Reproducibility of automated measurements of Diffusion Tensor Imaging at 3T Using Histogram Analysis

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Background and Purpose:

Quantitative analysis of diffusion tensor imaging (DTI) has proven to be a very useful technique in tracking and detecting neurodegenerative diseases such as Parkinson's disease (PD), Alzheimer's disease (AD), and Multiple Sclerosis (MS). Although numerous studies have been conducted validating the reliability of measurements taken from segmented regions using 1.5T scanners, very few have been done using 3T scanners.[1,6] Reliable scan modalities at 3T will allow for clinicians to detect the onset of these neurodegenerative diseases earlier than scans acquired at 1.5T due to the increased spatial resolution.[3] By using an integrated automated data analysis pipeline, DTI measurement variability at 3T and human error can be minimized. This study further investigated the reliability of the histogram approach and compared it to another commonly used mean approach for deriving FA metrics.[2] Manual method was also conducted to demonstrate the benefits of using automated post processing methods.

Methods:

MR Image Acquisition: MR Image Acquisition: Nine healthy volunteers (8 males, 1 female, mean age 35.1 yrs.; range: 21-59) were scanned twice in an interval of one week. Images were acquired using a 3 Tesla Siemens system (MAGNETOM Verio, Siemens Healthcare, Erlangen, Germany). DTI was performed with an echo planar sequence and bandwidth of ±1132 Hz. A b=0 reference image and 13-26 diffusion-weighted images with a b-value of 1000 sec/mm² were acquired at each slice location (FOV: 256 mm, matrix size: 2.0×2.0×2.0 mm , TR= 9800ms).

Quantitative Analysis of Diffusion Tensor Imaging

FA Map:Pixel-by-pixel maps for fractional anisotropy (FA) maps were constructed on a Linux workstation using FDT (FMRIB's Diffusion Toolbox). ***Segmentation:*** Automated segmentation was implemented on the structural MR using FreeSurfer (1). ***Co-registration*:** FA maps were spatially aligned to the structural MR providing brain regional masks.. Segmentation masks for 14 regions of interest (ROI's) were projected onto the DTI maps to mask out and produce a separate NIfTI-1 file (.nii) for each ROI. This procedure was fully automated and required no operator intervention. The ROIs used in this study include: CC Anterior, CC Posterior, as well as left and right: Caudate, Cerebral Cortex, Cerebral White Matter, Hippocampus, Putamen and Thalamus Proper. ***Production of histogram metrics:*** Histogram production was automated using a custom Matlab program. Seven metrics were calculated from the Gaussian fits of each histogram. Peak height, peak location, mean, median, Median 25%, Median 75% and Interquartile Range (IQR) were determined for each ROI of each patient.[5] ***Production of mean***: Mean FA was computed as average of FA of total pixels within each ROI. ***Manual measurements*:** ROIs corresponding to aforementioned automated ROIs were manually traced to derive the mean FA using Siemens' Leonardo workstation (software: Syngo MMWP).

Statistic Analysis: The reproducibility of the segmented regions was determined by calculating the coefficient of variance (COV=SD/Mean %), intraclass correlation coefficient (ICC) and instrumental standard deviation (ISD) for each region. Bland-Altman analysis was used to estimate the SD of a single measurement, and ISD is calculated as the root mean square (RMS) value of the differences divided by 1.4.

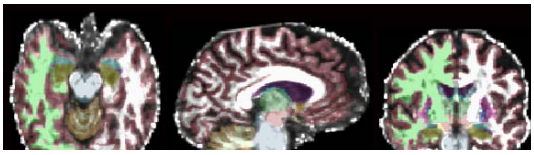

Figure 1: Automated Brain Mask overlaid on FA map displayed in three special orientations (from left to right: axial, sagittal and coronal.

Table 1: Comparisons of the Reliability Measures of the Automated and Manual Methods and FA Metrics

			Average COV	Average ICC	Average ISD
Automated	Histogram	Median 75%	7.15%	0.91	0.01785
		Mean	7.12%	0.90	0.015
		Median	7.90%	0.87	0.01429
		Peak Location	9.21%	0.85	0.01786
		Median 25%	9.41%	0.78	0.01429
		IQR	13.75%	0.87	0.01357
		Peak Height	16.00%	0.72	0.70714
	Mean Approach		7.59%	0.75	0.01583
Manual			17.72%	0.18975	0.0425

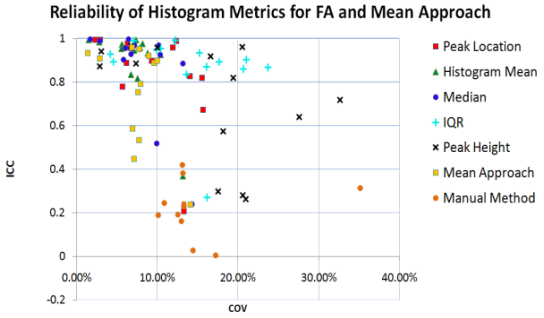

Figure 2: Reliability of quantitative metrics of FA at 3T. Each point represents a single ROI. The high concentration of points in top left region indicates higher ICC and low COV. The median (blue circles) and histogram mean (green triangles) appear to have the greatest concentration in the region of high reliability.

Results: Good to excellent scan-rescan agreement of FA measurements (ICC>0.7 and COV<10%)[4] were seen in 5 of the 7 histogram metrics. Among the histogram approach, the Peak height and IQR were less reliable with COV above 10%; the ISD of peak height was above 0.7 indicating large instrumental variations. When compared to the more commonly used mean approach the other 5 histogram metrics, including peak location, histogram mean, median, and median 25% and 75% were superior, if not comparable, to the mean approach (see table 1). Additionally, all of the automated metrics outperformed the manual method. Figure 2 is a scatter plot that illustrates that the automated methods are more concentrated at the top left corner with higher ICC and lower COV compared to the manual method that located at the low right corner (orange dots at low right corner).

Discussion: While the mean approach had been used in the past, this study indicated that several histogram metrics such as mean, median and peak location have greater reliability for deriving FA metrics. These findings suggest histogram metrics may be a useful in complement to the mean approach in the longitudinal investigation of neurodegenerative diseases such as Alzheimer's and Parkinson's.

References:

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