Optimization of ARC In Sagittal T2 FSE Thoracolumbar MRI: Impact On Image Quality And Diagnostic Information In Clinical HNP

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Abstract. MRI has a sensitivity and specificity of 96%–97%. The Autocalibrating Reconstruction for Cartesian Imaging (ARC) technique is an acceleration method that reduces acquisition time. Although ARC2 is commonly applied in clinical practice, other ARC variations are available. This study aimed to evaluate differences in signal-to-noise ratio (SNR) and diagnostic clarity among ARC settings and to determine the optimal configuration for thoracolumbar MRI. An experimental study was conducted on ten patients scanned using ARC 1, 1.5, and 2. SNR was measured using ROI, and diagnostic evaluation of intervertebral discs, vertebral bodies, cerebrospinal fluid, and spinal cord was independently assessed by radiologists. Data were analyzed using ANOVA, Friedman, and Wilcoxon tests with a significance level of $\alpha = 0.05$. Results showed significant SNR differences across ARC settings ($p < 0.001$). Post hoc analysis indicated differences between ARC1 and ARC1.5 ($p = 0.041$) and between ARC1.5 and ARC2 ($p = 0.002$), but not between ARC1 and ARC2 ($p = 0.861$). Diagnostic clarity also different significantly ($p < 0.001$), with ARC1 providing the highest clarity (mean rank = 2.39). Wilcoxon confirmed significant differences between ARC1 and ARC1.5 ($p < 0.001$) and between ARC1.5 and ARC2 ($p < 0.001$), but not between ARC1 and ARC2 ($p = 0.083$). ARC1 offers the best balance of image quality and diagnostic clarity for thoracolumbar sagittal T2-weighted FSE MRI.
Keywords: Thoracolumbar MRI, ARC, SNR, Diagnostic information

1 Introduction

Hernia Nucleus Pulposus (HNP) is the displacement of part of the intervertebral disc beyond the normal limits of the disc space, especially the nucleus pulposus and annulus fibrosus [1,2]. The recommended supporting examination as an appropriate non-invasive test to confirm a herniation is Magnetic Resonance Imaging [3,4]. MRI is the primary modality for diagnosing HNP, with sensitivity and specificity rates of 96%-97% [4,5]. The advantages of MRI include high sensitivity in assessing soft tissue morphology, the ability to produce multiplanar images without requiring patient position changes, the absence of ionizing radiation, and the capability to distinguish between solid tissue, fat, fluid, bleeding, and blood vessels [3,6]. Additionally, MRI is useful in evaluating the angles of the spinal facet joints and analyzing the relationship between discs to detect herniations [7,8].

Thoracic and lumbar MRI examinations typically employ routine sequences, including Coronal SE/FSE T1, Sagittal SE/FSE T1, Axial/Oblique SE/FSE T1/T2, and Sagittal SE/FSE T2. In HNP cases, a sagittal section is mandatory, as it can visualize the vertebral body, intervertebral disc, spinal cord, and anterior and posterior longitudinal ligaments, with an axial section serving as a complement [9–11].

T2-weighting plays a crucial role in displaying pathological images because it is sensitive to fluid, causing fluid structures to appear hyperintense. Fast Spin Echo (FSE) sequences, as a modification of Spin Echo (SE), are applied to accelerate image acquisition. FSE sequences have the advantage of faster scanning time than SE [9,10].

MRI image quality is influenced by several main factors, namely Signal-to-Noise Ratio (SNR), Contrast-to-Noise Ratio (CNR), spatial resolution, and scan time. SNR is the ratio between the received signal and the average noise amplitude, while CNR indicates the difference in SNR values between adjacent tissues. Scan time is the duration required to complete data acquisition [12].

In vertebral examinations, image quality is often compromised by artefacts resulting from breathing, peristalsis, blood vessels, heart rate, and patient movement. (Sánchez et al., 2022). Patients with HNP generally find it difficult to lie down for long periods of time due to pain, thus risking motion artefacts and repetition of examinations. Therefore, a method is needed that can accelerate data acquisition [15].

Parallel Imaging (PI) is an advanced technique that can speed up MRI data acquisition, although it comes with a decrease in SNR [16]. One of the k-space-based PI methods is GRAPPA (Generalised Autocalibrating Partial Parallel Acquisition). Each MRI vendor has different terms, such as EXSPER (Canon), GRAPPA (Siemens), and ARC (Autocalibrating Reconstruction for Cartesian Imaging) on the GE [16]. The ARC method works by autocalibrating to speed up scanning time [17]. However, there is no comparative study that systematically analyses the effect of variations in ARC values on image quality and diagnostic clarity in thoracolumbar MRI examinations. Thus, the selection of ARC parameters in hospital facilities remains empirical and lacks evidence-based support.

In some hospitals, Thoracolumbar Sagittal T2 FSE MRI examinations use ARC with a fixed value of 2. In fact, the GE Signa Explorer 1.5 Tesla MRI has variations of ARC values of 1, 1.25, 1.5, 1.75, and 2. This is the background of this study, which aims to analyze the use of three variations of ARC values (1, 1.5, and 2) on the Sagittal T2 FSE sequence and determine the ARC value that produces image quality (SNR and scan time) and the most optimal diagnostic information.

2 Methods

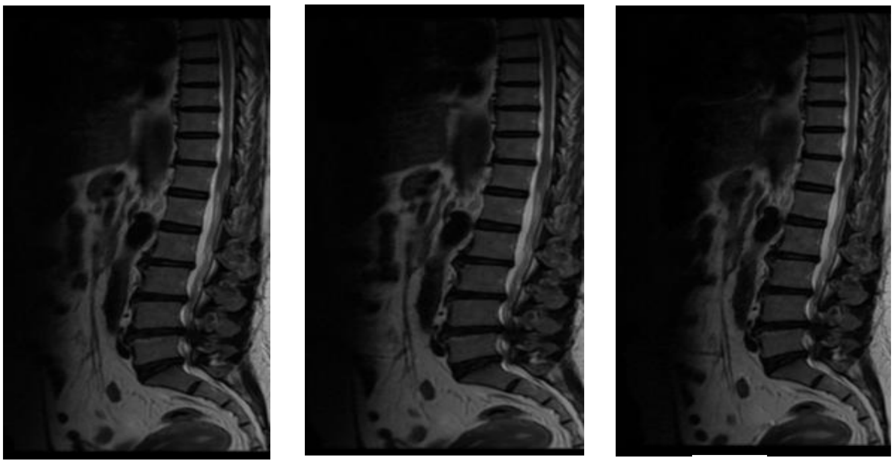
This type of research is experimental with a test only without a control group design. The population consisted of all patients undergoing Thoracolumbar MRI examinations with clinical HNP, from whom 10 patients were selected through purposive sampling and were willing to participate in this study by signing informed consent. Each patient was scanned three times (ARC value 1, 1.5, and 2) with Sagittal T2 FSE sequences. The order of scanning within a session, along with other parameters (TR, TE, and slice thickness), was kept constant. Image quality (SNR) was measured using manually placed Region of Interest (ROI) on the vertebrae, discs, cerebrospinal fluid, and spinal cord in the same slice. Diagnostic information was assessed by a radiologist regarding the intervertebral discs, vertebral bodies, cerebrospinal fluid, and spinal cord on a Likert scale of 1 (not clear), 2 (clear), and 3 (very clear). Statistical analysis of image quality (SNR) using repeated-measure ANOVA followed by a further difference test using the Post Hoc test to determine differences in SNR between variations in ARC values. In assessing diagnostic information, the similarity of perceptions between two expert assessors was evaluated using Cohen's test. Analysis of different diagnostic information using the Friedman test, followed by the Wilcoxon test to determine differences in diagnostic information between variations in ARC values. All data analysis was performed with SPSS Version 32 with a significance level of $\alpha = 0.05$.

This study received approval from the Health Research Ethics Committee of Poltekkes Kemenkes Semarang, with certificate number 0312/EA/KEPK/2024.

3 Results And Discussion

3.1 Results

The characteristics of the study sample consisted of seven female patients (70%) and three male patients (30%) with an age range of 15-75 years. Each patient underwent three MRI examinations with varying ARC values of 1, 1.5, and 2 on the Sagittal T2 FSE sequence. The images of all patients were then measured by determining the Region of Interest (ROI) in the anatomical areas assessed, namely the intervertebral disc, vertebral bodies, cerebrospinal fluid (CSF), and spinal cord. ROIs with a diameter of 5 mm^2 were placed on the predetermined organs to obtain the average signal value (Mean). In addition, ROI is also placed on the background outside the organ area, with as many as four points on each image, to obtain the average value of standard deviation as a noise value, which is then used in the calculation of the Signal-to-Noise Ratio (SNR). The image results of using ARS variations are shown in Figure 1.



(a) (b) (c)

Fig. 1. Clinical HNP Thoracolumbar Sagittal T2 FSE MRI Image Results (a) ARC 1 (b) ARC 1.5 (c) ARC 2

In the thoracolumbar MRI image, the SNR value is then measured by manually placing the ROI at the points shown in Figure 2.

Fig. 2. ROI placement of T2 FSE Thoracolumbar Sagittal MRI Image on ARC value variation
1: Cerebrospinal fluid (CSF)
2: Spinal cord
3: Vertebral bodies
4: Intervertebral disc
5-8: Background Image

The calculation of the SNR value is done by dividing the signal value (mean) of the organ area by the noise value (average standard deviation) of the background outside the organ area, with the following formula:

$$\boldsymbol{SNR} = \frac{Mean\ Organ\ Signal}{Mean\ of\ standard\ deviation\ Background}$$

After obtaining the SNR value, the SNR value difference test is then carried out on the ARC value variation. SNR data that has been tested for normality is then tested for differences in SNR values with repeated-measure ANOVA to determine the difference in SNR at various ARC values, as in Table 1.

Table 1. SNR Difference Test Results on ARC Value Variations

No.	Variation of ARC value	Mean	Significance
1.	ARC 1	216.38	< 0.001
2.	ARC 1.5	155.09	
3.	ARC 2	128.89	

The results of the SNR difference test on the variation of ARC values show a $p < 0.001$ ($p < 0.05$), so it can be concluded that there is a significant difference in image quality (SNR) in the use of ARC 1, 1.5, and 2 in clinical HNP Thoracolumbar Sagittal T2 FSE MRI examinations. The SNR value of ARC 1 is better than that of ARC 1.5 and ARC 2. Furthermore, additional tests (Post Hoc) were conducted to determine the difference in SNR between variations in ARC values, as shown in Table 2.

Table 2. SNR Difference Test Results Between Variations of ARC Value

No.	Variation of ARC value	Significance
1.	ARC 1 – ARC 1.5	0.041
2.	ARC 1.5 – ARC 2	0.861
3.	ARC 1 – ARC 2	0.002

The results of the SNR difference test on the variation of ARC values showed a significant difference in image quality between ARC 1 and ARC 1.5, as well as between ARC 1 and ARC 2. However, there was no significant difference between ARC 1.5 and ARC 2 on the Thoracolumbar Sagittal T2 FSE MRI examination of clinical HNP. The scan time for each ARC variation is 03:16 for ARC 1, 02:24 for ARC 1.5, and 01:50 for ARC 2. These results indicate that the increase in ARC value is directly proportional to the decrease in scan time, with ARC 2 exhibiting the fastest scan time among the three ARC values. Image assessment of each variation of ARC value was performed by two radiology specialists, yielding good inter-rater agreement (Kappa coefficient = 0.776). Furthermore, an analysis using the Friedman test was conducted, and the results of the diagnostic information difference test for each variation in ARC values are shown in Table 3.

Table 3. Differential Test of Diagnostic Information Between Variations of ARC Value

No.	Variation of ARC value	Mean Rank	Significance
1.	ARC 1	3.00	< 0.001
2.	ARC 1.5	1.60	
3.	ARC 2	1.40	

The results of the diagnostic information difference test on the variation of ARC values showed a $p < 0.001$ ($p < 0.05$), indicating a significant difference in diagnostic information between the Thoracolumbar Sagittal T2 FSE MRI examination and clinical HNP. The diagnostic information of ARC 1 is better than that of ARC 1.5 and ARC 2. To examine the detailed differences between variations of ARC values, the Wilcoxon test was performed, with the results presented in Table 4.

Table 4. Differential Test Results of Diagnostic Information Between Variations of ARC Value

No.	Variation of ARC value	Significance
1.	ARC 1 – ARC 1.5	0.004
2.	ARC 1.5 – ARC 2	0.156

3.	ARC 1 – ARC 2	0.004

The results of the differential test of diagnostic information between variations of ARC values showed that there was a significant difference in diagnostic information on the use of ARC values 1 with 1.5 (p = 0.004 and ARC value 2 with 1 (p = 0.004). However, there was no significant difference in diagnostic information regarding the use of ARC values (1.5 vs. 2) on Thoracolumbar Sagittal T2 FSE clinical HNP MRI examinations (p = 0.156). The results of this study indicate a significant difference in image quality (SNR) when using ARC value variations of 1, 1.5, and 2 in Thoracolumbar Sagittal T2 FSE MRI examinations of clinical HNP.

3.2 Discussion

The results showed that ARC 1 produced better image quality (SNR) than ARC 1.5 and ARC 2. The decrease in SNR at various ARC values is consistent with Hamilton's theory, which states that parallel imaging techniques are employed to accelerate MRI data acquisition. However, the decrease in SNR does not completely hinder image interpretation, as diagnostic quality can still be assessed. [17]. This finding is also reinforced by other studies, which explain that although parallel imaging can speed up the examination time, its weakness is the decrease in SNR, especially when the acceleration factor used is higher [18,19]. This finding is consistent with the results of this study, which shows that the increase in ARC value is directly proportional to the decrease in image quality (SNR). In addition, previous research also shows that GRAPPA variations have a significant effect on SNR, and it can be concluded that the higher the acceleration factor, the lower the SNR value due to reduced k-space data [15,18,20]. In this study, the scan time of Thoracolumbar Sagittal T2 FSE MRI examination with various ARC values showed different results: at ARC 1 for 3 minutes 16 seconds, ARC 1.5 for 2 minutes 24 seconds, and ARC 2 for 1 minute 50 seconds. This result shows a decrease in scan time as the ARC value increases, where ARC 2 produces the fastest scan time compared to ARC 1 and ARC 1.5. This finding is in line with the theory that parallel imaging techniques are used to speed up data acquisition so that examination time can be reduced [17, 21], and supported by other studies that mention parallel imaging is commonly used to reduce MRI acquisition time with a consequent decrease in SNR [17]. The results of this study are in line with previous research, which states that the greater the value of the acceleration factor used, the less the scanning time will be [22,23]. Diagnostic information in this study was obtained from the radiologist's assessment of Thoracolumbar Sagittal T2 FSE MRI images. In clinical cases of Herniated Nucleus Pulposus (HNP), the aspects assessed include the intervertebral disc, the vertebral bodies, cerebrospinal fluid (CSF), and the spinal cord. Assessment of the intervertebral disc involves evaluating the position, direction, shape, and size of the nucleus pulposus or annulus fibrosus tear, as well as its relationship to the surrounding nerve roots [8]. The results showed a significant difference in diagnostic information when using variations in ARC values of 1, 1.5, and 2, where ARC 1 provided better diagnostic information than ARC 1.5 and ARC 2. This finding aligns with Kartiksari's research, which indicates that the use of higher acceleration factors in parallel imaging techniques is typically accompanied by a decrease in signal-to-noise ratio (SNR) [24]. This finding is also consistent with previous research, which confirms that an increase in acceleration factor results in a decrease in SNR, thereby reducing the clarity of diagnostic information required by radiologists to make a diagnosis, especially in HNP cases [21]. Based on the results of the research and analysis, it can be concluded that the application of various ARC values has an influence on the scan time and the quality of diagnostic information on Thoracolumbar Sagittal T2 FSE MRI examination of clinical HNP. Although increasing the ARC value speeds up the scan time, using too high an ARC has implications for decreasing the signal-to-noise ratio (SNR) and reducing image clarity. Thus, ARC 1 provides the best balance between time efficiency and diagnostic clarity, and can be recommended as an optimal choice in clinical practice.

4 Conclusion

This study demonstrates that variations in ARC values have a significant impact on the SNR and clarity of diagnostic information in thoracolumbar sagittal T2 FSE MRI examinations of HNP cases. Increasing the ARC value was shown to speed up the scan time; however, this was accompanied by a decrease in SNR and a loss of clarity in anatomical structures. Among the variations tested, ARC1 provided the most optimal results and is recommended as the ideal parameter setting for thoracolumbar MRI examination in HNP patients.

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