Automated liver parenchyma and vessel segmentation in radial Gradient and Spin-Echo (GRASE) datasets for characterization of diffuse liver disease

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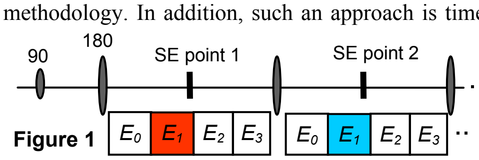
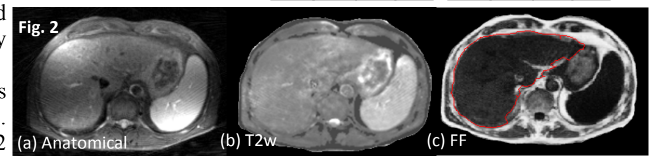
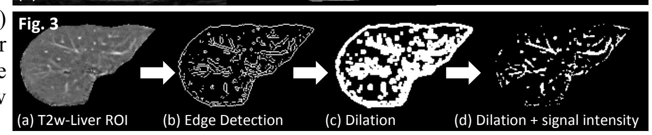
Introduction: The need for a non-invasive tool for diagnosing diffuse liver disease has resulted in development of imaging techniques such as MRE[1], DWI[2], perfusion MRI[3] and T2 mapping[4]. The analysis of data obtained by these techniques needs to be performed on as much of the liver parenchyma as possible due to the diffuse nature of the disease. Thus analyzing selected ROIs within the liver is not the best methodology. In addition, such an approach is time consuming and impractical for routine clinical use since the analysis requires manually positioning the ROIs within the liver to avoid other tissue types such as blood vessels (which are distributed throughout the liver). Recently, our group developed a radial Gradient and Spin-Echo (GRASE) acquisition strategy for the estimation of the T2 of the water component (T2w) and fat fraction (FF)[5] and showed its potential for characterization of diffuse liver disease[6]. In this work we propose and evaluate an automated liver parenchyma and vessel segmentation methodology. The proposed algorithm benefits from advantages provided by radial GRASE, where perfectly registered images and parameter maps of various contrast are generated.



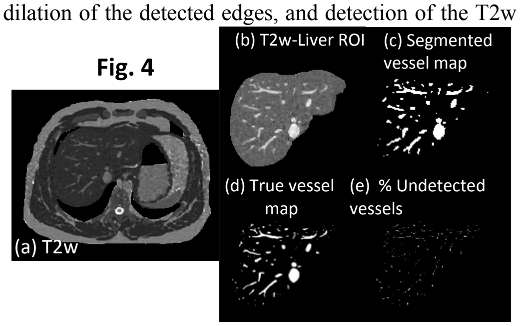




Methods: A diagram of the radial GRASE technique is shown in Fig. 1. The echoes E0-E3 collected through all the SE periods are used to generate a T2w and FF map. First, all four gradient echoes are used to obtain initial fat-water estimates. For T2 estimation we use the gradient echoes that are closest to the SE point (E1 in the figure) to generate images at various TE_{eff} from which the T2w and the final fat-water estimates are calculated[5]. Since on every excitation of the GRASE sequence we sample data from all TEs and from all echoes used in the fat-water estimates the resulting T2w and FF maps are perfectly registered.

For evaluation of the segmentation algorithms we used in vivo radial GRASE data acquired at 1.5T (GE Signa NV-CV/i scanner) on a breath hold (18 s). Imaging parameters were: BW=±125 kHz, ETL=12, matrix size=256×192, TR=1s, NEX=1, slice thickness=8 mm. A recently developed numerical abdominal phantom[7] was also used in the evaluation since it provided a gold standard for segmentation. The segmentation process consisted of two stages: Segmentation of liver parenchyma followed by segmentation of the blood vessels within the parenchyma. The liver parenchyma segmentation was performed using an active contour model[8] on the FF map. The segmented liver ROI can be transferred to the T2w map for blood vessel segmentation since these maps are perfectly registered. The T2w map of the liver parenchyma was processed using edge detection, dilation of the detected edges, and detection of the T2w values > 70 ms within the dilated edge map.

Results and Discussion: ***Liver parenchyma segmentation:*** A representative anatomical (water) image of the liver and the corresponding T2w and FF maps are shown in Fig. 2. Note the signal intensity variation in the anatomical image due to coil sensitivities. Such variation confounds segmentation and leads to significant errors if the anatomical image is used to segment liver parenchyma (not shown). T2w and FF maps are not affected by coil sensitivities and are more suitable for segmentation. The boundaries of the liver are better defined in the FF maps and the active contour model yields a good estimate of the liver ROI when used on the FF map (red curve in Fig. 2c). Since images of various contrast and the parameter maps are perfectly registered in radial GRASE, the ROI can be applied to other images/maps.



Blood vessel segmentation: The signal from vessels within the liver confounds statistical analysis of parameters. Regardless of whether vessels have high intensity (as shown in Fig. 2) or low intensity (due to suppression by saturation pulses), the inclusion of vessels in subsequent statistical analysis skews the shape of the parameter distribution. Thus, for accurate statistical analysis of parameters, all vessels need to be segmented out. Images obtained at each stage of blood vessel segmentation for representative in vivo data set are shown in Fig. 3.

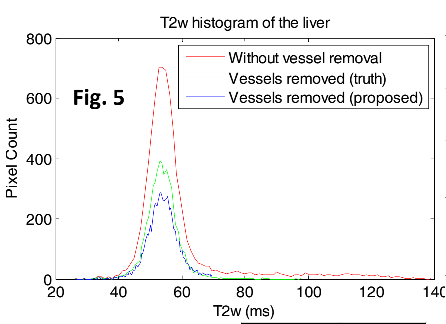


Table 1

	Mean T2w (ms)	Std. T2w (ms)
Without vessel removal	58.6698	15.1391
Vessels removed (truth)	53.9299	5.2625
Vessels removed (proposed)	54.0747	5.0517

To evaluate the performance of vessel segmentation, we used a numerical abdominal phantom (Fig. 4a) where the partial volume fraction of vessels in each pixel is known. Vessel segmentation was applied to the liver ROI shown in Fig. 4b and the resulting vessel map is shown in Fig. 4c. The map is comparable to the true vessel map (Fig. 4d) with a slight overestimation of vessel pixels (i.e., the estimated vessels are slightly wider). It is important to note that misclassifying a small number of liver pixels as vessel does not affect the subsequent statistical analysis of parameter maps significantly. On the other hand not detecting pixels with significant vessel fraction will confound the statistical analysis. Our results indicate that very few pixels containing vessels are undetected (Fig. 4e) and that 98% of the undetected pixels had a vessel fraction < 0.5.

Since the ultimate goal of segmentation is to improve the estimation of parameters we also evaluated the effect of segmentation in T2w estimation. Fig. 5 shows the histogram of T2w and Table 1 tabulates the mean and standard deviation of T2w for three cases: No vessel removal, vessels removed according to the gold standard, vessels removed using the proposed segmentation. The results show that if the vessels are not removed the T2w histogram has a very heavy tail and the T2w mean and standard deviation deviate significantly from the true values. If vessels are removed using the proposed approach, the T2w mean and standard deviation are very close to the true values.

Conclusions: An automated liver parenchyma and vessel segmentation method for radial GRASE was proposed. It was shown that the proposed approach can identify the liver parenchyma and the vessels within it. Removal of the segmented vessels improves estimation of parameters such as T2w. The general methodology presented here can be extended to other imaging methodologies used for the diagnosis of diffuse liver disease.

Acknowledgement: NIH grant HL08538. **References:** [1] Talwalkar JA et al, Hepatology 2008; 47: 332. [2] Taouli B et al AJR, 189:799, 2007. [3] Materne R, MRM 2002; 47:135-142. [4] Kim D, MRM 2009: 62:300. [5] Li Z et al, MRM 61:1415, 2009. [6] Altbach M et al, ISMRM 18, 261, 2010. [7] Graff C, et al ISMRM, 16, 492, 2008. [8] Xu C. and Prince JL, IEEE Trans. Image Proc., 7:359-369, 1998.