Evaluation of image quality improvement using wavelet denoising based on Stein's Unbiased Risk Estimate (SURE)

T. Zhang[1], P. Lai[2], S. Vasanawala[3], R. Herfkens[3], K. Khare[4], L. Marinelli[4], K. F. King[5], and A. Brau[2]
[1]Electrical Engineering, Stanford University, Stanford, CA, United States, [2]Applied Science Laboratory, GE Healthcare, Menlo Park, CA, United States, [3]Radiology, Stanford University, Stanford, CA, United States, [4]GE Global Research Center, Niskayuna, NY, United States, [5]GE Healthcare, Waukesha, WI, United States

Introduction: MRI images are corrupted by random noise that originates from data acquisition and propagates through image reconstruction. Low signal-to-noise ratio (SNR), usually implying poor image quality (IQ), can be commonly found in cases with parallel imaging, acquisitions with high spatial resolution, etc. SNR can be increased by applying various image denoising methods [1,2], but some methods introduce additional artifacts such as image blurring. In this work, wavelet denoising based on Stein's Unbiased Risk Estimate (SURE) [3,4] was evaluated on various MRI applications. Noise statistics was estimated from the finest wavelet scale, and each wavelet scale got its own soft-threshold based on SURE. An IQ survey of overall image quality and image sharpness between images from traditional reconstruction and those after SURE was carried out.

Table 1: Comparison criterion

	Overall IQ		Sharpness: original images (A) vs. denoised images (B)
5	Outstanding	2	A much sharper than B
4	Excellent	1	A slightly sharper than B
3	Acceptable	0	A and B equally sharp
2	Limited	-1	B slightly sharper than A
1	undiagnosable	-2	B much sharper than A

Methods: The following ten applications (11 datasets) were involved in the IQ survey: 1.contrast-enhanced abdominal MRA; 2.T2-weighted 3D FSE knee with fat saturation; 3. noncontrast-enhanced renal artery MRA with in-flow inversion recovery; 4. Non contrast-enhanced peripheral MRA; 5. T2-weighted brain using fast spin echo; 6. contrast-enhanced chest MRA at two different phases; 7. inversion recovery prepped SPGR for neuro imaging; 8. whole-heart coronary MRA; 9. proton density weighted 3D FSE knee; and 10. free-breathing T1-weighted SPGR for contrast-enhanced liver (fully sampled, high resolution). Application 1-2, 4-7, and 9 were 2x2 undersampled; 3 and 8 were 2x undersampled. All datasets were acquired on 1.5 T or 3T GE Signa Excite scanners with clinical protocols for each specific application. For image reconstruction, first, the original images were reconstructed using ARC [5] in cases with accelerated data acquisition, and otherwise directly with Fourier transform. Next, SURE denoising [4] was applied on the original images from each single channel, and combined afterwards by a sum of squares. For each dataset, the original and denoised images were randomly ordered and graded independently by 2 board certified radiologists with respect to overall IQ and image sharpness on a 5-point scale (shown in Table 1).

Fig.1 Overall Image Quality

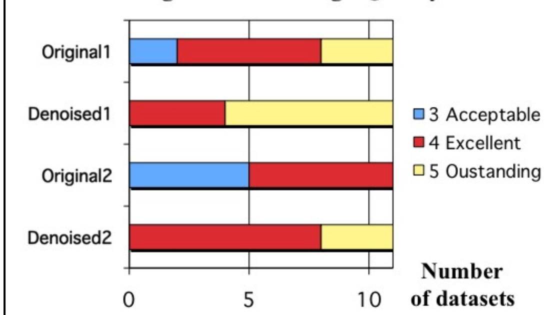
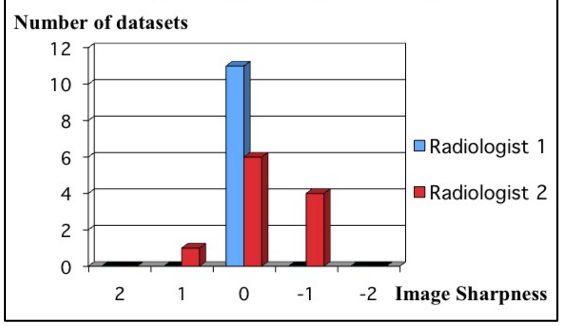


Fig.2 Image Sharpness Comparison



Results: Fig.1 shows the overall IQ scores of the 11 datasets obtained from the two radiologists (original 1 and denoised 1 from the first radiologist, and the rest two from the second radiologist). The average IQ score of the original images was 4.09 for radiologist 1 and 3.72 for radiologist 2; while that of the denoised images was 4.64 and 4.23 for radiologist 1 and 2 respectively. The two-sided paired t-test values are p=0.0061 and 0.0039 respectively, which indicates the general image quality was improved after SURE denoising. The result of image sharpness comparison is shown in Fig.2. Denoised images were scored to be equally sharp as the original images (in some cases the denoised images looked slightly sharper). No noticeable blurring after SURE denoising was observed in the study. Both radiologists preferred the denoised images over the originals for all the datasets. As an example, application 8 and 10 were shown in Fig.3. From Fig.3 (a) and (b), SNR is apparently improved in liver, while edges for blood vessels were preserved. The heart wall also appeared sharper after SURE denoising in Fig 3(d).

Conclusion: In this work, wavelet denoising based on Stein's unbiased risk estimate was applied on 11 clinical datasets representing 10 MRI applications. The overall image quality and image sharpness before and after denoising was compared on these datasets. According to the comparison results, SURE denoising can effectively increase SNR without introducing image blurring.

References: 1. Manjon J, *et al.* Med Image Anal 12(4):514-523, 2008; 2. Zhang T, et al. Proc 18th ISMRM, p4883, 2010; 3. Donoho D, *et al*. J. Amer. Statistical Assoc 90: 1200-1224, 1995; 4. Khare K, *et al*. Proc 18th ISMRM, p346, 2010; 5. Beatty P, *et al.* Proc 15th ISMRM, p1749, 2007.

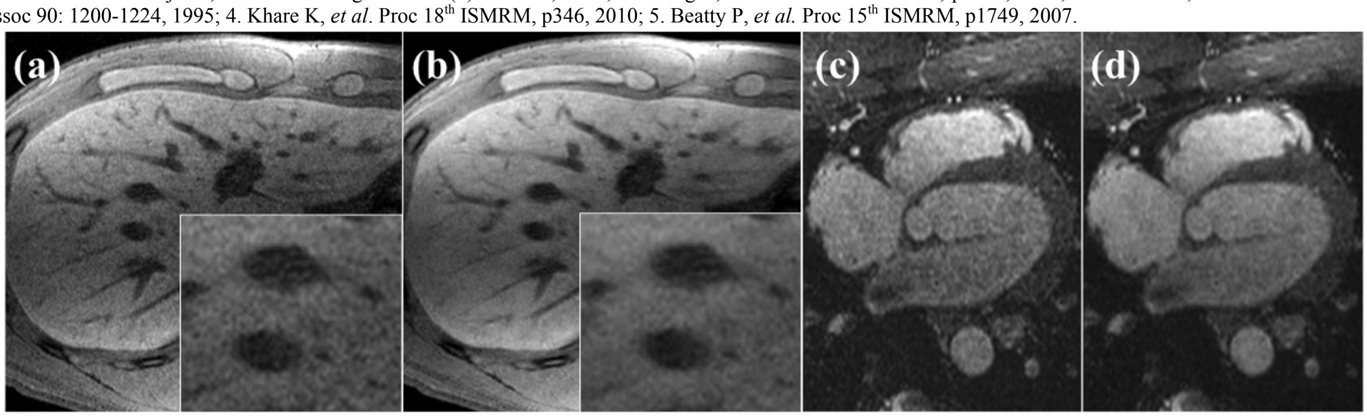


Fig.3 Applications of SURE denoising on high resolution T1-weighted liver imaging and whole-heart coronary MRA: (a,c) original image (b,d) denoised image.