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Assessment of Singular Value Decomposition (SVD) Based Denoising on Brain Diffusion Weighted Images Acquired on a 0.35T Magnetic Resonance Imaging-Guided Linear Accelerator

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ABSTRACT

Purpose: To assess the effectiveness of SVD-based denoising on the brain Diffusion Weighted images acquired from a 0.35T ViewRay Magnetic Resonance Linac (MRL) and enhance the image quality while preserving the diffusion information.

Methods: Brain DWI scans of five subjects were obtained from a 0.35T ViewRay MRL at Dartmouth Hitchcock Medical Center using a multi-slice echo-planar imaging (EPI) sequence (matrix size100x100x21, FOV= 350x350x190 mm³, TR=3200ms, TE=120ms, bandwidth=1352 HZ, flip angle=90º, 6 averages). Diffusion weighting was applied along three directions using b-values of 0,200,300,500 and 800 s/mm². Apparent diffusion coefficient (ADC) maps were generated in MATLAB Version R2021a by voxel-wise exponential fitting along each diffusion direction and averaging across directions. SVD was applied on DWI images at different b values. Signal-to-Noise Ratio (SNR) and ADC values were calculated before and after applying SVD in different ROI in the brain. The optimized singular value was obtained by analyzing the SNR gain and ADC accuracy at different singular values. Percentage changes in SNR and ADC values were found from the optimized singular value for all five subjects.

Results: SVD denoising resulted a significant improvement in visual image quality and increased SNR across all subjects with consistent ADC measurements. The average percentage change in SNR of the brain DWI after the implementation of SVD at b-value 800 s/mm² for all five subjects were found to be 5%,6%,33%,36% and 23%. The percentage change in the ADC value was found to be less than 5% for all five subjects

Conclusion: The application of SVD-based denoising was effective in resulting SNR gain without compromising the ADC accuracy on brain DWI images obtained from a 0.35T ViewRay MRL. Implementing SVD based denoising improves low field DWI image quality sufficiently to support its potential application in MR guided radiotherapy workflows and longitudinal diffusion monitoring during brain radiotherapy.

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INTRODUCTION

Diffusion weighted Imaging(DWI) offers quantitative insight into tissue cellularity[1] via apparent diffusion coefficient(ADC) mapping. Integration of DWI into MRI-guided linear accelerators(MRLs) could pave the way for biologically guided adaptive radiotherapy (BGART), approach in which radiation doses are adjusted according to regional physiological characteristics within the tumor. DWI on low field MRL is constrained by inherently low signal-to-noise ratio(SNR),which degrades brain DWI quality at 0.35T magnet[2]. There is a critical need for denoising approaches that enhance ethe image quality without altering quantitative diffusion metrics, enabling reliable use of ADC in MRL based brain radiotherapy applications.

This study utilizes the Singular Value Decomposition(SVD)-based denoising as a method to improve brain diffusion image quality obtained on a 0.35T MRL. SVD improves the SNR by decomposing an image into structured and noise components and reconstructing it from only the dominant patterns, preserving image detail while suppressing random fluctuations[3].

METHODS AND MATERIALS

- DWI scans of NIST-traceable diffusion phantom and five volunteer human brains were acquired on a 0.35T MRL (ViewRay MRIdian).
- Scans were acquired using a multi-slice echo-planar imaging (EPI) sequence[4] (matrix size = 100×100×21, FOV = 350×350×190 mm³, TR = 3200 ms, TE = 120 ms, bandwidth = 1352 Hz, flip angle = 90°, 6 averages).
- Diffusion weighting was applied along the three principal directions using b-values of 0, 200, 300, 500, and 800 s/mm².
- Apparent diffusion coefficient (ADC) maps were generated in MATLAB Version R2021a (The MathWorks, Inc.) by voxel wise exponential fitting along each diffusion direction and averaging across directions.
- SVD was applied as a denoising technique by decomposing the data matrix into singular values.
- Components representing the dominant signal were retained, while smaller, noise-associated components were discarded, and the images were reconstructed from the retained elements.
- SNR and ADC values were calculated before and after applying SVD in different vials of the phantom and different ROI in the brain of five subjects.
- The optimized singular value was obtained by analyzing the SNR gain and ADC accuracy at different singular values.
- Percentage changes in SNR and ADC values were found from the optimized singular value for the phantom and all five subject brains.

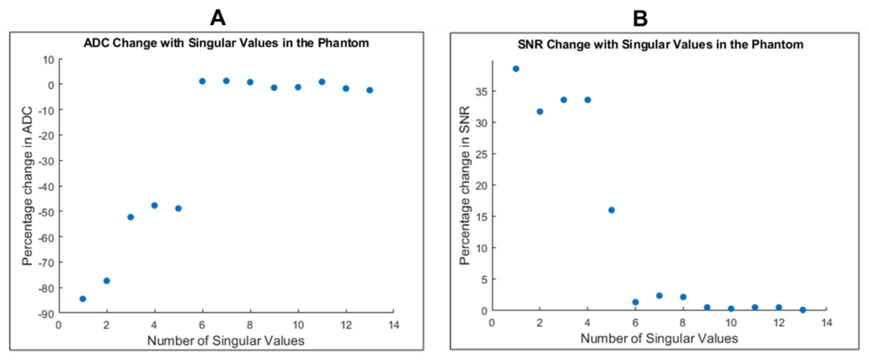

Figure 1: 1A shows the percentage change in ADC versus number of singular values in a phantom imaged on a 0.35 T MRL. 1B shows the percentage increase in the SNR versus number of singular values. One can see that using five singular values in the reconstruction results in negligible degradation of ADC accuracy while netting an SNR gain of greater than 15%.

RESULTS

SVD denoising resulted a significant improvement in visual image quality and increased SNR across all subjects with consistent ADC measurements. The average percentage change in SNR of the brain DWI after the implementation of SVD at b-value 800 s/mm² for all five subjects were found to be 5%,6%,33%,36% and 23%. The percentage change in the ADC value was found to be less than 5% for all five subjects.

Subject	Percentage Change in SNR	Percentage Change in ADC
1	5	<1
2	6	3
3	33	1
4	36	2
5	23	5

Figure 2: The table shows the percentage change in SNR and ADC for all five subjects after the application of SVD in the DWI images of b value 800 s/mm².

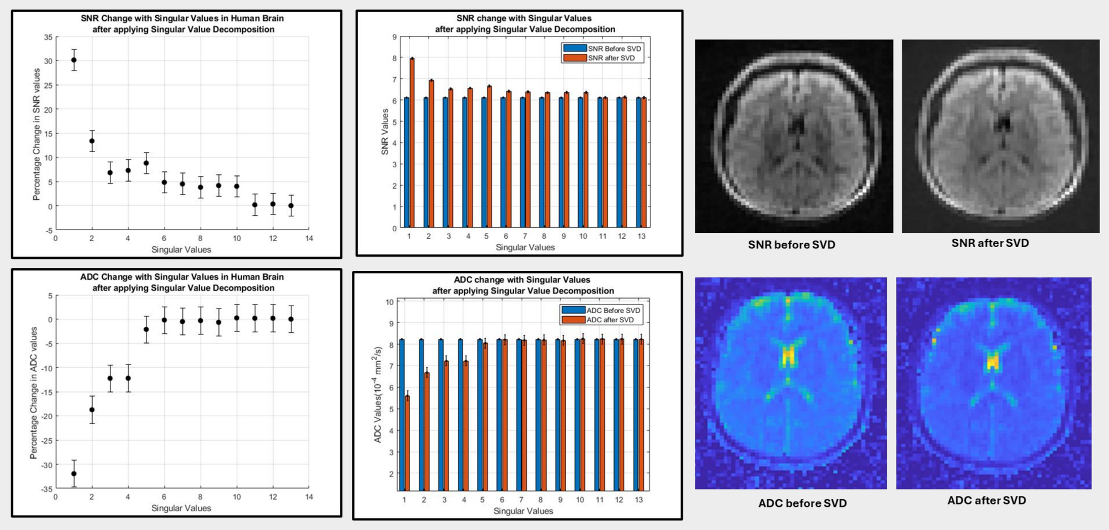

Figure 3: The top row shows the change in SNR with the singular values and the improvement in SNR of the image after the implementation of SVD with five singular values. The bottom row shows the change in ADC with singular values and the minimal change in ADC with five singular values in SVD implementation. The SNR change for this subject 2 was found to be 3%.

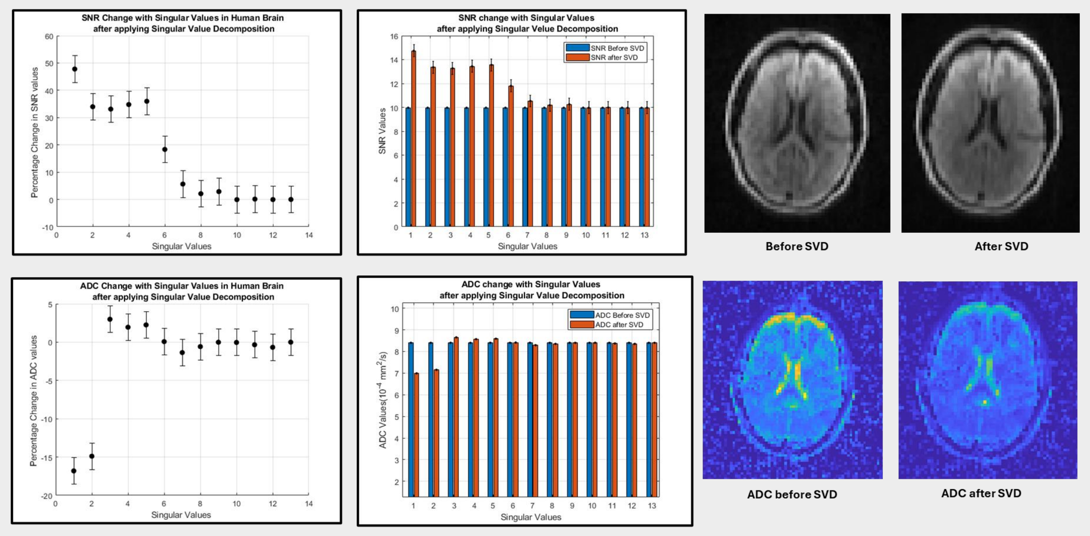

Figure 4: The top row shows the change in SNR with the singular values and the improvement in SNR of the image after the implementation of SVD with five singular values. The bottom row shows the change in ADC with singular values and the minimal change in ADC with five singular values in SVD implementation. The SNR change in this case was found to be 33%.

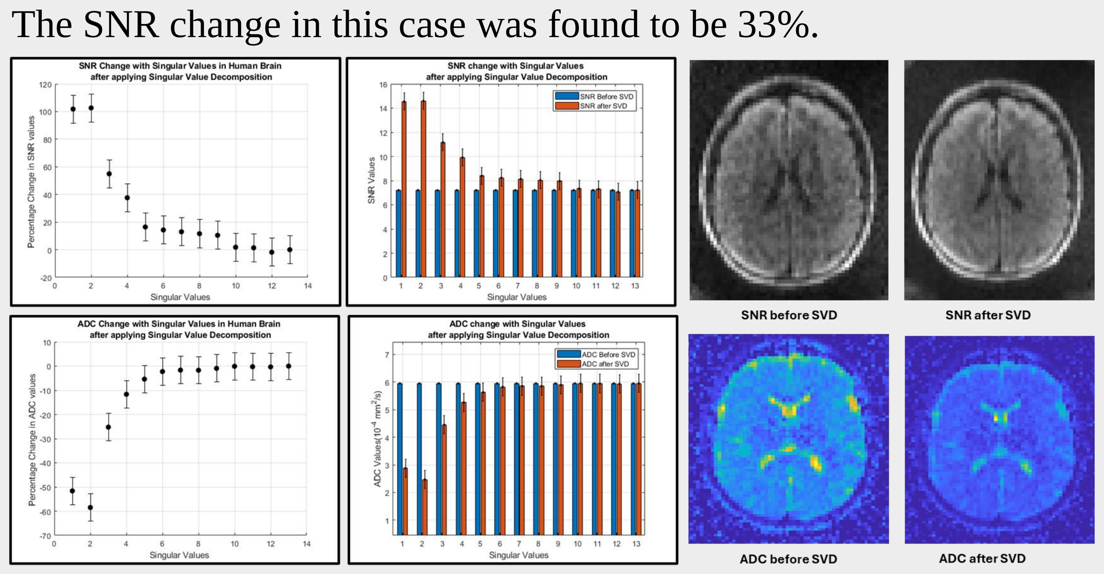

Figure 5 : The top row shows the change in SNR with the singular values and the improvement in SNR of the image after the implementation of SVD with five singular values. The bottom row shows the change in ADC with singular values and the minimal change in ADC with five singular values in SVD implementation. The SNR change in this case was found to be 36%.

DISCUSSION

In this study, SVD-based denoising was evaluated as a method to improve diffusion image quality on a 0.35 T MRL. The results show that a modest increase in SNR can be achieved without altering ADC quantification beyond measurement uncertainty. Retaining five singular values provided the best compromise between SNR improvement and preservation of ADC accuracy in both phantom and brain data. This balance is important, as excessive truncation of singular values can suppress fine structural detail, while retaining too many unnecessarily retains noise. The approach offers a straightforward means of mitigating the signal limitations inherent to low-field diffusion imaging without modification to acquisition parameters or scan time. Although limited in scope, this work supports the feasibility of SVD-based denoising for quantitative diffusion imaging on MRI-guided radiotherapy systems. By improving the reliability of ADC measurements, this technique may enhance the ability to perform longitudinal imaging on the treatment unit, where stable diffusion quantification is essential for evaluating temporal changes in tissue cellularity and could potentially enable BGART. Further studies across additional anatomical sites and imaging parameters are warranted to determine the generalizability of these findings.

CONCLUSIONS

The application of SVD successfully enhanced the SNR of brain DWI images acquired on the 0.35 T MRL, with more pronounced improvements at higher b-values due to their lower initial sensitivity. These findings highlight the potential of SVD-based techniques to overcome the challenges of low-field MRL imaging, supporting the future integration of DWI into clinical radiotherapy workflows.

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