Spinal cord is affected by a number of diseases, such as multiple sclerosis (MS) and traumatic injury. MRI-based quantitative information could greatly help in noninvasive and objective evaluation of spinal cord pathology and therapeutic efficacy. Extraction of quantitative information from spinal MRI requires significant image processing. The most commonly extracted quantitative measures from spinal cord include atrophy, diffusion measures, lesion segmentation, and perfusion. While robust processing methods are developed and applied to brain MRI, quantitative analysis of spinal cord MRI is rather limited for a number of reasons. Here we review some of the processing methods that are relevant for extracting quantitative information about spinal cord pathology.

**Image Preprocessing**: The image preprocessing steps that are described below are necessary to condition the images for quantitative analysis. The preprocessing steps include: 1) image denoising, 2) intensity inhomogeneity correction, 3) spinal cord extraction, and 4) image registration.

**Denoising**: Because of the small structure, MRI of spinal cord tends to be noisy. The noise is generally minimized by the application of appropriate filters. Filters such as median and Gaussian can reduce noise, but they also tend to blur the images. Adaptive filters such as anisotropic diffusion filters (1) Perona and Malik) are commonly used to reduce the noise without concomitant image blurring. Recently, nonlocal means (NLM) filter was proposed, which seems to outperform the anisotropic diffusion filter (2). The computational burden of the NLM filter can be considerably reduced by adapting a block-wise approach (3).

**Intensity Inhomogeneity Correction**: Generally spinal cord images are acquired using phased array coils. These coils introduce significant intensity inhomogeneity in the images. While this does not have a significant effect on qualitative image interpretation, intensity inhomogeneity has significant effect on quantitative image analysis. Bias or intensity inhomogeneity correction is an area of considerable interest (see for example 4). The performance of the most popularly used retrospective bias correction techniques has been reviewed (5, 6). These comparative studies suggest that N3 (7) and bias field corrector (BFC; 8) work best. All these algorithms have been mainly focused on T1-weighted images of brain and their performance on the T2-weighted
images is unknown. This is particularly relevant since T2-weighted images are commonly used for visualizing pathology in spinal cord. Recently, Hui et al (9) proposed a statistically robust algorithm that is based on the reconstruction of inhomogeneity field from the partial derivatives involves simple step-wise integration from the partial derivatives. This algorithm is fast and is independent of the structure being imaged. Its performance is comparable to the best published algorithms.

**Spinal Cord Extraction:** Extraction of spinal cord from MRI is a critical step for tissue segmentation and estimating atrophy. Many SC extraction techniques are slow and involve considerable human intervention (10-12). This introduces significant operator bias and is not practical when the analysis involves a large number of images. An automated and fast technique based on polar B-spline snake was developed to extract the spinal cord from the MR images (13). Typical results obtained using this algorithm, are shown in Fig. 2. A similar method was also proposed by Mukherjee et al (14).

**Image Registration:** Image registration is critical for correcting some of the artifacts seen in MRI (such as DTI and fMRI) and for group analysis. Image registration is well developed for brain, but these techniques are suboptimal for spinal cord. The movement of the spinal cord due to physiological motion will have a significant effect on the spinal cord registration. In addition, lack of well defined landmarks in spinal cord images pose problems in image registrations. Currently, registration modules in the software packages such as SPM (http://www.fil.ion.ucl.ac.uk/spm/) are used for registering spinal cord images.

**Image Quantification:**

Atrophy represents neurodegeneration and is of considerable interest and importance in multiple sclerosis (MS) and traumatic spinal cord injury (SCI). For example, relatively strong correlation between atrophy and clinical disability has been consistently demonstrated in MS (see for example, 14). Similarly, cord atrophy is an important measure for following the

![FIG. 2. Contours detected using our technique (green) and expert drawn contours (red) in slices rostral to T7 (left), at T7 (middle), and caudal to T7 (right) for normal rat (Deng et al)](image-url)
progression of SCI and evaluating the treatment efficacy (13). Atrophy calculation is straightforward after the spinal cord is extracted.

The usefulness of DTI has been demonstrated by multiple investigators in a number of pathologies, including MS and SCI. DTI measures are particularly useful in detecting pathology in the so-called normal appearing tissue that appears normal on conventional MRI, but is abnormal. The most commonly used MRI measures or fractional anisotropy (FA) and mean diffusivity (MD). FA is affected both by myelin and axonal morphometry and is not pathologically specific. There is some evidence that individual diffusivities may provide information that is pathologically more specific (16). For example, radial diffusivity is thought to reflect compromised myelin, while axial diffusivity is more sensitive to axonal damage. However, this interpretation is not always consistent (17, 18). But there is some evidence that radial diffusivity may have a predictive value in MS (19).

Lesion segmentation is a very active area of research in brain. However, except for recent studies in rodents that implemented segmentation techniques (20), lesion segmentation in spinal cord tissue in humans is based mainly on manual tracing. However, there is no reason why segmentation techniques developed for brain cannot be adapted for spinal cord.

References: