Defining the interactions of SNR and resolution in classifying carotid plaque

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Introduction

Carotid plaque composition is believed to be a stronger indicator of stroke risk than the predominant clinical measure of atherosclerotic disease burden, which is degree of stenosis. Combining several MRI contrast methods with various automated classification techniques has been a focus of recent research to differentiate plaque composition. The majority of this research uses excised plaque (endarterectomy) specimens, where multi-hour scans and specialized hardware (including closely coupled RF coils, high field MR and specialized gradient coils) produce very high resolution, as well as high signal to noise ratio (SNR) images.

The accuracy in differentiating components of endarterectomy specimens is continually improving through refinement of imaging sequences, scan parameters and classification tools. However, with the time and hardware constraints of in-vivo imaging, it is unclear how well these classification routines will transfer to patient studies. The main effects of moving from an ex-vivo to an in-vivo system will be loss in both resolution and SNR. As such, we investigated how plaque characterization accuracy using multi-contrast MRI and the maximum likelihood classification algorithm is affected by reduction in SNR or resolution or both.

Methods

Fifteen endarterectomy specimens were imaged using the three best contrasts found to date for plaque compositional assessment [1]: proton density weighted (PDw), T2w and diffusion weighted (Dw). Imaging was done on a 1.5 T GE CV/i scanner with the use of a 2 cm diameter solenoid RF coil, and custom-made gradient insert coil. Resulting in-plane resolution was 156µm, slice thickness of 0.5 mm for PDw and T2w, and 1 mm for Dw. SNR was approximately 57 for PDw, 33 for T1w, and 9 for Dw. The specimens were then sectioned, stained, imaged by conventional light microscopy, and resulting multi-colour histological images classified manually by a pathologist. Forty-five of the histological slices were matched to the MR images using a non-linear registration algorithm, and formed the data set used. The maximum likelihood classifier used the intensity from each of the three MR contrast methods as features, and segmented each of the 45 slices into up to 5 components: fibrous tissue, loose connective tissue, necrotic tissue, calcification, and hemorrhage. The classified slices were then compared on a per pixel basis to the segmented histology. Classification accuracy, defined as the percentage of correctly labeled pixels, was found to be 72%.

The SNR and resolution of the original images were then degraded; SNR was decreased to 50%, 25%, 12.5%, 6.25%, and 3.125% of the original SNR; in plane voxel linear dimension was increased to 312µm, 625µm, and 1250µm in each of the two in-plane dimensions. SNR was decreased by adding white Gaussian noise to the real and imaginary components of k-space. Taking the magnitude image of the fourier transform of the modified k-space data resulted in characteristic MRI Rayleigh distributed noise. Resolution was degraded by filtering the k-space data with a hanning window to remove the high spatial frequency information that would not have be included in actual scans at lower resolution. The maximum likelihood algorithm classified the 45 plaques at each combination of SNR and resolution.

Results

Figure 1 depicts one plaque which has been classified at various levels of SNR and resolution reduction. Each of the instances of classified plaque was compared on a per pixel basis to the classified histology (Figure 2). Table1 shows the resulting accuracy, normalized to the accuracy of the best ex-vivo parameters (highest SNR and spatial resolution), and averaged across the entire plaque data set. Accuracy decreases according to a two-way interaction with decreased SNR and decreased resolution. However, at low to moderate decreases in resolution and SNR, we do not see sizeable differences in classifier accuracy. Table1 also displays in superscript the relative acquisition time, a value that provides an overall imaging benefit of each given SNR and resolution pair; the lower the relative acquisition time, the greater the benefit.

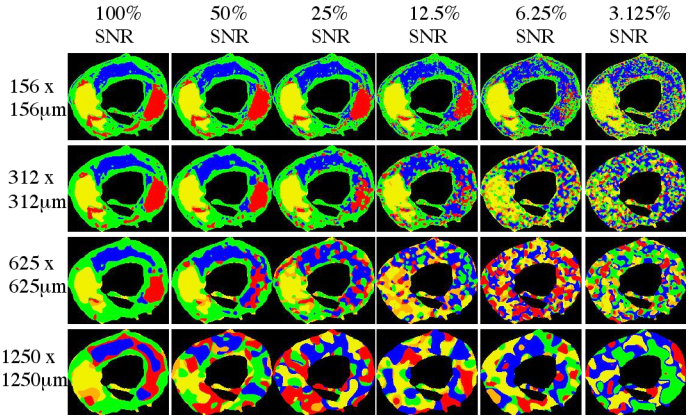

Figure 1 – Classified plaque at various resolution and SNR values. Green is classified as fibrous, red is necrotic, blue is loose connective, yellow is calcification and purple is hemorrhage.

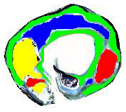

Figure 2 - Classified histology

Table1 – Relative classification accuracy as a function of SNR and in-plane resolution for complete data set with relative acquisition time in superscript

In plane resolution (µm)	% of original SNR: 100% SNR	50% SNR	25% SNR	12.5% SNR	6.25% SNR	3.125% SNR
156x156	1.00 (1)	1.00 (0.25)	0.99 (0.06)	0.92 (0.02)	0.75 (4e-3)	0.53 (1e-3)
312x312	1.01 (0.06)	1.00 (0.02)	0.89 (4e-3)	0.73 (1e-3)	0.44 (2e-4)	0.38 (6e-5)
625x625	0.95 (4e-3)	0.81 (1e-3)	0.63 (2e-4)	0.26 (6e-5)	0.26 (2e-5)	0.29 (4e-6)
1250x1250	0.58 (2e-4)	0.35 (6e-5)	0.30 (2e-5)	0.39 (4e-6)	0.36 (9e-7)	0.35 (2e-7)

Legend for Table1

Colour					
Reduction in accuracy	< 2%	< 15%	< 30%	< 45%	> 45%

Discussion

These above accuracy results can be directly applied as a guide in designing in-vivo imaging protocols. For example, a minimum of 625µm in-plane resolution, independent of SNR is required to achieve an overall accuracy within 5% of the ideal ex-vivo accuracy. However, in order to best use these results as a guide for future studies, we need a unifying measure that amalgamates the concepts of decreased SNR and decreased resolution. This would allow us to choose the best pairing of resolution and SNR decrease, from pairs with similar classification accuracy. The common factor of acquisition time $time \alpha \left(SNR / \Delta x \Delta y \right)^2$ provides such a measure. Using it, we determine that of the SNR-resolution pairs with less then 2% decrease in accuracy, the greatest acquisition time decrease, or 'time advantage' occurs at in-plane resolution of 312µm, with SNR decreased to 50% of its original value. The derivation of a general formalism for stating SNR and spatial resolution requirements to achieve minimum scan-time, subject to the constraint of sufficient overall accuracy in plaque compositional assessment, is likely to evolve from these initial efforts.

References

[1] Clarke SE, et al. *Magn Reson Med.* 2003 Dec; 50(6):1199-208.