Development and Optimization of Multiparametric MRI for Bladder Cancer: Opportunities for Standardization and Quality Improvement

Christopher M. Walker, Joshua P. Yung, Ken Hwang, R. Jason Stafford, and Aradhana M. Venkatesan
Bladder MR Imaging at MD Anderson Cancer Center

- Unmet need for dedicated urinary bladder MR imaging & structured reporting for suspected high risk muscle invasive bladder cancer (MIBC)

- Additional, unmet need for dedicated bladder MR imaging for evaluation of patients following adjuvant/neoadjuvant systemic therapy
  - Clinical need historically addressed with:
    - Routine pelvis MRI protocol
    - MR Urogram Protocol
    - Female pelvis MRI protocol
  - Bladder focused add on series, when added, limited to additional small FOV T2 series
  - Limitations:
    o Heterogenous FOVs & supplemental series depending upon base protocol
    o No multi-plane small FOV DWI
    o No bladder focused dynamic series

Implemented & optimized a dedicated bladder specific MRI protocol in keeping with the Vesical Imaging-Reporting and Data System (VI-RADS)
VI-RADS

• **Vesical Imaging Reporting and Data System (VI-RADS)**
  • Standardized system for MR imaging and interpretation for urinary bladder cancer

• **Requirements:**
  • Delayed void and antispasmodic agent administration
  • Multi-planar T2w
    • At least 2 planes
    • High spatial resolution
  • DWI
    • At least 2 planes
    • Two b-values, low and high 800-1000 s/mm²

• DCE-MRI
  • At least 30s temporal resolution
  • High spatial resolution
  • Fat saturation
  • Larger FOV T1w
General Protocol

- 4 major sub-parts
  - Large FOV Imaging
    - Assist is positioning
    - Evaluate nodes
  - Small FOV T2 Imagining
    - Focused on the bladder
    - All 3 planes
  - Small FOV DWI
    - Sagittal and Axial
  - Contrast Imaging
    - Dynamics and delayed
- No more than 45 minutes active scanning
## Protocol Specifics

<table>
<thead>
<tr>
<th>Iteration #</th>
<th>T2 w</th>
<th>DWI</th>
<th>DCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TR (ms)</td>
<td>&gt;6000</td>
<td>&gt;6000</td>
<td>&gt;6000</td>
</tr>
<tr>
<td>TE (ms)</td>
<td>140</td>
<td>116</td>
<td>119</td>
</tr>
<tr>
<td>Flip Angle (deg)</td>
<td>120</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>FOV (mm)</td>
<td>240</td>
<td>230</td>
<td>220</td>
</tr>
<tr>
<td>Resolution (mm)</td>
<td>[0.75,0.94]</td>
<td>[0.58,0.90]</td>
<td>[0.57,0.86]</td>
</tr>
<tr>
<td>Slice Thickness (mm)</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Slice Gap (mm)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Acceleration</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>k-Space</td>
<td>Cart</td>
<td>Cart</td>
<td>Cart</td>
</tr>
<tr>
<td>NEX</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>b-value</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Temporal Resolution</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Scan Time per Slice (s)</td>
<td>9.40</td>
<td>6.30</td>
<td>6.00</td>
</tr>
<tr>
<td>Receive BW (Hz)</td>
<td>83.33</td>
<td>83.33</td>
<td>83.33</td>
</tr>
</tbody>
</table>
T2 Change

- **Initially focused on**
  - Reducing scan time
  - Protocol Iteration 3 had a 36% reduction in scan time
  - Improving resolution
    - $[0.75 \times 0.74] \rightarrow [0.57 \times 0.86]$ mm
  - At the expense of SNR
- **Due to motion, non-Cartesian acquisitions (PROPELLER/BLADE) employed for final protocol**
  - Required modest scan time increase
  - 18% from protocol iteration 3 → 4
  - Forced isotropic resolution 0.57 mm

![Image Derived SNR](chart.png)

**Initial**

**Final**
**DWI Change**

- Initially acquiring DWI at higher spatial resolution and SNR than needed
- Reduced time by ~25%
  - Increased slice thickness 3-> 4
  - Reduced NEX 14 ->10
- Saved time then used on other sequences
- SNR Impacts mitigated by Slice thickness change

---

**Initial**

**Final**

---

**Image Derived SNR**

<table>
<thead>
<tr>
<th>Protocol Iteration Number</th>
<th>SNR (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
</tr>
</tbody>
</table>

---

**Graph**

- DWI
- ADC
### DCE Change

- **Dynamic Image Quality** was improved by increasing scan time at the expense of temporal resolution.

- **Scan Efficiency** reduced by a factor of ~2.5
  - Temporal Resolution ~10s -> 25s
  - Still met VIRADs suggested temporal resolution of 30s

- **Done to improve SNR and resolution**
  - Lower acceleration 2 -> 1.5
  - Better slice resolution 2 -> 1 mm

---

<table>
<thead>
<tr>
<th>Protocol Iteration Number</th>
<th>SNR (AU)</th>
<th>Image Derived SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre C</td>
<td>~4</td>
<td></td>
</tr>
<tr>
<td>Post C</td>
<td>~6</td>
<td></td>
</tr>
<tr>
<td>Pre C</td>
<td>~8</td>
<td></td>
</tr>
<tr>
<td>Post C</td>
<td>~10</td>
<td></td>
</tr>
<tr>
<td>Pre C</td>
<td>~12</td>
<td></td>
</tr>
<tr>
<td>Post C</td>
<td>~10</td>
<td></td>
</tr>
</tbody>
</table>

---

![Initial Pre C and Post C images](image1)

![Final Pre C and Post C images](image2)
Benefits of Non-Cartesian Acquisitions

- T2 sequences sensitive to bowel motion
- Acquisition reduces motion artifacts
- 18% slower but increased SNR
- Optimized by:
  - maximizing receive BW
  - using 2 NEX with 2-fold acceleration
Impact of Deep Learning-Based Image Reconstruction

• DL recon evaluated on Cartesian T2 Datasets
  • Improved apparent SNR
  • Suffered from motion artifacts

• Non-Cartesian DL Recons an avenue for future development
  • Potential to reduce scan time and/or increase resolution