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Original Article

Optimization Axial T2WI Lumbar MRI in Spinal Stenosis: Effects of GRAPPA Acceleration Factor on Image Quality and Anatomy

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Abstract

Background : Patients with lumbar spinal stenosis (LSS) who struggle to lie down for long periods may encounter issues during lumbar MRI exams. GRAPPA, a parallel imaging method to speed up MRI scans, can reduce the Signal to Noise Ratio (SNR), affecting image quality and anatomical information. This study aims to find the best GRAPPA acceleration factor by assessing its effect on image quality and anatomical information.
Methods : This study involved scans on 10 Lumbar MRI patients with LSS cases. The scans were performed using a Siemens Magnetom Aera 1.5 Tesla MRI machine with T2WI TSE axial cut. Each patient underwent 4 treatments with acceleration factors of 1 (without GRAPPA acceleration factor), 2, 3, and 4. Image quality was analysed using ROI to obtain SNR and CNR values. The radiologist assessed the anatomical information on the images. The analysis included a one-way ANOVA and the Kruskal-Wallis test was performed for image quality and anatomical information.
Results : The research found that the GRAPPA acceleration factor significantly affects image quality and anatomical information in axial T2WI TSE Lumbar MRI scans for patients with LSS (*p-value* < 0.01). A factor of 3 reduces examination time by 65.35% without significant differences ($p > 0.05$) in image quality and anatomical information.
Conclusion : The acceleration factor in axial T2WI TSE lumbar MRI significantly affects image quality and anatomical information for lumbar spinal stenosis cases. An acceleration factor of 3 is optimal for maintaining quality and anatomical information.

Keywords : GRAPPA acceleration factor; T2WI TSE; image quality; anatomical information

INTRODUCTION

Lumbar spinal stenosis (LSS) is the narrowing of the vertebral canal and/or intervertebral foramen, which leads to compression of the spinal cord or nerve roots, resulting in low back and leg pain.[1] Additionally, calcification or ossification of the posterior longitudinal ligament or ligamentum flavum, along with the development of intraspinal synovial cysts, may also contribute to spinal stenosis.[2] MRI is widely considered the gold standard for diagnosing LSS.[1] Lumbar MRI for diagnosis of patients with LSS cases using Sagittal T2WI and T1WI, along with Axial T2WI protocols.[3,4] Axial sections are important for determining the severity (grade) associated with clinical symptoms felt by patients with LSS.[5-7]

MRI poses a drawback due to its longer examination duration compared to conventional radiology or CT scans.[8] Prolonged MRI exams may cause patient discomfort and potential movements,[9] leading to artefacts in the images.[10] Parallel imaging offers a method to accelerate MRI data acquisition.[11]

GRAPPA is a widely used parallel imaging method aimed at accelerating acquisition time.[12] However, it does have certain drawbacks that can effect the Signal To Noise Ratio (SNR), Contrast to Noise Ratio (CNR), and scan time. Specifically, employing acceleration factor or R-factor values to speed up acquisition leads to a reduction in SNR due to a decrease in the number of k-space lines, consequently affecting the anatomical information captured by the image.[13]

The author observed that motion artefacts are more common in axial cuts because these cuts are generated at the end. This study aims to determine the best GRAPPA acceleration factor by evaluating its effect on the image quality and anatomical information in axial T2WI TSE lumbar MRI scans of Lumbar Spinal Stenosis cases.

METHODS

This research is a quantitative study employing an experimental approach. Data was gathered at Prof. Dr. R. Soeharso Orthopedic Hospital in Surakarta using a Siemens Magnetom Aera 1.5 T MRI and a standard spine coil. The study involved selecting 10 samples from the entire population of lumbar MRI images of patients with LSS. The sample images were obtained using axial T2WI TSE cuts without varying the GRAPPA acceleration factor and with acceleration factors of 2, 3, and 4.

Image quality is assessed using SNR and CNR which are sought by performing ROI (Region of interest) organ images with anatomy on the nucleus pulposus, ligamentum flavum, cerebrospinal liquid, and spinal cord. The SNR assessed is the SNR of the organ nucleus pulposus, ligamentum flavum, cerebrospinal fluid, and spinal cord. SNR was calculated using the formula:

$$\text{SNR} = \frac{\text{mean organ value}}{\text{standar deviation background noise value}}$$

The mean organ value is the average value of the organ points after performing ROI on the organ. The standard deviation value represents the signal noise in the background of the image, outside the organ.

CNR measurement involves calculating the difference in SNR at adjacent organ points using the following formula:

$$CNR = |SNR_1 - SNR_2|$$

SNR1 represents the SNR at organ point 1. SNR2 represents the SNR at organ point 2. The assessed CNRs are liquid cerebrospinal-ligamentum flavum, liquid cerebrospinal-medulla spinalis, and medulla spinalis-ligamentum flavum.

The anatomical information value of Axial Cut Lumbar MRI images with varying GRAPPA acceleration factors was evaluated by three radiologist. They assessed the clarity of the nucleus pulposus, ligamentum flavum, cerebrospinal fluid, and spinal cord using a scoring system (1=unclear, 2=less clear, 3=moderately clear, and 4=clear).

The data underwent analysis using the statistical software SPSS version 25. In determining the most optimal GRAPPA acceleration factor variation that closely aligns with non-accelerated image quality, one-way ANOVA and the Kruskal-Wallis test were performed for image quality and anatomical information, respectively. A p-value of less than 0.05 indicates statistically significant results. An analysis was performed to assess scan time based on the duration of image acquisition for each GRAPPA acceleration factor variation.

This research was carried out with a strong emphasis on respecting: a) Human dignity, b) The privacy and confidentiality of research subjects, c) Justice and inclusiveness, and d) The benefits and losses incurred. This research has undergone an ethical review and has complied with the ethical clearance letter bearing reference number IR.03.01/D.XXV.2.3/49/2024. The following statement was issued by the ethics team of Prof. Dr. R. Soeharso Surakarta Orthopedic Hospital.

RESULTS

The visible image features were reconstructed through different techniques, including standard (non-accelerated) methods and GRAPPA acceleration factors 2, 3, and 4, can be objectively observed and assessed based on signal intensity. Furthermore, radiologists can subjectively evaluate the contrast, sharpness, and

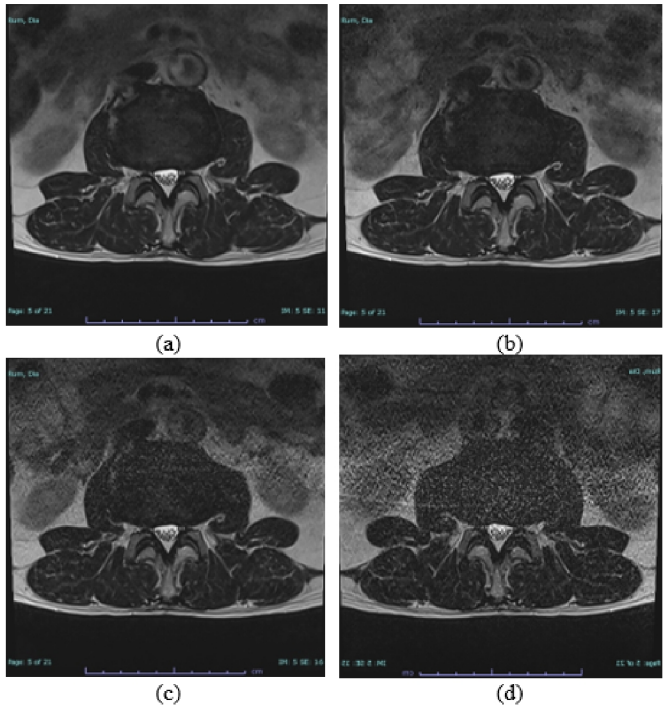

Figure 1. Image result of Lumbar MRI Axial cut T2WI TSE using GRAPPA Acceleration Factor variation (a) without GRAPPA (we designate this as AF 1) (b) GRAPPA AF 2 (c) GRAPPA AF 3 (d) GRAPPA AF 4

TABLE 1
Average SNR of each anatomical organ

GRAPPA variation	*Nucleus pulposus*	*Ligamentum flavum*	*Liquid cerebrospinal*	*Medulla spinalis*
AF 1	55.49098	24.49181	337.4425	172.9885
AF 2	35.85072	20.64401	230.652	130.2049
AF 3	40.87231	18.36493	213.62	116.5652
AF 4	25.52507	16.96186	104.7124	62.97111

intricate details of the resultant images. Figure 1 shows the resulting image in that particular variation.

Image Quality Assessment

Table 1 and 2 show the average SNR and CNR of 10 images in each organ with acceleration factor variation.

Table 2 and 3 show the results of the normality test for the overall SNR and CNR value of each axial T2WI TSE lumbar MRI image with GRAPPA acceleration factors of 1, 2, 3, and 4. *P-value* > 0.05 indicates the SNR and CNR data are normal.

A one-way ANOVA Post hoc test was conducted to determine which GRAPPA acceleration factor had the closest or almost the same quality as the variation without the GRAPPA acceleration factor (AF 1).

From Table 5 we can see that the values of AF (GRAPPA acceleration factor) 2 and 3 have a *p-value* > 0.05 against AF 1 (without GRAPPA acceleration factor) in each organ that we studied. This means that the image quality produced by AF 2 and 3 does not have a significant difference compared to the image quality produced by AF 1.

Anatomical Information Assessment

Anatomical information assessment was carried out with radiologists on the scoring system by comparing the image produced in every variation of the GRAPPA acceleration factor. Score 1 means unclear, 2 means less

TABLE 2
Average CNR in particular organ

GRAPPA Variation	*Liquid cerebrospinal-Ligamentum flavum*	*Liquid cerebrospinal-Medulla spinalis*	*Medulla spinalis-Ligamentum flavum*
AF 1	311.6867	164.454	147.2327
AF 2	209.9069	100.4471	109.4598
AF 3	195.545	97.05482	98.49021
AF 4	88.82571	41.74132	47.08439

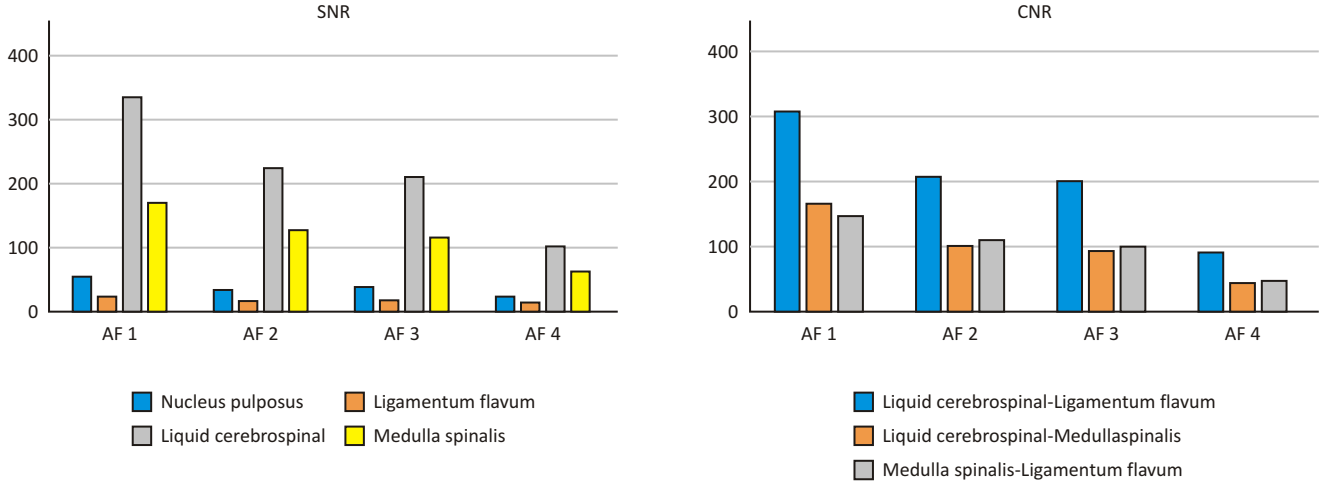

Figure 2. SNR and CNR graph with GRAPPA acceleration factor variation

clear, 3 means moderately clear, and 4 means clear. The total assessment of 10 images for every variation. This assessment can be seen in Table 6.

Table 7 shows the mean rank of anatomical information at every GRAPPA variation level, significantly decreasing with increasing GRAPPA acceleration factor. The correlation test (Table 8) reveals a strong and significant correlation between acceleration factors and anatomical information (*p-value* < 0.01). The data in Table 9 illustrates that the comparison of GRAPPA acceleration factors 2, 3, and 4 with those not employing the GRAPPA acceleration factor did not yield statistically significant differences, except for variation 4.

Scan Time Assessement

According to Table 10, the scan time is significantly slower when GRAPPA acceleration is not utilized than when the acceleration factor is employed; specifically, variation 4 produces the fastest results.

DISCUSSION

Any increase in the GRAPPA acceleration factor will cause a decrease in SNR.[11,13] This is due to the k-space used to make the image was decreased by an increased GRAPPA acceleration factor.[13]

Maulidya & Murniati's (2018) research indicated that the image quality remains optimal for GRAPPA acceleration factors 2 and 3, providing good diagnostic information quality.[14] However, variation with a GRAPPA acceleration factor of 4 results in poor image quality.[15] This is consistent with the findings of our study, where the post hoc test results show that the general SNR organ with a variation of GRAPPA acceleration factor 3 has a significance level >0.05 (*p-value* > 0.05) compared to the variation without GRAPPA acceleration factor. This indicates that the image quality of the variation with GRAPPA acceleration factor 3 is not significantly different from the image quality of the variation without GRAPPA acceleration factor. On the other hand, for the variation with GRAPPA acceleration factor 4, a

TABLE 3
SNR normality test results for each organ

SNR	AF Variation	Shapiro-Wilk	
		N	Sig.
Nucleus pulposus	1	10	0.153
	2	10	0.130
	3	10	0.081
	4	10	0.116
Ligamentum flavum	1	10	0.658
	2	10	0.079
	3	10	0.523
	4	10	0.094
Liquid cerebrospinal	1	10	0.504
	2	10	0.490
	3	10	0.412
	4	10	0.129
Medulla spinalis	1	10	0.329
	2	10	0.428
	3	10	0.083
	4	10	0.064

TABLE 4
CNR Normality Test Results

CNR	AF Variation	Shapiro-Wilk	
		N	Sig.
Liquid cerebrospinal-Ligamentum flavum	1	10	0.743
	2	10	0.846
	3	10	0.431
	4	10	0.161
Liquid cerebrospinal-Medulla spinalis	1	10	0.217
	2	10	0.072
	3	10	0.104
	4	10	0.291
Medulla spinalis-Ligamentum flavum	1	10	0.967
	2	10	0.831
	3	10	0.089
	4	10	0.436

TABLE 5
Post Hoc SNR

Organ	AF	AF	Sig.	Annotation
SNR Nucleus pulposus	1	2	0.151	Not significantly different
		3	0.383	Not significantly different
		4	0.011	Significantly different
	2	1	0.151	Not significantly different
		3	0.945	Not significantly different
		4	0.667	Not significantly different
	3	1	0.383	Not significantly different
		2	0.945	Not significantly different
		4	0.341	Not significantly different
	4	1	0.011	Significantly different
		2	0.667	Not significantly different
		3	0.341	Not significantly different
SNR Ligamentum flavum	1	2	0.557	Not significantly different
		3	0.199	Not significantly different
		4	0.062	Not significantly different
	2	1	0.557	Not significantly different
		3	0.895	Not significantly different
		4	0.582	Not significantly different
	3	1	0.199	Not significantly different
		2	0.895	Not significantly different
		4	0.939	Not significantly different
	4	1	0.062	Not significantly different
		2	0.582	Not significantly different
		3	0.939	Not significantly different
SNR Liquid cerebrospinal	1	2	0.003	Significantly different
		3	0.000	Significantly different
		4	0.000	Significantly different
	2	1	0.003	Significantly different
		3	0.927	Not significantly different
		4	0.000	Significantly different
	3	1	0.000	Significantly different
		2	0.927	Not significantly different
		4	0.002	Significantly different
	4	1	0.000	Significantly different
		2	0.000	Significantly different
		3	0.002	Significantly different

TABLE 5. Continued

Organ	AF	AF	Sig.	Annotation
SNR Medulla spinalis	1	2	0.210	Not significantly different
		3	0.058	Not significantly different
		4	0.000	Significantly different
	2	1	0.210	Not significantly different
		3	0.920	Not significantly different
		4	0.017	Significantly different
	3	1	0.058	Not significantly different
		2	0.920	Not significantly different
		4	0.078	Not significantly different
	4	1	0.000	Significantly different
		2	0.017	Significantly different
		3	0.078	Not significantly different

TABLE 6
Anatomical information assessment of MRI lumbal axial T2WI TSE on GRAPPA acceleration factor variation

AF Variation	Score	Total Assessment				Score Annotation
		Nucleus pulposus	*Ligamentum flavum*	*Liquid cerebrospinal*	*Medulla spinalsis*	
AF 1	1	0	0	0	0	1 = unclear
	2	0	0	1	0	2 = less clear
	3	0	9	6	8	3 = moderately clear
	4	10	1	3	2	4 = clear
AF 2	1	0	0	0	0	
	2	0	0	0	2	
	3	10	10	9	8	
	4	0	0	1	2	
AF 3	1	1	0	0	1	
	2	9	4	2	1	
	3	0	6	7	8	
	4	0	0	1	0	
AF 4	1	10	2	0	1	
	2	0	8	6	8	
	3	0	0	4	1	
	4	0	0	0	0	

TABLE 7
Friedman's rank based on anatomical information assessment

GPAPPA *acceleration factor*	Mean Rank
AF 1	3.45
AF 2	2.89
AF 3	2.36
AF 4	1.30

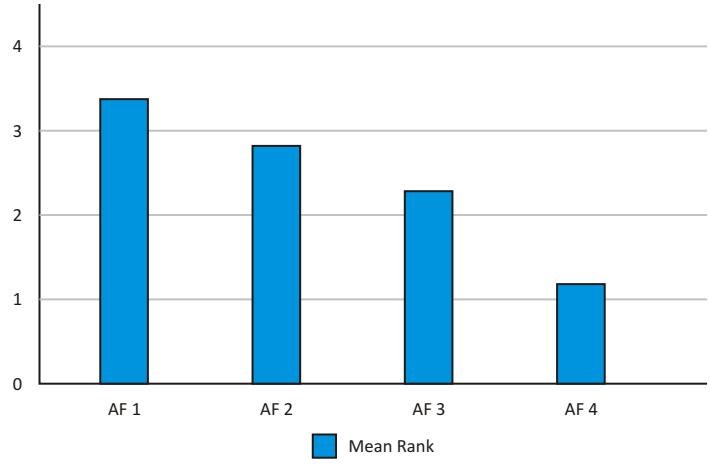

Figure 3. Mean rank graph

TABLE 8
Kendall's Tau correlation test results on variations in GRAPPA acceleration factor on anatomical information

GPAPPA *acceleration factor*	Sig. (2-tailed)	Annotation
AF vs Informasi Anatomi	0.000	Significant, Strong

TABLE 9
Pairwise comparison Kruskal Willis test result

Acceleration Factor	Sig.	Annotation
AF1 vs AF2	0.172	Not significantly different
AF1 vs AF3	0.173	Not significantly different
AF1 vs AF4	0.005	Significantly different

significance level < 0.05 (*p-value* < 0.05) was obtained, indicating a significantly different image quality compared to the image quality without GRAPPA acceleration factor. Based on the visual grading assessment using the Kruskal-Wallis test, it is evident that the GRAPPA acceleration factor 3 produces anatomical information comparable to the results obtained without GRAPPA acceleration factor variation.

In its application parallel imaging (GRAPPA) is used to reduce scan time.[13,16] Based on the findings of this study, employing a GRAPPA acceleration factor of 2 leads to a 44.74% reduction in scan time compared to the absence of GRAPPA acceleration (AF 1). Furthermore, utilizing a GRAPPA acceleration factor of 3 results in a

TABLE 10
Scan time on GRAPPA acceleration factor variation

Variation	*Scan time*	Reduction persentage (%)
AF 1	3.48	- %
AF 2	2.06	44.74%
AF 3	1.19	65.35%
AF 4	0.56	75.44%

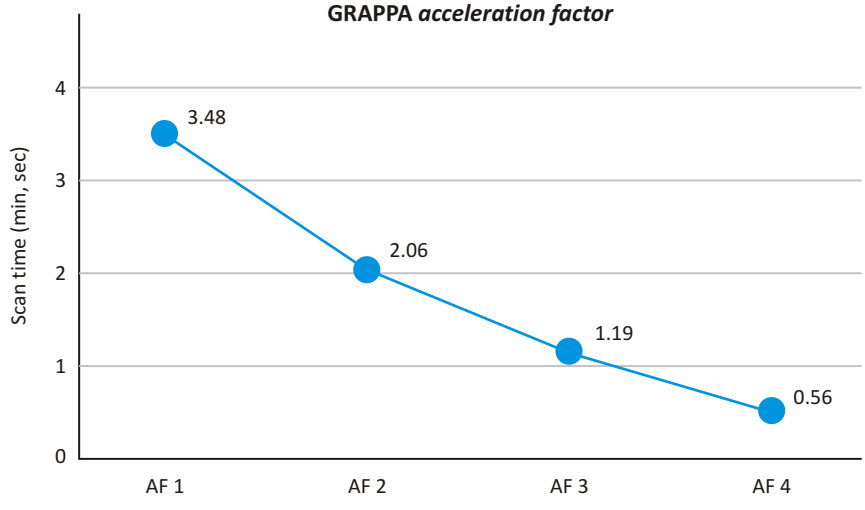

Figure 4. Scan time graph on GRAPPA variation

65.35% decrease in scan time, while a factor of 4 yields a 75.44% reduction, both in comparison to the scenario without GRAPPA acceleration (AF 1). In another study by Nölte *et al*. (2008), the use of GRAPPA acceleration factor 2 will reduce scan time by about 50% of the original sequence (without variation of the GRAPPA acceleration factor).[16]

Numerous studies, mainly conducted using 1.5T scanners, have demonstrated that the implementation of parallel imaging can significantly reduce examination time while maintaining the image quality. The advantages of shorter breath-hold times in parallel MRI have been evidenced in cardiac, thoracic, and liver imaging,[17] as well as in cardiac MR imaging with free breathing.[18]

In non-cooperative patients, or in patients who are in pain when lying down for a long time on examination such as LSS cases,[6,19] parallel imaging is expected to avoid motion artefact,[15] and several other benefits in examinations with patients who have difficulty lying down for a long time.[16] With a scan time reduction of up to 65.35%, acceleration factor 3 is particularly advantageous for examining non-cooperative patients.

CONCLUSION

The optimal acceleration factor value used in Lumbar MRI Axial Cut T2WI TSE with LSS Case is acceleration factor 3 where there is no significant difference in image quality and anatomical information produced by variations without GRAPPA acceleration factor (*p-value* >0.05). With a time reduction of 65.35% in acceleration factor 3, it is very helpful in examining non-cooperative patients or patients with conditions that cannot survive lying down for a long time. The use of GRAPPA acceleration factor 3 in MRI examinations can still maintain the optimal image quality and anatomical information with a fast scan time.

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