Denoising Diffusion-Weighted Images of Rectal Cancer Acquired on a 0.35T Magnetic Resonance Imaging-Guided Linear Accelerator Using Singular Value Decomposition

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ABSTRACT

Purpose: The MR-linac provides unique opportunities for integrating advanced imaging into radiotherapy workflows, but the lower sensitivity of systems like the 0.35T model can pose challenges for diffusion-weighted imaging (DWI). To mitigate this issue, singular value decomposition (SVD) was applied to enhance signal-to-noise ratio (SNR), enabling the acquisition of higher-quality DWI images for potential clinical use.

Methods: DWI scans were obtained from rectal cancer patients treated on a 0.35 T MR-linac. The scans were acquired at multiple treatment time points using a multi-slice echo-planar readout with b-values of 0, 200, 300, 500, and 800 s/mm². To enhance the quality of these images, singular value decomposition (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. Signal-to-noise ratio (SNR) measurements were calculated in regions of interest, including a vial with well-defined diffusion properties used for standardization, as well as muscle, bladder, and rectum. SNR values before and after applying SVD were compared across the different b-values, and averages from all treatment fractions were analyzed to assess improvements.

Results: The application of the SVD method resulted in a notable improvement in image SNR, with the enhancement becoming more pronounced at higher b-values. Specifically, the average SNR increased by 1.0%, 20.7%, 45.4%, 57.2%, and 94.9% for b-values of 0, 200, 300, 500, and 800 s/mm², respectively.

Conclusion: The application of SVD successfully enhanced the SNR of DWI images acquired on the 0.35 T MR-linac, 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 MR-linac imaging, supporting the future integration of DWI into clinical radiotherapy workflows.

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INTRODUCTION

Diffusion weighted imaging(DWI) is an MRI-based functional imaging technique that allows for the evaluation of tumor cellularity[1,2]. The implementation of DWI on MRI-guided linear accelerators (MRL) could facilitate the utilization of physiological information in the adaptive workflow. However, the low magnetic field strength of the 0.35T MRL results in lower than optimal SNR in DWI images[3], particularly at high b-value.

This study aims to utilize a singular value decomposition(SVD)-based method to enhance the image quality and Signal to Noise Ratio (SNR) of the diffusion weighted images obtained from MRIdian system and ultimately use to guide in the radiotherapy treatment of rectal cancer.

METHODS AND MATERIALS

- DWI scans were obtained from rectal cancer patients treated on a 0.35 T MR-linac.
- Scans were acquired at multiple treatment time points using a multi-slice echo-planar readout with b-values of 0, 200, 300, 500, and 800 s/mm².
- 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.
- Percentage change in ADC value was calculated for each singular values.
- SNR measurements were calculated in ROI, including a vial with well-defined diffusion properties used for standardization, as well as muscle, bladder, and rectum.
- SNR values before and after applying SVD compared across different b-values, and averages from all treatment fractions were analyzed to assess improvements.
- Percentage change in SNR was calculated for each singular values.
- The threshold for the number of singular value to be used was decided based on the minimizing the error and maximizing the SNR.

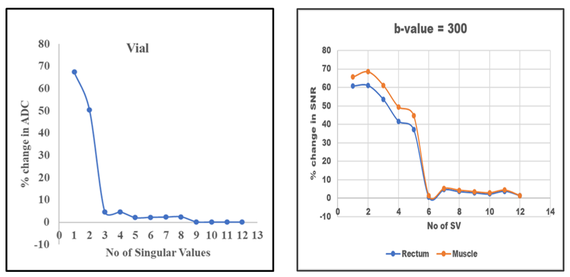

Figure 1: The figure shows the percentage change in the ADC value and percentage change in SNR with respect to different singular values

- Threshold was taken to be 3 in our case based on the figure 1.

RESULTS

The application of the SVD method resulted in a notable improvement in image SNR, with the enhancement becoming more pronounced at higher b-values. Specifically, the average SNR increased by 1.0%, 20.7%, 45.4%, 57.2%, and 94.9% for b-values of 0, 200, 300, 500, and 800 s/mm², respectively.

b-value	% increase in SNR
0	1.0
200	20.7
300	45.4
500	57.2
800	94.9

Table 1: The table shows the percentage increase in the average SNR of the DWI images across the different b-values when the single value decomposition method was applied.

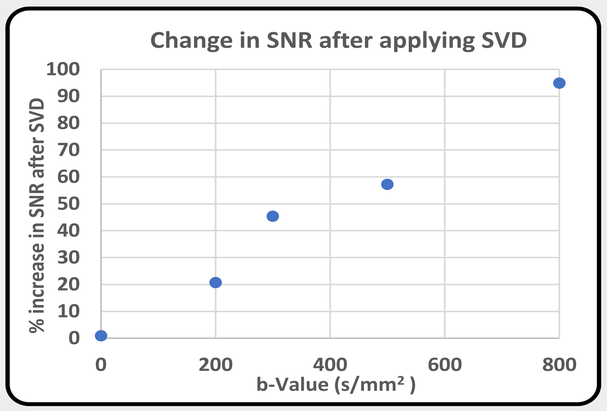

Figure 2: The figure shows the percentage increase in the average SNR of the DWI images across the different b-values when the single value decomposition method was applied.

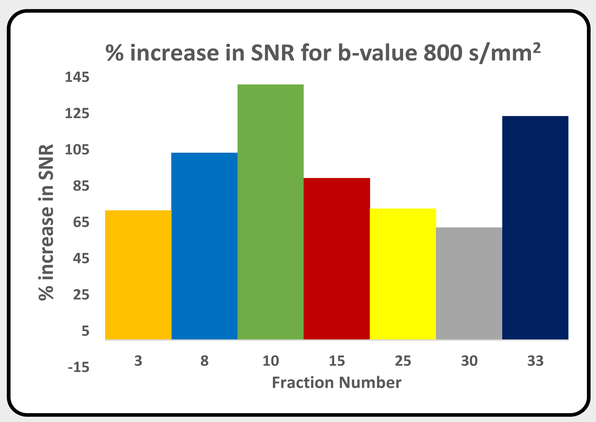

Figure 3: The figure shows the distribution of the percentage increase in the SNR of the images at different treatment fractions for b-value 800s/mm²

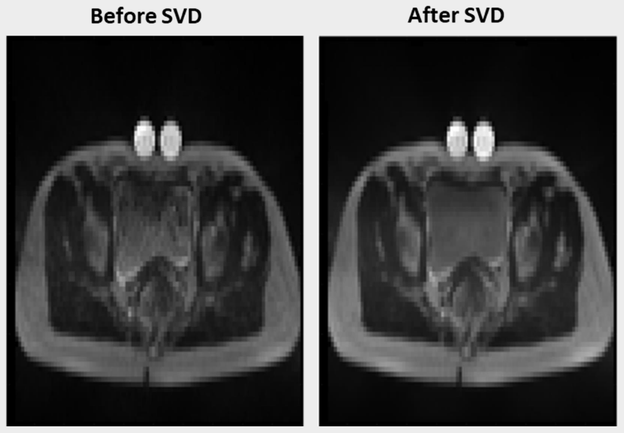

Figure 4: This figure illustrates the improvement in SNR before and after the application of the SVD. The left figure shows a DWI image of a rectal cancer patient with a b-value of 800 s/mm², and the right figure shows the same image after SVD was applied.

CONCLUSIONS

The application of SVD successfully enhanced the SNR of DWI images acquired on the 0.35 T MR-linac, 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 MR-linac imaging, supporting the future integration of DWI into clinical radiotherapy workflows.

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