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# Evaluation of stiffness of rotator cuff tendons, coracohumeral ligament, tendon of long head of biceps and posterior capsule by strain and shear wave elastography in frozen shoulder vs normal shoulder

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***Abstract*---**Background: Frozen shoulder is an idiopathic condition which presents with the loss of both active and passive movement at the shoulder joint over a period of time, associated with pain on movement. The wide range of clinical conditions with similar symptoms make the diagnosis difficult, hence making imaging studies mandatory. An increase in stiffness is noted by shear wave and strain ultrasound elastography of rotator cuff tendons, coracohumeral ligament, tendon of long head of biceps, posteriorcapsuleina patient affected with frozen shoulder. Objectives: To evaluate the stiffness of rotator cuff tendons,


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coracohumeral ligament, tendon of long head of biceps and posterior capsule in frozen shoulder by strain elastography and shear wave elastography and compare it with normal shoulder. Materials and Methods: The study was conducted with twenty-nine patients with frozen shoulder. Limited and painful motion without tendinitis or tendon tears were considered. in inclusion criteria. Strain and shear wave lastography were performed on rotator cuff tendons, coracohumer alligament, tendon of long head of biceps and posterior capsule on affected side and normal side to assess and compare the strain ratios and stiffness values on both sides. Receiver operating characteristic curva turewasplottedfor the obtained values. Results: The strainratios for rotator cuff tendons and coracohumer alligament were significantly lower on affected shoulder 0.16 compared to normal shoulder of 0.21. The stiffness values for rotator cuff tendons and coracohumeral ligament were significantly higher on affected shoulder compared to normal shoulder ($p < 0.001$). Conclusion: The stiffness values of supraspinatus, infraspinatus and coracohumeral ligament are higher in strain elastography and shear wave elastography in frozen shoulder compared to normal shoulder.

***Keywords*---**stiffness, thickness, strain ratio, acoustic force, tendinitis.

## Introduction

Frozen shoulder is an idiopathic condition which presents with the loss of both active and passive movement at the shoulder joint over a period of time, associated with pain on movement [1]. With the cause being unclear, underlying mechanism for this condition is thought to be due to inflammation of the synovium and joint capsule fibrosis [2]. With a distribution of 2–5 % in the population, most affected age group is 40 years and beyond, with women being affected slightly more than men [3].

Frozen shoulder is clinically confirmed when there is pain and restricted movement of the shoulder both actively and passively for more than 3 months, without any obvious causes [4]. The wide range of clinical conditions with similar symptoms make the diagnosis difficult, hence making imaging studies mandatory [5]. Few studies have documented changes in rotator cuff tendons, long head of biceps [6], capsule [7], coracohumeral ligament [8]. Ultrasound is useful in patients presenting with frozen shoulder [5]. Yet, B-mode ultrasound technique has many drawbacks due to its limited scope and the small details imaged in our study. A number of studies performed on Achilles tendon and common extensor tendon show that Shear wave US elastography and Strain US elastography techniques are more efficient than conventional ultrasound for tendon studies [9, 10].

Many elastography studies have been performed on tendons around shoulder in various clinical settings. To our knowledge, no studies have compared the shear wave and strain ultrasound elastography values in supraspinatus tendon, infraspinatus tendon, coracohumeral, ligament, posterior capsule and long head of biceps tendon of frozen shoulder with normal shoulder. Our hypothesis states that there is an increase in stiffness noted by shear wave and strain ultrasound elastography of rotator cuff tendons, coracohumeral ligament, tendon of long head of biceps, posterior capsule in a patient affected with frozen shoulder. Hence, the objective of this study is to evaluate the stiffness of rotator cuff tendons, coracohumeral ligament, tendon of long head of biceps and posterior capsule in frozen shoulder by strain elastography and shear wave elastography and compare it with normal shoulder.

**Materials and Methods**

A cross sectional study was conducted from June 2021 to September 2021 on 34 patients . The patients had restricted shoulder movement both actively and passively, with normal radiographic features. Our institutional review board approved the study and informed consent was taken from each patient. As per previous studies, restriction of motion was limited to 100 degrees in forward flexion, 10 degrees in external rotation, up to L 5 level in internal rotation [11]. Cases were referred from the orthopaedic department based on clinical history and examination followed by normal findings on radiographs.

Inclusion criteria for frozen shoulder cases were 1) Shoulder pain for past 6 months, 2) Restriction of both active and passive movements at shoulder joint associated with pain for past 6 months, 3) Age of 40 and above.
Exclusion criteria for frozen shoulder cases were 1) Pathologies like fracture, inflammation, impingement, 2) Age below 40 years, 3) History of trauma.

Out of total 34 patients 5 did not meet the inclusion criteria with 3 patients having rotator cuff tear and 2 patients having nerve impingement. 29 patients were included and underwent shear wave and strain ultrasound elastography of the mentioned tendons, ligament and capsule, with the opposite unaffected shoulder considered as control.

An ultrasound machine (LOGIQ E9, GE HEALTHCARE) was used to perform shearwave and strain US elastography by a radiologist with 4 years of experience in musculoskeletal ultrasound. Ultrasound was done with the patients sitting with the arm in resting position with no abduction or rotation. The transducer was aligned along the fibers of the supraspinatus tendon, infraspinatus tendon, tendon of long head of biceps, coracohumeral ligament and posterior capsule for ultrasound and elastography measurements of these structures. Internal rotation of the arm by 30 degrees was required for elastography measurement of posterior capsule.

To have a clear demarcation from capsule, the region of interest was selected in the superficial portions of supraspinatus and infraspinatus tendons. Due to the unclear boundary between supraspinatus and infraspinatus tendons, stiffness measurements were taken from anterior to mid part of supraspinatus tendon and mid to posterior part of infraspinatus tendon. A region of interest was placed on the tendons, 1 cm away from greater tuberosity for measuring stiffness in shear wave US. The ROI measured 0.09 mm2. The mean stiffness values were measured. Two regions of interest were set for strain elastography with one in the tendon and other in subcutaneous fat for measurement of strain ratio (SR= strain ratio of subcutaneous fat/strain of the tendon). The stiffness range for shear wave US elastography was 0 – 600 kPa while the range for strain ratio was 0 - 1. All measurements were taken 3 times and mean was considered. A region 2 mm away from coracoid process was used to measure the thickness of coracohumeral ligament, while a region 5 mm from glenoid labrum was used to measure the thickness of posterior capsule.

**Statistical Analysis**

All the data obtained through the study were statistically analyzed using the Statistical Package for Social Science (SPSS, version 22).

1. Mann-Whitney tests were used to analyze stiffness and strain ratios;
2. Receiver operating characteristic curve was used for determining the cut-off values for stiffness and strain ratios. Area under the receiver operating characteristic curve was also calculated.

Probability (p) values of less than or equal to 0.05 was taken as statistically significant.

**Results**

The study group consisted of 29 patients with a mean age of 53.7 ± 19.7years (40 – 69 years range), comprising of 11 male and 18 female patients.

Table-1. Shear wave elastography values in frozen shoulder and normal shoulder

| Shear wave elastography (mean kPa) | Frozen shoulder | Normal shoulder |
|---|---|---|
| Supraspinatus tendon | 198.1±42.1 | 129.9±34.9 |
| Infraspinatus tendon | 226.5±62.6 | 158.6±38.2 |
| Coracohumeral ligament | 227.2±59.6 | 168.3±39.3 |
| Long head of biceps | 171.6±40.9 | 159.4±39.9 |
| Posterior capsule | 82.1±22.9 | 71.5±12.4 |

Table-2. Strain elastography values in frozen shoulder and normal shoulder

| Strain elastography (mean ratio) | Frozen shoulder | Normal shoulder | P-Values |
|---|---|---|---|
| Supraspinatus tendon | 0.18 | 0.24 | <0.0001* |
| Infraspinatus tendon | 0.15 | 0.22 | <0.0001* |
| Coracohumeral ligament | 0.16 | 0.21 | <0.0001* |
| Long head of biceps | 0.20 | 0.21 | 0.028 |
| Posterior capsule | 0.29 | 0.30 | 0.028 |

The mean values of shear wave and strain elastography are shown (Table 1 and Table 2.). The supraspinatus tendon, infraspinatus tendon and coracohumeral ligament showed significantly higher mean stiffness values in the symptomatic shoulder than the unaffected shoulder in shear wave elastography ($p < 0.05$). The strain ratios of supraspinatus tendon, infraspinatus tendon and coracohumeral ligament were significantly lower on affected side than on the unaffected side ($p < 0.05$).

With an increase in stiffness of tissue, the color in shear wave elastography changed from blue to green, yellow and red, while strain elastography conversely showed a change in color from red to yellow, green and blue with an increase in stiffness of tissue. The rotator cuff tendons and coracohumeral ligament showed mostly blue color on unaffected side and mostly yellow to red color on the affected side on shear wave elastography. On strain elastography, they showed mostly red to yellow color on unaffected side and mostly green to blue color on affected side (Table 3, Fig 1(A)(B), Fig 2 (A)(B)).

Table-3. Thickness measurements on conventional ultrasound

| Region (mean thickness) | Frozen shoulder | Normal shoulder |
|---|---|---|
| Coracohumeral ligament | 4.1±1.3 | 3.5±0.9 |
| Posterior capsule | 1.3±0.5 | 1.0±0.6 |

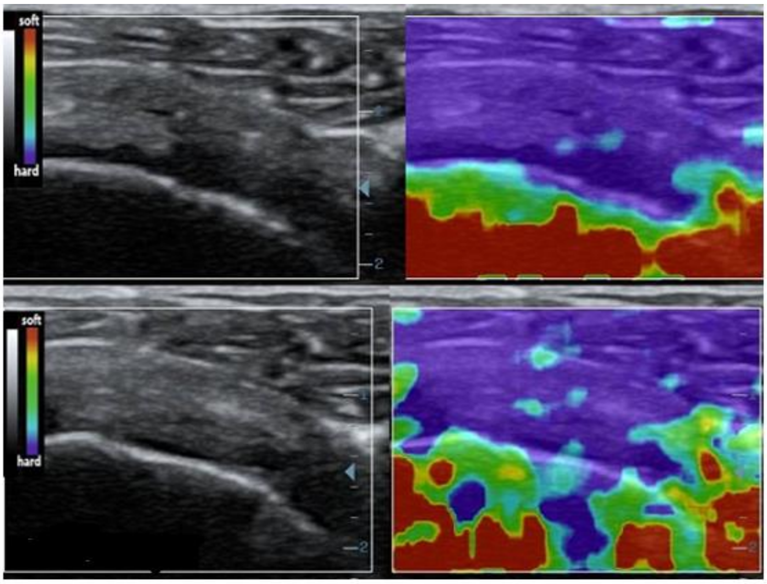


Figure-1-A

Figure 1.Elastography images as seen in (A) Strain elastography of supraspinatus tendon on right side in frozen shoulder (upper) and normal shoulder (lower). The supraspinatus tendon appears blue to green on affected side indicating higher stiffness and red to yellow on unaffected side indicating lower stiffness. (B) Shear wave elastography of supraspinatus tendon on right side in frozen shoulder (upper) and normal shoulder (lower). The supraspinatus tendon appears red to yellow on affected side indicating higher stiffness and blue to green on unaffected side indicating lower stiffness.

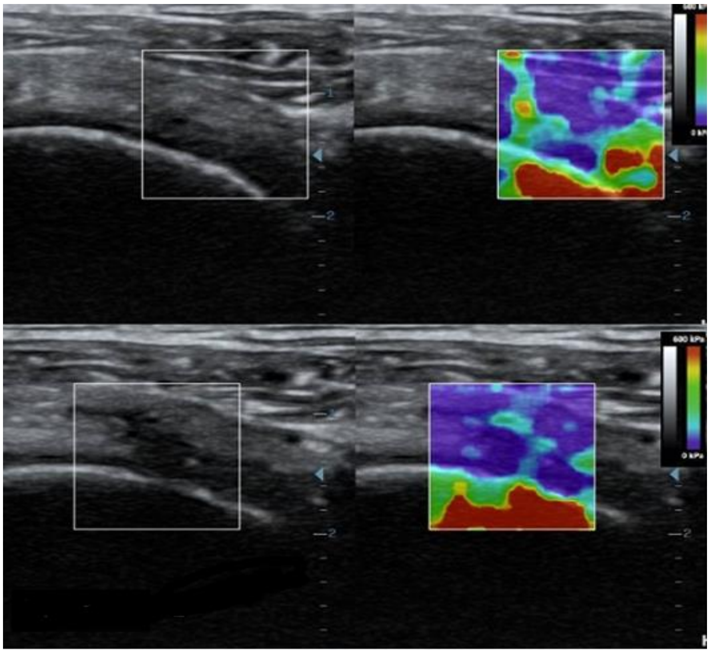

Figure-1-B

Figure 2.Elastography images as seen in (A) Strain elastography of infraspinatus tendon on right side in frozen shoulder (upper) and normal shoulder (lower). The infraspinatus tendon appears blue to green on affected side indicating higher stiffness and red to yellow on unaffected side indicating lower stiffness. (B) Shear wave elastography of infraspinatus tendon on right side in frozen shoulder (upper) and normal shoulder (lower). The infraspinatus tendon appears red to yellow on affected side indicating higher stiffness and blue to green on unaffected side indicating lower stiffness.

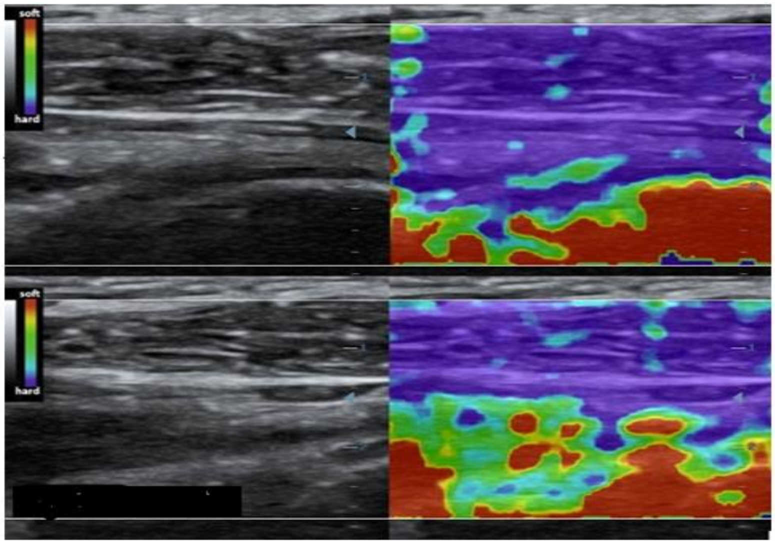


Figure-2-A

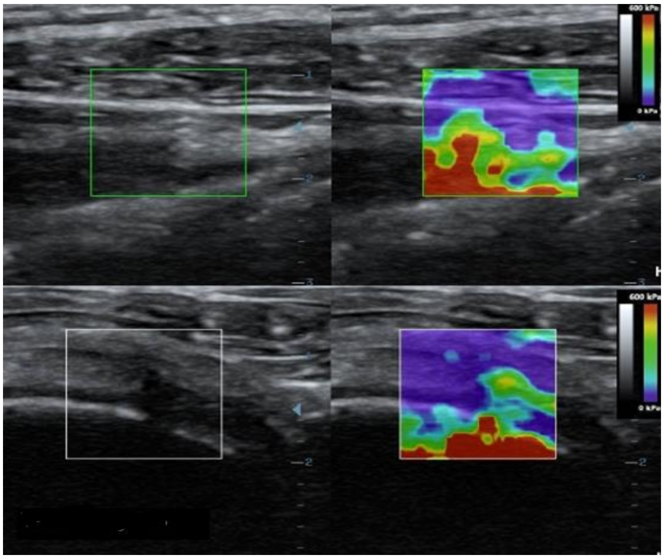

Figure-2-B

On B-mode US, the thickness of coracohumeral ligament had a mean value of 4.1 mm on the affected side and 3.5 mm on the normal side. The thickness of posterior capsule had a mean value of 1.3 mm on the affected side and 1.0 on the normal side. The coracohumeral ligament and posterior capsule showed higher thickness values in the frozen shoulder compared to normal shoulder ($p < 0.05$) (Fig 3(A)(B))

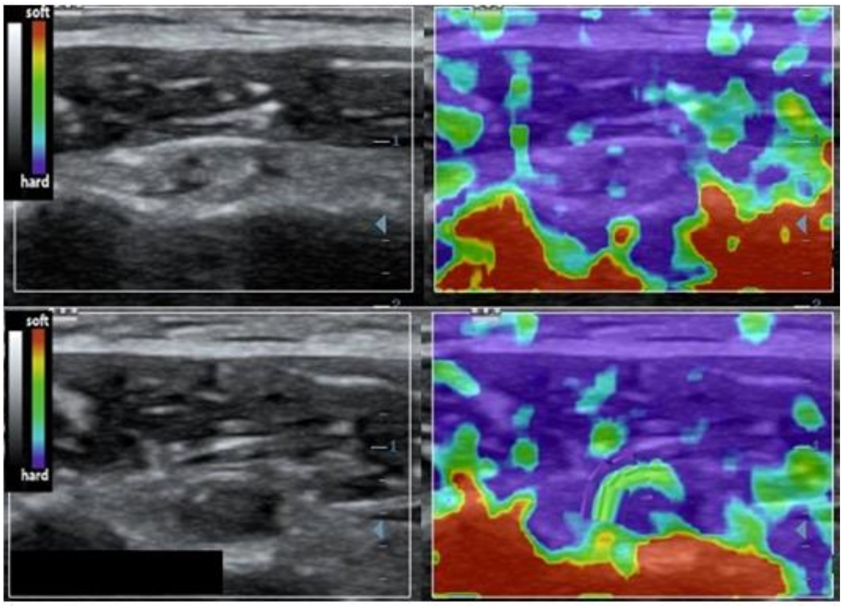


Figure-3-A

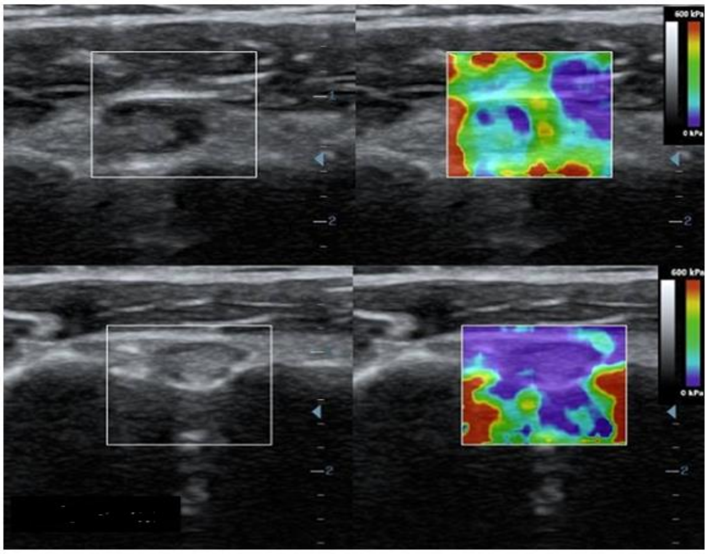

Figure-3-B

Figure 3.Elastography images as seen in (A) Strain elastography of coracohumeral ligament on right side in frozen shoulder (upper) and normal shoulder (lower). The coracohumeral ligament appears blue to green on affected side indicating higher stiffness and red to yellow on unaffected side indicating lower stiffness. (B) Shear wave elastography of coracohumeral ligament on right side in frozen shoulder (upper) and normal shoulder (lower). The coracohumeral ligament appears red to yellow on affected side indicating higher stiffness and blue to green on unaffected side indicating lower stiffness.

Table-4. Diagnostic parameters on shear wave elastography mean values

| Shear wave elastography | Cutoff(kPa) | AUC | Sensitivity(%) | Specificity(%) | PLR | NLR |
|---|---|---|---|---|---|---|
| Supraspinatus tendon | 148.2 | 0.832 | 82.4 | 100 | NA | 0.176 |
| Infraspinatus tendon | 176.8 | 0.861 | 85.2 | 100 | NA | 0.148 |
| Coracohumeral ligament | 184.7 | 0.805 | 78.0 | 100 | NA | 0.22 |
| Long head of biceps | 164.3 | 0.582 | 56.7 | 100 | NA | 0.433 |
| Posterior capsule | 75.6 | 0.563 | 53.8 | 100 | NA | 0.462 |

AUC=Area under receiver operating characteristic curvature, PLR= Positive likelihood ratio, NLR= Negative likelihood ratio

Table-5. Diagnostic parameters on strain elastography mean values

| Strain elastography | Cutoff(strain ratio) | AUC | Sensitivity(%) | Specificity(%) | PLR | NLR |
|---|---|---|---|---|---|---|
| Supraspinatus | 0.208 | 0.848 | 80.6 | 100 | NA | 0.194 |

| | | | | | | |
|---|---|---|---|---|---|---|
| tendon | | | | | | |
| Infraspinatus tendon | 0.174 | 0.872 | 82.1 | 100 | NA | 0.179 |
| Coracohumeral ligament | 0.183 | 0.813 | 75.4 | 100 | NA | 0.246 |
| Long head of biceps | 0.207 | 0.596 | 61.2 | 100 | NA | 0.398 |
| Posterior capsule | 0.296 | 0.581 | 57.8 | 100 | NA | 0.422 |

AUC=Area under receiver operating characteristic curvature, PLR= Positive likelihood ratio, NLR= Negative likelihood ratio

The optimal cutoff values were calculated using ROC curve (Table 4 and Table 5) The mean stiffness values on shear wave elastography and strain ratios on strain elastography of supraspinatus tendon, infraspinatus tendon, coracohumeral ligament showed high area under curvature.

**Discussion**

Ultrasonography is the primary investigation preferred over MRI in cases of shoulder pain evolving insidiously, as it is less expensive as a primary investigation [12]. Ultrasound elastography has increased the scope of ultrasound from Gray scale and dynamic imaging to measurement of mechanical properties like stiffness of tissues [9]. In shear wave US elastography, an applied acoustic force causes shear waves to be produced whose velocity is measured which provides an indirect quantitative measure of tissue stiffness [13, 14].Strain elastography displays the ratio between tissue strains (subcutaneous tissue/ tendon) produced due to manual compression with transducer and is a semiquantitative method showing lower strain ratio in stiffer tissues [13]. Increased stiffness of tendons was associated with degeneration of rotator cuff tendons in a study conducted on animal model by Morikawa et al [15]. Krepkin et al [16] noted an increase in shear wave elastography values in degenerated supraspinatous tendons.An increase in stiffness of degenerated rotator cuff tendons was noted in the above studies. In our study, elastography values of rotator cuff tendons and coracohumeral ligament were higher in the frozen shoulder compared to the normal shoulder. Our results are in favour of our hypothesis. A proposed mechanism for pathogenesis states that increased stiffness is due to decreased glycosaminoglycans, hyaluronic acid, water content in the tendons which in turn is due to joint immobilization [17]. A study performed on animal model concluded that shortening and hence higher strain of a tendon around an immobilized joint is due to higher tension in tendon due to muscle contraction adapted to the new resting position [18]. While most shoulder diseases like rotator cuff tears or shoulder impingement show decreased stiffness of the tendons [19,20], frozen shoulder is associated with increased stiffness of the tendons. Hence, we used elastography values of these tendons as an indirect indicator for frozen shoulder. The coracohumeral ligament showed increased thickness and stiffness in the frozen shoulder. A study by Mengiardi et al [21] used MR arthrography to conclude that coracohumeral ligament was thickened in frozen shoulder. A study by Homsi et al [8] used B-mode ultrasound to conclude that coracohumeral ligament was thickened in frozen shoulder.

In a study by Wu et al [22], using shear wave elastography, elastic modulus of coracohumeral ligament was reported to be higher on the affected side than the normal side. The results of these studies are in coherence with results of our study. In frozen shoulder, capsular fibrosis is associated with synovitis and inflammation of the whole capsule [7, 23]. One study showed thickened inferior capsule [24] while other studies showed thickened rotator interval and axillary pouch. Our study showed a thickened posterior capsule in frozen shoulder, consistent with the findings of previous studies[21, 25].

Table-6 Previous studies on ultrasound and ultrasound elastography in shoulder

| Author | Year | Ultrasound method | Inference |
|---|---|---|---|
| Homsi C | 2006 | Ultrasound | Increased thickness of coracohumeral ligament is suggestive of frozen shoulder. |
| Schmalzl J | 2017 | Shear wave elastography, Strain elastography | Ultrasound elastography can be used for screening, monitoring of effects of new treatments, cost effective follow up examination in tendon injuries. |
| Taljanovic MS | 2017 | Continuous wave elastography, 3D shear wave elastography, 2D shear wave elastography | Continuous-wave and 3dimensional shear wave elastography along with 2 dimensional shear wave elastography help in early disease diagnosis of musculoskeletal soft tissues. |
| Krepkin K | 2016 | Shear wave elastography, MRI | T2* values and shear wave velocity values showed a correlation in the supraspinatus tendon while evaluating the tendons of rotator cuff. |
| Lee SU | 2016 | Strain elastography, MRI | Stiffness values in strain elastography showed association with tendinosis grade in MRI in patients with tendinopathy. |
| Tudisco C | 2015 | Strain elastography | Shear wave elastography is a useful method in assessment of small supraspinatus tears. |
| Wu CH | 2016 | Shear wave elastography | Shear wave elastography showed higher stiffness values in coracohumeral ligament in |
| Michelin P | 2013 | | |

| | | | |
|---|---|---|---|
| | | Ultrasound | symptomatic patients of frozen shoulder compared to normal shoulders.<br><br>The inferior glenohumeral capsule appears thickened on ultrasound in patients with contracture of the capsule. |

A study by Moet al [26] concluded that stiffness of thin layers could not be measured properly as the speed of shear wave is less in thin tissues. Stiffness of posterior capsule could not be measured properly in our study as the capsule was thinner than the spatial resolution of the machine.

Rotator cuff tendons and coracohumeral ligament in patients with frozen shoulder showed higher stiffness values on shear wave elastography and lower strain ratios on strain elastography as compared to controls. The posterior capsule and coracohumeral ligament were thicker in frozen shoulder as compared to controls. The elastography of rotator cuff tendons and thickness of coracohumeral ligament and posterior capsule may be used as a radiological correlation for confirming frozen shoulder.

**Limitations**

Our study has many limitations. First, this study did not include degenerative changes around the shoulder, which is a very common finding in middle age group, which is our study population. Including patients with degenerative changes around shoulder would make the study more practicable. Second, the sample size selected was small. A bigger sample size would get better results. Third, being a cross sectional study, intraobserver agreement could not be evaluated. This should be evaluated in a future study. Fourth, the various phases of adhesive capsulitis of shoulder like freezing, frozen and thawing phase were not taken into account. A study considering these phases can better delineate changes in stiffness during each phase. Finally, the control used was the opposite shoulder presumed to be normal by ruling out adhesive capsulitis of shoulder after thorough clinical examination. Studies have showed that bilateral involvement is seen in 14% of frozen shoulder cases. A study having unaffected patients as controls can be done in future.

**Conclusion**

The stiffness values of supraspinatus, infraspinatus and coracohumeral ligament are higher in strain elastography and shear wave elastography in frozen shoulder compared to normal shoulder.

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