Reproducibility of Shear Modulus Estimates in Clinical Steady State MR Elastography

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Introduction: Reproducibility is critical to longitudinal studies or studies comparing multiple subjects. Significant effort has been expended to measure the accuracy of the shear modulus estimates obtained from MR elastography (MRE)[1]. Conversely, very little data has been generated establishing the reproducibility with patients in a clinical context. The reproducibility in phantoms is 3% for repeated measurements without moving the phantom and 5% when the phantom was moved[2],however, reproducibility in humans is much more difficult to ascertain because there are more diverse sources of error: 1) positioning variations, 2) computational noise in the reconstruction, 3) motion during the scans, 4) image noise. In this set of experiments we were able to estimate the magnitude of the error generated from the first and second and the combination of the third and fourth sources of error.

Methods: The reproducibility of the method was estimated by repeated scanning of the heel fat pad on a GE 1.5T scanner using previously described methods[3,4]. Six subjects were scanned three times on different days (termed non-consecutive) and three of them were scanned three more times in the same session without changing the position of the foot (termed consecutive).

All four factors contribute to the variation between non-consecutive scans but only the last two contribute to the variation between consecutive scans so the difference is the combination of the first two factors. Computational noise is largely dominated by calculating on different finite element meshes which amplifies the noise in the data differently and results in some variance in the reconstructed modulus. Data from four randomly selected subjects was reconstructed on three different overlapping regions and the variation in the shear modulus in the volume common to all three provided an estimate of the computational noise.

Results: The shear modulus reconstructions are summarized in Table 1 where the average shear modulus is presented with some demographic data for each subject. Estimates of the computational noise from the four subjects, the standard deviations of the mean shear modulus in the common region, were 3.43%, 3.50%, 2.26%, and 3.11% for the four data sets so the computational noise was estimated to be 3.0%.

Table 1: Showing the reproducibility of the mean value of the reconstructed shear modulus for all 6 of the subjects.

Age	Gender	Weight	# of Scans	μ (kPa)	Non-Consec/μ%	Consec /μ%
27	M	150	6	4.571	10.7	1.0
37	M	185	6	4.463	10.8	9.3
51	M	210	6	5.043	3.8	5.6
52	F	105	3	3.877	11.0	-
64	M	165	3	4.937	2.6	-
76	M	190	3	5.538	7.6	-
			Mean Errors:		**7.75% ± 3.76%**	**5.30% ± 4.16%**

Discussion: The consecutive scans average 5.3% error which represents the combination of the third and fourth factors: patient motion during the scan and MR noise. This is congruent with the average error in repeated phantom scans, 3%, where there is no motion. Patient motion was estimated from the movement of a level set contour from one image to the next. Most of the motion occurs between scans when the scanner noises are interrupted so the phase contrast estimates of motion were largely uncorrupted but were simply translated.

The variation due to positioning error depends on the spatial variation of the shear modulus within the structure imaged; positioning is irrelevant in a homogeneous media. MR noise depends on the SNR in the raw MR images which depends on the experimental set up and coils used but the SNR obtained in the heel is not radically different from that obtained in the breast. Beyond these factors, the results with minor changes are applicable to other types of MRE scans; i.e., computational noise scales directly with SNR and patient motion should be similar for most other scans.

Conclusions: Reproducibility of repeated measurements of the shear modulus is 7.8% which is relatively small compared to changes in the shear modulus from pathology which can be a factor of four to ten. Positioning error was 4.8%; computational noise was 3.0%; and the MR noise and patient motion during the scan accounted for 5.3% error.

References:

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