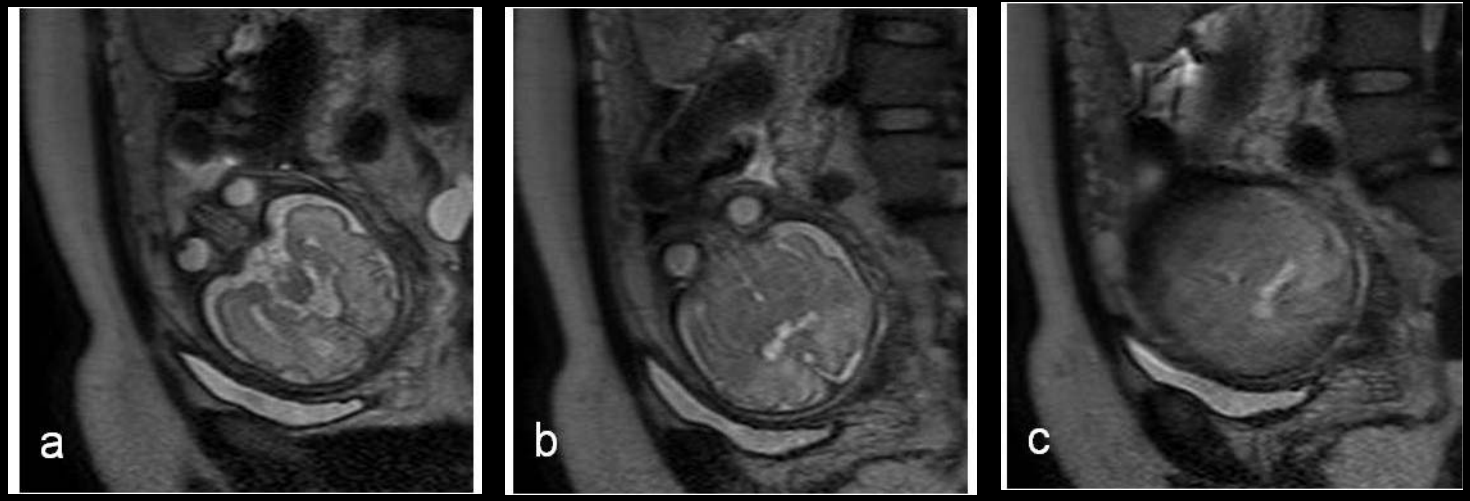
- Use of spin echo acquisitions where feasible
- Minimum TE
- More signal averages (NSA, NEX etc..)

Patient motion and associated artefacts

Motion in fetal MRI: negative effects

Motion artefacts may:

- degrade image quality
- overlap with normal anatomy
- hide or mimick pathology,
- decrease diagnostic confidence
- may turn images non-diagnostic

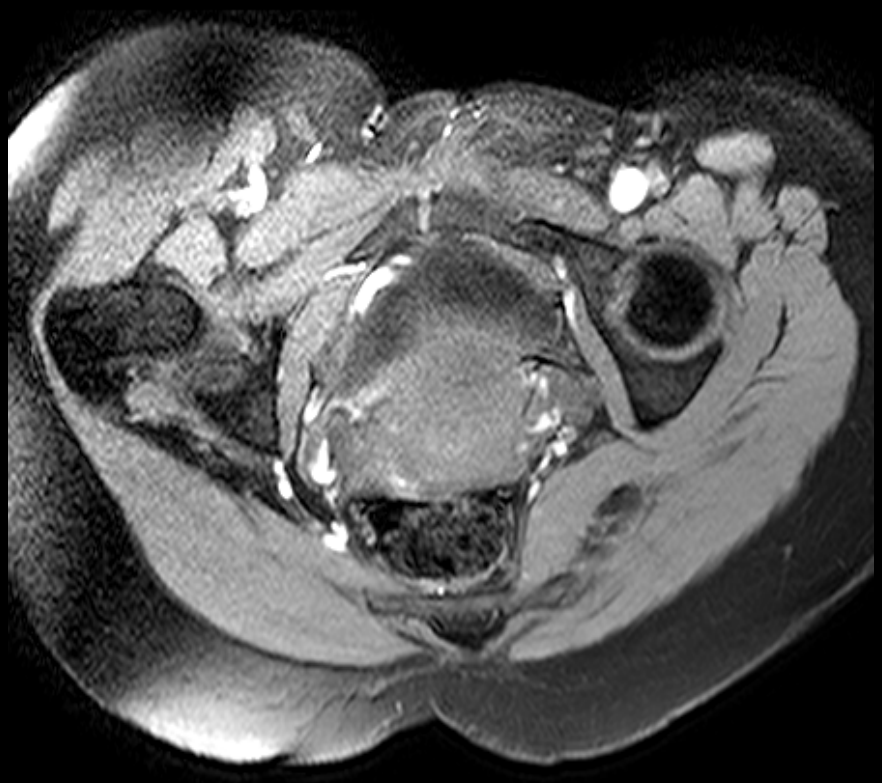


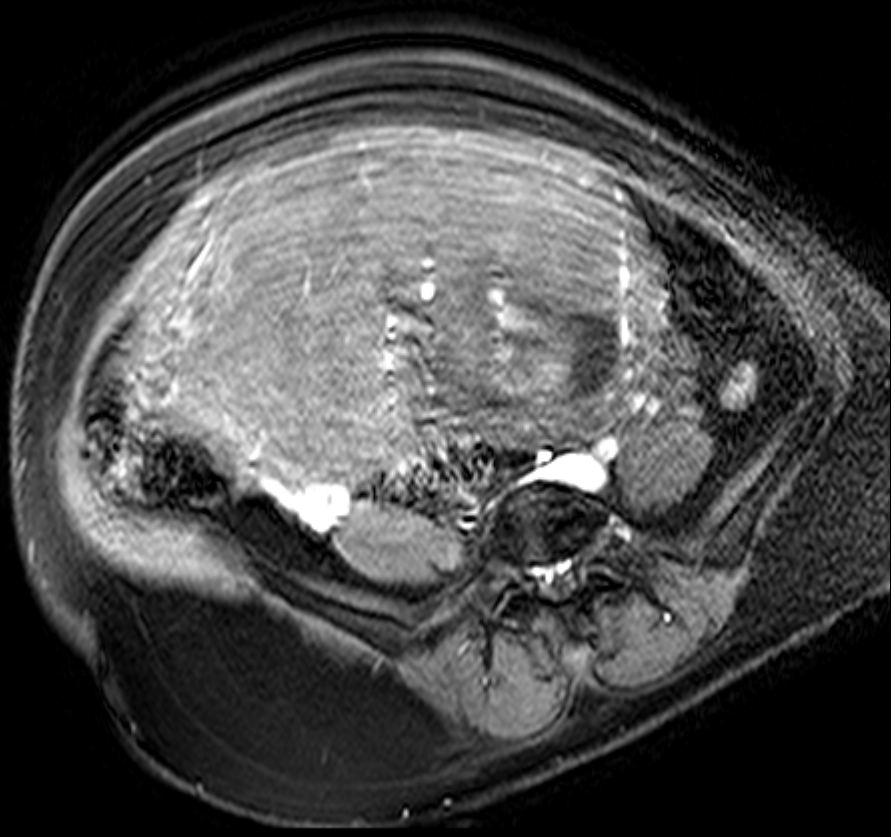
MILD MODERATE SEVERE

Maternal motion characteristics

- Voluntary (Bulk) motion
- Involuntary
  - Breathing
  - Peristalsis

Maternal breathing during MRI scan



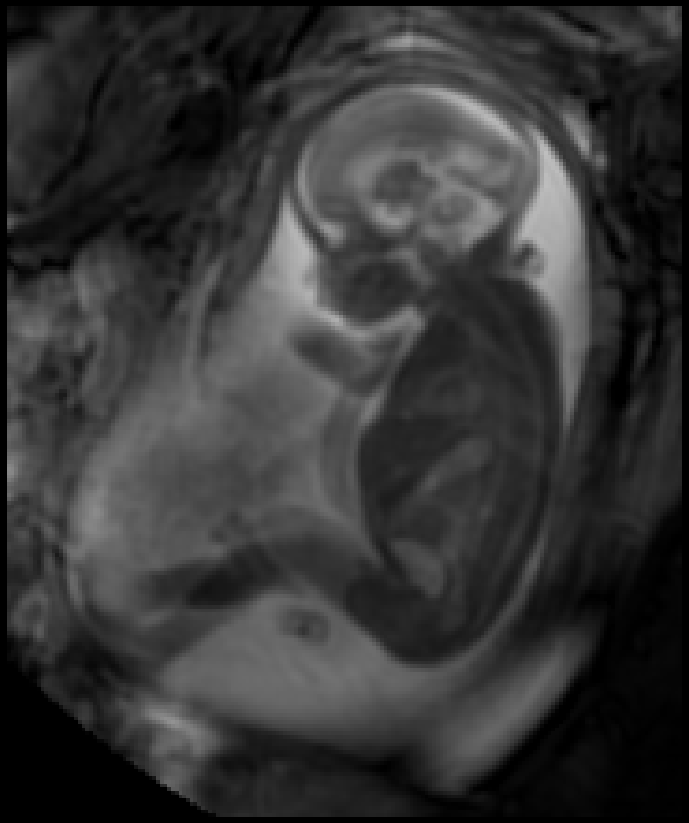


What may provoke maternal motion

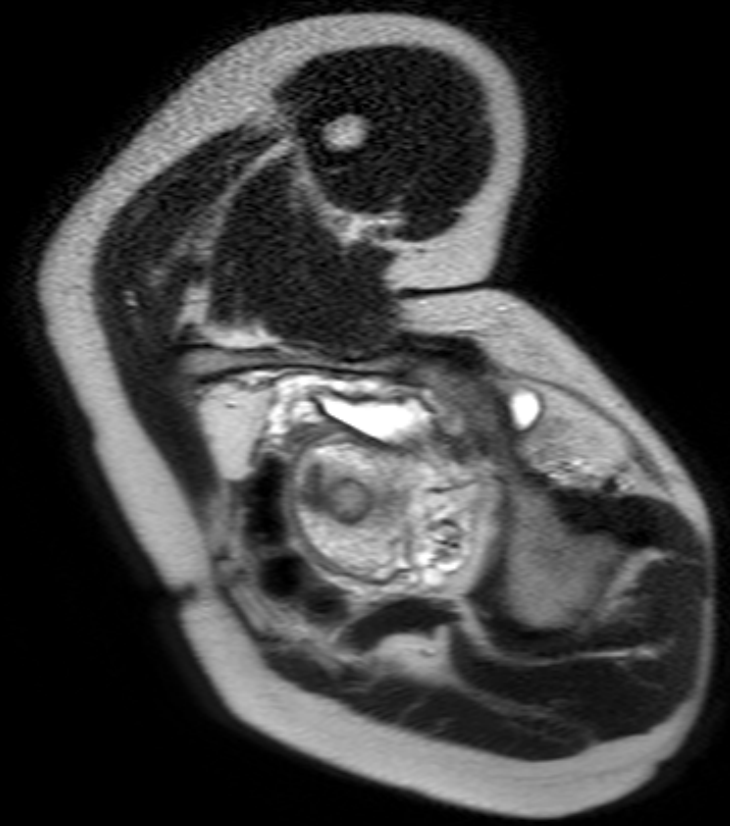
- Uncomfortable positioning
- Poor communication
- Maternal stress

Fetal motion characteristics

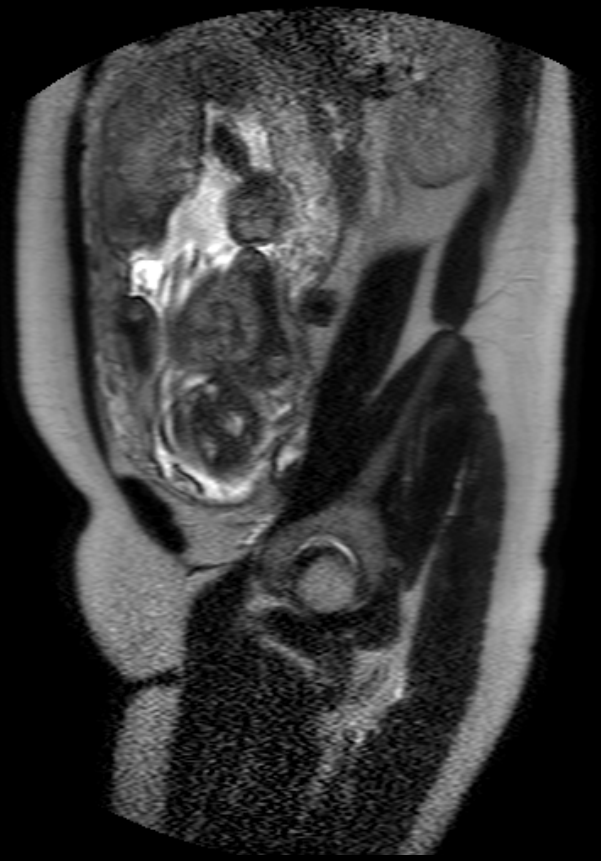
- Unpredictable (baby “chasing”)
- Uncontrollable
- Within flowing/moving maternal tissues
- Three-dimensional
- Substantial, considering relative sizes



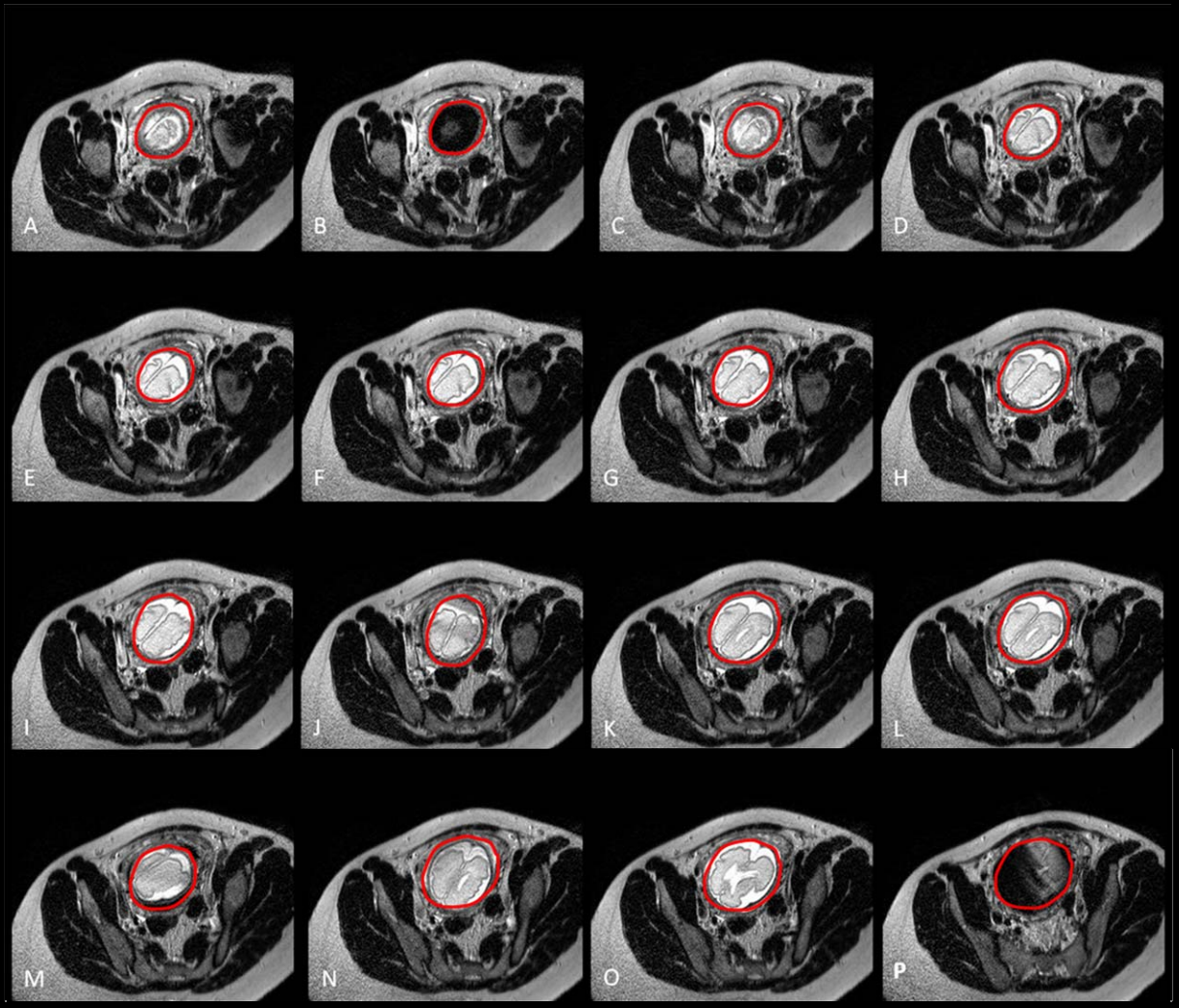
A good T2-weighted examination



A poor T2–weighted examination



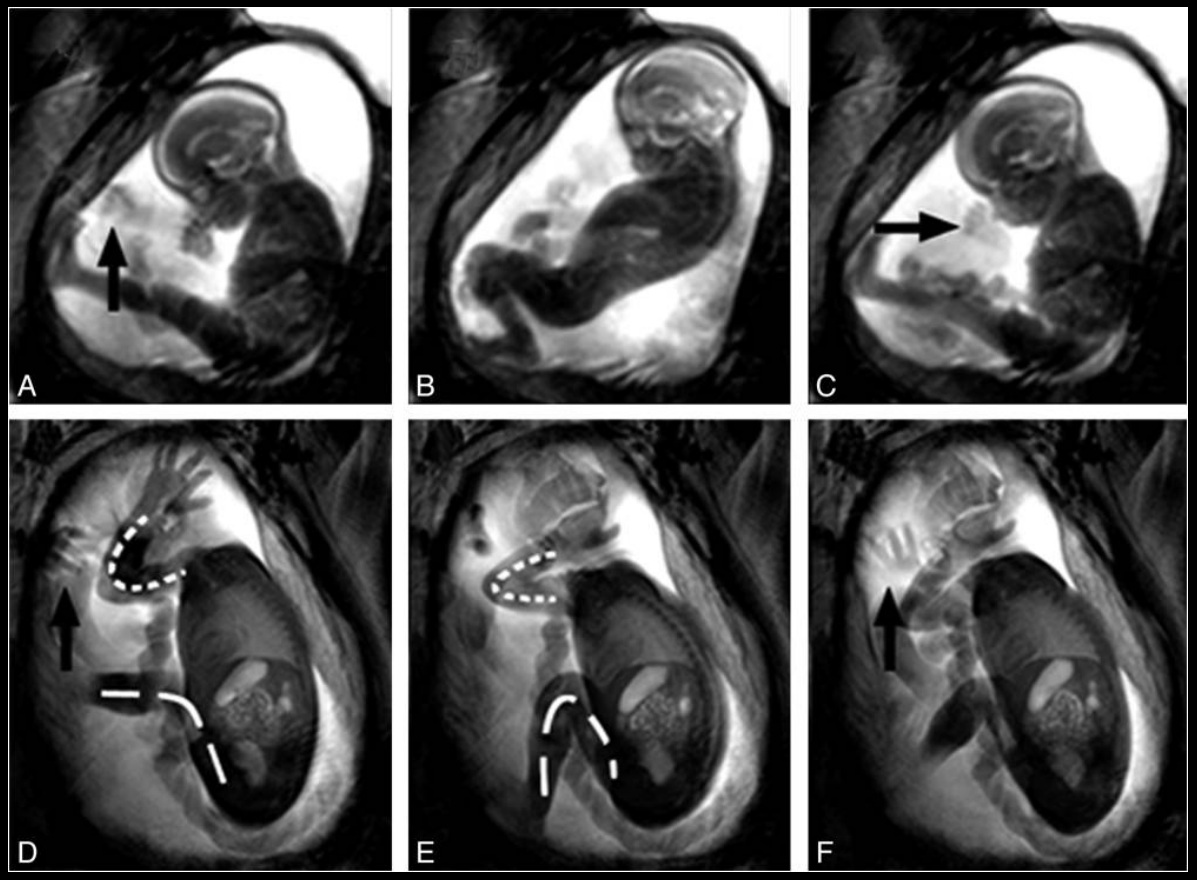
Fetal motion during MRI scan



Motion compensation techniques in neonatal and fetal MRI: a review, AJNR , e-pub May 10th 2012

Christina Malamateniou, Shaihan J Malik, Serena J Counsell , Joanna M Allsop, Amy K McGuinness, Tayyib Hayat, Kathryn Broadhouse , Rita G Nunes, Ash M Ederies, Jo V Hajnal, Mary A Rutherford.

Repertoire of fetal motion

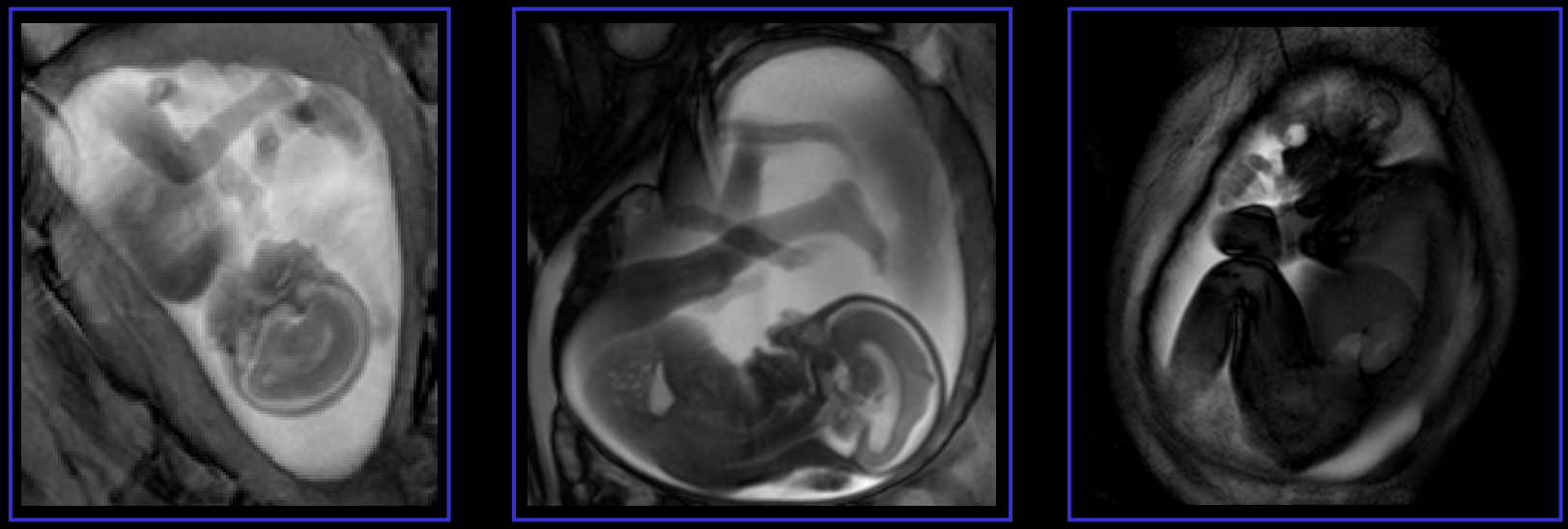


Hayat T et al, 2011, AJNR

Fetal motion considerations

- Gestational age
- Range of neurological abnormalities
- Fetal presentation
- Maternal stress?
- Maternal nutrition?

Gestational age



18 GW 25 GW 36 GW

Courtesy Tayyib Hayat, PhD candidate, Robert Steiner MRI Unit

Fetal Movement

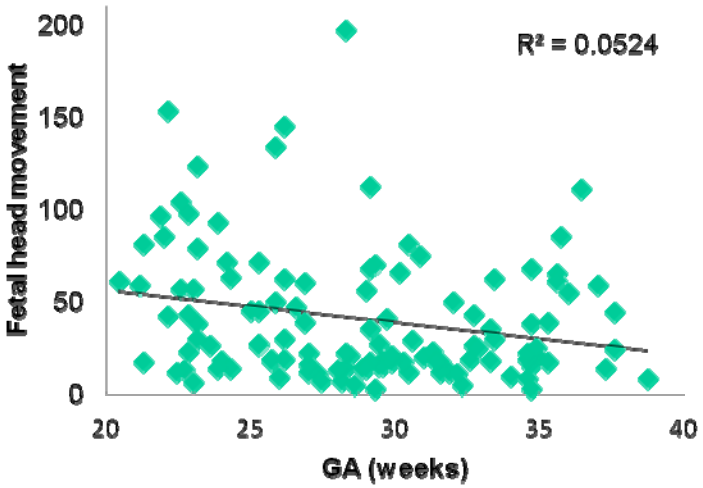
Aim to investigate factors influencing fetal head motion

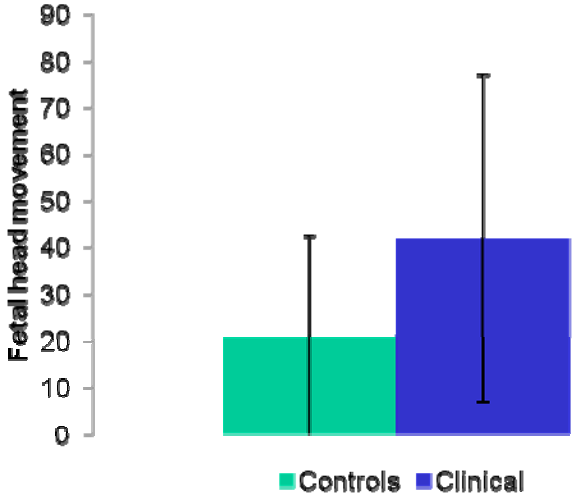
A pre-scan motion assessment was conducted on all women undergoing a fetal MRI between November 2010 and July 2011

Gestational age	Reason for scan
Maternal BMI	Twins compared to singletons
Maternal temperature (before and after scan)	Time point during scan
Music listened to during scan	Controls compared to clinical scans
Fetal gender	Maternal exercise before scan
Fetal lie (breech, cephalic)	Maternal food intake before scan
Maternal anxiety (before and immediately after scanning)	Maternal caffeine intake before scan

c/o Georgia Lockwood-Estrin, PhD student

Motion Assessment - results



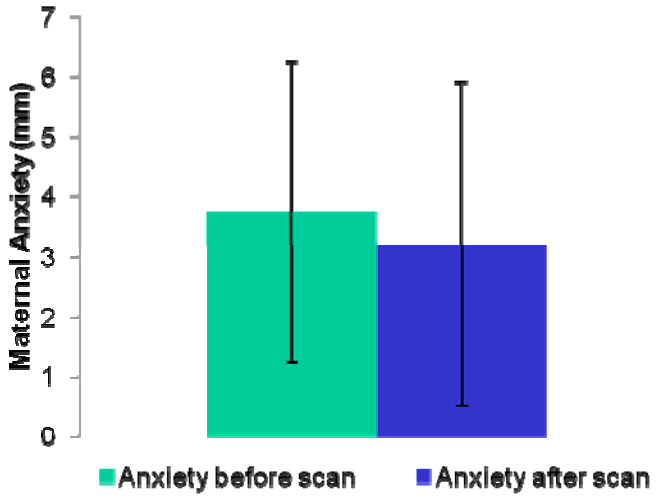


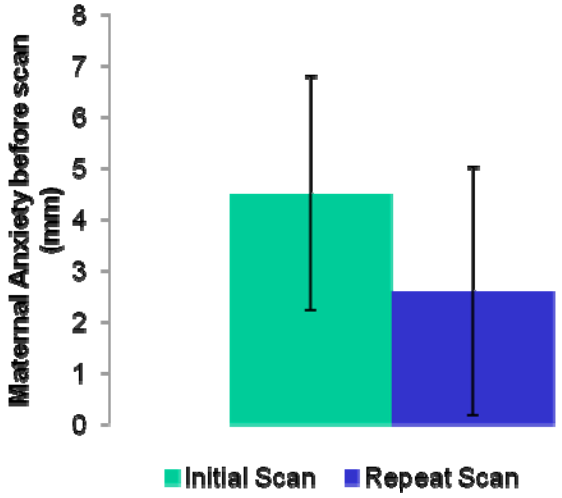
120 mothers with pre-scan motion assessment.

1. More head motion with younger gestation (p=0.01)
2. Control subjects have significantly less head motion than clinical. N.B. control data n = 7.
3. No significant correlation between fetal head motion and any other studied factor
4. No obvious method to decrease motion

c/o Georgia Lockwood-Estrin, PhD student

Maternal Anxiety





1. Anxiety scores reduced immediately after the scan, but before results are given
2. Anxiety reduced in patients coming for a repeat scan
3. No difference in anxiety scores between controls and clinical subjects.

Concern about the MR examination itself causes maternal anxiety

To decrease anxiety, we produced a short film - http://vimeo.com/37368763 - explaining the examination procedure.

c/o Georgia Lockwood-Estrin, PhD student

Fetal Presentation

Courtesy Tayyib Hayat, PhD candidate, Robert Steiner MRI Unit

Coping with motion

What to do about motion artefacts?

- Understand
- Minimise
- Correct
- Accept but re-orientate
- Accept and recognise (it may be useful!)

Motion artefact compensation strategies

- Patient preparation
- Optimisation of image acquisition
  - Fast acquisitions
  - Motion resistant acquisitions
  - Scanning Time reducing strategies
  - Advanced Image Post-processing

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I.Patient preparation: keeping moms happy and comfy!

- Nutrition,
- fluids to a minimum,
- empty bladder
- Acoustic noise reduction
- Comfortable (pillows, foam pads)
- Temperature maintained 24º degrees (fan, barefoot)
- Clear instructions
- Interpreter, if required
- Music, if requested
- Partner in room, if requested

Positioning

- 20º tilt on left side (inferior vena cava syndrome)

II. Data acquisition

- Fast imaging
  - Shortening scanning time by reducing TR, # of phases, # of averages
  - Half scan
  - Inherently faster sequences (FSE, EPI, Single shot etc)
- Different data sampling strategies
  - Radial
  - Spiral
  - PROPELLER/BLADE/Multi-VANE
- Parallel imaging (SENSE, GRAPPA, ASSET)
- Dynamic scans
- Navigators

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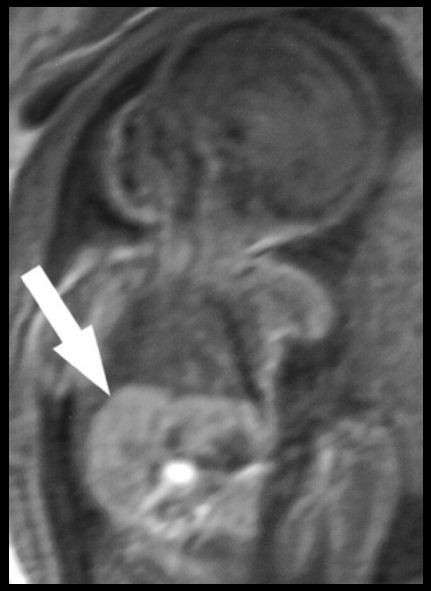
Multi-shot FSE vs Single-shot FSE

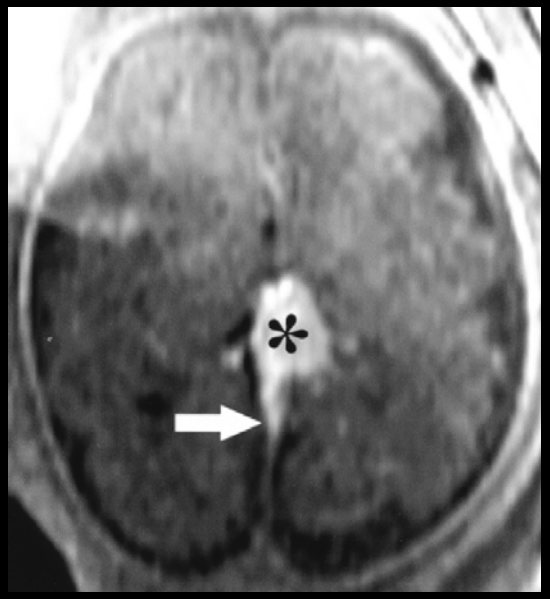
Multi-shot

Single-shot

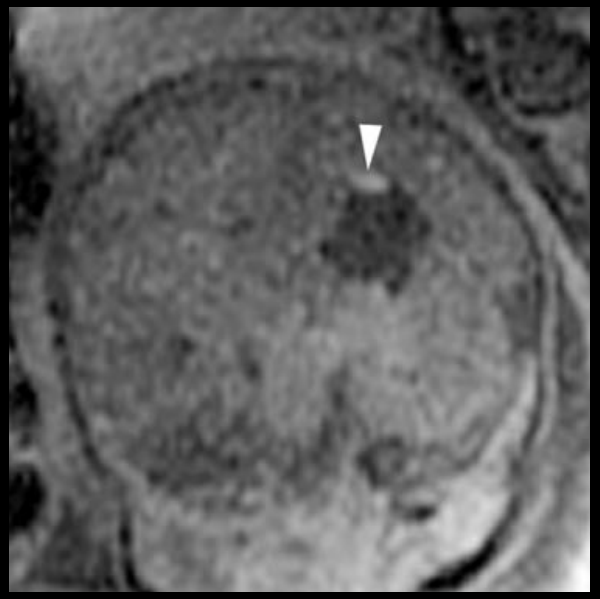
An example of optimisation in the fetal MRI context

- Snapshot Inversion Recovery=SNAPIR

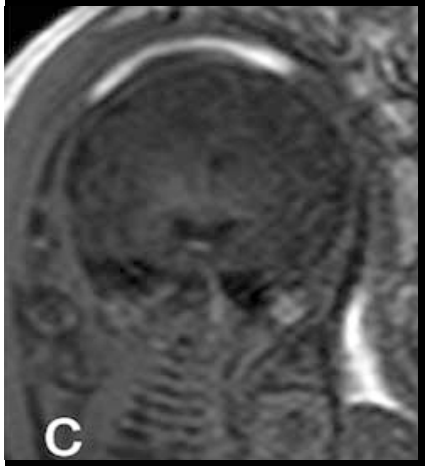


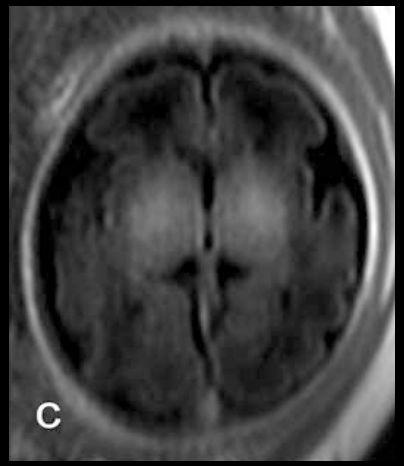


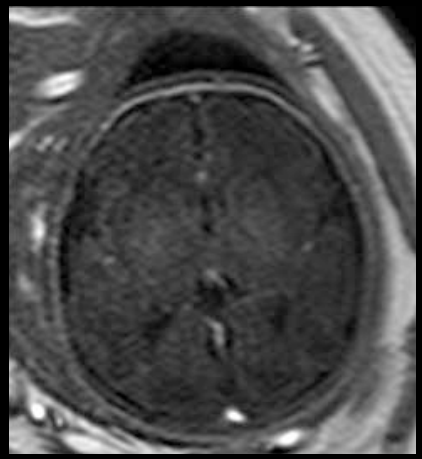
Coackley FV, 2004, AJR

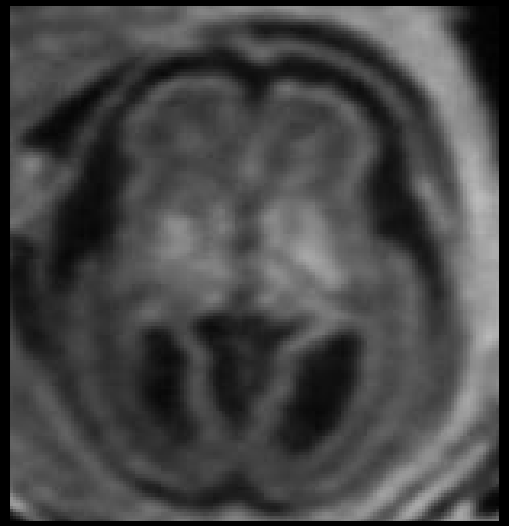


Levine D, 2006, JMRI









Coronal T1 w GRE

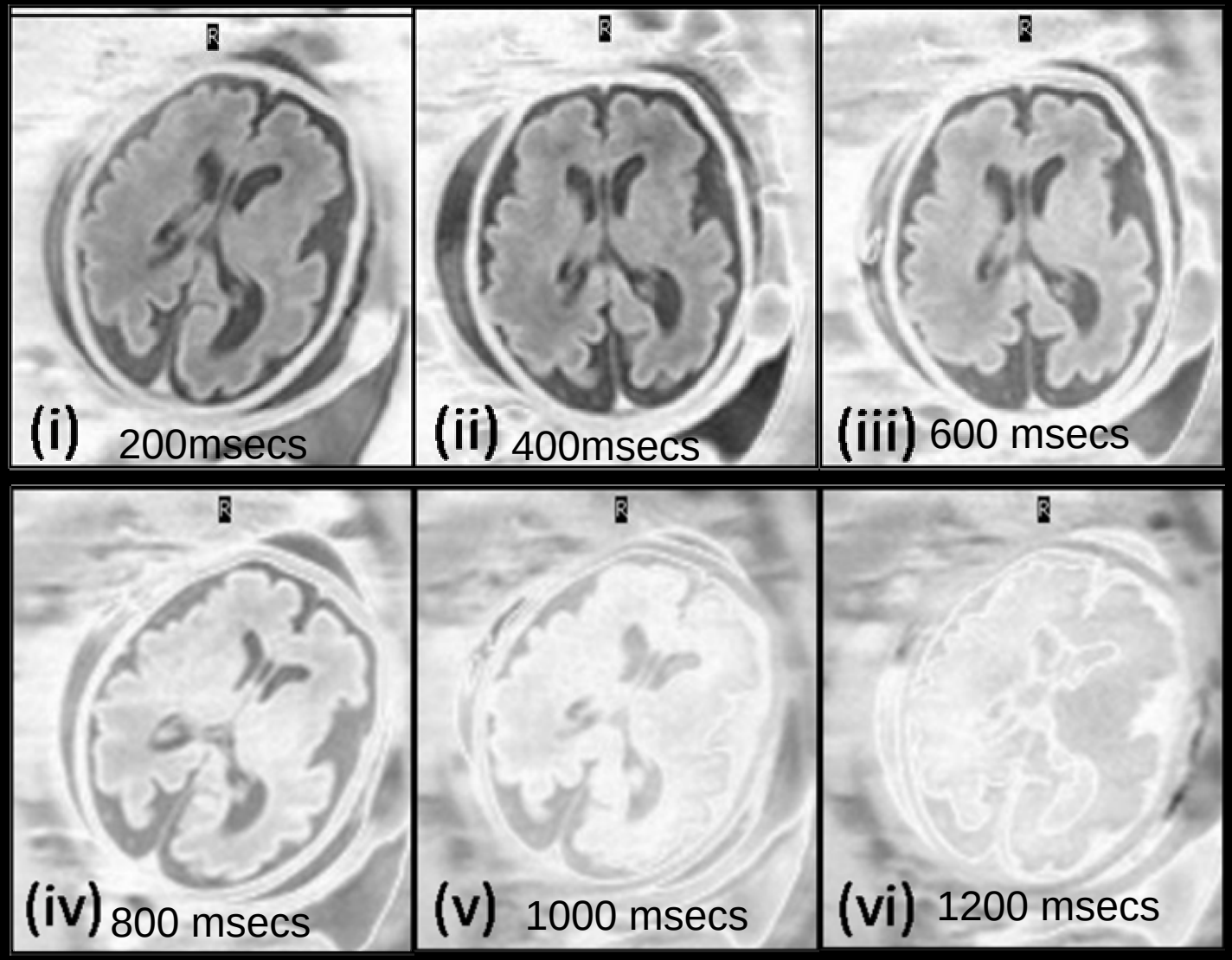
T1 FLAIR

axial T1 weighted on a 32 week fetus

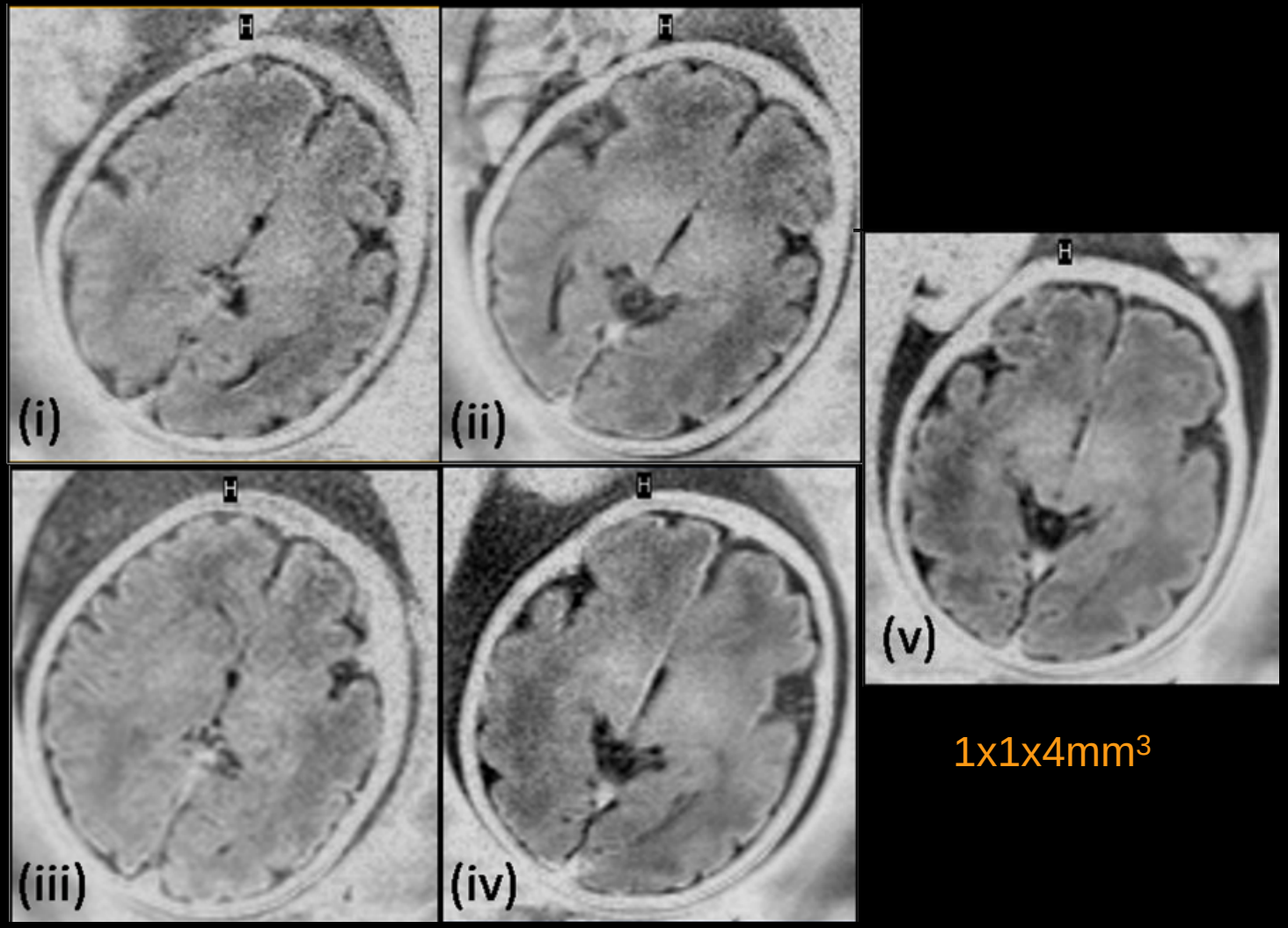
Brunel H et al, 2004, J Neuror

Prayer D, 2004, Ped Rad

Single shot inversion recovery: different TIs



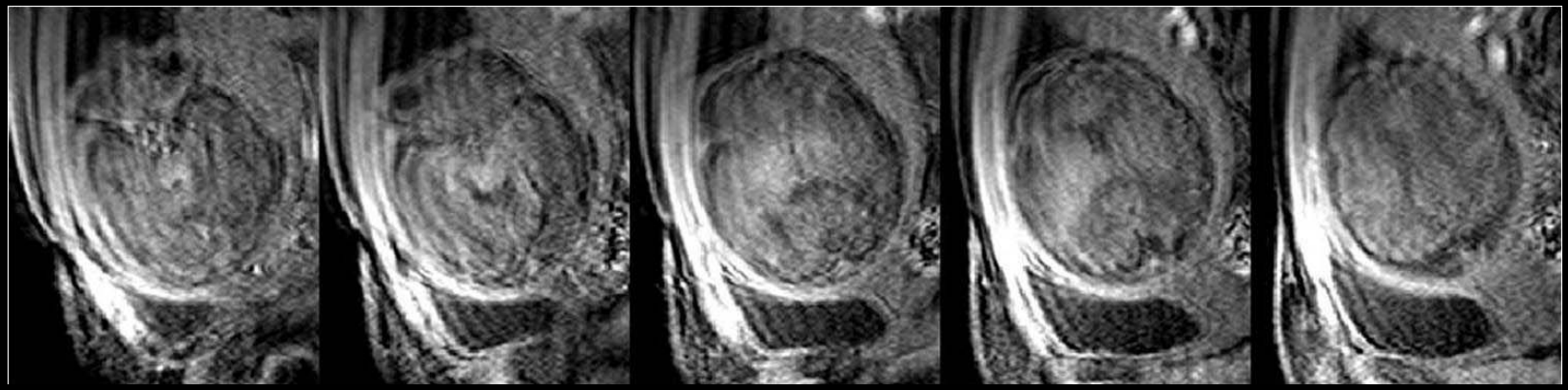
Spatial resolution

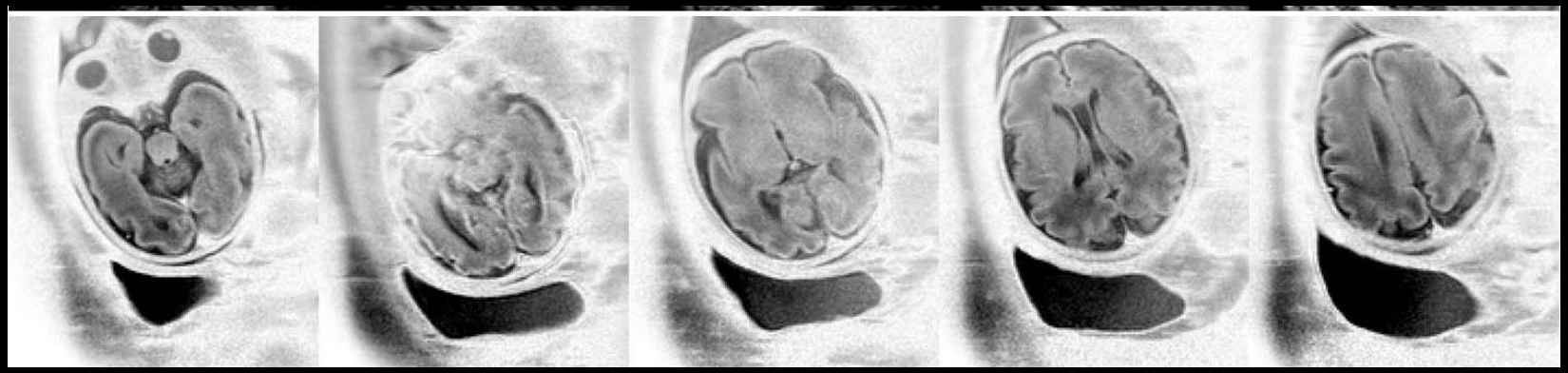


1x1x4mm^3

Snapshot Inversion Recovery

Conventional T1-weighted

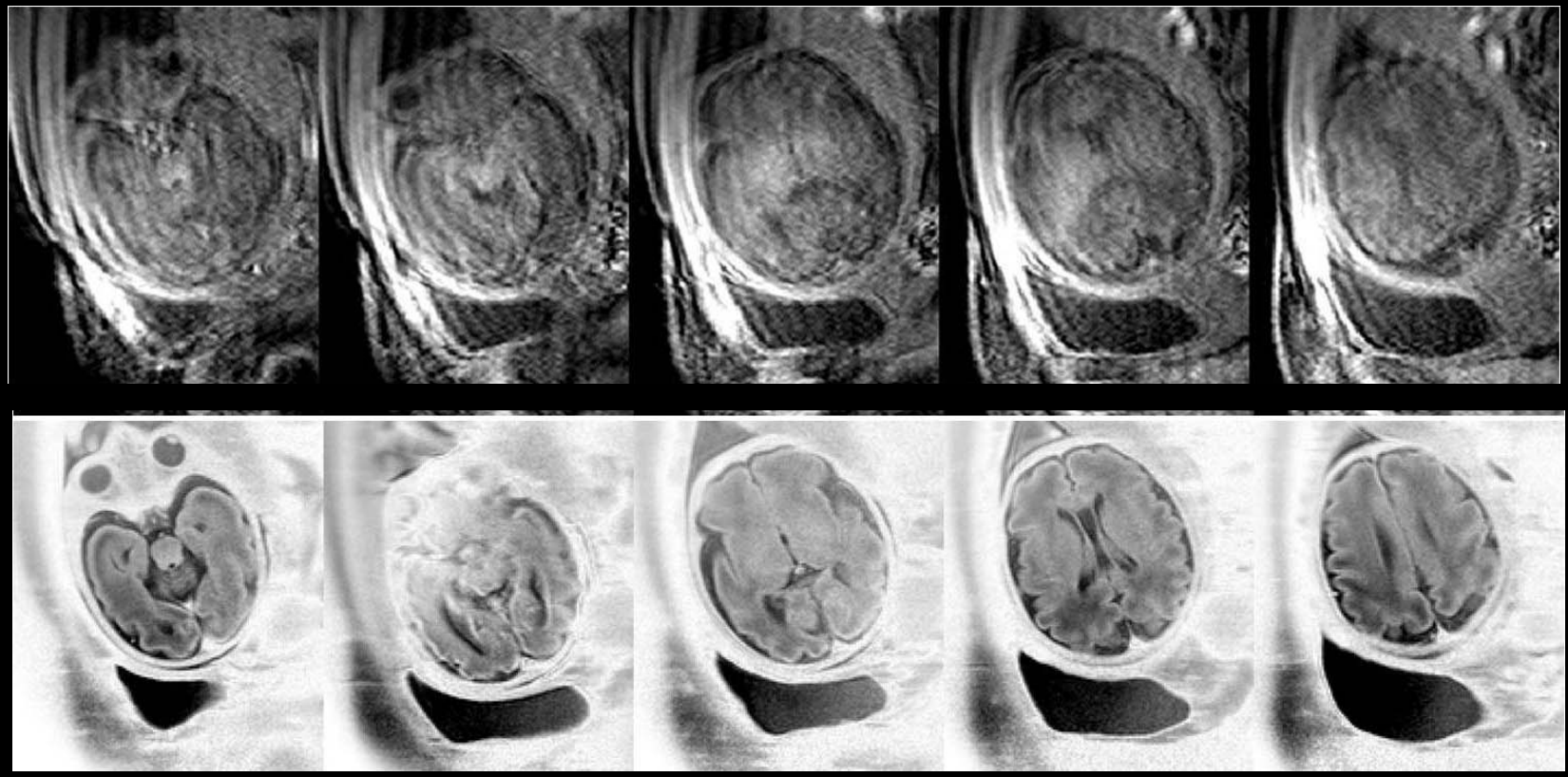




Optimised SNAPIR

Snap I R

Conventional T1-weighted



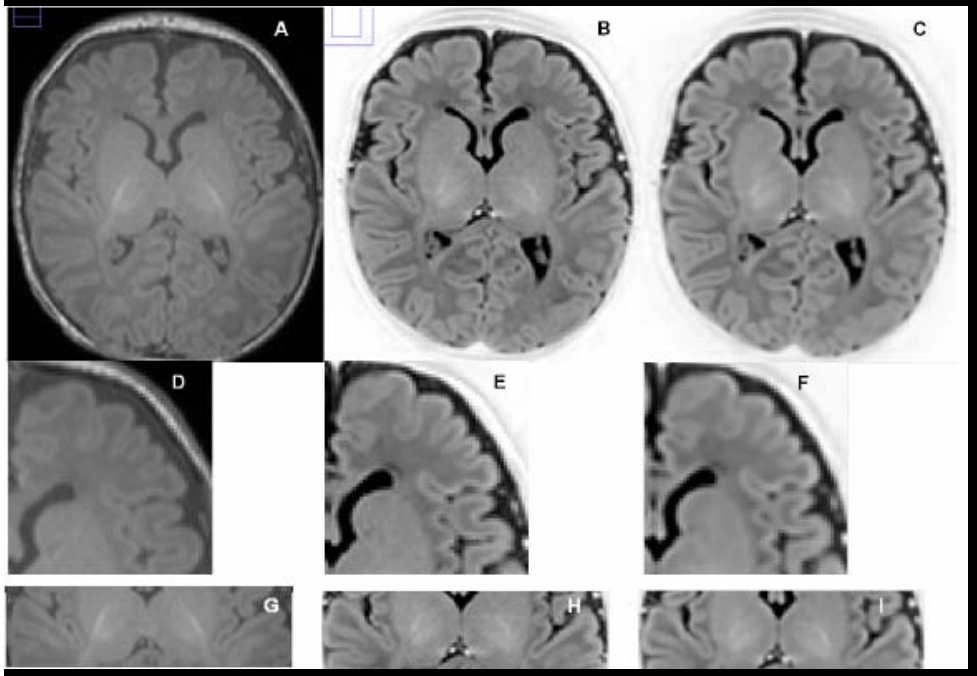
Optimised SNAPIR

Malamateniou C, Mc Guinness AK, Allsop JM, O'Regan D, Rutherford MA, Hajnal JV, Radiology, 2011,
An Optimized Single-Shot T1-weighted Inversion-Recovery Sequence for Improved Fetal Brain Anatomic Delineation

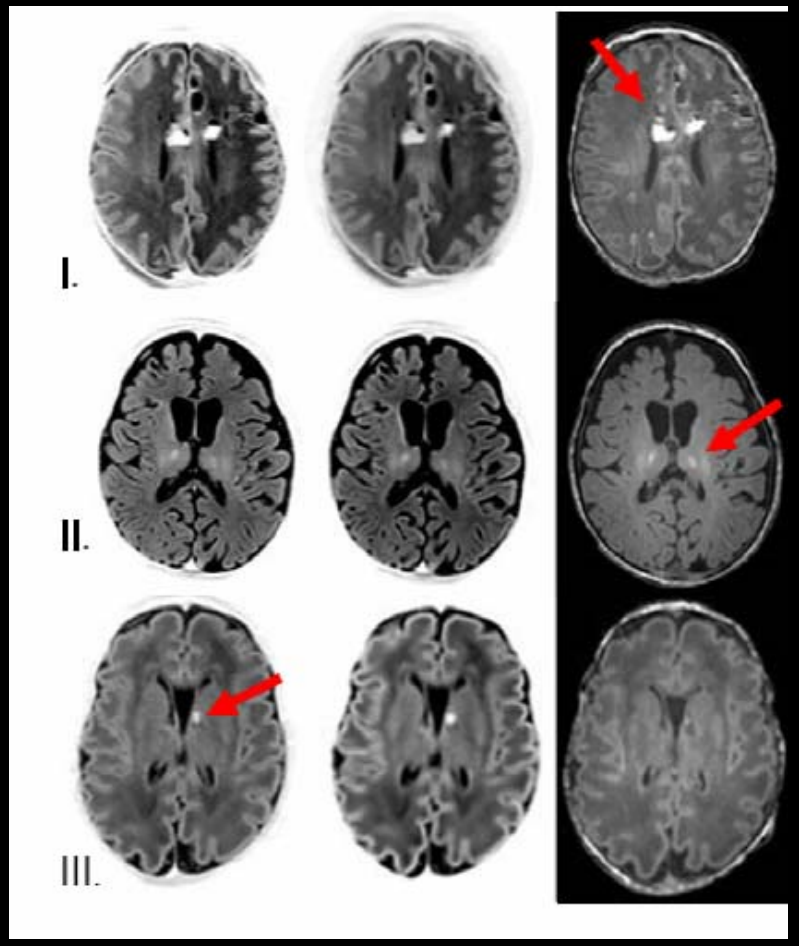
Protocol parameters

Sequence	SNAPIR	Standard T1
Breath hold	No	Yes
TE (msec) (minimum)	8-9	6
TR (msec)	20000 – 22000 (shortest)	142
FOV (mm)	320 x 340	320 x 300
Resolution (mm)	1 x 1	1.2 x 1.6
Slice Thickness (mm)	4	6
Number of slices	20	12
SENSE factor	2	2
Half Fourier	No	No
Water-Fat shift (pixels)	0.75	0.921
Total Time	40 sec	17 sec

Neonatal SNAPIR



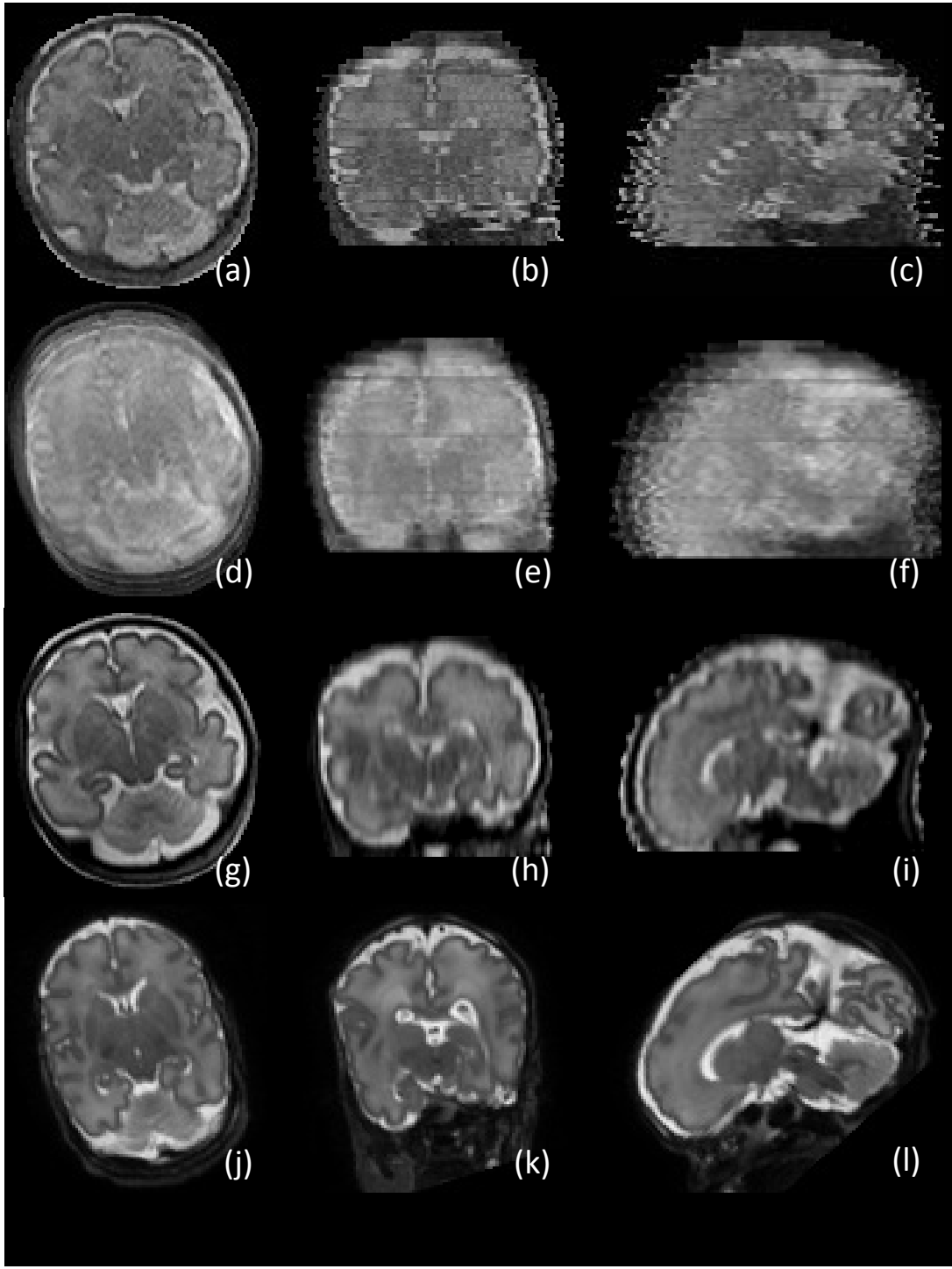
Ederies C et al, ISMRM 2011



McGuinness C et al, ISMRM 2011

III. Data reconstruction

- registration,
- realigning,
- reject analysis,
- thresh-holding techniques
- Advanced methods
  - Snapshot-to-Volume Reconstruction or SVR,
    - » Rousseau F et al, Academic Radiology, 2006
    - » Jiang S et al. IEEE Trans med Imaging 2007



33 weeks
gestational age

4 transverse loops

Registered and reformatted

Ex utero 3 Tesla preterm
infant 33 weeks

Jiang et al, IEEE TMI 2007

Conclusion I

- Fetal MRI is perhaps the most challenging area for patient motion
- Optimisation important in terms of
  - Patient preparation
  - Patient/coil positioning
  - Image protocol choice and optimisation
  - Image quality analysis
- Since there is currently not a single way to address the fetal motion problem interdisciplinary team work and effective communication of all medical imaging professionals is essential for a successful scan

Conclusion II

- Image quality is governed by many factors, often competing with each other
- Optimisation should take into account all these different factors but focus on the ones that really matter for the clinical case

Acknowledgements

- Mary Rutherford
- Jo Hajnal
- Serena Counsell
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