REDUCING SEDATION & ANESTHESIA IN PEDIATRIC MRI

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Conflicts of Interest: none
Acknowledgment

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Background

• Acute risks from sedation & general anesthesia (S/GA) in pediatrics*
  – Cardiorespiratory depression
  – Upper-airway obstruction
  – Hypoventilation
  – Hypoxia (most common side effect**)
  – Hypotension
  – Post-sedation nausea, vomiting, disorientation, sleep disturbance and nightmares

*Arlachov BJR 2012 85(1019): e1018-31
**Horton US Pharm 2008 33(3): HS2-HS8
Background

• Long term effects (mixed results)
  – Intelligence quotient and attention/executive functioning deficits*
  – No long term effect (5 yr follow up) found for S/GA in preemies**
  – FDA warning (12-14-2016): negative effects on developing brain

• Removing the discussion of side effects
  – S/GA incurred the greatest cost and had the longest visit duration***
  – Most MR schedules have substantial backlog
  – Quicker imaging is generally results in better imaging

*Zellem et al. pediatr crit care med 2014 15(3):189-96
**Roze et al JAMA 2018 162(8): 728-33
***Vanderby et al. Radiology 256(1):229-237
Patient Preparation

• Child life coaching patients
  – Preparation videos
    • Patients/parents see the department and the MR experience before beginning screen process
    • Minimize nervousness
  – Mock scanner
    • Simulates sounds
    • Simulate claustrophobic scenario
    • Review patients ability to lie still

Courtesy: Nathan Artz, PhD St Jude Children’s Res. Hosp.
Approaches to Reduce Sedation/GA

• Distractions-videos, music, light shows, parents involvement, etc.
• Noise-reduction
• Feed-and-bundle techniques
• Free-breathing acquisitions
• Sparse imaging algorithms
• Motion compensation algorithms
  – Gross motion
  – Cardiac
  – Respiratory
• Protocol brevity-eliminate unnecessary sequences/steps
• Use alternative imaging methods: e.g., CT or US

Sequence Options

• Latest technological breakthroughs changing how we acquire MR
  – Synthetic MR: simultaneous multi contrast acquisition
  – Fast acquisition
  – Quiet sequences
  – Free breathing imaging
Simultaneous Multi-Contrast Acquisition

• Synthetic MR: allows retrospective manipulation of image
  – Proposed in 1984, but computational power was lacking
  – GE (MAGiC); Philips (SyntAc, QMap); Siemens (SyntheticMR); independent vendors (SyMRI)
Simultaneous Multi-Contrast Acquisition

• Measure parametric properties of tissue
  – T1 (R1), T2 (R2), proton density ($\rho_H$), and B$_1$ values
  – E.g., single acquisition (e.g., QRAPMASTER-SyMRI; 6 min)
    • TR = 4000 ms, TE = 22 & 90 ms ETL = 12
  – Change the “signal” by manipulating ETL, ESP,
  – Create synthetic images by manipulating TI, TR, and TE

\[
signal \approx \rho_H \left( e^{-\frac{TE}{T2}} \right) \left( 1 - 2e^{-\frac{TI}{T1}} \right) \left( 1 - e^{-\frac{TR-TI}{T1}} \right)
\]

\[
signal \approx \rho_H \left( e^{-\frac{TE}{T2}} \right) \left( 1 - e^{-\frac{TR-(ETL*ESP)}{T1}} \right)
\]

Simultaneous Multi-Contrast Acquisition

- Contrasts: T1, T2, STIR, T1 FLAIR, T2 FLAIR, dual IR, phase sensitive IR, and PDW

Courtesy GE
Simultaneous Multi-Contrast Acquisition

• How accurate is synthetic MR?
  – Tanenbaum et al. AJNR 2017 http://dx.doi.org/10.3174/ajnr.A5227
  – N = 109 (45 M; 64 F)
  – Conventional images acquired first
    • 2D T1W, T2W, T1W & T2W FLAIR & STIR, and PD
  – Multiple dynamic multiple echo MDME (many TE samples) synthetic MR sequence
    • MDME data reconstructed using MAGiC (GE)
    • Randomized blinded review by 7 neuroradiologists (> 10 yr experience)
      – Intra observer test after 4 week memory washout period
  – Image quality: 5 point Likert scale, artifact analysis, clinical findings recorded (Osborn classification)
Simultaneous Multi-Contrast Acquisition

Tanenbaum et al. AJNR 2017 38(6):1103-1110
Simultaneous Multi-Contrast Acquisition

• How accurate is synthetic MR?
• Positives:
  – Diagnostic performance of synthetic imaging was similar to that of conventional MR imaging
  – Conventional morphology agreed > 95%
  – Suggested with shorter scan times less motion artifacts
• Negatives:
  – Except in the posterior limb of the internal capsule for T1, T1 FLAIR, and PDW (> 80%)
Simultaneous Multi-Contrast Acquisition

Tanenbaum et al. AJNR 2017 38(6):1103-1110
Simultaneous Multi-Contrast Acquisition

• **Continued…** How accurate is synthetic MR?
  – Synthetic MR *did not* improve sensitivity and specificity of diagnostic read
  – MR imaging in neuroradiology
    • Sensitivity: 39% to 98%
    • Specificity: 33% to 100%
    • Still depends on training/reader experience
  – Fewer artifacts (all characterizations) were identified in synthetic

• Synthetic MR is mostly used for quantitative purpose, but may offer the opportunity to reduce scan time in the future
Fast Acquisition

• Compressed Sensing (CS)
  – 1999: SENSE [parallel imaging (PI)]
    • Parallel imaging
      – Fills k-space using multiple RF coils coupled together w/ independent channels
  – 2016: multiband SENSE
  – 2017: compressed SENSE (CS; Philips)
    • CS + PI = complementary
      – PI produces more incoherent samples for CS
        » Reduces incoherent aliasing artifacts
      – CS prevents high g-factors due to irregular sampling
Fast Acquisition

• How does compressed sensing (CS) work?
  1. MR data is redundant, i.e., MR imaging can be compressed
  2. MR scanners naturally acquire encoded samples, NOT direct pixel sampling
     • E.g., CT reconstruction matrix directly correlates with a spatial domain location (x,y)
     • E.g., MR reconstruction the received signal at time (t) is the Fourier transform of the object (O) sampled at spatial frequency (w)

\[ s(t) = \int_{R} O(\vec{r})e^{-i2\pi\omega(t)\vec{r}} d\vec{r} \]
Fast Acquisition

• “Simple” images
• Some MR exams, such as angiograms, are inherently sparse
  – i.e., filled with very little pixel information
  – Sparse image data: Not acquiring some of this information will not affect image reconstruction
    • Thus allowing speeding up of the acquisition
Fast Acquisition

- Complex images, such as brains, are not inherently sparse
  - Must be made to be sparse
  - Using a sparsifying transform (e.g., Wavelet domain)
Fast Acquisition

\[ s(t) = \int_R O(\vec{r}) e^{-i2\pi \bar{\omega}(t) \vec{r}} d\vec{r} \]

Fully sampled k-space takes time
Fast Acquisition

• Must properly under sample k-space
• Coherent vs. incoherent k-space sampling
  – Coherent sampling leads to aliasing artifacts
  – Incoherent sampling leads to noise image
Fast Acquisition

Incoherent sampled k-space

Fourier Transform

$$s(t) = \int_O^e O(\vec{r}) e^{-i2\pi \vec{\omega}(t) \vec{r}} \, dr$$

image-space

Sparse sampled k-space $\rightarrow$ noisy image
Fast Acquisition

image-space  Wavelet Transform  Denoising  Denoised image
Fast Acquisition

Denoised image  Inverse Fourier Transform  Denoised k-space

\[ \mathcal{F}^{-1}\{s(t)\} \]
Fast Acquisition

Incoherent sampled k-space

Subtract k-spaces

Common points = patient data
Uncommon points = noise

Denoised k-space
Fast Acquisition

Iterate this process
Fast Acquisition

Iterate this process
Fast Acquisition

Fully Sampled  Incoherently sampled  30 iterations
Fast Acquisition

• Compressed Sensing (CS)
  – Cannot use with EPI, MultiVane (PROPELLER), partial NSA, MRS, OMAR (MARS/VAT/SEMAC), etc.
  – CS does best for sparse data sets, e.g. TOF MRA, REACT, MRCP
  – Aggressively apply CS: 3T and 3D
  – Less sensitive to coil geometry (number of coil elements and arrangement) vs SENSE
  – Does not do well with gross motion (worse than SENSE)
    • But minimizes patient breathing/cardiac motion because faster
Fast Acquisition

- Initial examination *average* time reduction

<table>
<thead>
<tr>
<th></th>
<th>Original Time (min)</th>
<th>New Time (min)</th>
<th>Reduction (min)</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle</td>
<td>22:03</td>
<td>13:20</td>
<td>8:43</td>
<td>40%</td>
</tr>
<tr>
<td>Trauma Knee</td>
<td>19:07</td>
<td>19:07</td>
<td>4:08</td>
<td>18%</td>
</tr>
<tr>
<td>Elbow</td>
<td>31:47</td>
<td>26:21</td>
<td>5:26</td>
<td>17%</td>
</tr>
<tr>
<td>Whole Body (6 stations)</td>
<td>35:28</td>
<td>29:30</td>
<td>5:58</td>
<td>17%</td>
</tr>
<tr>
<td>Routine Brain (&gt; 2yr old)</td>
<td>18:27</td>
<td>17:09</td>
<td>1:18</td>
<td>7%</td>
</tr>
</tbody>
</table>
3D PDW View

16yo male with ridged planovalgus with bilateral chronic foot pain

Ingenia 1.5T

4:24 min 3:51 min

CS = 6
Brain 2D FLAIR

14yo male with headache, low body temp and reported episodes of LOC

Ingenia 1.5T

4:00 min

2:56 min
CS = 1.8
Brain T2

13yo female, new onset hallucinations (visual and auditory)

Ingenia 1.5T  4:11 min

CS = 2
3D TOF MRA

12yo male, new onset dystonia, facial droop lasting 30min 3x a week

6:33 min

4:27 min

Ingenia 1.5T

CS = 3
Abdomen FSE

20 yo woman with right upper quadrant pain following cholecystectomy

Elition 3T

3:54 min

1:54 min CS = 6
136 kg (300 lb) Adult

Elition 3T

No CS (4:33 + RespTr)  CS=4 (1:08 + RespTr)  CS=24 (0:15 BH)
Cardiac REACT

Young adult with left subclavian vein stenosis (with respiratory triggering)

Ingenia 1.5T

5:27 min

3:04 min CS = 3
mDixon Quant

Ingenia 1.5T

10.1 sec

4.7 sec CS = 5
Fast Acquisition

• Quantitative accuracy
  – Need to determine how CS affects quantitative MR metrics, e.g.:
    • Elasto: kPa
    • T2*
    • PDFF
    • mDixon Quant
Quiet Sequences

• Current techniques to reduce MRI noise:
  – Gradient insulation
  – Force compensation

• Neither directly address the root cause:
  – Rapid directional gradient switching

• Siemens’ QuietX & GE’s Silenz are software solutions
Quiet Sequences

- Characteristics of a quiet sequence (per TR):
  - Gradients are on during the whole TR
  - But with very small TE (TE = 0.016 ms)
  - Acquired in radial k-space instead of Cartesian
  - Smaller tip angles
  - Reduces slew rates
Quiet Sequences

Siemens

GE BRAVO sequence

Fig. 1: Sequence diagram of the PETRA sequence.

Quiet Sequences

• Advantages:
  – Kids: reduced sedation
  – Patients can hear the movies used for distraction
  – FMRI: no auditory stimulation
  – Image Quality: Less vibrations from gradient banging equals less image artifacts
  – Bioeffects: No peripheral nerve stimulations
  – Intraoperative surgery: MD’s can communicate easier
Quiet Sequences

• Quantitative contrast comparison
  – Myelination assessment in children w/ conventional SE
  – Compared using GE 750w 3T
    • 24 channel head coil
  – T1W: 3D GRE short TE and small flip angle and radial k-space
  – T2W: 2D SE w/ PROPELLER

Quiet Sequences

Quiet Sequences

Quiet Sequences

- Gross anatomical comparison agreed with $\kappa \sim 0.8$

Quiet Sequences

- Cerebellar myelination poor agreement $\kappa \sim 0.14$

Quiet Sequences

• Noise reduction:
  – T1W: 82 dB → 53 dB (~ 30 dB)
  – T2W: 85 dB → 59 dB (~26 dB)

• How does that compare with ear plug noise reduction?
  – NRR rating of 33
    • \( NRR = \frac{33-7}{2} = 13 \text{ dB} \)
  – NRR rating of 22
    • \( NRR = \frac{22-7}{2} = 7.5 \text{ dB} \)
Free Breathing Imaging

• Major **challenges** in cardiovascular MRI:
• Image quality degradation due to **respiratory motion**
• Long scan times need
  – Breath hold (BH) acquisition
  – BH can be difficult for sick patients and pediatrics
Free Breathing Imaging

• Long scan times using diaphragmatic navigator gating
  – Predefined acceptance window of breathing cycle (e.g., end expiration)
    • All other data rejected for image reconstruction
  – Small gating window 3-5 mm
    • Prolonged acquisition times
  – Irregular breathing may require scan abortion
Free Breathing Imaging

• Free breathing acquisition requires:
  – Shorter scan time
  – 3D CINE acquisition
  – Novel data sampling schemes
    • Binning data WRT respiratory cycle
  – Under sampling reconstruction (e.g. CS) + motion correction
Free Breathing Imaging

mDIXON IP

mDIXON OP
Conclusion

• MRI is a rapidly evolving field
• New technologies are largely software-based
  – Used to speed up MR
  – Fast & accurate MR = better MR
• Some software technologies require new scanner platforms
  – $$$
  – Usually with time, manufacturers will make software available for older (legacy) scanners
Conclusion

• Staying current with new technologies
  – Will require additional training
    • Radiologists
    • Technologists
    • Medical physicists
  – Team work will aid in enable proper technology implementation
  – Goal: improved patient care
Thank you

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