Measurement of subtle scanner instability using a stable thermally-insulated phantom

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Introduction

Dynamic contrast enhanced (DCE) imaging allows the study of changes to the blood brain barrier permeability caused by disease [1]. Imaging normal controls without contrast agent injection, has shown subtle signal changes of -0.8 to 4.8% on proton density weighted (PDw) and T_1-weighted (T1w) images during continuous imaging over 70 minutes [2]. This drift introduces errors in quantitative imaging. Possible causes of drift are listed in figure 1. Scanner instability is investigated during continuous imaging of phantoms (test objects), therefore excluding both patient and post-processing factors. Additionally, phantom temperature is stabilized to prevent temperature-dependent spin-density and relaxation time changes.

Hardware and phantom factors
Radio Frequency (RF) receiver instability
RF transmit amplifier instability
RF coil tuning
Gradient amplifier instability or coil heating
Phantom temperature
Patient factors
Patient movement
Hydration level or heart rate
Post-processing
Image registration

Figure 1. Potential causes of signal instability.

Methods & Materials

Phantoms and Thermal Insulation Eurospin T05 gel tubes [3] were insulated within a phenolic foam cylinder [4], shaped to fit inside a saline filled loading-ring. Prior to acquisition, each component was equilibrated to room temperature. Six thin T-type thermocouple probes were positioned to monitor the temperature of the phantoms, an internal air cavity, the loading ring and the scanner bore.

Image Acquisition Alternating PDw (Gradient Echo TR/TE/FA 1500/11/45) and T1w (Spoiled Gradient Echo 50/11/45) images were acquired on a 1.5 T Signa Excite scanner with whole body 33mT/m gradients (General Electric, Milwaukee, WI). This was repeated approximately seven times over 80 minutes. On two occasions, data acquisition was continued for up to 250 minutes. Transmitter gain, receiver gains and the central frequency were set automatically for the first scan and kept constant thereafter. Data were collected before and after an upgrade of the scanner software (5.x to 11.x) and the RF and gradient hardware. For phantoms, 14 slices were collected in 6 minutes (PDw) and 4 minutes (T1w). Human control data were acquired using the same sequences, 28 slices being acquired in 12 minutes (PDw) and 8 minutes (T1w).

Temperature Monitoring Temperatures were recorded relative to an ice-water reference using a dual input digital thermocouple meter. A signal dropout of 2-4mm radius around the thermocouples was observed but this did not interfere with image analysis.

Data Analysis The mean background noise was measured in large regions of interest (ROIs) on all slices. The signal from each gel was measured by averaging over five ROIs. Exponential curves were fitted numerically to the signal as a function of time from which the initial rate of change (iROC) was calculated at the time of the first T1w image. Linear regression in SPSS software was used to test iROC for the effect of T_1 value, PDw versus T1w, previous scanner usage (hours) and the scanner upgrade. The signals from different gel tubes in the same image were then normalized relative to the first time point, and averaged. This was used to compare phantoms with human subjects.

Gradient Stability As a separate experiment, a 3D volume phantom was scanned repeatedly with a 3D SPGR sequence for 300 minutes during the night. Phantom temperature was not controlled. To test for stretches in the image X, Y, and Z dimensions, images were co-registered to the first time point with translations, rotations and linear scale factors as free parameters [5]. The signal variation for regions within the phantom was compared with the signal in an ROI surrounding the phantom to detect intensity scaling due to voxel size change.

Figure 2 Temperature Stability

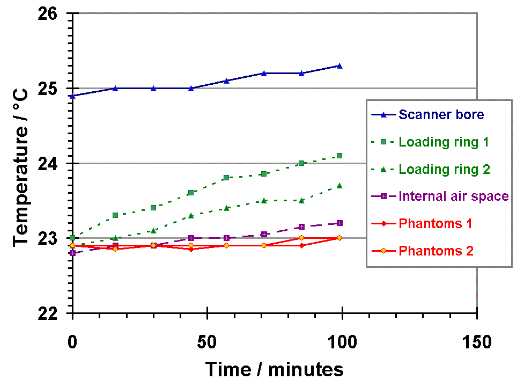
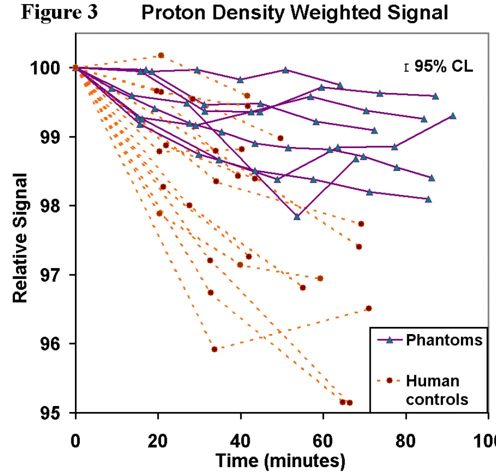


Figure 3 Proton Density Weighted Signal



Results

Temperature Stability Insulation reduced phantom temperature variation to 0.1 ± 0.1°C per hour (95% Confidence limits). The mean difference between phantom and bore temperature was 1.3 ± 1.6°C (95% CL). Figure 2 compares temperature variation in phantoms with other components

Signal Intensity Stability A temperature rise of 0.2°C is expected to give a 0.06% decrease in PDw signal and an increase of 0.4% in T1w signal. Figure 2 shows signal intensity changes of 0–2.2% were observed in phantoms, compared to -0.8–4.8% for human controls. The 95% confidence interval of 0.05% shown for phantoms is based on the signal in background noise [6-7]. The background noise averaged over the slices outside the phantoms did not correlate with signal change in phantoms.

Gradient Stability Co-registration gave scaling factors of less than 0.05%, in the X, Y and Z directions which could account for a signal change through change in voxel size of at most 0.2% over 300 minutes. The actual measured signal change was 5%, independent of ROI location. ROIs enclosing the object measured the same change as ROIs within it. This implies that the observed intensity changes arise from factors other than gradient instability.

Data Analysis The T_1 value of phantoms did not affect iROC. Linear regression showed a significant difference (P=0.032) between phantoms and controls in the iROC. The other variables in the model, T1w versus PDw, Previous scanning time, and the upgrade failed to reach significance. If found, a significant difference in drift between PDw and T1w signal would imply RF transmitter instability. That none of these factors correlates with the iROC suggests other, possibly environmental factors should be investigated. Both human and phantoms show a non-zero iROC ($P < 0.001$).

Discussion and Conclusions

1) Stabilizing phantom temperature with phenolic foam insulation reduced temperature related signal changes to below 0.1% (PDw), enabling subtle scanner changes of 0–2.2% to be measured over the course of 70 minutes continuous scanner operation. **2)** Phantoms were shown to have a lower initial rate of change of signal than human controls. **3)** A global change in mean background noise signal, implying RF receiver change, was not detected. **4)** A separate experiment suggests that gradient instability accounts for a small fraction (4%) of the total observed change. **5)** Initial rate of signal change was not found to be dependent on previous scanner usage. The drift of signal intensities appears to be non linear with time, with behaviour over a range of time constants. In general the signal tends towards a baseline value after hour of continual use. Further characterisation and understanding of scanner instability may lead to increased sensitivity of DCE imaging.

References [1] Tofts PS, (1991) Magn Reson Med. 17:357-67 [2] Soon D, (2003) Measurement of BBB permeability in MS. Proc: MR Techniques in MS, 7th Adv. Course, Milan, Italy [3] Lerski RA, (1993). Magn Reson Imaging 11: 817-833 [4] Tofts PS, Personal Communication [5] vtkCISG version 2.0, www.image-registration.com [6] Tofts PS (2003) Quantitative MRI of the Brain, page 35, Wiley, Chichester. [7] Edelstein WA, (1984), Med Phys 11: 180-185

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