Calibration of ADC Values for Quantitative MRI

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1. qMRI and Diffusion weighted Imaging

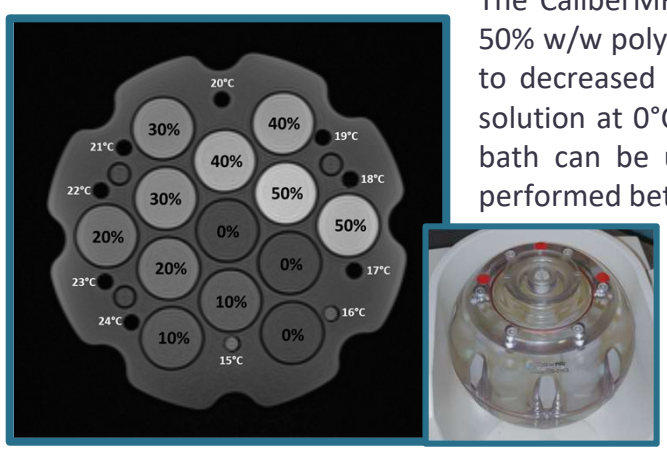
The apparent diffusion coefficient (ADC) is a measurable quantity from diffusion-weighted MRI (DWI), an MRI technique that uses the diffusion of water molecules to give image contrast. Changes in ADC have been shown to enable diagnosis, monitor disease, and predict treatment outcomes. However, poor standardisation limits clinical use. [1]

The Quantitative Imaging Biomarkers Alliance (QIBA) aim to promote standardisation of biomarkers, such as ADC, through use of phantoms and standardised protocols. QIBA specify technical performance requirements within profiles [2], and conformance to a profile gives confidence in clinical measurements.

Aims

- Evaluate a new quantitative DWI phantom and its associated analysis software
- Explore ADC calibration at room temperature
- Assess the technical performance of two MRI scanners for conformance to the QIBA DWI Profile, to confirm that high quality ADC measurements can be delivered by NHS GGC.
- Investigate the variability of ADC values depending on the choice of head coil and DWI parameters

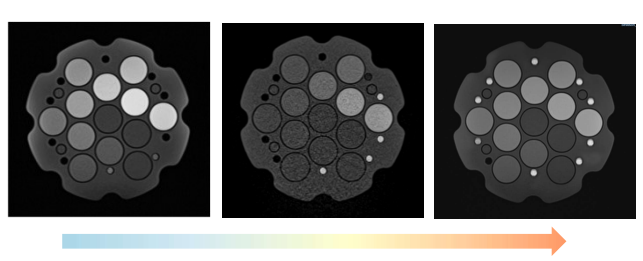
2. Methods



The CaliberMRI diffusion phantom contains 0%, 10%, 20%, 30%, 40%, and 50% w/w polyvinylpyrrolidone (PVP) solutions. Increased %PVP corresponds to decreased ADC. Traceable reference ADC values are provided for each solution at 0°C and 16-24°C, so either the phantom thermometer or an ice bath can be used. To compare the two methods, an ice bath scan was performed between two at room temperature.

The phantom allows integrated room temperature measurements with a novel liquid crystal MR-readable thermometer [3]. When imaging the phantom with a T1-weighted sequence, the phantom temperature corresponds to the number of 'bright' vials.

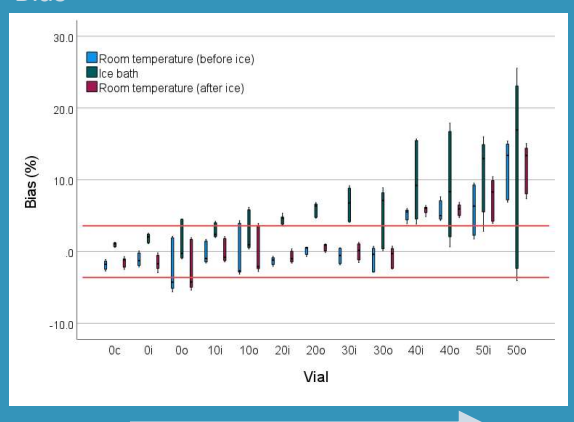
Technical performance of two scanners was assessed following the QIBA DWI profile.



3. Bias and Precision

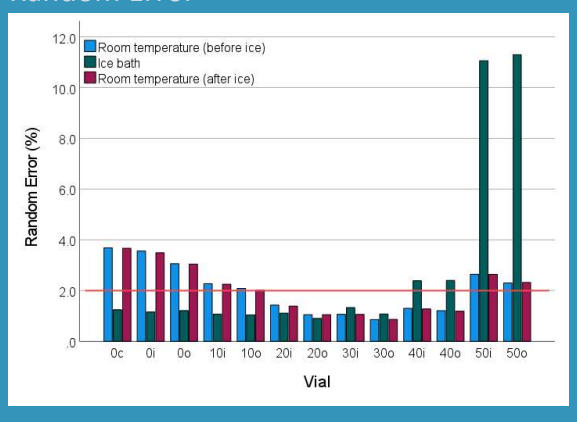
The results shown are for the 1.5T MR-Simulator at the Beatson West of Scotland Cancer Centre. Applying the QIBA tolerances (red lines) across all vials, vials with lowest ADC had inferior performance metrics, associated with an increase in artefacts with increasing %PVP. Conformance to the QIBA profile is assessed using the central water vial (0c) at 0°C, so the scanner was able to achieve conformance. QIBA tolerances specified for 0°C water generally provide a good baseline for room temperature tolerances, however, once more data has been collected at room temperature, these could be revised for routine QA.

Bias



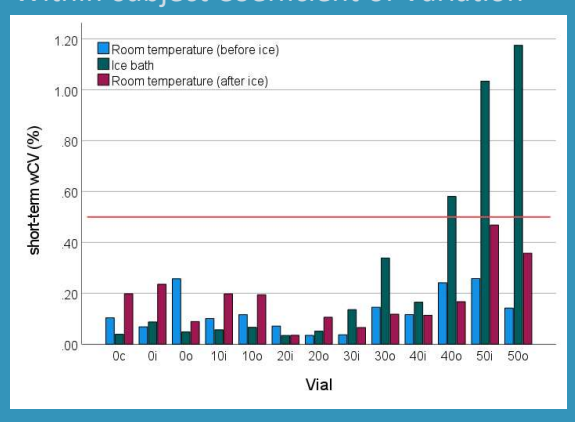
Decreasing ADC

Random Error



c = centre, i = inner, o = outer vial, value represents % w/w PVP

Within-subject Coefficient of Variation



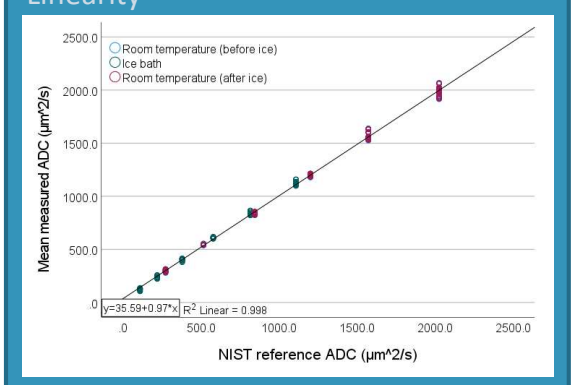
Short-term wCV of 4 immediate repeats

1.5T Siemens Sola

4. Room temperature calibration

- The liquid crystal thermometer allows integrated temperature measurements embedded in the image data; however, it has much larger temperature uncertainty compared to the ice bath method (up to +/- 1.1°C, compared to +/- 0.04°C for a digital thermometer).
- Random error of 0-10% PVP vials is outside of the QIBA tolerance at room temperature, which may be due to the decreased viscosity with increased temperature, increasing sensitivity to vibrational and convective motion.

Linearity



Ice bath (0°C)

20.5 +/- 1.1°C

'Ideal' ADC phantom [4]

- Room temperature calibration is more convenient than an ice bath and offers reduced artefacts.
- A wider range of ADC values are available at room temperature, that better reflect the range seen in the body.
- Repeatability between room temperature sessions could also be assessed, and this was within the QIBA tolerance for all vials.

5. Discussion

Both the 1.5T MR-Simulator and a 3T research scanner were able to achieve conformance to the QIBA DWI profile using an ice bath scan. Poorer performance was associated with artefacts and poor region of interest placement. Room temperature measurements showed good accuracy and precision for the central water vial, generally within the QIBA tolerances defined for 0°C, supporting that room temperature ADC calibration is possible.

Additionally, the room temperature QA protocol was performed with three different head coils on the 3T scanner, with little variation between results (0-30% PVP measured within +/- 2.5% bias for all coils), suggesting results obtained from each coil are comparable. Two clinical research protocols were successfully run on the phantom and demonstrated good performance at biologically relevant ADC values.

Key points

- Room temperature calibration of ADC measurement is possible, and covers a wider and more physiologically-relevant ADC range.
- The MR-readable thermometer allows non-invasive, integrated temperature measurements of MR phantoms.
- Conformance to the QIBA profile was achievable on both scanners tested, providing confidence in the use of ADC as a biomarker.

References

[1] K. E. Keenan et al., "Recommendations towards standards for quantitative MRI (qMRI) and outstanding needs," Journal of Magnetic Resonance Imaging, vol. 49, no. 7, pp. e26-e39, 2019.
[2] Quantitative Imaging Biomarkers Alliance, "QIBA Profile: Diffusion-Weighted Magnetic Resonance Imaging (DWI)," 2019. Accessed: July 28, 2022. [Online]. Available: https://qibawiki.rsna.org/images/6/63/QIBA_DWIProfile_Consensus_Dec2019_Final.pdf
[3] K. E. Keenan, K. F. Stupic, S. E. Russek, and E. Mirowski, "MRI-visible liquid crystal thermometer," Magnetic Resonance in Medicine, vol. 84, no. 3, pp. 1552-1563, 2020.
[4] P. S. Tofts et al., "Test liquids for quantitative MRI measurements of self-diffusion coefficient in vivo," Magnetic Resonance in Medicine, vol. 43, no. 3, pp. 368-374, 2000.