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Pulse Sequence Optimization for non-EPI Diffusion-Weighted Imaging Sequences for Head & Neck on a 1.5 T MR-Linac

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INTRODUCTION

- The clinical implementation of a 1.5 T MR-linac has enabled the possibility of serial diffusion-weighted imaging (DWI) for treatment response assessment and biologically-directed adaptive radiation therapy (RT)
- Because geometric accuracy is essential for RT, we are focusing on two geometrically stable DWI sequences available on the MR-linac, TSE and SPLICE, rather than the most common DWI sequence, EPI
- Due to limitations of the MR-linac's MRI hardware, including reduced gradient strength and the lack of dedicated head & neck coils, these sequences must be optimized for this system
- After a series of preliminary image acquisitions for sequence optimization using qualitative scoring, the factors that were anticipated to have the largest effect on image quality (flip angle for SPLICE, half-scan factor for TSE, and fat saturation (FS) method) were selected for further quantitative analysis in this abstract

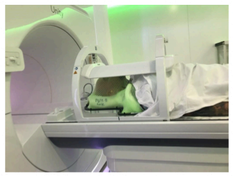

Figure 1: The head and neck setup on the MR-linac, including the immobilization mask and the all-purpose MR-linac anterior coil.

METHODS

Images

- A series of images were taken on a ground truth DWI phantom (QIBA DWI phantom) and a healthy volunteer:
  - SPLICE with variable flip (refocusing control) angle: 60, 70, 80, 90, 100 deg.
  - TSE with variable half scan factor: 0.6, 0.7, 0.8, 0.9
  - SPLICE and TSE with variable fat suppression (FS) methods: SPIR, SPAIR, STIR, no FS
  - b-values were 0 and 500 s/mm^2
  - For variable flip angle and half scan factor acquisitions, SPIR was used as the FS method
  - For variable FS acquisitions, 90 deg. was used for SPLICE and 0.8 half scan factor for TSE

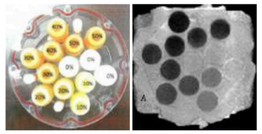

Figure 2: The QIBA DWI phantom (left), which contains vials of polymer liquid with known ADC values, and an ADC map (right) derived from a SPLICE DWI on the MR-linac.

***In Vivo* Image Analysis**

- SNR (mean divided by standard deviation within an ROI) was calculated *in vivo* using high-diffusion organs (spinal cord, parotid glands, submandibular glands)
- Images were scored qualitatively by three expert observers (radiologist, radiation oncologist, MRI physicist) blinded to acquisition parameters. Categories included SNR, CNR, blurring, and quality of FS
- Observers also ranked images based on overall impression. Univariate linear regression was performed to determine the categories that contributed most to overall rank

Phantom Image Analysis

- Percent bias in apparent diffusion coefficient (%ADC bias) was calculated for each vial by taking the percent difference between the average ADC value within an ROI and the known ADC value

RESULTS

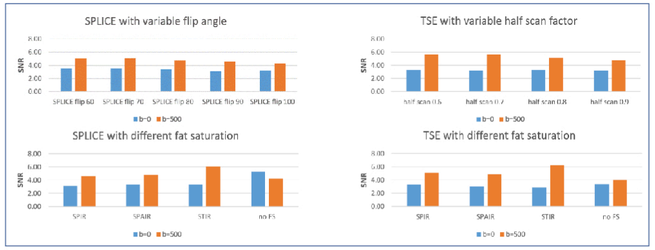

Figure 3: SNR values averaged over the five contoured ROIs (right and left parotid glands, right and left submandibular glands, and spinal cord) from the *in vivo* images.

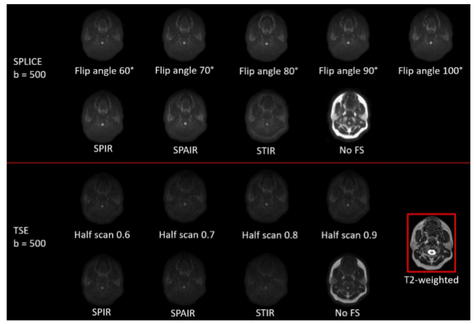

Figure 4: Each DWI variation displayed in the same slice and with the same window/level settings to highlight differences in SNR and CNR.

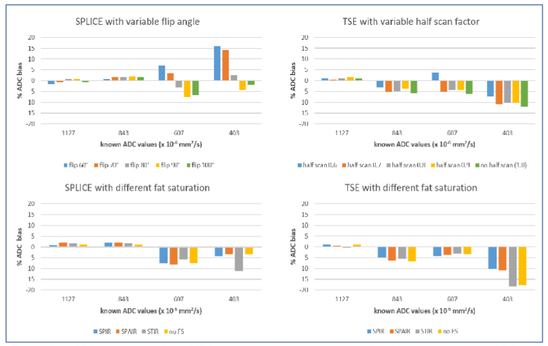

Figure 5: %ADC bias values from QIBA phantom data. Values from vials with the same known ADC values were averaged, and values were averaged over two repetitions of each sequence. Data from vials with the lowest known ADC values (248 and 128 x 10^{-6} mm^2/s) were excluded because they fell outside the range of physiological ADC values and exhibited extremely poor SNR, resulting in %bias values of up to 150%.

Table 1: Average scores from the three reviewers for the b=0 and b=500 images for each sequence. Rankings are on a scale of 1-4, with 1 representing the worst image quality for each category. Images are ordered in terms of the overall rank (average of b=0 and b=500 ranks), with 1 representing the best image. In sequence names, values in parentheses are the parameters kept constant (e.g. SPIR was used for all SPLICE images with variable flip angle, while flip angle 90 was used for SPLICE images with different FS).

Sequence	Peripheral blurring		Central blurring		SNR		CNR		Degree of FS		Homogeneity of FS		Average rank		
	b=0	b=500	b=0	b=500	b=0	b=500	b=0	b=500	b=0	b=500	b=0	b=500	b=0	b=500	Overall
SPLICE no FS (flip 90)	2.3	3.0	2.7	3.0	3.3	3.3	2.7	3.7	1.7	1.7	2.3	2.3	4.7	2.3	3.5
SPLICE flip 100 (SPIR)	1.7	2.7	2.3	3.3	2.3	2.0	2.7	2.0	3.3	3.0	2.7	2.7	4.7	4.0	4.3
SPLICE flip 60 (SPIR)	2.0	2.7	2.7	3.3	2.7	1.7	2.3	1.7	3.0	3.0	3.0	2.7	2.0	6.7	4.3
SPLICE SPAIR flip 90	1.3	2.3	2.0	2.7	1.7	2.0	2.0	2.0	3.0	3.0	2.3	2.3	3.0	6.0	4.5
SPLICE flip 70 (SPIR)	2.7	2.7	2.3	3.3	1.7	1.3	1.7	1.3	3.0	3.0	2.3	2.3	5.7	6.7	6.2
SPLICE SPAIR (flip 90)	2.7	2.0	2.7	3.0	2.3	1.7	2.7	1.7	3.3	3.0	2.7	2.7	7.3	5.3	6.3
SPLICE flip 80 (SPIR)	2.0	2.0	2.3	2.7	2.0	1.7	2.0	2.0	2.7	2.3	2.3	2.3	5.0	8.7	6.8
TSE half scan 0.9 (SPIR)	1.7	2.0	2.3	3.0	1.7	1.3	1.3	1.3	3.3	3.0	2.7	2.3	8.0	7.3	7.7
TSE no FS (half scan 0.8)	1.7	2.7	1.7	2.7	2.3	3.3	2.0	2.7	1.3	1.7	2.0	2.3	12.0	3.3	7.7
SPLICE STIR (flip 90)	1.7	1.3	2.0	2.3	1.7	2.7	1.7	2.0	3.3	1.7	3.3	1.7	6.3	13.0	9.7
TSE SPIR half scan 0.8	1.3	2.7	2.7	2.3	2.0	1.0	1.3	1.7	2.7	2.7	2.3	3.0	11.0	8.7	9.8
TSE SPAIR (half scan 0.8)	1.7	2.0	1.0	2.3	1.3	1.0	1.3	1.3	2.7	3.0	2.0	2.3	10.7	9.7	10.1
TSE SPIR half scan 0.6 (SPIR)	2.0	2.3	2.0	2.0	1.7	1.0	1.7	1.0	2.7	2.7	2.0	2.7	12.3	11.3	11.8
TSE SPIR half scan 0.7 (SPIR)	1.3	2.0	1.3	2.0	1.3	1.0	1.3	1.0	3.0	2.3	2.7	2.0	13.3	12.0	12.7
TSE STIR (half scan 0.8)	1.0	1.0	1.3	1.3	1.7	2.0	1.0	1.0	3.0	2.7	3.0	2.3	14.0	15.0	14.5
Correlation w/ b-value rank (r^2)	0.16	0.62	0.28	0.74	0.34	0.08	0.49	0.41	0.04	0.02	0.00	0.15			

DISCUSSION

- From the qualitative analysis, the preferred:
  - flip angles in SPLICE were 60° and 100°
  - half-scan factor in TSE was 0.9
  - FS in both TSE and SPLICE was SPIR
- SNR and CNR were the most important factors for the b=0 images, and blurring was most important for b=500
- *In vivo* SNR results were surprising, with STIR performing highest of the FS methods on both TSE and SPLICE despite performing poorly in the qualitative analysis
- SNR decreased with increasing TSE half scan factor, which contradicts the qualitative rankings
- %bias values grew larger with decreasing ADC values but did not show any consistent trends with flip angle, half-scan factor, or FS

CONCLUSION

- Further investigation with more volunteers and more expert observers is needed to determine the optimal SPLICE and optimal TSE sequences
- Different *in vivo* SNR metrics should be tested to see if quantitative results can better agree with the qualitative results

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