Comparison of T1 measurement using ISMRM/NIST phantom

Ad Hoc Committee on Standards for Quantitative MRI of the ISMRM
Multi-site, multi-vendor comparison of T1 measurement using ISMRM/NIST system phantom

Keenan KE¹, Stupic KF¹, Boss MA¹, Russek SE¹, Chenevert TL², Prasad PV³, Reddick WE⁴, Cecil KM⁵, Zheng J⁶, Hu P⁷, Jackson EF⁸, and the Ad Hoc Committee on Standards for Quantitative MRI⁹

¹Physical Measurement Laboratory, National Institute of Standards and Technology, Boulder, CO; ²University of Michigan, Ann Arbor, MI; ³NorthShore University Health System, Evanston, IL; ⁴St. Jude Children’s Research Hospital, Memphis TN; ⁵Cincinnati Children’s Hospital Medical Center, Cincinnati, OH; ⁶Washington University in St. Louis, St. Louis, MO; ⁷University of California, Los Angeles, CA; ⁸University of Wisconsin, Madison, WI; ⁹International Society of Magnetic Resonance in Medicine
Multi-site, multi-vendor T1 measurement

- How does T1 measurement vary at one site day-to-day?
- How does T1 measurement vary across manufacturers?
- Is the variation different between 1.5 T and 3 T?
- Is the variation different between inversion recovery and variable flip angle methods?

ISM RM/N IST system phantom supports quantitative T1 and T2 measurements and can be used to answer these questions.
ISMRM/NIST System Phantom

• NiCl$_2$ solutions with varying concentrations for T1 range 20 to 2000 ms
• Reference T1 values measured on NMR by inversion recovery at 20 °C, 1.5 T and 3 T

Photos courtesy of High Precision Devices.
Multi-site, multi-vendor Comparison

- Two system phantoms traveled the continental US
- Repeatability measurements \(n=3\) at one 3 T system for each manufacturer, coefficient of variation \((CV)^1\)
- Receive-only, head coils with 8 to 32 channels
- Reported temperature ranges: 17.1 to 23.3 °C (of MRI room or bulk water in the phantom)

<table>
<thead>
<tr>
<th>Vendor</th>
<th>1.5 T</th>
<th>3 T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vendor A</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Vendor B</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Vendor C</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

---

T1 Measurement Protocol

<table>
<thead>
<tr>
<th>Inversion Recovery</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence</td>
<td>Fast, SE-IR, 2D</td>
</tr>
<tr>
<td>Scan Plane</td>
<td>Coronal</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>6</td>
</tr>
<tr>
<td>TR (ms)</td>
<td>4500</td>
</tr>
<tr>
<td>TE (ms)</td>
<td>~ 7 (minimum full)</td>
</tr>
<tr>
<td>Inversion Times (ms)</td>
<td>35*, 50, 75, 100,</td>
</tr>
<tr>
<td></td>
<td>125, 150, 250, 1000,</td>
</tr>
<tr>
<td></td>
<td>1500, 2000, 3000</td>
</tr>
<tr>
<td>Averages</td>
<td>1</td>
</tr>
<tr>
<td>Echo Train Length</td>
<td>6</td>
</tr>
<tr>
<td>Pixel Size (mm x mm)</td>
<td>0.98 x 0.98</td>
</tr>
</tbody>
</table>

Note: TI = 35 ms not available on Vendor A.

<table>
<thead>
<tr>
<th>Variable Flip Angle</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence</td>
<td>Fast, SPGR, 3D</td>
</tr>
<tr>
<td>Scan Plane</td>
<td>Coronal</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>3 (no gap)</td>
</tr>
<tr>
<td>TR (ms)</td>
<td>~ 6.6</td>
</tr>
<tr>
<td>TE (ms)</td>
<td>Minimum: 1.5-2.5</td>
</tr>
<tr>
<td>Flip Angles</td>
<td>2, 5, 10, 15, 20, 25, 30</td>
</tr>
<tr>
<td>Averages</td>
<td>4</td>
</tr>
<tr>
<td>Echo Train Length</td>
<td>1</td>
</tr>
<tr>
<td>Pixel Size (mm x mm)</td>
<td>0.98 x 0.98</td>
</tr>
</tbody>
</table>

Note: Prescan on FA=15°, no subsequent gain changes.

- Data fit using custom software (PhantomViewer, developed at NIST)
Vendor A, 3T, repeatability measurements

Colored bands show the range of values at a single repeatability site.
Vendors B and C, 3T, repeatability measurements

Colored bands show the range of values at a single repeatability site.
All repeatability measurements at 3 T

Colored bands show the range of values at a single repeatability site.
Inversion Recovery: MRI comparison to NMR measured values

Overall, Inversion Recovery is accurate. Difficulty fitting short T1 times likely due to selected inversion times.
Variable Flip Angle: MRI comparison to NMR measured values

Can we understand the systematic patterns in the 3 T data?

Note: 3 T y-axis range is 2x the 1.5 T y-axis range.

Colored bands show the range of values at a single repeatability site.
Spatial dependence of variations: Inversion Recovery

ISMRM/NIST system phantom: Results

1.5 T data from Vendor A

Deviation from NMR values ranges from -3.6 to 5.8 %

<table>
<thead>
<tr>
<th>Position</th>
<th>Deviation (% NMR value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-2.1%</td>
</tr>
<tr>
<td>50</td>
<td>-3.6%</td>
</tr>
<tr>
<td>25</td>
<td>-1.7%</td>
</tr>
<tr>
<td>-25</td>
<td>-1.1%</td>
</tr>
<tr>
<td>-50</td>
<td>-0.7%</td>
</tr>
<tr>
<td>-75</td>
<td>-0.7%</td>
</tr>
<tr>
<td>0</td>
<td>-0.7%</td>
</tr>
<tr>
<td>50</td>
<td>-1.0%</td>
</tr>
<tr>
<td>25</td>
<td>-1.2%</td>
</tr>
<tr>
<td>-25</td>
<td>-0.4%</td>
</tr>
<tr>
<td>-50</td>
<td>-1.6%</td>
</tr>
<tr>
<td>-75</td>
<td>-1.1%</td>
</tr>
</tbody>
</table>

Program #3290
Spatial dependence of variations: Inversion Recovery

ISMRM/NIST system phantom: Results

Program #3290

1.5 T

Vendor A deviation: -3.6 to 5.8 %
Vendor B deviation: -11.8 to 8.9 %
Vendor C deviation: -4.8 to 6.3 %

3 T

Vendor A deviation: 0.9 to 13.2 %
Vendor B deviation: -8.0 to 1.7 %
Vendor C deviation: 0.4 to 9.7 %
Spatial dependence of variations: Variable Flip Angle

There is spatial variation, and it is different for each system.

Vendor A deviation: -2.1 to 20.0 %
Vendor B deviation: -20.2 to -3.4 %
Vendor C deviation: -18.2 to 13.4 %

Vendor A deviation: -14.8 to 3.3 %
Vendor B deviation: -33.3 to -8.8 %
Vendor C deviation: -6.6 to 16.3 %
Spatial dependence of variations: **Fiducial Sphere Plane**

Fiducial spheres are located below the T1 array, within the 3D VFA imaging section. Fiducial spheres all contain the same concentration of CuSO$_4$. 
Spatial dependence of variations: Variable Flip Angle

CuSO₄ is more temperature sensitive than NiCl₂, which affects our ability to interpret these results.

Vendor A deviation: -0.7 to 37.3 %
Vendor B deviation: -37.1 to -4.7 %
Vendor C deviation: -16.6 to 32.4 %

Vendor A deviation: -42.9 to 51.2 %
Vendor B deviation: -65.0 to -13.2 %
Vendor C deviation: -46.7 to 50.7 %
Why the deviation from known values?

• NMR methods v. MRI methods

• Temperature sensitivity over the reported temperatures
  • Non-linear, increases by 7.2% over the range of reported temperatures
  • *Deviation from reference T1 cannot be attributed only to temperature*

• Best efforts for similar protocol, but B1 pulse profiles unknown and could change across range of flip angles

• NMR deviation patterns suggest possible B1 effect
Multi-site, multi-vendor T1 variation

- T1 variations from NMR-measured value are correlated site-to-site within a vendor and by position within the head coil
- ISMRM/NIST system phantom is an excellent tool for evaluation multi-site acquisition protocols
Acknowledgments

• We appreciate the efforts of all those who completed the scans of the phantom, especially when we asked them to repeat their efforts.

• We thank the SQMR committee past and present. Current members of the SQMR committee are:

  Michael A. Boss       Jeff L. Gunter       Kim Maria Cecil       Thomas L. Chenevert
  Daniel Gembris       Alexander S. R. Guimaraes   Peng Hu       Xiaoping P. Hu
  Clifford R. Jack       Edward F. Jackson       Kathryn E. Keenan       Pottumarthi Vara Prasad
  Wilburn E. Reddick       Stephen E. Russek       Michael Salerno       Amita Shukla-Dave
  Michael Steckner       Karl F. Stupic       Chung Yuan       Huiming Zhang
  Jie Zheng
For more information on NIST phantoms in development, the NIST/ISMRM phantom and to provide input, please visit:

http://collaborate.nist.gov/mriphantoms

To contact the author:

Reference Measurements: 1.5 T NMR

Aliquots of each solution were sealed into 2 mm outside diameter (OD) quartz (NiCl₂ solutions) or 3 mm (OD) PTFE (MnCl₂ solutions) NMR tubes. Quartz samples were sealed using a methane/oxygen torch to flame seal. PTFE samplers were sealed with a PTFE plug inserted 1 cm into the sample tube. A fiber optic temperature probe was positioned with the sensor in the middle of the radiofrequency (RF) coil. Each sample was equilibrated to 293.00 K (conditions noted below) for a minimum of 15 minutes. Samples were shimmed using the Berger-Braun shimming method prior to collecting relaxation time data.


Aliquots of each solution were sealed into 2 mm outside diameter (OD) quartz (NiCl$_2$ solutions) or 3 mm (OD) PTFE (MnCl$_2$ solutions) NMR tubes. Quartz samples were sealed using a methane/oxygen torch to flame seal. PTFE samplers were sealed with a PTFE plug inserted 1 cm into the sample tube. A fiber optic temperature probe was positioned with the sensor in the middle of the radiofrequency (RF) coil. Each sample was equilibrated to 293.00 K (conditions noted below) for a minimum of 15 minutes. Samples were shimmed using the Berger-Braun shimming method prior to collecting relaxation time data.


Preliminary assessment of temperature dependence

Sample spheres, the same as those used in the commercial phantoms, were imaged on a 1.5 T small-bore system. A temperature-control system was used with a fiber-optic probe to achieve temperatures of approximately 10, 17, 20, 23, 30 and 37 °C.

Inversion recovery spin-echo was used to measure T1 relaxation time with: TR = 10 s, TE = 20 ms, TI = 50, 75, 100, 125, 150, 250, 500, 1000, 1500, 2000 and 3000 ms.

Spin echo was used to measure T2 relaxation time with: TR = 10 s, TE = 15, 20, 40, 80, 160, and 320 ms.
Preliminary assessment of temperature dependence

Sample spheres, the same as those used in the commercial phantoms, were imaged on a 1.5 T small-bore system. A temperature-control system was used with a fiber-optic probe to achieve temperatures of approximately 10, 17, 20, 23, 30 and 37 °C. Inversion recovery spin-echo was used to measure T1 relaxation time with: TR = 10 s, TE = 20 ms, TI = 50, 75, 100, 125, 150, 250, 500, 1000, 1500, 2000 and 3000 ms. Spin echo was used to measure T2 relaxation time with: TR = 10 s, TE = 15, 20, 40, 80, 160, and 320 ms.