Temporal Texture Analysis of Normal Appearing White Matter in Multiple Sclerosis

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Synopsis
Detecting abnormalities in normal appearing white matter (NAWM) may help reveal the subtle pathological changes in multiple sclerosis (MS). We developed a novel texture analysis technique based on the polar S-transform (PST), a localized Fourier transform providing local frequency information with multi-scale analysis. We applied this algorithm to analyze regions of NAWM on serial T1-weighted Gadolinium-enhanced MRI, and detected early textural changes even before lesion activity becomes evident in terms of focal contrast-enhancement.

Introduction
Tissue image texture refers to a local characteristic pattern of image intensity that identifies a tissue, such as the subtle “mottle” pattern in NAWM on T2-weighted (T2-w) MRI. Our hypothesis is that as WM becomes abnormal, its underlying texture in MRI may change. Our goal is to develop a sensitive technique to detect subtle textural changes within NAWM, particularly to investigate whether those subtle changes predict subsequent MS lesion formation. Texture analysis using statistical approaches has been applied with some success to the spinal cord, the brain in MS, and other diseases. However, limited success was found in analyzing cerebral NAWM. Texture, by definition, also determines local spectral/frequency content in an image; therefore, texture in this study is defined by local frequency content. The polar S-transform is a new localized Fourier analysis combined with the multi-scale scheme in wavelets. Thus, it provides local Fourier spectral information around each pixel. In addition, the PST has a unique representation of an image, i.e., subtle image intensity changes yield different local frequency distributions. Furthermore, the PST is rotation-invariant, i.e., rotating an image does not change its spectrum. These properties suggest that texture analysis via the PST may provide information on subtle structural changes.

Methods
One patient with relapsing-remitting MS was examined monthly over a 2-month period on a 3 Tesla MR scanner (GE, Waukesha, WI). In each examination, cross-sectional T1-weighted (T1-w) pre- and post-contrast and T2-w images were acquired. The Day 0 scan as a reference, all scans were co-registered by rigid body mappings and corrected for signal intensity variation by calibrating intensity of ventricular CSF over time. MS lesions were identified by a neuro-radiologist. Regions of two T2-w lesions were selected for detailed analysis: an inactive lesion over Days 0-60 and an active lesion first evident at Day 60. For each lesion, an ROI in the T2-w image was centered over each lesion large enough to include surrounding NAWM; the same ROI was then placed in the co-registered T1-w Gadolinium(Gd)-enhanced images at all time points. Texture analysis was performed on each ROI in the T1-w Gd-enhanced images in the following way: the PST spectrum of the ROI was computed to generate a local 2D Fourier spectrum for each pixel; the 2D local Fourier spectrum was reduced into a local 1D spectrum by integrating it along rings of constant width (0.33 cycles/cm) in the Fourier plane (i.e. k-space). The local 1D spectrum of a 5x5 ROI within the lesion was averaged and normalized for display and analysis.

Results
Figures 1 and 2 show the average local 1D spectra derived from the T1-w Gd-enhanced images, from the inactive and active lesions, at 3 examination time points. Note that low frequencies correspond to coarse texture while high frequencies to fine texture. Within the inactive lesion (Figure 1), there is little low frequency content (≤4 cycles/cm); most spectral energy is distributed over frequencies 4-10 cycles/cm. This pattern is maintained over time. Figure 2 shows the spectral pattern over time from a region of NAWM that developed a new lesion at Day 60. The Day 60 spectrum is markedly different from both the NAWM and inactive lesion spectra, with high spectral energy at low frequencies (≤4 cycles/cm). More interestingly, this spectral difference is already detected at Day 30: the Day 30 spectrum increases slightly at low frequencies than that of Day 0, indicated by the arrow.

Discussion
Serial texture analysis of T1-w Gd-enhanced MRI demonstrated that significant spectral differences exist between active lesions and NAWM at low frequencies. We also detected a subtle shift of local spectrum towards low frequencies prior to the appearance of a new lesion. These findings suggest that local texture analysis via the PST may help provide an early indication of MRI intensity changes in NAWM in MS.

References