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Original Article

Compressed sensing magnetic resonance imaging (CS-MRI) diagnosis of rotator cuff tears

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Abstract: Objective: The present prospective study was performed to evaluate the diagnostic efficiency of compressed sensing magnetic resonance imaging (CS-MRI) for rotator cuff tears. Methods: Between December 1, 2021 and April 1, 2022, 62 patients with suspected rotator cuff tears were admitted to Affiliated Hospital of Jinggangshan University and received CS-MRI and arthroscopy to determine the diagnosis and the disease type of tears. Their medical data were obtained and analyzed to evaluate the clinical feasibility of CS-MRI in diagnosing rotator cuff tears. Results: Of the 62 cases of suspected rotator cuff tears, 45 were confirmed by arthroscopy, including 31 cases of total tears and 14 partial tears. Using arthroscopic findings as the gold standard for the diagnosis of rotator cuff tears, the sensitivity of clinical signs to diagnose rotator cuff tears was 66.67%, the specificity was 70.59%, and the accuracy was 67.74%, while the sensitivity of CS-MRI in diagnosing rotator cuff tears was 84.44%, the specificity was 88.24%, and the accuracy was 81.54%. The accuracy of CS-MRI was significantly higher than that of clinical signs as determined by chi-square test within groups (P=0.019). Conclusion: CS-MRI provides high resolution for muscles, tendons, and soft tissues, significantly contributing to the diagnosis of soft tissue injuries. Although there were no significant differences in the sensitivity and specificity of CS-MRI for the clinical diagnosis of rotator cuff tears compared to the clinical signs, CS-MRI significantly improved the diagnostic accuracy.

Keywords: Rotator cuff tears, magnetic resonance imaging, diagnostic efficiency, compression sensing

Introduction

Rotator cuff tears are a common cause of shoulder pain and impaired mobility [1] and are mostly attributed to progressive degeneration of the shoulder tendons. In the United States, the number of rotator cuff tear cases have exceeded 4.5 million people each year, and surgical interventions are required for approximately 5.5% of cases [2]. Moreover, research has suggested there may be a potentially higher prevalence of rotator cuff tears, as the special anatomical structure of the shoulder may result in asymptomatic cases [3]. Arthroscopy is the gold standard for the diagnosis of rotator cuff tears but is limited for extensive clinical use due to its invasiveness and high risk of damage to the rotator cuff during examinations [4]. In contrast, magnetic resonance imaging (MRI) and ultrasound are highly appreciated [5]. MRI and ultrasound have high resolution for articular cartilage, tendons, soft tissues, and ligaments, and provide clear imaging features of the scanned area. In a meta-analysis, Roy et al. revealed that the diagnostic sensitivity and specificity of ultrasound and MRI for rotator cuff tears have exceeded 90%, suggesting a promising diagnostic efficiency of imaging approaches for rotator cuff tears [6].

Conventional MRI is time-consuming, has a limited scanning coverage, and is predisposed to motion artifacts [7]. The concept of compressed sensing (CS) was proposed by Candes et al. [8] in 2004 and applied to vascular MRI by Lustig et al. in 2007, with promising diagnostic outcomes [9]. CS refers to the reconstruction of the original signals by selectively acquiring or sensing a small amount of important data or signals after compression and using efficient algorithms to reduce the time required for signal acquisition, so as to maximize the quality of

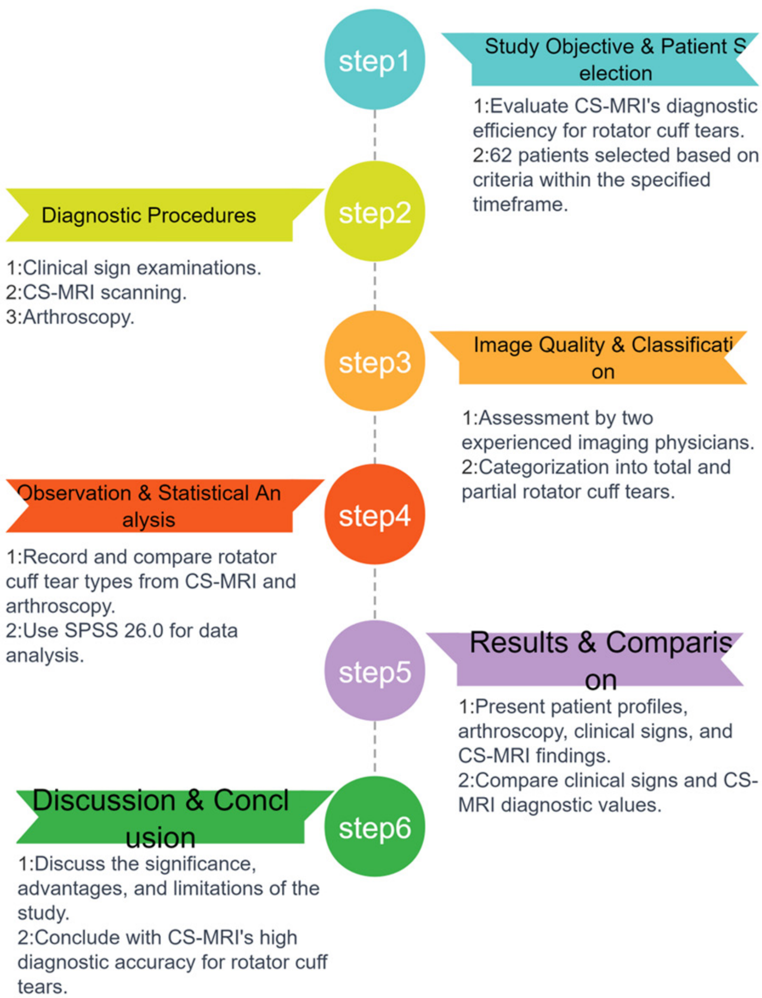

Figure 1. Flow chart of this study.

the original signals [10, 11]. To our knowledge, compressed sensing magnetic resonance imaging (CS-MRI) is less associated with imaging diagnosis of rotator cuff tears due to the unstable quality of CS-MRI images [12, 13]. To this end, the present study was performed to evaluate the diagnostic value of CS-MRI for rotator cuff tears.

Materials and methods

Medical data collection

This is a prospective cohort study. A total of 62 patients admitted to Affiliated Hospital of Jinggangshan University with suspected rotator cuff tears between December 1, 2021 and April 1, 2022 were enrolled for this study. Prior to enrollment, informed consent was obtained from all subjects. This study protocol was approved by the ethics committee of Affiliated Hospital of Jinggangshan University (JGSAH-20210114). All procedures comply with the ethical guidelines of the Declaration of Helsinki. A flow chart of this study is presented in **Figure 1**.

Inclusion criteria: (1) patients with clinical manifestations of shoulder pain or discomfort; (2) patients with at least one positive result in the four tests: drop arm test, impingement test, painful arc syndrome, and cracking shoulder test; (3) patients without previous shoulder disease; (4) patients without previous shoulder surgery; (5) patients with age over 18 years.

Exclusion criteria: (1) patients with poor MRI image quality due to excessive motion artifacts; (2) patients with implanted electronic devices such as pacemakers; (3) patients who were pregnant or had claustrophobia.

Methods

CS-MRI scan: Each patient was in a supine position with the shoulder joint abducted 60-120° to keep the shoulder joint as close to the midline area as possible. The Philips Ingenia 3.0T MR System (Philips Healthcare, Netherlands) was used to scan the transverse, oblique coronal, and oblique sagittal views using the PSE sequences, with the oblique coronal T1WI of TR/TE=640/16 ms, T2WI of TR/TE=2360/89 ms and T2WI fat suppression sequences of TR/TE=5000/85 ms, and a layer thickness of 3 mm. To reduce motion artifacts, a sponge pad and sandbag were used to immobilize the shoulder joint in the coil.

Arthroscopy: Under general anesthesia, each patient was placed in a lateral position with a 25° posterior tilt of the torso, 45° abduction of the upper extremity, and 15° anterior flexion with 3-4 kg traction on the affected extremity. A standard posterior approach was performed, and the arthroscope was placed to explore the glenohumeral structures, such as the long head of the bicep tendon, glenoid labrum, rostro-humeral ligament, glenohumeral ligament, rotator cuff stop, and humeral head. After establishing an anterior approach, we assessed the texture and tension of the rotator cuff tissue at the articular surface, removed the hyperplastic synovium, explored subacromial space, and cleared the subacromial space using a radio frequency surgical knife. Acromioplasty was performed if there was an impingement on the subacromial surface or an abnormal bursal layer of the rotator cuff. The tear site, depression site, or bubble sign positive site was determined, and the rotator cuff tissue was debrided using a radio frequency surgical knife, followed by the fixation of the tears. The number of rivets was determined according to the width of the rotator cuff tears.

Image quality evaluation

All imaging data were analyzed by two clinically experienced imaging physicians. Rotator cuff tears are classified as total and partial tears according to the magnitude of injury. A partial tear is defined as a limited high signal on the bursal or articular surface of the tendon on T2WI. A total tear is defined as a high T2 signal within the tendon that penetrates the whole layer, with tendon thickening, thinning or tendon rupture.

Observation indices

The cases and types of rotator cuff tears diagnosed by CS-MRI and arthroscopy were recorded and compared. The diagnostic indexes, including sensitivity, specificity, accuracy, positive predictive value, and negative predictive value, of CS-MRI for the diagnosis of rotator cuff tears were evaluated. Also, the correlation between CS-MRI and the efficiency of surgical treatment was analyzed.

Statistical analysis

According to literature, the incidence of rotator cuff tears is around 20-30%. To evaluate the diagnostic efficacy of CS-MRI, we determined that the minimum sample size for each group should be 50. Considering a 10% drop-out rate, the sample size for each group was set at 110, thus the total target sample size was determined to be 220. To calculate this sample size, we assumed equal variances and a normal distribution. Moreover, a power analysis was conducted to ensure that this sample size would provide sufficient power to detect significant differences in the diagnostic efficacy of CS-MRI at a significance level of $\alpha=0.05$. During the actual patient enrollment period between December 1, 2021 and April 1, 2022, we recruited 62 patients due to the limited number of eligible patients.

SPSS 26.0 statistical software was used for data analyses. Count data were expressed as cases (%) and examined using the paired chi-square test and paired three-dimensional chi-square test. Measurement data were expressed as mean ± standard deviation (Mean ± SD) and analyzed by independent sample t-test. The difference was considered statistically significant at $P<0.05$.

Results

Baseline patient profiles

The present study included 62 patients with suspected rotator cuff tears who met the inclusion and exclusion criteria, including 30 males and 32 females, with a mean age of 41.82±8.28 years, and a duration of illness from 3 days to 1 year (82.59±10.82 days). There were 49 patients with suspected unilateral rotator cuff tears and 13 patients with suspected bilateral rotator cuff tears. Besides, 9 patients complained of pain at other joints, 5 patients had a history of tears at other joints, and 2 patients had a history of surgery at other joints.

Arthroscopy results

All eligible patients received arthroscopy, and the results showed 31 cases (16 males and 15 females) of total tears and 14 cases (9 males and 5 females) of partial tears. The remaining 17 patients (5 males and 12 females) showed a normal shoulder joint structure (**Table 1**).

Clinical signs

Clinical sign examinations such as drop arm test, impingement test, painful arc syndrome, and cracking shoulder test were performed on all 62 patients. Rotator cuff tears were con-

Table 1. Diagnostic results of arthroscopy in patients with suspected rotator cuff tears

Sex	Total tear	Partial tear	No abnormalities	X^2 Value	*P* Value
Male	16	9	5	3.997	0.136
Female	15	5	12		

Table 2. Diagnostic results of clinical signs in patients with suspected rotator cuff tears

Signs	Drop arm test	Impingement test	Painful arc syndrome	Cracking shoulder test
n	35	30	33	28
Positive rate (%)	56.45	48.39	53.23	45.16

firmed if the patient had shoulder pain with positive results of any of the above tests. The results showed 36 patients with a positive drop arm test result, 42 patients with a positive impingement test result, 48 patients with a positive painful arc syndrome result, and 28 patients with a positive cracking shoulder test result (**Table 2**). There were 35 patients with rotator cuff tears determined by clinical signs, including 30 with positive arthroscopic findings, 27 patients with negative clinical signs, and 12 with negative arthroscopic findings (**Table 3**). There was no statistically significant difference between arthroscopy and clinical sign examination in the diagnosis of rotator cuff tears (χ^2=3.523, P=0.061). The sensitivity of clinical signs examination in diagnosing rotator cuff tears was 66.67% (30/45), the specificity was 70.59% (12/17), the accuracy was 67.74% (42/62), the positive predictive value was 85.71% (30/35), and the negative predictive value was 44.44% (12/27).

CS-MRI results

CS-MRI results suggested 40 patients with rotator cuff tears, including 38 with positive arthroscopic findings, 22 with a normal shoulder structure on CS-MRI (15 with negative arthroscopic findings) (**Table 4**; **Figure 2**). Of the 7 patients with no rotator cuff tears detected arthroscopically, there were 6 cases of partial supraspinatus tendon tears and 1 case of total lamina tear misdiagnosed by CS-MRI. Of the 40 patients diagnosed with rotator cuff tears by CS-MRI, 28 had total tears (22 cases were diagnosed arthroscopically) and 12 had partial tears (6 cases were diagnosed arthroscopically). The sensitivity of CS-MRI in diagnosing rotator cuff tears was 84.44% (38/45), the specificity was 88.24% (15/17), the accuracy was 81.54% (53/62), the positive predictive value was 95.00% (38/40), and the negative predictive value was 68.18% (15/22). The sensitivity of CS-MRI was 70.97% (22/31) in diagnosing total rotator cuff tears and 42.86% (6/14) in diagnosing partial rotator cuff tears.

Clinical signs findings and CS-MRI findings

The sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of CS-MRI were all higher than those of clinical signs, suggesting that CS-MRI has a higher diagnostic value for rotator cuff tears than clinical signs (**Tables 5**, **6**). Furthermore, the accuracy of CS-MRI was significantly higher than that of clinical signs as determined by chi-square test within groups (P=0.019).

Discussion

The shoulder joint has good mobility and is rich in surrounding muscles, tendons, and soft tissues. Rotator cuff tears are a common cause of pain and disability among adults. The rotator cuff is a group of four muscles and their tendons that surround the shoulder joint, providing stability and enabling a wide range of movements [14]. The muscles involved are the supraspinatus, infraspinatus, teres minor, and subscapularis. The main causes of rotator cuff tears are trauma and shoulder impingement syndrome, which account for 95% of all rotator cuff tears cases [15, 16]. Individuals who frequently perform activities of the upper extremity are susceptible to injury of the rotator cuff from overuse or heavy overhead lifting [17]. People who suffered from rotator cuff tears may have clinical manifestations including: (1) recurrent pain, especially along with certain activities; (2) pain at night, particularly if lying on the affected shoulder; (3) weakness when lifting or rotating the arm; (4) crepitus or crackling sensation when moving the shoulder in certain positions. Arthroscopy is considered the gold standard for diagnosing rotator cuff tears because it allows direct visualization and assessment of the tears, but its invasiveness may

Table 3. Clinical signs and arthroscopic findings in patients with suspected rotator cuff tears

Diagnostic methods	Diagnostic findings	Arthroscopy		Total	X^2	P
		Rotator cuff tear	No abnormalities			
Clinical signs	Rotator cuff tear	30	5	35	3.523	0.061
	No abnormalities	15	12	27		
Total		45	17	62		

Table 4. CS-MRI and arthroscopic results in patients with suspected rotator cuff tears

Diagnostic methods	Diagnostic findings	Arthroscopy		Total	χ^2	P
		Rotator cuff tear	No abnormalities			
CS-MRI	Rotator cuff tear	38	2	40	0.935	0.334
	No abnormalities	7	15	22		
Total		45	17	62		

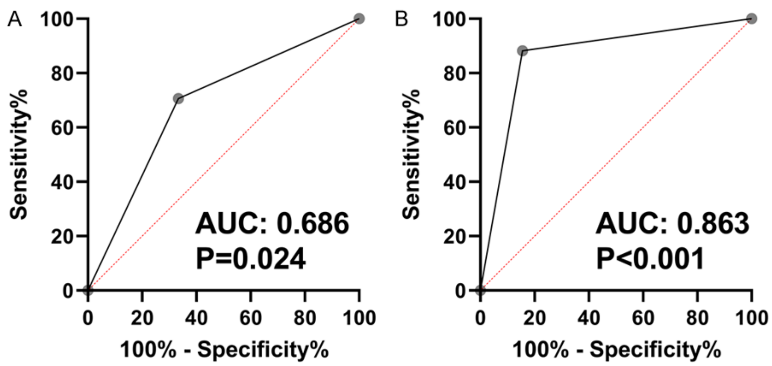

Figure 2. ROC curves. A. ROC curve of arthroscopic diagnosis for rotator cuff tears. B. ROC curve of CS-MRI for rotator cuff tear. Note: ROC, receiver operating characteristic; CS-MRI, sensing magnetic resonance imaging.

cause further injury to the rotator cuff [14]. In addition to a direct visualization of the tears, arthroscopy can also assess the severity of the tears and other concurrent shoulder pathologies [18, 19]. Most importantly, therapeutic interventions can be performed during the same procedure. However, it has associated risks such as infection or complications from anesthesia in arthroscopy, and it costs more than imaging [1, 20, 21]. Therefore, accurate diagnosis of rotator cuff tears with less damage to the joint has constituted a clinical challenge that needs to be addressed. MRI features high resolution of soft tissues and yields good diagnostic efficacy for soft tissue injuries [22]. Its short imaging time is more comfortable for patients and reduces the chance of movement artifacts. Also, the cost is potentially lower due to the shorter duration of imaging [9, 23]. However, the long scanning duration and restricted scanning coverage of MRI prevent its extensive application [24]. CS-MRI can maximize the acquisition of important clinical information from limited data by optimizing the algorithm structure, shorten the detection duration, and enhance image quality [25, 26]. Hence, it has been frequently adopted in the diagnosis of knee and ankle-related injuries [27, 28]. The results of the present study found that CS-MRI had high diagnostic efficacy for rotator cuff tears, with a sensitivity of 84.44%, specificity of 88.24%, and accuracy of 81.54%, all of which were higher than the corresponding indicators of diagnosing using clinical signs. These results suggested that CS-MRI could provide the optimal evidence-based results for clinical decision-making within a short time.

CS-MRI is rarely used in bone and joint diseases, so limited reliable previous studies have confirmed its reliability and effectiveness in the diagnosis of shoulder tear. However, Ahn et al. [29] used arthroscopy to accurately diagnose 35 patients with type I rotator cuff tears, 70 patients with type IIA rotator cuff tears, 35 patients with type IIB rotator cuff tears, 9 patients with type III rotator cuff tears, and 9 patients with type IV rotator cuff tears, and they found that the diagnostic efficiency of conventional MRI for the injury degree of patients with above rotator cuff tears was about 78.5-82.5%. Zappia et al. [30] used conventional MRI to

Table 5. Results of CS-MRI and arthroscopy of rotator cuff tears

Diagnostic methods	Diagnostic findings	Arthroscopy			Total	X^2	P
		Full tear	Partial tear	No abnormalities			
CS-MRI	Full tear	22	5	1	28		
	Partial tear	5	6	1	12	5.469	0.140
	No abnormalities	4	3	15	22		
Total		31	14	17	62		

Table 6. Diagnostic value of clinical signs and CS-MRI for rotator cuff tears

	Sensitivity	Specificity	Accuracy	Positive predictive value	Negative predictive value
Clinical Signs	66.67%	70.59%	67.74%	85.71%	44.44%
CS-MRI	84.44%	88.24%	85.48%	95.00%	68.18%
X^2	*2.084*	3.537	5.446	1.363	0.426
P	0.148	0.060	0.019	0.243	0.513

evaluate patients with rotator cuff tears and found a diagnostic sensitivity of 90.9%, a specificity of 98.8%, a positive predictive value of 95.2%, a negative predictive value of 97.7%, and an accuracy of 97.2%. They also employed a within-group chi-square test, which determined that MRI was significantly more accurate than the clinical signs. The above results indicate that MRI has a certain degree of accuracy and reliability in the diagnosis of rotator cuff tears. Compared with their clinical studies, MRI with higher resolution for tendon joint soft tissue injury was conducted in this study for the diagnosis of rotator cuff tears. In addition, imaging evaluation and arthroscopy were performed on the same patient, and imaging results were evaluated by two radiologists with rich clinical experience, which greatly reduced the contingency and inaccuracy of the results and made the conclusion more convincing. The accurate assessment of rotator cuff injury is also an important reference index to evaluate the diagnostic value and significance of a tool. However, in this study, we did not further evaluate the injury classification of patients with rotator cuff injury, and we will improve this in subsequent clinical studies. MRI is important for the diagnosis of soft tissue, tendon and nerve injuries. In the future, we believe that with the continuous development of MRI technology, clinical studies on the diagnosis of rotator cuff tears and other joint ligament injuries with CS-MRI will continue to rise, and CS-MRI will gradually be accepted by patients and doctors and widely used in clinic.

This study has the following limitations: (1) the sample size was small: only 62 patients with rotator cuff tears were included in this clinical study, so the number of patients will be increased in the future; (2) the evaluation criteria were insufficiently clarified; (3) the consistency of CS-MRI and clinical signs examination were inadequate; (4) the severity of injury in patients with rotator cuff tears was not graded, which may reduce the diagnostic value of CS-MRI. In subsequent clinical studies, we will evaluate the injury severity of patients with rotator cuff tears using corresponding classification criteria to further clarify the diagnostic significance of CS-MRI for rotator cuff tears. Future trials with a larger sample size and more well-designed evaluation methods will be conducted to further validate the diagnostic efficacy of CS-MRI for rotator cuff tears.

Conclusion

CS-MRI provides high resolution images for muscles, tendons, and soft tissues, significantly contributing to the diagnosis of soft tissue injuries. Although there were no significant differences in the sensitivity and specificity of CS-MRI for the clinical diagnosis of rotator cuff tears compared to the clinical signs, CS-MRI significantly improved the diagnostic accuracy.

Disclosure of conflict of interest

None.

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