Why MRI for Image-Guided Intervention?

- **Imaging**
  - planning
  - targeting
  - monitoring/control
  - verification

- **Synergy with biological and physical modeling & simulation**

- **Endgame**
  - “Close the loop”
  - increase procedure safety + efficacy
  - facilitate minimally invasive approaches previously not considered possible or safe

### Why MRI for Image-Guided Intervention?

- **Planning**
  - T2-W FLAIR

- **Verification**
  - T1+CE

- **Model**
  - Arrhenius Damage

- **Monitoring**
  - MR Temperature

Example: MR-guided laser ablation of metastatic melanoma in brain

### Intraoperative vs Interventional paradigms

**Intraoperative**
- Craniotomy
- Laser Ablation
- Biopsy

**Interventional**
- Angio-MRI (MIYABI)
- BrainSUITE™

**Intraoperative**
- Extended anatomic imaging for stereotactic approaches.
- Geometric accuracy is critical.

**Interventional**
- Fast imaging for percutaneous procedure guidance.
- Access to patient in magnet is helpful.

### Review:

### Procedures:
- Craniotomy
- Laser Ablation
- Biopsy
Intraoperative vs Interventional paradigms

1. MR-guided biopsy of mixoid sarcoma: bSSFP + FS provides real-time imaging with T2-like contrast.

2. Fine needle aspiration vs Core Biopsy

3. Intraoperative vs Interventional paradigms


6. Biopsies: renal, liver, MSK, prostate and breast

7. Cryoablation: renal, liver, bone

Note: Guidance specific to safe practices in the iMRI/ioMRI environment not explicitly addressed

8. MR safety considerations begin during siting of the suite

- Suites increasingly embedded in departments outside diagnostic radiology (OR, IR, Cath lab, etc)
- Zoning & access considerations for patients and staff
  - Fringe field considerations
  - Multi-room design? Where will procedures be performed?
  - Appropriate training & credentialing
- In-room workflow + instrumentation + storage
- Anesthesia + patient management workflow
- Ancillary equipment in Zone IV
  - Procedure mix? Multi-modal? Integrated therapy devices?
  - Emergent procedure considerations

9. Ancillary equipment and room integration

- Ancillary equipment and room integration fringe field considerations

- 5G: Distance from scanner

- 4.2G

- 3.0G

- 2.0G

- 1.0G

- Equipment and room integration considerations

- Technical Corridor

- Storage

- STORAGE

- CYTOMETRY

- TECHNICAL CORRIDOR

- Hybrid single-room interventional MRI (iMRI) + fluoroscopy suite

- Need to address securing equipment in room, demarking regions of use and procedures for interventional cases, power management issues and assessing MR conditional status.
Hybrid single-room intraoperative MRI (ioMRI) suite

Zone III

Zone IV

TECHNICAL CORRIDOR

MAIN ENTRANCE

COMPUTER CLOSET

OPERATOR CONSOLE

PREP

Orion

Ankle

Foot

Keycard access (automatic door)

Ancillary equipment and integration considerations: single room?

- Siemens Espree 1.5T Magnet
- VectorVision Sky and VectorVision Software Cranial
- Vector NC4 Multivision with advanced integration
- OR Table with integrated headclamp and coil
- Automatic Image Registration
- BrainSUITE Data Billboard
- Digital Data Management and OR Device and Room Control System
- BrainSUITE RF Shielded OR Cabin
- Telemetry

Most integrated equipment cannot be on during procedure. Equipment power procedures needed.

Hybrid MR Suites: Single vs Multi-Room solutions

Some safety concerns can be addressed via use of a multi-room option.

Patient transfer from procedure arena to MRI arena

- Remove surgical instruments/sutures/patients from table + count
- Remove ground patches, leads and/or electrodes from patient/arena
- Remove MR unsafe navigation instruments
- Prepare patient drapes
- Non-antimicrobial drapes, drapes, towels, etc.
- Clean skin/antimicrobial drapes
- Prepare patient drapes
- Remove metal clips, wire edges, drain plugs
- Prepare and manage sterile field and wound for transfer/imaging
- Prepare anesthesia team
- Remove laryngoscope handles, blades, stylets, nerve stimulator + count
- Prepare IV, air, catheter and monitoring lines
- Position patient and RF coils for imaging
- Management/removal of conducting wires and skin-to-skin contacts
- Personnel MRI safety check (i.e., ferromagnetic objects, hearing protection, etc.)
- Ferromagnetic screening (if available)
- MR time out, visual checks and audibles + assess room readiness (Procedure specific CHECKLISTS strongly encouraged)

Anesthetized patients in hybrid suites: concerns

- Careful patient screening for appropriateness of procedure
  - MRI compatible equipment, procedure times and limitations
  - Isolation of patient
- Patient inability to report sensations or pain during procedure
- Patient setup and positioning for MR
  - RF coils & conductors needed for monitoring
- Rapid removal of patient from Zone IV in case of an emergency
  - Isolation of suite and patient

Anesthesiology and RF

- MRI vendor safety manual:
  - For ferromagnetic fields in the Field Level Code 0.1T

Primary Safety Concerns

- Static Magnetic Field (B0)
  - Spatial field gradient (NB:B0)
  - Translation projectile "missile" hazards
  - Local tissue and whole body heating
- Radiofrequency Field (B1)
  - Specific Absorption Rate (SAR)
  - Specific Energy Deposition (SED)
  - Exposure time and/or temperature
  - Pulsed Gradient Magnetic Field (G)
    - Slew rate (T/m/s)
    - Max dB/dt (T/s)
  - Peripheral nerve stimulation
  - Acoustic noise

Anesthetized patients in hybrid suites: concerns

- From an MRI vendor safety manual:
  - Patient awareness
  - Non-antimicrobial drapes, drapes, towels, etc.
  - Clean skin/antimicrobial drapes
  - Patient management devices: warmers, compression boots, etc.
  - Position/secure infusion pumps
  - Patient positioning and padding (longer OR procedure times)
- Patient Hearing Protection
  - Noise shielding
  - Position patient and RF coils for imaging
  - Management/removal of conducting wires and skin-to-skin contacts
- Rapid removal of patient from Zone IV in case of an emergency
  - Isolation of suite and patient

MRI environment and medical devices

- Source
  - Primary Safety Concerns
  - Static Magnetic Field (B0)
    - Spatial field gradient (NB:B0)
    - Translation projectile "missile" hazards
    - Local tissue and whole body heating
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MRI environment and medical devices

Table: MRI environment and medical devices

<table>
<thead>
<tr>
<th>Environment</th>
<th>Primary Safety Concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Magnetic Field</td>
<td>Equipment failure &amp; patient hazards</td>
</tr>
<tr>
<td>Anisotropic Field</td>
<td>Equipment failure &amp; patient hazards</td>
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<tr>
<td>Temperature rise</td>
<td>Patient comfort &amp; safety</td>
</tr>
<tr>
<td>Partially implanted devices</td>
<td>Heating &amp; patient discomfort</td>
</tr>
</tbody>
</table>

Figure: MRI environment and medical devices

Several key MR safety standards & guidance

- **FDA**: Standard Test Method for Measurement of Magetically Induced Heating Rate ofMedical Devices in the Magnetic Resonance Environment
- **ASTM F2052**: Standard Test Method for Measurement of Magetically Induced Heating Rate of Medical Devices in the Magnetic Resonance Environment
- **ASTM F2119**: Standard Test Method for Measurement of Magetically Induced Heating Rate of Medical Devices in the Magnetic Resonance Environment
- **ASTM F2182**: Standard Test Method for Measurement of Magetically Induced Heating Rate of Medical Devices in the Magnetic Resonance Environment
- **ASTM F2213**: Standard Test Method for Measurement of Magetically Induced Heating Rate of Medical Devices in the Magnetic Resonance Environment

Figures: Several key MR safety standards & guidance

Localized heating: thermal dose & risk assessment

- **SAR**: Specific Absorption Rate (W/kg)
- **ω**: Temperature (Kelvin)
- **ρ**: Blood density (kg/m³)
- **C**: Blood viscosity (Pa·s)
- **V**: Blood flow rate (m/s)
- **Q**: Perfusion (s⁻¹)
- **P**: Power density (W/m³)

Equation: Bioheat Equation

- **ε**: Local perfusion
- **ε(1-T/T₀)**: Local perfusion factor

Figures: Localized heating: thermal dose & risk assessment

Partially implanted and procedure devices in MRI

- **Devices in fringe field or in-bore**
  - In-bore: partially implanted device concerns
  - Artifacts: issues with imaging
  - Heating: concerns with heating
  - Compromises: between safety & function
  - Changes: in procedures for high fields

Figures: Partially implanted and procedure devices in MRI

Partially implanted and procedure devices in MRI

- **Example devices**
  - Imaging: MRI & MR spectroscopy
  - Monitoring: vital signs & ECG
  - Therapy: radiofrequency & acoustic energy

Figures: Partially implanted and procedure devices in MRI
Partially implanted and procedure devices in MRI

Example devices:
- Neuromonitoring leads
- Biopsy needles and guns
- Treatment applicators
  - Cryotherapy needles have similar heating risk
  - Biopsy needles
  - Multiple probes often placed at once
  - Close proximity of probes can promote unintended stimulation
  - Guidewires and catheters
- Primary safety concern regarding the long metallic guidewires, such as those made of Nitinol, used in image-guided vascular procedures is heating
- New PTFE coated glass bead systems resistant to heat

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Geometric & signal distortions also safety issues in ioMRI and iMRI

Geometric & signal distortions also safety issues in ioMRI and iMRI

Personnel training and screening in ioMRI and iMRI suites

- MR Screening for employees
  - BIB’s & visitors, nurses, transitional care nurses, surgeons, anesthesia
- MR Safety training (annually)
  - Level 1 versus Level 2 training
  - Suite Orientations
    - Emergency procedure and patient transfer
    - Equipment operation and safety interlocks
- Procedure Orientations
  - Standard operating procedures/checklist
    - Special equipment, monitoring, etc.
  - Dry runs for new procedures
  - Observational supervision of new staff
- Access control and core MR procedure group supervision

Deep brain stimulation lead placement
Summary

- Intraoperative and interventional MRI use expanding
- Systems often placed remote from MR department and resources with many traditionally non-MRI personnel involved
- Procedures can be complex and involve a variety of non-standard devices and instrumentation in the suite and patient
- Risk to staff and patient from missile effects and acoustic noise as well as heightened concern over patient heating and artifact management
- A small, highly trained team with clearly written and periodically reviewed policies and procedures is essential to both safety and long term success

Thank you for your time!

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