The ADNI Phantom and Analysis Algorithm: A New and Accurate Tool to Measure Scanner Performance

J. L. Gunter[1], P. J. Britson[1], J. P. Felmlee[1], C. P. Ward[1], N. Schuff[2], M. Weiner[2], J. Levy[3], and C. R. Jack,Jr.[1]

[1]Mayo Clinic and Foundation, Rochester, MN, United States, [2]UC SanFrancisco, SanFrancisco, CA, United States, [3]The Phantom Laboratory, Salem, NY, United States

Introduction: The Alzheimer's Disease Neuroimaging Initiative is a five year natural history study of Mild Cognitive Impairment and Alzheimer's Disease. Eight hundred (800) elderly individuals will be scanned on eighty (80) different MRI systems at approximately 6 month intervals with some variation determined by clinical disease state. All subjects are scanned at 1.5T and 25% are also scanned at 3T. In total over 5000 MRI studies will be performed at sites which cover the spectrum from academic to community setting. To facilitate longitudinal tracking over the five year project, individual subjects at a given MRI site are scanned on only one MRI system at each field strength.

In order to track the performance of the systems, each enrolling site has received a phantom which was designed specifically for this study. The phantom is imaged at the end of each scanning session for each patient at every time point. This guarantees that nearly contemporaneous phantom images will exist on all days in which ADNI subjects are scanned on a given system. This abstract reports on the observed variation in voxel scaling for 55 systems (42 1.5T and 13 3.T) over approximately one year.

Materials and Methods: The ADNI phantom is a water-filled 20 cm diameter shell with 158 1.0 cm diameter spherical inclusions, two 1.5 cm diameter spherical inclusions, four 3.0 cm diameter spherical inclusions and one 6.0 cm diameter spherical inclusion. The 1.0 and 1.5 cm diameter spheres contain 3.3 mM copper sulfate solution, are positioned at known locations, and are used to measure spatial distortion. Additionally, location and size asymmetries in the layout of the smaller spheres allow the overall orientation of the phantom to be uniquely determined. The larger spheres (3.0 and 6.0 cm diameter) are used for measurements of T1 contrast and signal to noise. The 6.0cm sphere is has the greatest T1 contrast and is approximately concentric to the 20cm outer shell. The 3.0cm spheres are approximately 6cm from the center of the phantom.

Each phantom scan is analyzed to find the small contrast spheres. An affine transformation is determined which takes the known positions of contrast spheres in the physical phantom into the space of the spheres as determined from the scan. The transformation can be decomposed allowing one to determine the relative scaling along each principal axis in the scanner. Ideal scaling factors would be unity. For ADNI purposes, no attempt is made to disentangle specific underlying causes of scaling which could, for example, include gradient amplitude calibration and/or details of frequency encoding waveforms. The measured scaling factors are tracked over time for each scanner. The time course of scaling along the Z-axis for a single scanner is shown in Figure 1. There are four discrete clusters in time over which the scanner was quite stable. The discontinuities occurred when the scanner underwent upgrades and gradient hardware re-calibrations.

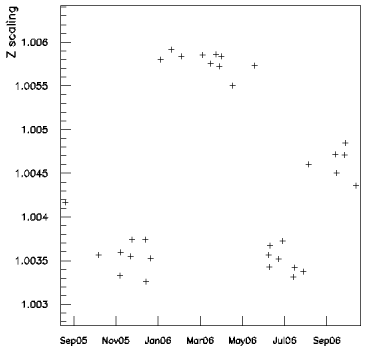

Figure 1. Time course of observed scaling along the Z-axis of a single MR scanner. The discrete jumps correlated with system upgrades and recalibrations.

To date a total of 622 phantom scans from 49 1.5T and 25 3T scanners have been acquired and analyzed. In order to investigate scanner stability only systems for which at least three scans were present were used in the following analysis, leaving 42 1.5T systems and 13 3T systems. For each scanner the time series of scale factors in the logical X, Y, and Z directions are summarized by a mean and square root of pooled variance over time clusters. Time clusters are defined by jumps in value of more than four standard deviations. Most scanners have only a single cluster to date and the pooled variance reduces to the simple variance. In the case of multiple clusters, however, this removes variance introduced by systematic shifting of the mean at discrete times. Shown in Figure 2 are plots of the mean scale factors (pooled variance reflected in the error bars) for all scanners with three or more scans. Separate vendors are enumerated 1, 2 and 3 and plotted with black, red and blue symbols respectively.

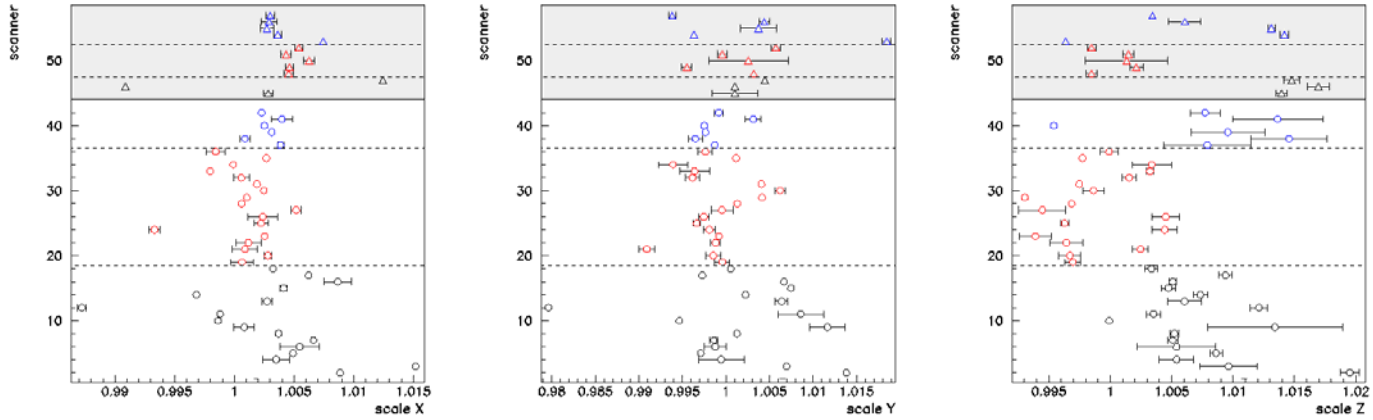

Figure 2. Plots of mean gradient scaling factor for 42 1.5T systems and 13 3T systems are shown. The horizontal error bars are the square root of the pooled variance for each system. Scanner number is purely for enumeration purposes. Scanners are grouped by field strength (1.5T shown with circles, 3T with triangles over a grey background). Symbol color represents MR system manufacturer, e.g. red circles for 1.5T and red triangles for 3T are from the same vendor. Horizontal lines delineate transitions across vendor or field strength. Points with no apparent error bars have error bars smaller than the symbol.

Results and Conclusions: The range of scale values across all systems in the study is 1-2%; the standard deviations of the distributions of per scanner mean scale factors (X,Y,Z) are (0.4%,0.5%,0.6%) for 1.5T systems and (0.5%,0.6%,0.7%) for 3T systems. Variability within a single scanner is smaller. Allowing for discrete calibration adjustments and using a pooled variance approach, the average standard deviations of scale factors across individual scanners are (0.04%,0.07%,0.11%) at 1.5T and (0.03%,0.10%,0.07%) at 3T. Variability across scanners along the Z-axis is larger than other axes. At 1.5T intra-scanner variability is largest along the Z-axis. At 3T intra-scanner variability is largest along the Y-axis. These data provide insight into the variation within and across scanners that can be expected in large multi-site studies. Compared to existing tools (e.g. the ACR-NEMA phantom), the ADNI phantom and analysis algorithm offers dramatically improved ability to monitor scanner performance. Highly accurate monitoring of geometric fidelity is critically important for both single and multi-site studies which incorporate quantitative imaging into the study design.