Comparison of Myocardial T1-mapping Protocols: Accuracy and Precision

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INTRODUCTION

- T1-mapping in the myocardium may be used to detect both focal and diffuse disease processes
- Both the accuracy and precision of T1-mapping are important for reliable detection of abnormal elevation of T1.
- Accuracy is affected by a large number of parameters including:
  - Sequence
  - Protocol
  - tissue T1 and T2
  - fitting method
  - scanner adjustments such as center frequency.
- Precision of T1 estimates is a function of:
  - number and timing of measurements along the T1-recovery curve
  - signal-to-noise ratio (SNR)
  - tissue T1
  - method of fitting
  - other protocol and sequence parameters.
- Accuracy reflects the systematic or bias errors while precision reflects the random error due to noise.
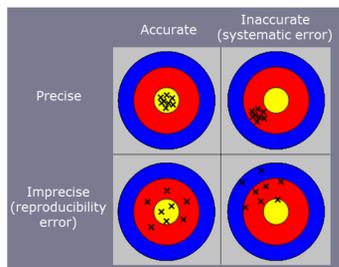

Figure 1. Illustration of accuracy vs precision

METHODS

- Accuracy and precision of several popular methods are investigated
  - Waveform level Bloch simulation to assess accuracy
  - Monte-Carlo method of repeated trials to assess precision

- Simulations validated against phantom measurements.
  - 65,536 simulated trials
  - 200 repeated phantom measurements

- Optimized inversion recovery protocols based on
  - MOLLI [1], hybrid MOLLI [2], Sh-MOLLI [3]
  - Saturation recovery method originally known as SAP-T1 [4], referred to here as SAturation-recovery single-SHot Acquisition or SASHA [5].

- Fitting models:
  - MOLLI 3-parameter fit
  - SASHA 2- and 3-parameter fits

- Protocols: acquired (recovered) acquired
  - MOLLI 3(3)3(3)5 sampling (11 images/17 heartbeats)
  - MOLLI 5(3)3 sampling (8 images/11 heartbeats)
  - MOLLI 4(1)3(1)2 sampling (9 images/11 heartbeats)
  - Sh-MOLLI 5(1)1(1)1 sampling (7 images/9 heartbeats)
  - SASHA 1(0)10 sampling (11 images/11heartbeats)
    1 steady state acquisition & 10 SR prepped images
  - MOLLI/Sh-MOLLI used TImin=105 ms, TIshift = 80 ms, FA 35°
  - SASHA used TImin=105 ms, TIshift = 80 ms, FA 70°
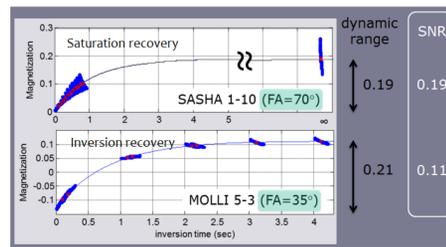 - All protocols used b-SSFP readout.

Figure 2. Illustration of SASHA (top) with FA=70° acquiring 10 SR images plus 1 initial steady state, and MOLLI (bottom) using FA=35 ° IR prepped with 5(3)3 sampling scheme.
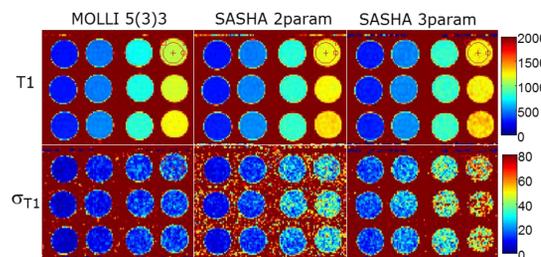

Figure 3. Phantom measurement of T1-maps and standard deviation maps (σ_{T1}) confirm accuracy and precision trade-offs between IR and SR approaches to T1-mapping
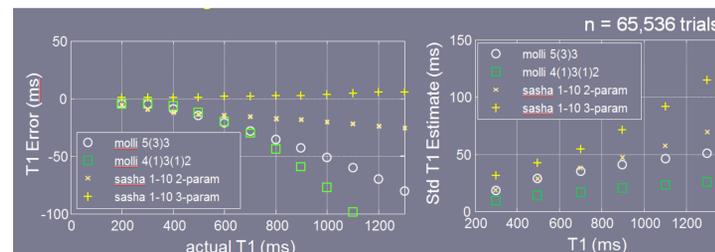

Figure 4. T1 measurement error (LEFT) for showing accuracy of various T1-mapping protocols based on waveform level simulation, and T1 measurement precision (RIGHT) for same T1-mapping protocols based on Monte-Carlo measurement of repeated trials.

RESULTS

- Measurement of T1 in phantoms (Fig 3) are consistent with simulations.
- MOLLI 4(1)3(1)2 protocol is proposed for measurements after Gd contrast at shorter T1; MOLLI 5(3)3 protocol is proposed for native (pre-contrast) myocardial T1.
- MOLLI 4(1)3(1)2 protocol achieves the best precision for post-contrast T1 with good accuracy
- IR greater dynamic range than SR (0.21 M0 vs 0.19 M0), however, the steady state magnetization of SR is greater (0.19 M0 vs 0.11 M0) results in a 1.7:1 advantage in raw SNR for 70° SASHA vs 35° MOLLI.
- SASHA precision with 3-parameter fit is considerably worse than 2-parameter fit or MOLLI (Fig 3).
- SASHA 2-param method has improved accuracy with only slightly worse precision than MOLLI for native (pre-contrast) T1
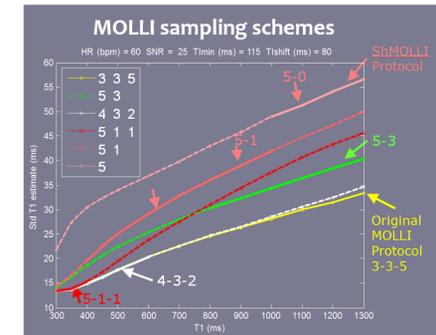

Figure 5. T1-measurement precision of various MOLLI sampling schemes versus T1 at fixed SNR.
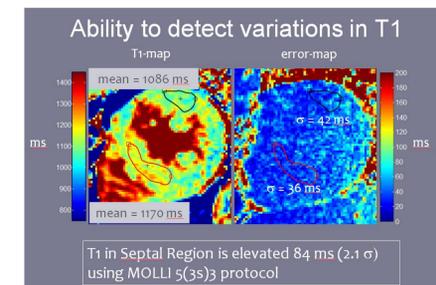

Figure 6. Precision in T1-mapping is important in order to detect small, subtle, focal elevated regions as in this example of subject with HCM.
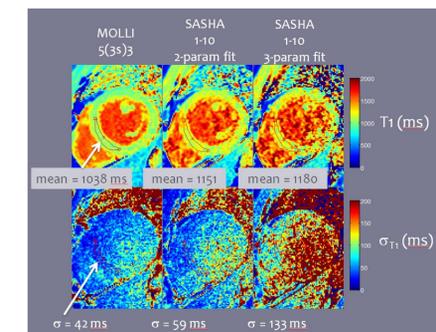

Figure 7. Invivo comparison (normal subject) of techniques illustrates tradeoff between accuracy (T1-underestimation error) and precision of MOLLI protocol versus SASHA 2 and 3 parameter fits.

CONCLUSION

- Accuracy and precision trade-offs predicted in theory are confirmed with experimental measurements in phantom.
- Protocols optimized for pre- & post- contrast
- MOLLI has excellent precision but degraded accuracy
- SASHA has improved accuracy but degraded precision
- Precision in T1-mapping is important in order to detect small, subtle, focal elevated regions.

REFERENCES

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