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Performance evaluation of the artificial intelligence assisted compressed sensing MR technique in routine clinical settings

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Abstract

Magnetic Resonance (MR) Imaging plays a valuable role in diagnosis and prognosis of diseases. However, the longer scanning time of MR examinations is considered one of the biggest challenges faced by radiology departments and their patients. Recently, the introduction of artificial intelligence (AI) and deep learning methods have made it possible to enable ultra-fast image acquisition while maintaining high resolution image quality. In this work, a deep-learning-based reconstruction technique by United Imaging Healthcare called AI-Assisted Compressed Sensing (ACS) was evaluated qualitatively and quantitatively for its utility in routine clinical settings for brain, knee, kidney, liver and spine. MR scans were conducted with ACS and without ACS sequences. Images were assessed by a Radiologist for their quality, artifacts, diagnostic efficacy and sharpness. A quantitative assessment was done by calculating signal to noise ratio (SNR) and contrast to noise ratio (CNR). A qualitative evaluation by a Radiologist showed that the overall quality and diagnostic information in images acquired with ACS was similar to images obtained without ACS. Similarly, the SNR and CNR values obtained from images with ACS demonstrates significantly higher values ($p < 0.05$) as compared with images acquired without ACS. Results obtained in this study also found that ACS-enabled images not only maintain good quality and high resolution with better sharpness but also takes much lesser time for acquisition. In conclusion, the ACS technique is easy to implement in routine clinical settings, provides considerable image quality as compared to those techniques with routine MR sequences, and saves significant time during acquisition, which helps Radiologists and imaging technologists plan more cases with an adequate quality of images for diagnostic purposes.

1. Introduction

MRI can provide multi-parameter and multi-directional imaging of organs, which has significant application value in disease diagnosis and prognosis monitoring. Much effort has been made in recent years to enhance the field of view (FOV), resolution, and acquisition time of MRI sequences. The long examination duration is one of the challenges faced by radiology departments and the patients being examined, making it difficult for some patients to hold still during the examination, leading to motion artifacts. Longer scanning time not only introduces artifacts in acquired images but also significantly increases health cost and availability, especially in countries where the number of MR scanners are limited [1]. The MR imaging cycle is repeated many times during the acquisition process and the number of cycles depends on the quality of the image that is required. Signal-to-noise ratio (SNR) is primarily used in MR for image evaluation and quality assurance; however, SNR in MR is inherently constrained. One must find an acceptable trade-off between spatial resolution and scan time in most clinical applications. With more clinical examinations being performed, innovative accelerated imaging is urgently needed to enable ultra-fast scanning while producing high-quality images [2]. In recent times, compressed sensing-based techniques, (nonlinear mathematical models that successfully suppress noise bands and acceleration-induced artifacts), have been developed and employed in several clinical studies [3-5]. These technologies effectively reduce imaging time, but at the cost of image quality. The number of studies examining the image quality of compressed sensing for therapeutic applications is growing. Nevertheless, image quality of compressed sensing for cardiac, brain, liver, cervical artery, and prostate MR is poorly studied, and analysis of its use in clinical routine is lacking. Several attempts have been made to overcome issues faced in compressed sensing as well as in other acceleration techniques such as half Fourier and parallel imaging methods. Recently, a deep- learning-based reconstruction technique called uAI®-Assisted Compressed Sensing (ACS) was introduced that is integrated with conventional acceleration techniques to provide better quality and reduced scanning time [6]. Despite the fact that ACS has been successfully applied to most body organs, its utility in a routine clinical setting has not been specifically tested. This study is thus conducted to measure performance of ACS in terms of scanning time, qualitative and quantitative parameters in depicting image quality in clinical settings.

2. Materials and Methods

2.1 Subjects

In this study, 25 subjects were randomly selected to undergo MR examination of different body regions such as brain, spine, knee, liver and kidney prospectively. For each body region, five subjects were chosen so that five MR datasets were acquired for each body region, with and without the ACS technique, using different MR contrasts.

2.2 MR Examination & protocols

All MR exams were performed on the 3T uMR® 780 system (United Imaging Healthcare Shanghai, China) at Sprint Diagnostics in Hyderabad, India. Before the examination, a consent form was signed by all subjects. For brain MR scanning, a dedicated 24 channel head-neck coil was used, while spine exams were performed using a 32-channel spine coil. For knee MR, a dedicated 12 channel coil was used, while for liver and kidney a combination of 12 channel body coil and 12 channel spine coil was used. A complete detail of different contrast and protocols parameters used in this study are included in Table 1. All sequence parameters were kept identical to acquire data with ACS and without ACS in all body regions.

Table 1. Scanning protocols of all sequences.

Region	Sequence Name	ACS/Non-ACS	Plane	TR	TE	ST	FA	#slice	AD	AF_ACS
Brain	T1-weighted FSE Flair	Non-ACS	Axial	2023	22.96	5	90	23	02:01	
	T2-weighted FSE Flair with FS	Non-ACS	Axial	9000	103.32	5	90	23	02:24	
	T1-weighted FSE	Non-ACS	Axial	375	6.32	5	90	23	02:08	
	T2-weighted FSE	Non-ACS	Axial	5552	118.08	5	90	23	01:07	
	T1-weighted FSE Flair	ACS	Axial	2023	22.96	5	90	23	00:53	2.5
	T2-weighted FSE Flair with FS	ACS	Axial	9000	103.32	5	90	23	01:30	2.5
	T1-weighted FSE	ACS	Axial	375	6.32	5	90	23	00:57	2.5
	T2-weighted FSE	ACS	Axial	5552	118.08	5	90	23	00:39	2.25
Spine	T1-weighted FSE	Non-ACS	Sagittal	750	9.26	4	90	11	01:49	
	T2-weighted FSE	Non-ACS	Sagittal	5421	121.8	4	90	11	02:21	
	T1-weighted FSE	ACS	Sagittal	750	9.26	4	90	11	00:51	2.25
	T2-weighted FSE	ACS	Sagittal	5421	121.8	4	90	11	01:00	2.25
Liver	T2-weighted_NAVI	Non-ACS	Axial	2775	84.8	6	90	24	03:53	
	T2-weighted FSE with FS and BH	ACS	Axial	2950	98.42	6	90	24	00:17	2.25
Kidney	T2-weighted_NAVI	Non-ACS	Axial	2700	84.8	6	90	24	04:08	
	T2-weighted FSE with FS and BH	ACS	Axial	8220	121	6	90	24	00:12	2.75
Knee	Proton Density FSE with FS	Non-ACS	Coronal	2780	38.3	3	90	26	03:34	
	T2-weighted FSE	Non-ACS	Sagittal	3200	118.08	3	90	26	04:10	
	T1-weighted FSE	Non-ACS	Axial	686	7.64	3	90	26	04:13	
	Proton Density FSE with FS	ACS	Coronal	2780	38.3	3	90	26	01:54	2
	T2-weighted FSE	ACS	Sagittal	3200	118.08	3	90	26	01:49	2.25
	T1-weighted FSE	ACS	Axial	686	7.64	3	90	26	01:47	2.25

FSE- Fast Spin Echo, FS- Fat Supression, BH- Breathhold, TR- Repetition Time, TE- Echo Time, ST- Slice Thickness, FA- Flip Angle, AD- Acquistion Duration, Acceleration Factor for ACS

2.3 Qualitative Evaluation

After the MR scan, images were transferred to a local clinical picture archiving and communication system (PACS) system and uWS® MR workstation (United Imaging Healthcare, Shanghai, China) available on the premises. For the qualitative evaluation of images acquired in different body regions from all subjects, a standard scoring was designed to evaluate quality in terms of artifacts in images, sharpness of tissue edges, overall images quality and the diagnostic efficiency of images. The scores were given on a 5-point scale ranging between 0 to 4 based on the parameters. Detailed information on the scoring is given in Table 2 below. A Radiologist with around 5 years of overall experience was asked to read all images and provide a rating based on the parameters shown here.

Table 2. Scoring criteria for qualitative analysis.

Parameters	Scores				
	0	1	2	3	4
Image Artefact	Non-Diagnostic Image Quality	Major Artifacts	Moderate Artifacts	Mild Artifacts	No Artifacts
Image Sharpness	Poor	Intermediate	Acceptable	Good	Perfect
Overall Image Quality	Poor	Intermediate	Acceptable	Good	Perfect
Diagnostic Efficiency	Poor	Intermediate	Acceptable	Good	Perfect

2.4 Quantitative Evaluation

Following the Radiologist's evaluation of qualitative criteria, all images were anonymised and transferred to a workstation. The quantitative assessment was further performed by calculating Signal to Noise ratio (SNR) and Contrast to Noise Ratio (CNR) in all the sequences for all body regions. To calculate these image quality parameters, multiple regions of interest (ROIs) in different tissue locations were drawn in the images to obtain average signal intensities and standard deviation of those signal intensities. The SNR and CNR measurements were performed using MATLAB (v.2018; MathWorks) functions using the formula given in Equation 1 and Equation 2. In order to demonstrate the capabilities of ACS enabled imaging, scanning time was also included in study as a quantitative parameter.

$$SNR = \frac{Average\ Signal\ Intensities}{Standard\ Deviation\ of\ noise} \dots\dots\dots\dots\dots\dots (1)$$

$$CNR = \frac{Difference\ in\ signal\ intensities}{Standard\ Deviation\ of\ noise} \dots\dots\dots\dots\dots (2)$$

SNR and CNR values were obtained in all sequences for five regions obtained from the 25 subjects and further used to conduct statistical analysis and correlations with qualitative evaluations done by the expert Radiologist.

2.5 Statistical analysis:

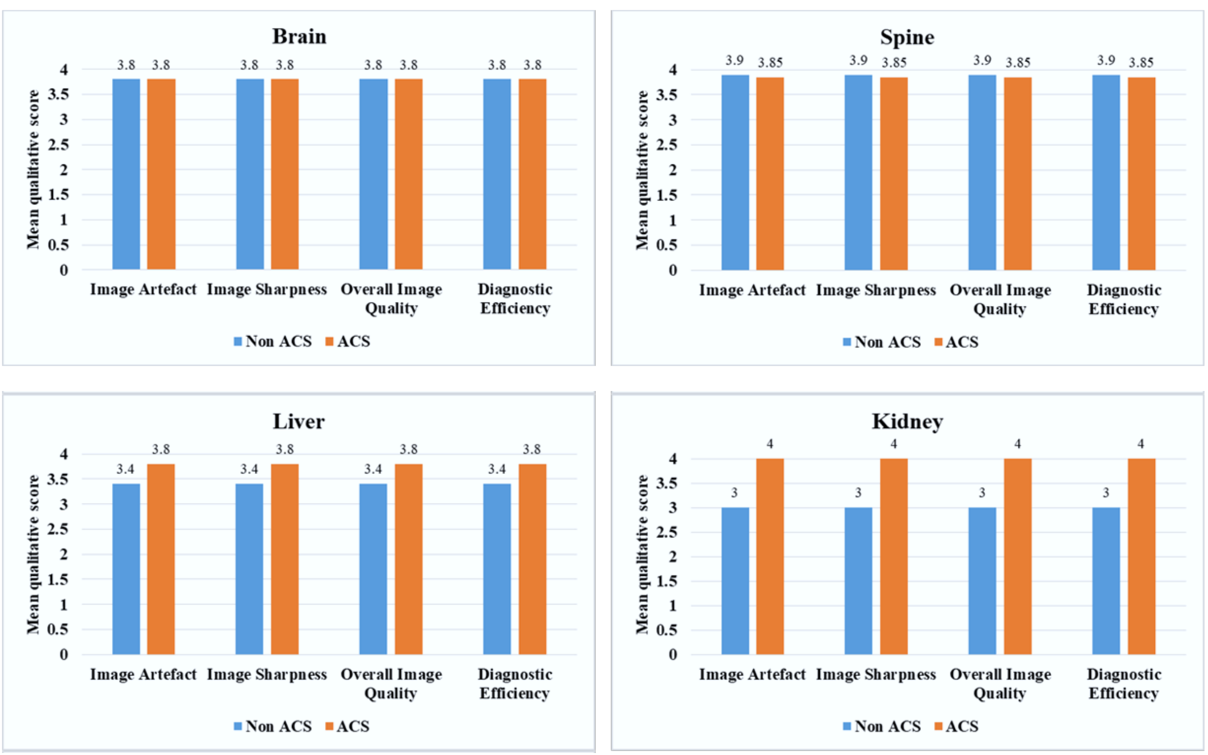
All the statistical analysis was done in MedCalc®, version 19.3 software (MedCalc Software Ltd). Qualitative and quantitative results obtained from both ACS and Non-ACS enabled image assessments were then compared using Mann-Whitney U-test and unpaired Student's t-test. Using Pearson's correlation coefficient, SNR and CNR values from non-ACS sequences were compared with those obtained from ACS sequences (r).

3. Results

One Radiologist interpreted and scored the images acquired in five different regions of all 25 subjects included in this study and was asked to evaluate quality in terms of artifacts, sharpness, overall image quality and diagnostic efficiency for two groups (ACS vs. Non-ACS) of images. The mean score of all assessments done by the Radiologist for each body region examined in this study are presented in Figure 1. Mann-Whitney U-test conducted in this study shows no significant difference ($p > 0.05$) in qualitative image quality between images acquired with ACS and images acquired without ACS, which means comparable results for both groups. A Radiologist's qualitative evaluation found that the diagnostic quality with all four parameters such as image artifact, image sharpness, overall image quality and diagnostic efficacy of images acquired with ACS was similar to or better than those obtained without ACS (Figure 1).

For the quantitative evaluation, SNR and CNR was measured in all sequences acquired with and without ACS as reported in Table 1 above for all body regions. The SNR values across all sequences for brain, spine, liver, kidney and knee were 37.92 ± 1.79, 44.2 ± 5.26, 43.26 ± 1.37, 43.41 ± 1.62 and 39.62 ± 3.63 in images acquired without ACS whereas the SNR values were 40.13 ± 2.00, 45.75 ± 4.90, 45.5 ± 2.20, 45.36 ± 2.56 and 41.60 ± 4.51, respectively in images acquired with ACS as shown in Figure 2. Similarly, CNR values obtained for brain, spine, liver, kidney and knee were 21.18 ± 5.23, 27.62 ± 5.90, 20.83 ± 3.62, 24.75 ± 2.95 and 24.75 ± 2.95 for images acquired without ACS and the CNR values were 22.10 ± 5.71, 29.70 ± 5.78, 22.54 ± 4.20 28.7 ± 3.68 and 28.80 ± 3.92, respectively for images acquired with ACS as shown in Figure 3. Both SNR and CNR values in 5 different regions were found to be slightly better in images acquired with ACS as compared to images acquired without ACS. According to the unpaired Student's *t-test*, ACS-based measurements showed substantially higher values ($p < 0.05$) for both SNR and CNR ac compared to non-ACS measurements. There was a good correlation ($r = 0.93$ for SNR and $r = 0.88$ for CNR) between non-ACS and ACS measurement.

In terms of scan time differences, total scanning time for all sequences acquired in each body region was calculated. For an example, T1-weighted FSE, T2-weighted FSE, T1-weighted FSE Flair, and T2-weighted FSE Flair with FS were acquired in the brain region with and without the ACS technique, and the total time was calculated for all 4 sequences acquired with ACS and without ACS. Similarly, the total scanning time was calculated for all five body regions for the respective sequences included in this study. Figure 4 shows the total scanning time values for each body region. The differences in scanning time of ACS enabled sequences showed significant improvements in scanning time compared to non-ACS sequences. For brain, spine, liver, kidney and knee examination, an improvement in scan time in terms of percentage of 48.10%, 55.52%, 92.80%, 95.15% and 54% respectively was observed, which shows impressive results while ensuring similar image quality. Examples of images acquired with ACS and without ACS technique in different body regions are shown in the Figures 5-9.



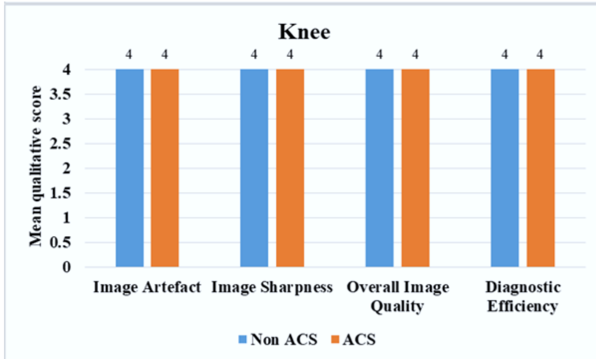


Figure 1. Mean qualitative score of ACS vs. Non-ACS for all body regions read by a Radiologist.

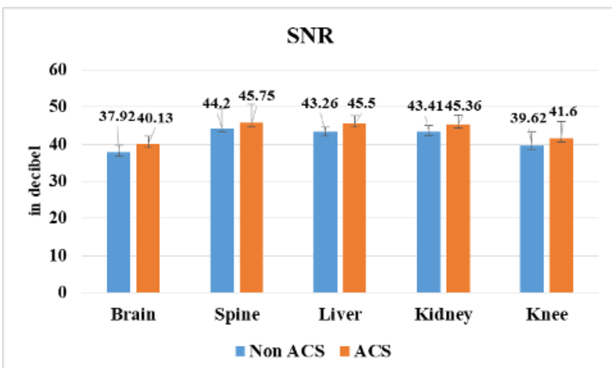


Figure 2. SNR across all body regions for non-ACS vs. ACS.

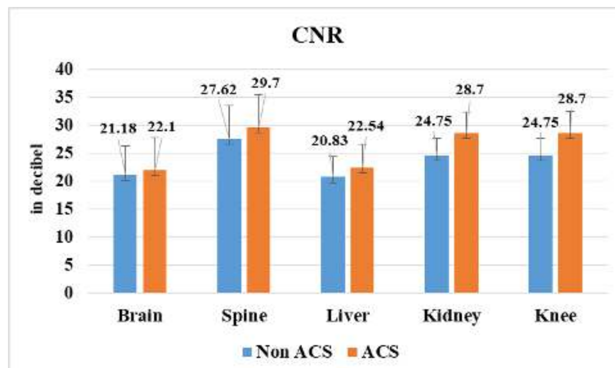


Figure 3. CNR across all body regions for non-ACS vs. ACS.

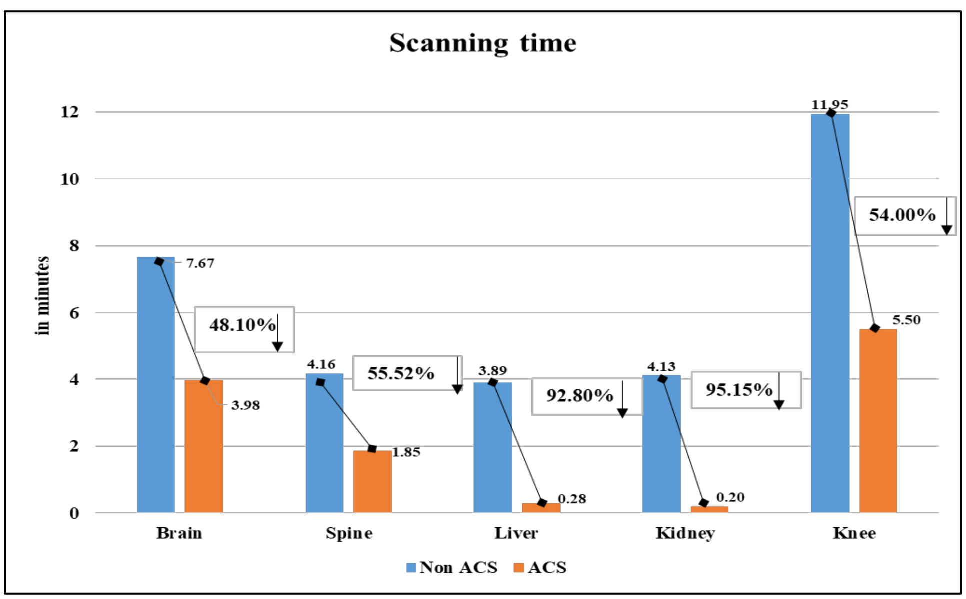


Figure 4. Total scanning time across all sequences for different body regions with percentage difference in scanning time between non-ACS and ACS in minutes.

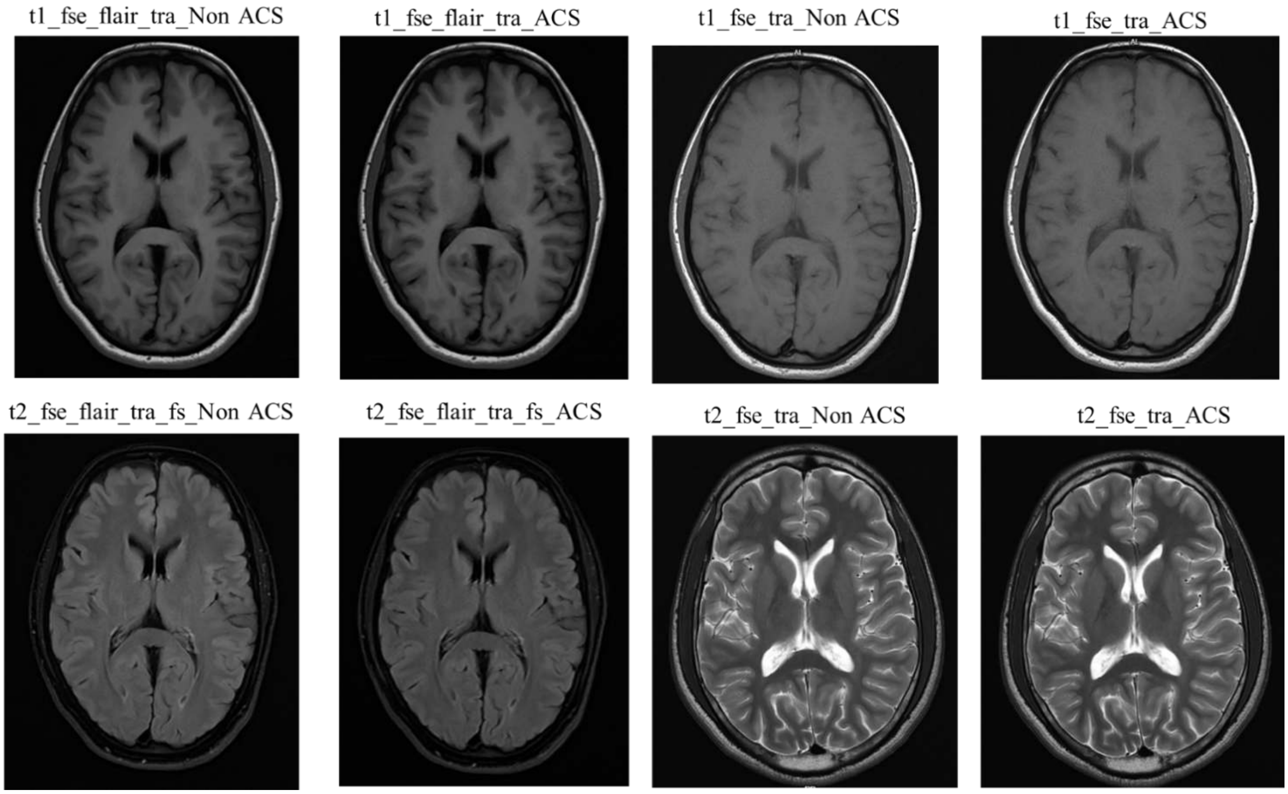


Figure 5. Brain MRI slices for all sequences of a representative subject.

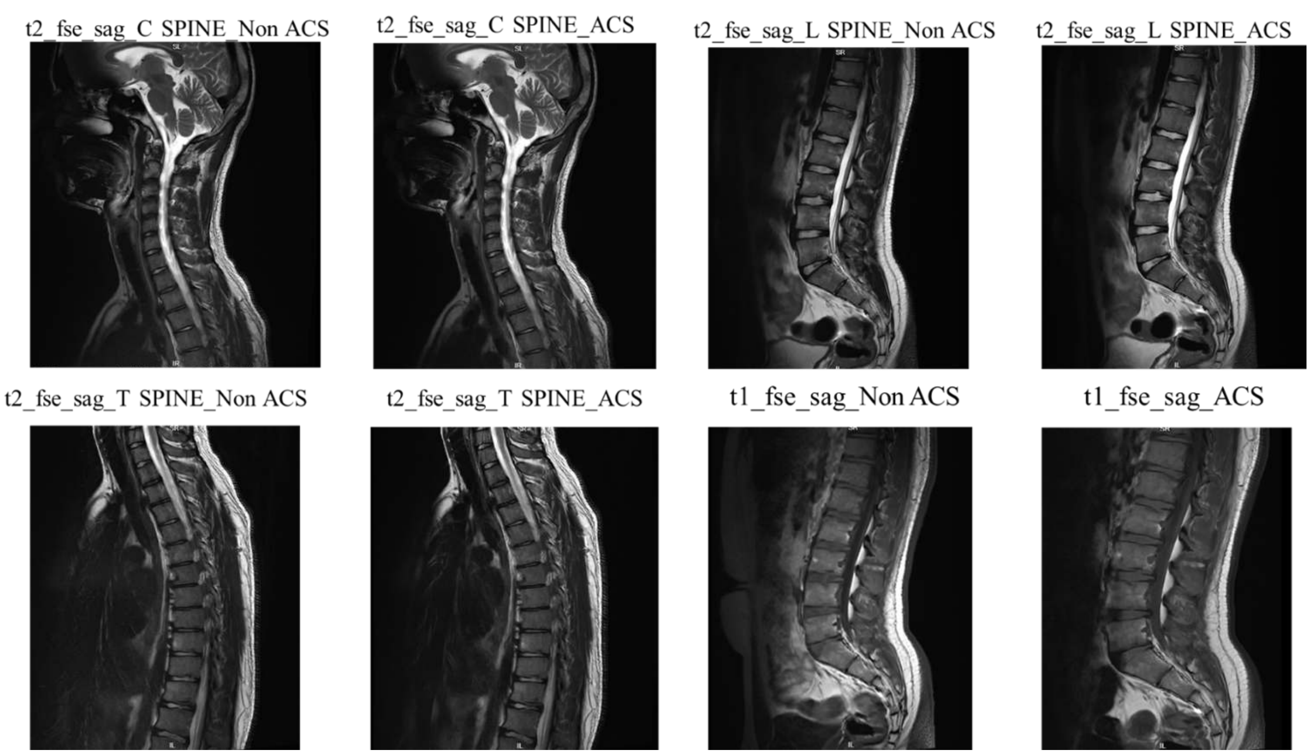


Figure 6. Spine MRI slices for all sequences of a representative subject.

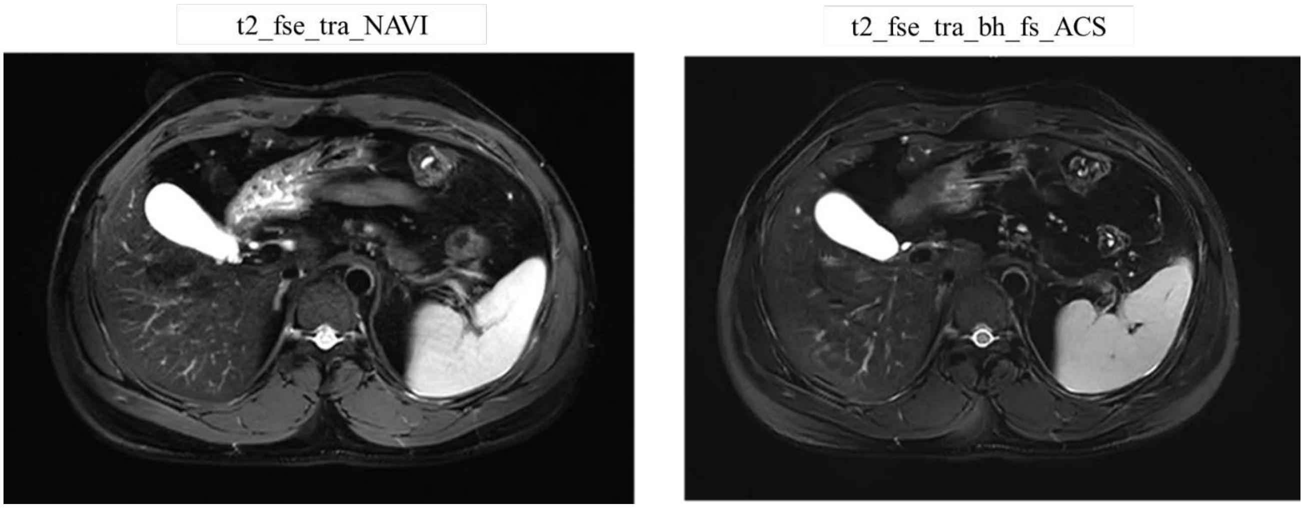


Figure 7. Liver MRI slice for all sequences of a representative subject.

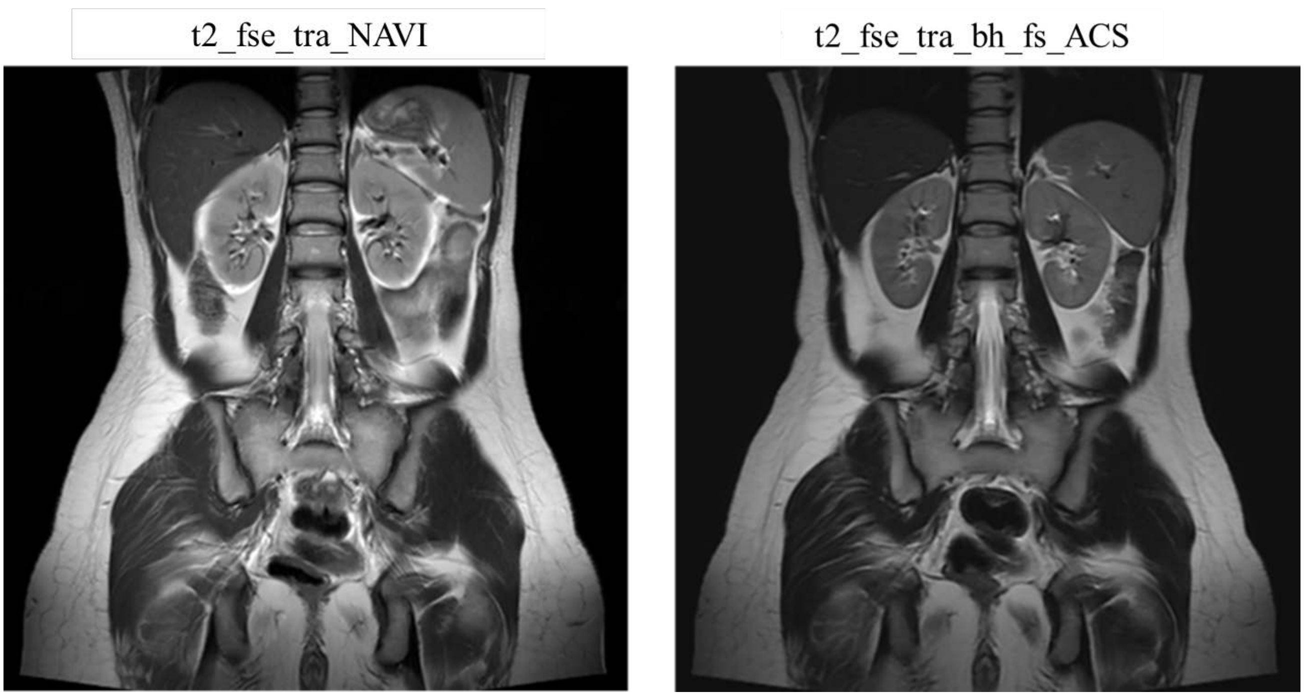


Figure 8. Kidney MRI slice for all sequences of a representative subject.

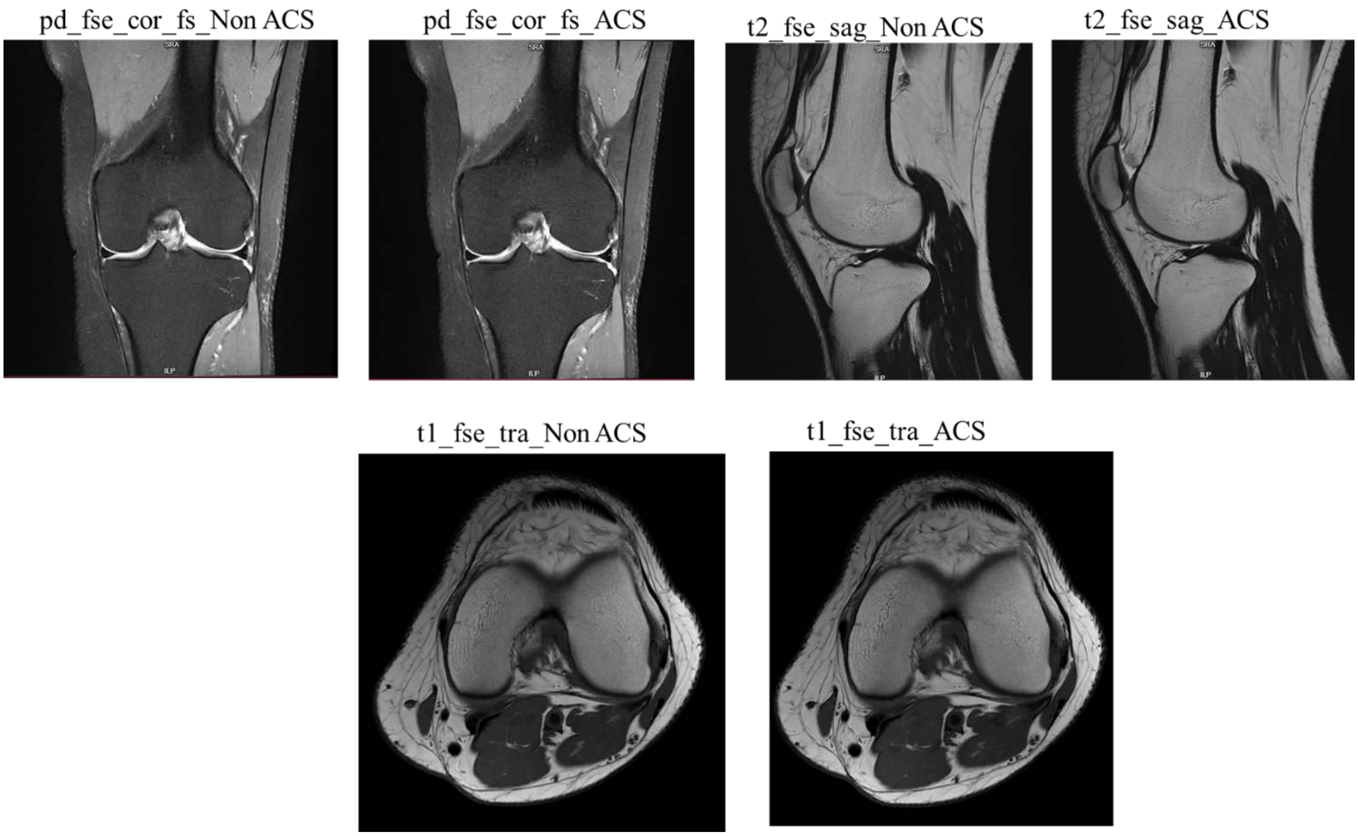


Figure 9. Knee MRI slices for all sequences of a representative subject.

4. Discussion/Conclusion

In this study, a clinical study of AI Assisted Compressed Sensing (ACS) magnetic resonance technology developed by United Imaging Healthcare was performed to measure its utility and effectiveness in routine clinical settings for different body regions (brain, spine, liver, kidney, and knee). Performance was measured in terms of scan duration, including both qualitative and quantitative parameters. The subjective image quality scoring parameters included artifacts in images, sharpness of tissue edges, overall image quality and the diagnostic efficiency of images and quantitative evaluation was done by measuring SNR and CNR. Often, compressed sensing methods are applied to different sequences, but they provide image artifacts and low quality of images for diagnostic purposes. In the past, several methods have also been introduced that help in image acquisition time reduction but lack in providing better outcomes for Radiologists to read or interpret those images for diagnostic accuracy. The findings of this study, on the other hand, revealed that the diagnostic quality of images acquired with ACS was similar to or better than images obtained without ACS.

Scan time, SNR, and CNR are the parameters traditionally used to demonstrate image quality with reasonable time for acquisition; there is typically a trade-off among all these parameters. Compared to non-ACS sequences, ACS has much shorter scan times for all body region sequences, enabling ultra-fast scans. Due to discomfort, disturbances in consciousness, and other factors, it might be difficult for some patients with severe disorders to maintain still for an extended period during imaging studies, which causes artifacts and lowers image quality. This issue can be resolved with ACS technology, which can also enhance image quality and clinical precision. Additionally, in line with literature [7], the SNR and CNR of the ACS subgroup were greater than those of the non-ACS or conventional group.

This study has some limitations. First, the data was acquired from a single institution and a small cohort, which may influence the outcomes. A large cohort and multicentre study can provide stronger evidence for larger clinical applications. Second, the reference measurement was done by only one Radiologist; inter-observer and intra-observer variability were not evaluated.

In conclusion, ACS technology not only substantially lowered scan time duration, but also provided diagnostic quality images without artifacts -- which enables this method to be clinically suitable, especially for the routine clinical settings where workload is high and patients may be non-cooperative. Sequences enabled with ACS should more frequently be used in the clinical settings to improve image quality, diagnostic value, and the effectiveness of radiology imaging departments.

5. Image/Figure Courtesy

All images are the courtesy of Sprint Diagnostics, Jubilee Hills, Hyderabad, Telangana 500033, India.

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