Original Article

Accuracy of MRI with Cinematic 3D Volume Rendering Reconstruction in Helping the Diagnosis of Partial Thickness Subscapularis Tendon Tear

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Abstract

OBJECTIVES: This study aimed to figure the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy in diagnosis of rotator cuff tears (RCT) using magnetic resonance imaging (MRI) with additional Cinematic three-dimension volume rendering (3D VR) reconstruction.

MATERIALS AND METHODS: A retrospective review of the all-arthroscopic proven cases of RCT, provisionally diagnosed via clinical and MRI findings since May 2020 to Mar 2021, were collected. Cinematic 3D VR reconstruction of the rotator cuffs was performed subsequently from the MRI images. The accuracy of MRI with Cinematic 3D VR reconstruction as compared to the conventional MRI alone was calculated.

RESULTS: Fifty-seven subjects were enrolled into the study, included 35 male and 22 female subjects. The average age was 60.58 ± 9.52 years old. Majority of the surgery side was right shoulder (56.1%). Fifty-two cases (91.23%) had supraspinatus tendon tear; 22 cases of full-thickness tear (42.3%) and 30 cases of partial-thickness tear (57.7%). Two cases had no treatment for supraspinatus tendon, 3 cases underwent debridement, and 47 cases received arthroscopic repair of supraspinatus tendon. Thirty-nine subscapularis tendon tear cases (68.42%) consisted of 4 cases of full-thickness tear (10.26%) and 35 cases of partial-thickness tear (61.4%). Seventeen cases underwent debridement, 17 cases underwent single row repair of the subscapularis tendon, and 5 cases received double row repair. Detecting of partial-thickness torn supraspinatus tendon, MRI with 3D VR revealed no further benefit from conventional MRI alone, in terms of any improving sensitivity, specificity, PPV, NPV or even accuracy. However, sensitivity, PPV and accuracy for depicting subscapularis tendon tear were increased. The full-thickness tear of both supraspinatus and subscapularis tendons showed no significant difference of sensitivity, specificity, PPV, NPV and accuracy between MRI with 3D VR and MRI alone.

CONCLUSION: The use of MRI with 3D VR technique may aid in detection of partial-thickness subscapularis tendon tear, increased sensitivity, PPV and accuracy, as compared to conventional MRI alone. Further new 3D reconstruction techniques should be promising for improving post processing time consume and be more user friendly, resulting in clearly recognized rotator cuff tear for both radiologists and orthopedists.

Keywords: rotator cuff tear, cinematic rendering, volume rendering reconstruction, 3D MRI, subscapularis tendon

Rotator cuff tears (RCT) are one of the most common cause of shoulder pain in elderly, directly affecting shoulder function in daily activity, and often associated with frozen shoulder and glenohumeral osteoarthritis in the advanced cases.[1]

Yamamoto et al.,[2] found the total prevalence of 20.7% (ROT), using 683 volunteers with the mean age of 57.9 years. Amongst these, 36% of the symptomatic volunteers were found to have a RCT [3] compared with only 16.9% of the asymptomatic volunteers, which could progress to symptomatic

patients about 50% in 2.8 years.[4] This study also showed an increasing prevalence from 6.7% to 45.8% in RCT amongst those in their fourth- compared with seventh-decade, respectively, highlighting the increasing association of RCT with age.

The number of populations projected by the Office of the National Economic and Social Development Board, was drawn from the data base from Population and Housing Census, another major source of data on population.[5] The number of projected populations for the next 10 years will slightly increase with a growth rate of 0.03% in 2030. The number of the elderly from the 2010 census was 12%, and was also estimated to be 26.6% in 2030. This elderly population would have shoulder problem resulting in limited daily living activities and/or eventually progression to becoming a dependent person. Early detection may be useful in proper decision making regarding the treatment and in a more efficient preoperative evaluation for the patients, with an expected good outcome of the treatment.

Usually, the diagnosis of rotator cuff tear consists of history, physical examination, and imaging studies. MRI is the investigation of choice; however, some types of RCT as partial-thickness tear (PT) and subscapularis tendon tear, are still a challenge to be clearly identified.

In 2011, Toby O Smith et al.,[6] proposed the meta-analysis study included 44 studies; 2,751 shoulders in 2,710 patients. For partial-thickness RCT, the pooled sensitivity and specificity values were 0.80 [95%confidence interval (CI): 0.79–0.84] and 0.95 (95% CI: 0.94–0.97), respectively. For full-thickness RCT, the sensitivity and specificity values were 0.91 (95% CI: 0.86–0.94) and 0.97 (95%CI: 0.96– 0.98), respectively. While there was no substantial difference in diagnostic test accuracy between MRIs reviewed by general radiologists and those reviewed by musculoskeletal radiologists, while higher-field-strength (3.0 T) MRI systems provided the greatest diagnostic test accuracy.

In 2015, Gyftopoulos S, et al.,[7] reviewed 34 patients with rotator cuff tear and performed arthroscopic surgery. The result showed that 3D MR reconstructions of the rotator cuff improved the accuracy of characterizing shape of RCT, compared with current 2D MRI–based techniques.

Cinematic rendering is a new type of photorealistic 3D visualization inspired by Hollywood. The novel way of reconstructing 3D visualizations from computerized tomography (CT) and MRI data could contribute well-prepared and well-planned interventions for patients of cardiac, abdominal, and trauma surgery, and facilitate communication in interdisciplinary boards and between doctors and patients as well.

This study aimed to measure the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and accuracy in diagnosis of RCT using of MRI with additional Cinematic 3D volume rendering (3D VR) reconstruction. This novel technique was presumed to improve the accuracy of the diagnosis of RCT.

Materials and Methods

A retrospective study of all suspected RCT patients who had undergone arthroscopic surgery at Bangkok Academy of Sports and Exercise Medicine (BASEM), Bangkok Hospital Headquarters, from May 2020 to Mar 2021, was performed. The fifty-seven subjects included 35 males (61.4%) and 22 Females (38.6%) who were enrolled in this study.

Inclusion criteria

1. Patient with suspected rotator cuff tear from physical examination and MRI.
2. Aged more than 18 years' old.
3. Fulfilled indication for arthroscopic surgery.
4. First time Arthroscopic surgery.
5. Underwent arthroscopic rotator cuff repair within 3 months after performing MRI.

Exclusion criteria

1. Incomplete data: MRI and intraoperative findings.
2. No consensus MRI interpretation.

Methods

After enrolling all the subjects and approving by IRBs, the retrospective review of medical records, MRI results, operative notes and arthroscopic findings, were retrieved and recorded.

MRI methods

Fifty-seven examinations of MRI shoulder were reviewed. The fluid-sensitive sequences were obtained to process Cinematic 3D VR reconstruction, operated on Syngovia® (Siemens, Germany) as follows;

1. Axial 3D proton density weighted (PDW) images with isovoxel, axial PDW or T2W with fat suppression images was post processed for 3D VR images, purposing to evaluate supraspinatus tendon.
2. Axial 3D PDW images with isovoxel, coronal PDW or T2W with fat suppression images was post processed for 3D VR images, purposing to evaluate subscapularis tendon.

The volume of 3D VR images were clipped from superior to inferior parts of the shoulder for demonstrating supraspinatus tendon, and further anterior to posterior parts of the shoulder for demonstrating subscapularis tendon. As a result, the acromioclavicular joint and most of overlying deltoid muscles were punched out. The residual curvilinear deltoid muscle covering footprint of the supraspinatus and subscapularis tendons was also punched out by the clipping plane tool function, adjusting in two axes, respectively (Figure 1). The muscle and tendon shadings were adjusted to clearly depict anatomical structures. The resulting volume of VR images could rotate in all axes for reviewing.

The supraspinatus and subscapularis tendons were interpreted with single two-dimensioned (2D) MRI images, followed by with simultaneous 2D and 3D VR MRI images (2D+3D). The findings were recorded as: no tear, partial-thickness tear or full-thickness tear, the torn location and the torn shape. The example cases of supraspinatus tendon tear and subscapularis tendon tear are shown in Figure 2 and Figure 3, respectively.

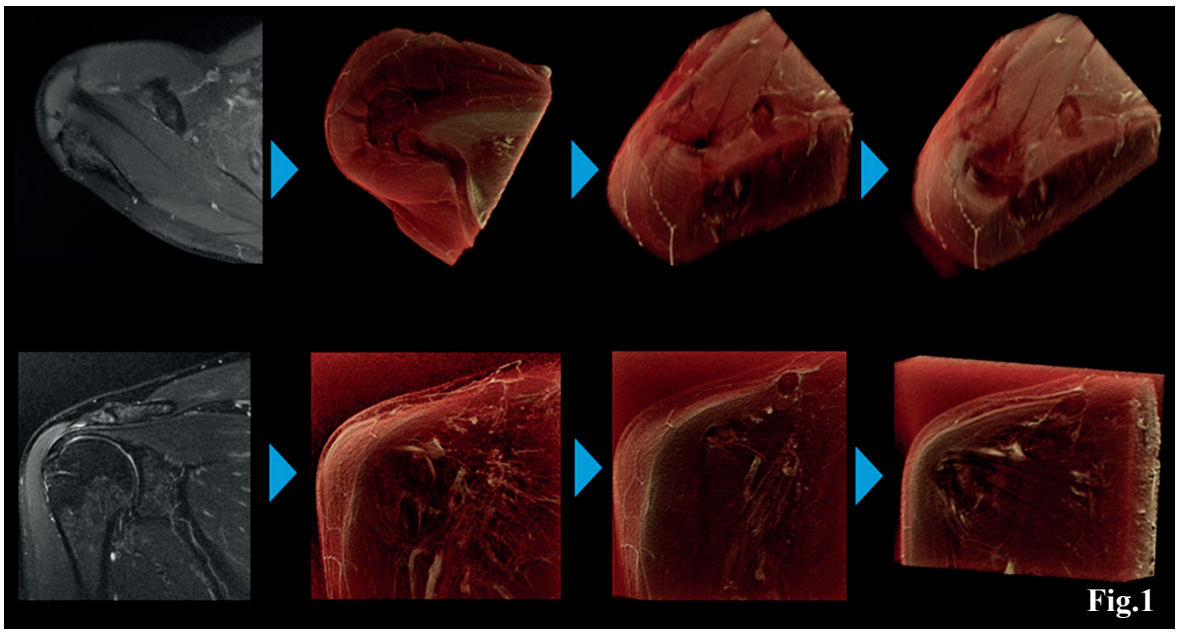

Figure 1: The processing steps of 3D Cinematic VR images of supraspinatus tendon (upper row) and subscapularis tendon (lower row). The axial and coronal fluid-sensitive images of the MRI shoulder were post processed on Syngovia for 3D VR image creation. Further clipping and punching out process were followed to remove the overlying deltoid muscles and acromioclavicular (AC) joint. The resulted volume of VR images revealed clearly anatomical structure for interpretation.

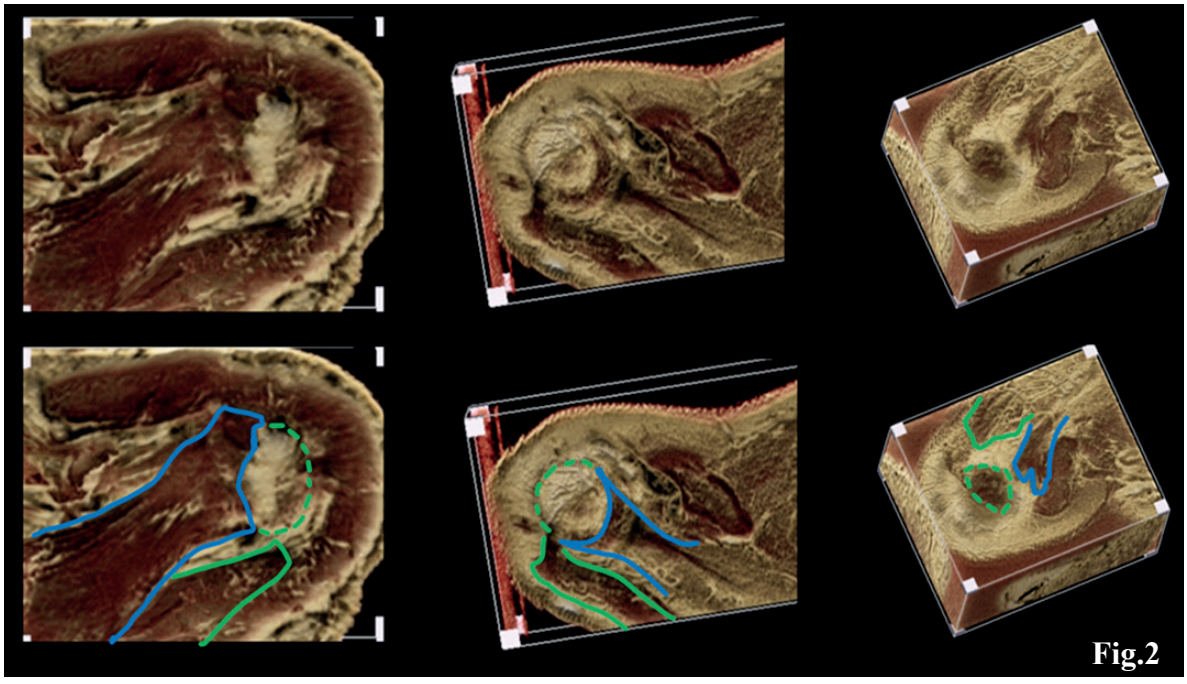

Figure 2: The three cases of 3D Cinematic VR shoulder images show full-thickness torn supraspinatus tendon in different characters. The light blue lines outlined the retracted supraspinatus tendon and muscle. The light green dots outlined greater tuberosity of humeral head. The light green line outlined infraspinatus muscle. The L-shaped and U-shaped tears of supraspinatus tendon were obtained in the first and second cases, respectively. The massive rotator cuff tendon tear is obviously observed in the last demonstrated case.

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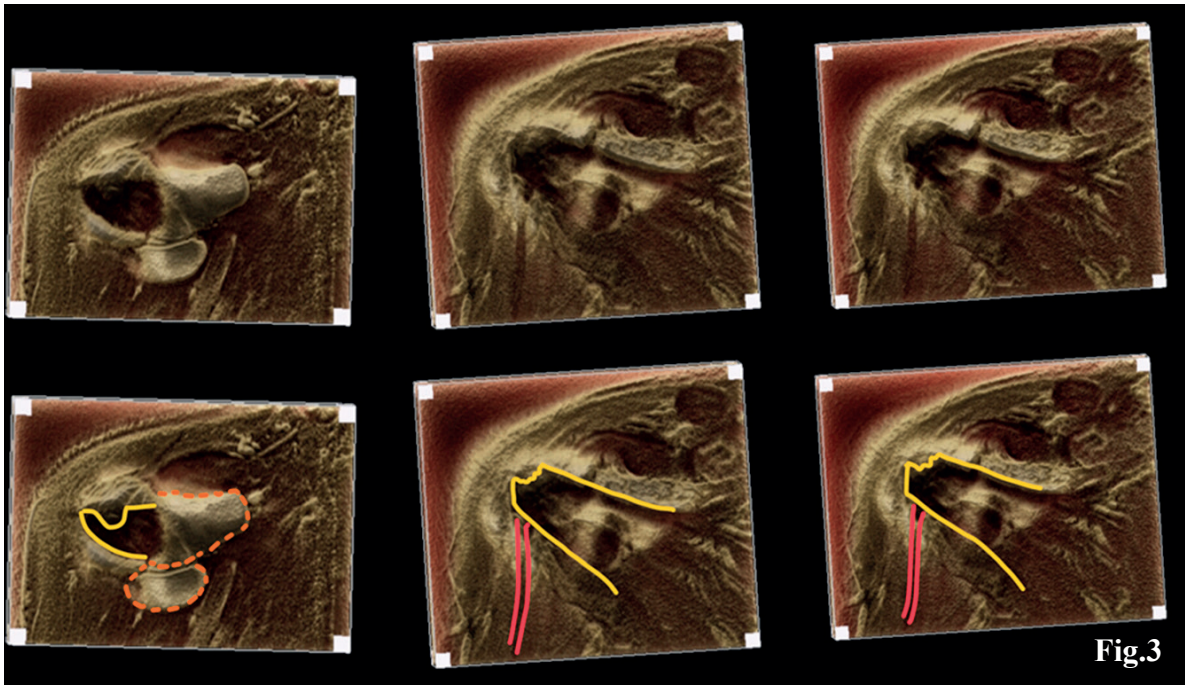

Figure 3: The two cases of 3D Cinematic VR shoulder images showed full-thickness and partial-thickness torn subscapularis tendon, depicted in coronal view. The yellow lines outlined the subscapularis tendon and muscle. The orange dots outlined subcoracoid bursitis. The red line outlined long head biceps tendon. The first case (first column) showed focal tendon defect at upper rim of the subscapularis footprint, filled with fluid, representing focal full-thickness tear. The second case (latter two columns) demonstrated two slightly different shading images. The partial-thickness torn subscapularis tendon at upper facet footprint was observed, but the subluxated biceps tendon could not be well-demonstrated at the torn site.

Statistical Analysis

Demographics data was explored by frequency, percentage, mean, and standard deviation for overall data. The rotator cuff tendons were only assessed for integrity of the supraspinatus and subscapularis tendons during MRI imaging, data was sent for analysis afterward. The results of standard MRI and 3D VR were reviewed by musculoskeletal radiologist and sport orthopedic surgeon, then compared separately to the operative findings. Operative findings were the reference standard for the accuracy of the MRI findings.

The result was divided into two groups; group 1 was conventional MRI alone, and group 2 was conventional MRI with 3D VR technique. Some 95% confidence intervals (95% CI) were calculated for the accuracy of both MRIs of the supraspinatus and subscapularis tears. The sensitivity, specificity, accuracy, PPV and NPV were also calculated for the diagnosis of this specific lesion by both techniques of MRI. All data were analyzed with Statistical software (STATA version 15)

Results

Fifty-seven subjects were enrolled in the study, 35 male and 22 female subjects. The average age was 60.58 ± 9.52 years old. The youngest and oldest subjects, were 41 and 80 years old respectively. The average body mass index was 26.82 ± 5.53 Kg/m^2. Majority of the surgery side was right shoulder (56.1%). Subject's demographic data is presented in Table 1.

Table 1: Demographic data of participants (n = 141).

Characteristics	Total (n = 57) n (%)
Gender	
Male	35 (61.4)
Female	22 (28.6)
Age (Year)	
< 60	27 (47.4)
60-69	20 (35.1)
≥ 70	10 (17.5)
Mean ± SD	60.58 ± 9.52
Min-max	41- 80
BMI (Kg/m^2)	
18.5 – 24.9	25 (43.9)
25.0 – 29.9	20 (35.1)
≥ 30	12 (21.1)
Mean ± SD	26.82 ± 5.53
Min-max	18.67- 46.56

BMI: body mass index; SD: standard deviation; cm: centimeter; Kg: kilogram; Kg/m2: kilogram / square meter)

There were 52 cases (91.23%) that had supraspinatus tendon tear included 22 cases of full-thickness tear (42.3%), and 30 cases of partial-thickness tear (57.7%). Two cases had no treatment for supraspinatus tendon, 3 cases underwent debridement, and 47 cases received arthroscopic repair of supraspinatus tendon. All repaired cases underwent double row suture bridge technique. (Table 2).

Thirty-nine subscapularis tendon tear cases (68.42%) consisted of 4 cases of full-thickness tear (10.26%), and 35 cases of partial-thickness tear (61.4%). Seventeen cases underwent debridement, 17 cases underwent single row repair of the subscapularis tendon, and 5 cases received double row repair. (Table 2).

Overall accuracy of conventional MRI and additional 3D VR for diagnosis of supraspinatus tear had no difference (92.98%). The sensitivity (92.31%), specificity (100%), PPV (100%) and NPV (55.56%) for conventional MRI technique and additional 3D VR technique, also had been no different, as shown in Table 3.

Accuracy

For subscapularis tendon tear, conventional MRI with 3D VR technique showed more accuracy (94.74%) than conventional techniques alone (92.98%). The sensitivity and NPV of MRI with 3D VR technique were 97.44% and 94.12% respectively, were more than conventional technique (92.31% and 85% respectively), but the specificity and PPV of MRI with 3D VR technique (88.89% and 95% respectively) were less than another group (94.44% and 97.30%, respectively) as described in Table 3.

Table 2: Comparison of Rotator cuff finding in each techniques.

	Arthroscopic (n = 57)	MRI 2D (n = 57)	MRI 2D+3D (n = 57)
	n (%)	n (%)	n (%)
Supraspinatus tendon tear			
Intact	5 (8.8)	9 (15.8)	9 (15.8)
Tear	52 (91.2)	48 (84.2)	48 (84.2)
Full-thickness	22 (42.3)	23 (47.9)	24 (50.0)
Partial-thickness	30 (57.7)	25 (52.1)	24 (50.0)
Treatment (n=52)			
No treatment	2 (3.8)		
Debride	3 (5.8)		
Repair	47 (90.4)		
Subscapularis tendon tear			
Intact	18 (31.6)	20 (35.1)	17 (29.8)
Tear	39 (68.4)	37 (64.9)	40 (70.2)
Full-thickness	4 (10.3)	6 (16.2)	6 (15.0)
Partial-thickness	35 (89.7)	31 (83.8)	34 (85.0)
Treatment (n=39)			
Debride	17 (43.6)		
Single row	17 (43.6)		
Double row	5 (12.8)		

Table 3: Sensitivity, specificity and predictive value of conventional MRI and additional 3D MRI in diagnosis of **rotator cuff tear** (n = 57).

		Arthroscopic		Sensitivity	Specificity	PPV	NPV	Accuracy
		Tear	No tear	(95%CI)	(95%CI)	(95%CI)	(95%CI)	(95%CI)
Supraspinatus tear								
MRI 2D	Tear	48	4	92.31%	100.00%	100%	55.56%	92.98%
	No tear	4	31	81.46% to 97.86%	47.82% to 100%)	-	32.77% to 76.22%	83.00% to 98.05%
MRI 2D+3D	Tear	48	5	92.31%	100%	100%	55.56%	92.98%
	No tear	4	30	81.46% to 97.86%	82% to 100%	-	32.77% to 76.22%	83.00% to 98.05%
Subscapularis tear								
MRI 2D	full	4	2	92.31%	94.44%	97.30%	85.00%	92.98%
	No full	0	51	79.13% to 98.38%	72.71% to 99.86%	84.25% to 99.59%	65.51% to 94.41%	83.00% to 98.05%
MRI 2D+3D	full	4	2	97.44%	88.89%	95.00%	94.12%	94.74%
	No full	0	51	86.52% to 99.94%	65.29% to 98.62%	83.71% to 98.60%	69.66% to 99.11%	85.38% to 98.90%

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For the detection of full-thickness tear of rotator cuff, the sensitivity, specificity, PPV, NPV and accuracy showed no improvement/increasing in conventional MRI with 3D VR group as described in Table 4.

For the detection of partial-thickness tear of supraspinatus tendon, 3D VR technique could not raise further sensitivity, specificity, PPV, NPV and accuracy), but for subscapularis tendon the sensitivity, NPV and accuracy did increase. (Table 5).

Table 4: Sensitivity, specificity and predictive value of conventional MRI and additional 3D MRI in diagnosis of **Full-thickness rotator cuff tear** (n = 57).

		Arthroscopic		Sensitivity	Specificity	PPV	NPV	Accuracy
		full	No full	(95%CI)	(95%CI)	(95%CI)	(95%CI)	(95%CI)
Supraspinatus tear								
MRI 2D	full	19	4	86.36%	88.57%	82.61%	91.18%	87.72%
	No full	3	31	65.09% to 97.09%	73.26% to 96.80%	65.04% to 92.38%	78.19% to 96.75%	76.32% to 94.92%
MRI 2D+3D	full	19	5	86.36%	85.71%	79.17%	90.91%	85.96%
	No full	3	30	65.09% to 97.09%	69.74% to 95.19%	62.40% to 89.69%	77.60% to 96.65%	74.21% to 93.74%
Subscapularis tear								
MRI 2D	full	4	2	100%	96.23%	66.67%	100.00%	96.49%
	No full	0	51	39.76% to 100%	87.02% to 99.54%	33.93% to 88.62%		87.89% to 99.57%
MRI 2D+3D	full	4	2	100%	96.23%	66.67%	100.00%	96.49%
	No full	0	51	39.76% to 100%	87.02% to 99.54%	33.93% to 88.62%		87.89% to 99.57%

Table 5: sensitivity, specificity and predictive value of conventional MRI and additional 3D MRI in diagnosis of **Partial-thickness rotator cuff tear** (n = 57)

		Arthroscopic		Sensitivity	Specificity	PPV	NPV	Accuracy
		Partial	No partial	(95%CI)	(95%CI)	(95%CI)	(95%CI)	(95%CI)
Supraspinatus tear								
MRI 2D	fullPartial	22	3	73.33%	88.89%	88.00%	75.00%	80.70%
	No partial	8	24	54.11% to 87.72%	70.84% to 97.65%	71.18% to 95.61%	62.02% to 84.64%	68.09% to 89.95%
MRI 2D+3D	Partial	21	3	70.00%	88.89%	87.50%	72.73%	78.95%
	No partial	9	24	50.60% to 85.27%	70.84% to 97.65%	70.13% to 95.43%	60.30% to 82.40%	66.11% to 88.62%
Subscapularis tear								
MRI 2D	Partial	30	1	85.71%	95.45%	96.77%	80.77%	89.47%
	No partial	5	21	69.74% to 95.19%	77.16% to 99.88%	81.48% to 99.51%	64.99% to 90.48%	78.48% to 96.04%
MRI 2D+3D	Partial	32	2	91.43%	90.91%	94.12%	86.96%	91.23%
	No partial	3	20	76.94% to 98.20%	70.84% to 98.88%	80.96% to 98.37%	69.15% to 95.20%	80.70% to 97.09%

Discussion

Shoulder pain is common, especially in the elderly, and affects function for daily living and quality of life. RCT is one of the most common causes of this problem. Nowadays, the management of rotator cuff tear patient is divided into conservative treatment and operative treatment. The more accurate the imaging modalities observed, the more efficient, for decision making and for performing preoperative planning.

Many imaging techniques have been developed for the detection of RCT, such as ultrasonography (US), MRI and magnetic resonance arthrography (MRA).

Sonographic evaluation was initially attempted over three decades ago, but this was not taken up in a popular manner though among radiologists. Fotiadou et al.,[8] reported a prospective cohort study of 96 patients with clinically suspected rotator cuff pathology who underwent US and MRI of the shoulder. The findings in 88 patients were compared with arthroscopy or open surgery. The accuracy in the detection of full-thickness tears was 98 and 100% for US and MRI, respectively. The accuracy in the detection of bursal or articular partial-thickness tears (PT) was 87 and 90% for US and MRI, respectively. US evaluation of the rotator cuff is a dynamic and real-time examination that is less expensive and less time-consuming than MRI, and is repeatable if necessary. The significant disadvantage of US is that it is operator dependent. Therefore, US may be considered as the imaging modality of choice for the initial detection of full- and/or partial-thickness RCT in patients with history and clinical findings not suggesting any other intra-articular disorder, if available.

Liu F et al.,[9] purposed systematic review in 2020, including 144 studies with 14,059 patients, to determine which of 3 most common imaging modalities revealed optimal results for the diagnosis of RCT. For the detection of FT tears, PT tears, or any tear, MRA had the highest sensitivity and specificity. For the detection of any tear, MRI had a better diagnostic value than US (sensitivity: 0.84 vs 0.81, specificity: 0.86 vs 0.82). With regard to FT tears, MRI had a higher sensitivity than US (0.91 vs 0.87, respectively) and a similar specificity (0.88 vs 0.88, respectively). The results for PT tears were similar to the detection of FT tears. Despite high sensitivity and specificity in detecting rotator cuff tear with MRA being noted, some complications might have occurred as infections or adverse reactions due to intra-articular contrast injection, and longer examination time.[10,11] The differences in specificity and sensitivity between MRA and MRI are quite small, and that may be a good reason to avoid the potential risk/cost of MRA, especially if one suspects an FT tear.

In 2017, T.Muto et al[12] compare accuracy for evaluating shape of torn tendon using 2D-MRIs and 3D-MRIs evaluated by 4 shoulder surgeons; 2 residents and 2 specialists. As a result, the accuracy using 2D-MRIs in a group of residents was significantly lower than a group of specialists. But there was no significant difference in the accuracy using 3D-shape model of rotator cuff tear. The findings in this study suggest that 3D-shape model could improve diagnosis of rotator cuff tear.

3D VR images are the post processing images that given more detailed images as the 3D model.[13] 3D cinematic VR images are a recent useful tool for CT images such as fracture evaluation on CT images, published by Rowe PR et al.[14]

Anastasi G et al.,[15] showed that the 3D VR images from MRI dataset could demonstrate ankle anatomy structures well. However, there is not one matched result on PubMed search for cinematic rendering of MRI shoulder.

Cinematic 3D VR images from Syngovia® in this study, can performed from MRI dataset, and demonstrate different tissue imaged shadings; muscle, tendon and marrow signals. From this point, cinematic 3D VR images for rotator cuff tendons were proposed for investigating the usefulness in the current study.

Supraspinatus tendon was evaluated on single 2D images of conventional MRI and simultaneous 2D MRI and 3D VR images, respectively. Full-thickness supraspinatus tendon tear was mostly well demonstrated on single MRI 2D images, MRI with 3D VR images could not show further usefulness for tear detection. However, 3D VR images as model visualization, improved overview pre-operative planning as more perceiving tear characteristic.

Additionally, evaluating subscapularis tendon, MRI with 3D VR images increased suspiciousness for detecting subscapularis tendon tear, especially partial-thickness tear, more than MRI 2D images alone. Although MRI with 3D VR images would help to detect torn subscapularis tendon, single 3D VR images could not differentiate partial or full-thickness tear well in some cases. Furthermore, biceps tendon subluxation could not be clearly seen on 3D VR images alone.

Limitations

3D VR technique for MRI images is the new technique that is not yet popular, especially in Thailand, and is available at only 2 private hospitals. The reconstruction process needs skill and experience of the radiologist to be performed. Further study may be needed to increase reliability of this technique by performing inter-observer and intra-observer reliability. 3D VR technique with CT database can make the reconstruction process and the image result more realistic and easier to understand, but the standard imaging modality for detect rotator cuff tear is MRI which all subjects have to have performed, so we decided to use MRI dataset to reconstruct the image for research investigation.

Conclusion

Using conventional MRI with 3D VR technique may aid in detection of partial-thickness subscapularis tendon tear. There is no significant evidence in assisting the detection of supraspinatus tendon tear.

The reconstruction process still has variable techniques which could be invented in the future to improve the time taken for the reconstruction process and to increase its popularity and improve its perception by radiologists and orthopedists.

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