Diagnostic Utility of Ultrasound Shear Wave Elastography in Frozen Shoulder: Added Value Beyond Conventional Imaging

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Abstract

Background: Frozen shoulder, or adhesive capsulitis, is a common but diagnostically challenging condition characterized by progressive pain and restricted range of motion in the glenohumeral joint. While clinical evaluation remains the cornerstone of diagnosis, imaging is critical to exclude mimickers and evaluate structural changes. Conventional imaging modalities, including radiographs, B-mode ultrasound, and MRI, offer valuable anatomical detail but lack sensitivity in detecting early capsular or ligamentous involvement. Recent advances in ultrasound shear wave elastography (SWE) have introduced the ability to quantitatively assess tissue stiffness, offering new diagnostic dimensions in musculoskeletal imaging. SWE enables objective measurement of mechanical properties of soft tissues, such as the coracohumeral ligament (CHL), joint capsule, and rotator cuff tendons, which are key structures implicated in frozen shoulder. Studies have demonstrated significantly higher shear wave velocities and elastic modulus values in the affected shoulders of patients with adhesive capsulitis compared to asymptomatic controls, suggesting its role in early detection, staging, and monitoring of treatment response.

Conclusion: Ultrasound SWE provides a reproducible, non-invasive, and quantitative method for evaluating soft tissue stiffness in frozen shoulder. It complements conventional B-mode ultrasound by offering additional information on tissue elasticity, which is especially beneficial in the early or atypical stages of the disease when structural changes may be subtle or absent. This added diagnostic capability not only enhances clinical decision-making but may also reduce reliance on more costly or invasive imaging modalities. SWE holds promise as a valuable adjunct in the diagnostic armamentarium for adhesive capsulitis and may serve as a biomarker for disease activity and recovery.

Keywords: *Ultrasound, Shear Wave Elastography, Frozen Shoulder*

Introduction

Frozen shoulder, clinically referred to as adhesive capsulitis, is a debilitating condition marked by progressive pain and loss of both active and passive motion of the glenohumeral joint. It affects approximately 2–5% of the general population and is more common in individuals between 40 and 60 years of age, with a slight predominance in females and in patients with diabetes and other metabolic or autoimmune disorders [1,2]. Despite its relatively high prevalence, the pathogenesis of frozen shoulder remains poorly understood and its diagnosis continues to rely heavily on clinical criteria due to the lack of definitive imaging biomarkers [3,4].

The classic pathophysiology of frozen shoulder involves fibrosis and thickening of the joint capsule, particularly in the rotator interval and around the coracohumeral ligament (CHL), leading to capsular contracture and decreased joint volume [5]. Histological studies have confirmed increased fibroblast proliferation, neovascularization, and inflammatory infiltration in affected tissues [6,7]. Conventional imaging modalities such as plain radiography and MRI play a limited role in early diagnosis and staging, as they often fail to detect subtle soft tissue alterations until the disease has progressed [8].

Ultrasound (US) has gained traction as a first-line imaging tool in the assessment of shoulder pathology due to its accessibility, dynamic capability, and cost-effectiveness. However, traditional B-mode ultrasound primarily offers morphological information and lacks the sensitivity to detect early capsular or ligamentous stiffness [9]. The advent of shear wave elastography (SWE), an advanced ultrasound technique capable of quantifying tissue stiffness, has provided a novel approach to evaluating the biomechanical changes characteristic of adhesive capsulitis [10,11].

This review aims to critically appraise the diagnostic utility of SWE in frozen shoulder and highlight its added value beyond conventional imaging, with a focus on its ability to detect early biomechanical changes, assess disease severity, and guide management.

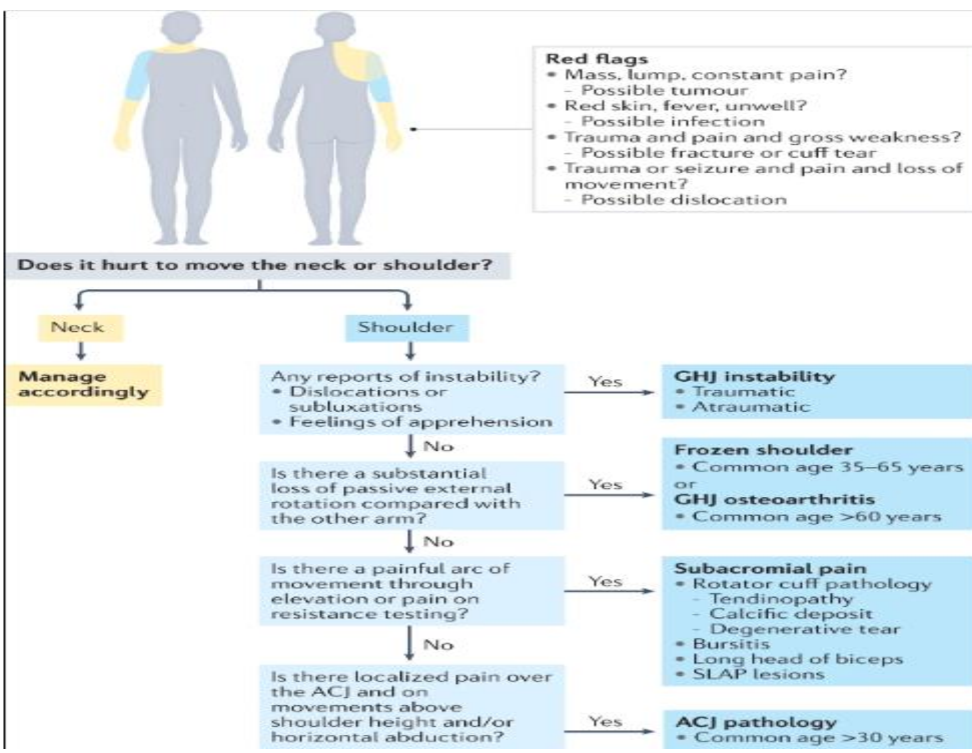


Fig.(1):This algorithm assists in distinguishing frozen shoulder from other shoulder pathologies that cause pain and/or restricted movement, including gleno-humeral joint (GHJ) osteoarthritis, sub-acromial impingement syndrome, and acromio-clavicular joint (ACJ) pathology. The diagnostic decisions are primarily based on the results of the physical examination, specifically the assessment of passive external rotation of the shoulder(11).

Pathophysiology and Imaging Limitations in Frozen Shoulder

The pathophysiology of frozen shoulder is characterized by chronic inflammation, fibrosis, and subsequent thickening of the joint capsule, particularly in the rotator interval and the coracohumeral ligament (CHL) [12]. The disease typically progresses through three clinical phases—freezing, frozen, and thawing—each associated with variable degrees of pain, stiffness, and range of motion limitation [13]. Histological evaluations have revealed increased myofibroblast activity, collagen deposition, neoangiogenesis, and inflammatory cytokine expression including IL-1, IL-6, and TGF-β, supporting its classification as a fibrotic capsulitis [14,15].

Despite this well-documented pathology, early diagnosis remains a challenge. Conventional radiographs are often unremarkable, serving primarily to exclude other causes of shoulder pain such as osteoarthritis or calcific tendinopathy [16]. MRI, while more sensitive to soft tissue changes, may still fail to detect the subtle capsular contractures and early fibrotic changes characteristic of the initial stages of frozen shoulder [17]. MR arthrography can reveal capsular volume loss and thickening of the CHL and inferior glenohumeral ligament (IGHL), but these findings tend to appear in the later stages of the disease [18].

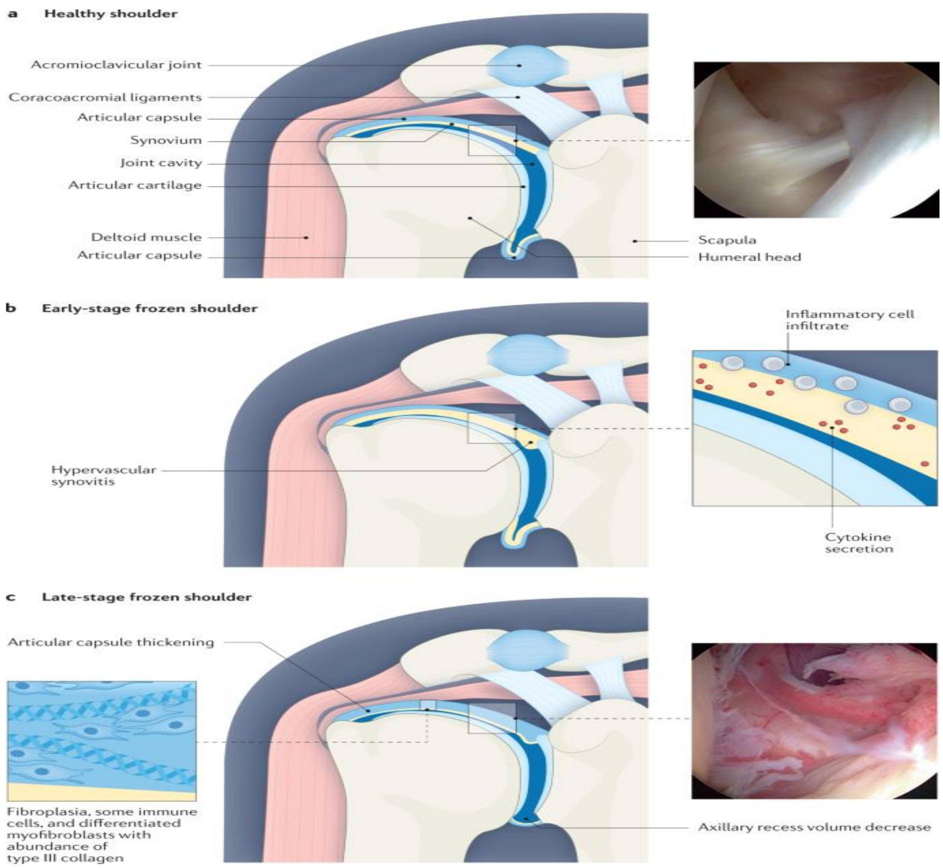


Fig.(2): histological stages of developing frozen shoulder (18).

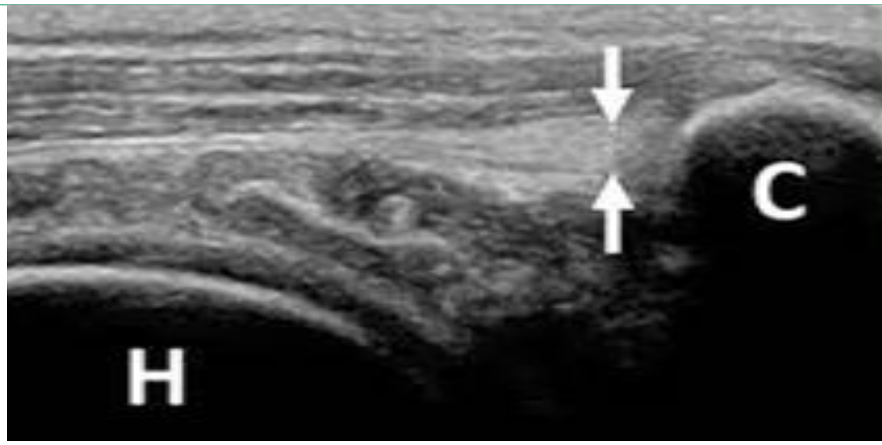


Fig.(3):B-mode US scan shows measurement of CHL thickness (arrows) in 47-year-old woman with ACS. *C* = coracoid process, *H* = humeral head (19).

a.In a healthy shoulder capsule, the structure is primarily collagenous, composed mostly of dense type I collagen and elastic fiber bundles. This capsule has a limited number of blood vessels and nerve fibers. The predominant cell type within the capsule is the fibroblast, which helps maintain the capsule's health by producing extracellular matrix (ECM) proteins that give the capsule both support and flexibility.

b.In frozen shoulder, fibrosis and thickening occur in both the connective tissue membrane and the adjacent synovial membrane.

c.Fibroproliferation leads to an increase in the number of fibroblasts, which produce excess ECM proteins, resulting in a dense and disorganized fibrillar structure. These fibrotic changes are accompanied by inflammation, the growth of new blood vessels (neoangiogenesis), and the formation of new nerve fibers (neoinnervation). As a result, the joint volume is reduced, and the capsule becomes stiffer, leading to restricted movement and pain. Ultrasound has become increasingly utilized due to its accessibility and real-time dynamic assessment capability. However, B-mode ultrasound is mainly limited to structural evaluation—detecting effusion, bursal thickening, and rotator cuff pathology—but lacks sensitivity to assess tissue elasticity or stiffness, which are key features in early frozen shoulder [19].

Consequently, there exists a diagnostic gap in identifying the early biomechanical changes of the capsule and surrounding ligaments. This gap highlights the need for a more sensitive imaging modality—such as shear wave elastography (SWE)—that can detect the altered mechanical properties of soft tissues before morphologic changes are evident on conventional imaging.

Principles of Shear Wave Elastography and Technique in Shoulder Imaging

Shear wave elastography (SWE) is an advanced ultrasound-based modality that quantitatively assesses tissue stiffness by measuring the velocity of shear waves propagated through soft tissues. These waves are generated by acoustic radiation force impulses (ARFI), and their velocity is directly proportional to the elasticity of the target tissue—higher velocities indicate increased stiffness, a hallmark of fibrotic changes as seen in adhesive capsulitis [20,21].

Unlike strain elastography, which provides relative stiffness maps based on manual compression, SWE offers real-time, operator-independent, and reproducible quantitative measurements expressed in kilopascals (kPa) or meters per second (m/s) [22]. This makes it especially useful in musculoskeletal applications where tissue mechanical properties, such as those of the capsule, ligaments, or tendons, are pathologically altered without clear morphologic abnormalities on B-mode imaging [23].

In the context of shoulder evaluation, SWE is typically performed with the patient seated, arm in a neutral or slightly abducted position to reduce anisotropy and maximize visualization of the rotator interval and coracohumeral ligament (CHL). The probe is placed longitudinally over the CHL, rotator cuff tendons, or posterior capsule depending on the structure of interest. Regions of interest (ROIs) are selected within the structure, avoiding artifacts from adjacent bone or anisotropy [24]. Several studies have standardized the use of SWE in the shoulder and demonstrated good intra- and inter-observer reliability [25].

Importantly, SWE can detect increased stiffness in the CHL and posterior capsule in frozen shoulder patients compared to the contralateral asymptomatic shoulder or healthy controls, even in the absence of gross structural thickening [26]. This ability to objectively quantify stiffness offers a valuable tool for diagnosing early adhesive capsulitis, staging disease progression, and monitoring treatment response.

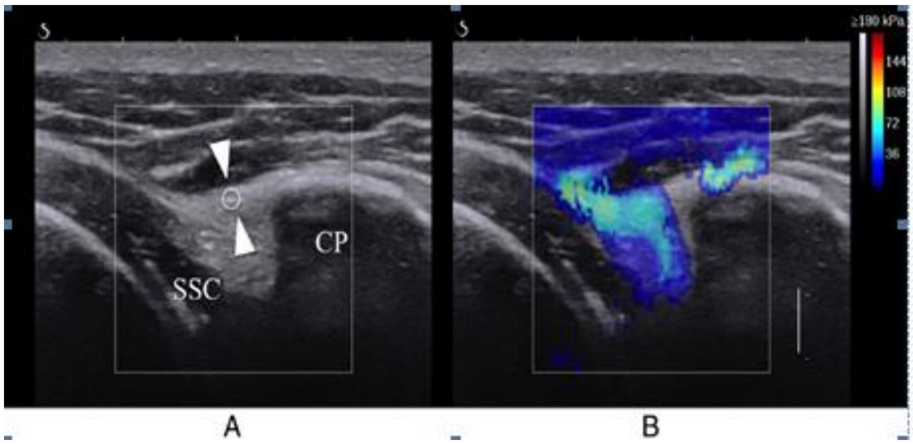


Fig.(4): Measurements of the elastic modulus of the coracohumeral ligament with shear-wave elastography in with shoulders placed in ER positions (A and B) . Measurements are obtained at a central point within the coracoid process and attachment segment of the subscapularis (arrowheads) A circular target of interest with a diameter of 1.5 mm is set at the measurement point (white circle) (25).

Clinical Evidence Supporting SWE in Frozen Shoulder Diagnosis

Accumulating clinical evidence underscores the diagnostic potential of shear wave elastography (SWE) in identifying and characterizing frozen shoulder, particularly in detecting tissue stiffness in anatomically relevant structures such as the coracohumeral ligament (CHL), posterior capsule, and rotator cuff tendons. In contrast to conventional ultrasonography and MRI, which primarily assess morphological changes, SWE provides quantitative data on viscoelastic properties, thus revealing subclinical pathological changes indicative of adhesive capsulitis [27,28].

One pivotal study by Wu et al. compared the elasticity of the CHL between patients with frozen shoulder and healthy controls. The authors reported a significant increase in stiffness (mean elasticity: 78.7 ± 15.3 kPa in affected shoulders vs. 33.1 ± 9.4 kPa in controls), supporting SWE as a highly sensitive modality for identifying fibrotic changes associated with adhesive capsulitis [29]. Similarly, Kanazawa et al. demonstrated that SWE-derived elasticity of the CHL correlated negatively with range of motion (ROM), especially in external rotation, highlighting its potential for disease staging and functional assessment [30].

Yun et al. further validated the utility of SWE in a prospective case-control study by comparing both supraspinatus and infraspinatus tendon stiffness in idiopathic adhesive capsulitis. The study revealed significantly higher shear wave velocities in the patient group, with SWE outperforming strain elastography and B-mode ultrasound in sensitivity (87.5%) and specificity (90.0%) [31].

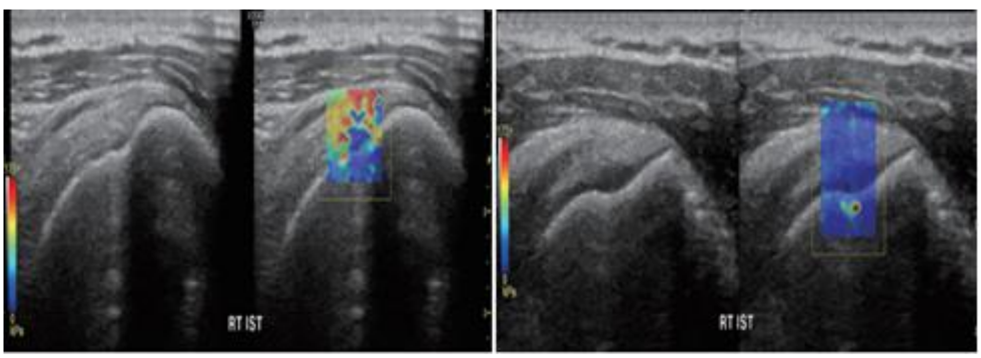
Moreover, SWE has shown promise in monitoring treatment outcomes. Lee et al. observed a gradual reduction in CHL stiffness following corticosteroid injection, which paralleled clinical improvement, indicating SWE's role as an objective biomarker of response to therapy [32].

Taken together, these findings confirm that SWE adds substantial diagnostic value beyond conventional imaging by enabling early detection, functional assessment, and longitudinal monitoring of frozen shoulder.

Advantages of SWE Over Conventional Imaging Modalities in Frozen Shoulder

Conventional imaging techniques such as plain radiography, ultrasound B-mode, and magnetic resonance imaging (MRI) have well-established roles in evaluating shoulder pathology. However, these modalities often fall short in the early or subclinical detection of adhesive capsulitis (frozen shoulder), especially when structural changes are subtle or absent. Shear wave elastography (SWE), by contrast, provides a non-invasive, quantitative assessment of soft tissue stiffness, offering clear advantages that complement and surpass conventional imaging in many clinical scenarios [33,34].

One of the primary advantages of SWE lies in its **ability to detect early biomechanical changes** in the shoulder capsule and ligaments—particularly the coracohumeral ligament (CHL)—before morphologic abnormalities become apparent on MRI or B-mode ultrasound [35]. This is especially valuable in diagnosing stage I frozen shoulder, when early intervention can prevent progression to more debilitating stages [36].



(A) (B)

Fig.(5):Increased share wave elastography of Symptomatic shoulder (A) and normal share wave elastography of non- affected shoulder (B) (37).

Another critical benefit of SWE is **its objectivity and reproducibility**. Unlike grayscale ultrasound, which is inherently operator-dependent, SWE provides numerical values (e.g., shear wave velocity or kPa) that can be tracked over time, allowing clinicians to monitor treatment response quantitatively [37]. This quantitative aspect has been shown to correlate well with clinical measures such as range of motion, pain scores, and disability indices, reinforcing its role as a reliable functional imaging tool [38].

Additionally, SWE is a **cost-effective and accessible alternative** to MRI, especially in low-resource settings. It can be performed alongside routine musculoskeletal ultrasound with minimal additional time or equipment, making it an attractive point-of-care modality [39].

In sum, the incorporation of SWE into the diagnostic pathway of frozen shoulder enhances diagnostic accuracy, enables early detection, supports functional assessment, and facilitates longitudinal monitoring—bridging critical gaps left by traditional imaging modalities.

Conclusion and Future Perspectives

Ultrasound shear wave elastography (SWE) has emerged as a transformative tool in the diagnostic landscape of frozen shoulder (adhesive capsulitis), offering substantial advantages over conventional imaging techniques. While modalities such as MRI and grayscale ultrasound have long played pivotal roles in assessing structural changes in shoulder pathology, they often fall short in detecting the subtle, early-stage alterations that characterize adhesive capsulitis. SWE addresses this diagnostic gap by providing real-time, non-invasive, and quantitative measurements of tissue stiffness—particularly in the coracohumeral ligament and surrounding rotator cuff structures—facilitating early diagnosis, objective monitoring, and assessment of disease progression [40–42].

Importantly, SWE's ability to correlate mechanical stiffness with clinical parameters such as pain, limited range of motion, and disability indexes makes it not just a diagnostic adjunct, but a potential tool for **personalized treatment planning**. For instance, patients with persistent ligamentous stiffness despite clinical improvement may benefit from prolonged therapy or alternative interventions. Furthermore, the incorporation of SWE into routine clinical practice may **reduce dependency on costly or less accessible imaging techniques** such as MRI, thereby broadening access to high-quality care in resource-limited settings [43].

Despite its promising utility, SWE is not without limitations. Variability in acquisition protocols, probe pressure, and interpretation standards can affect reproducibility. Standardized protocols and larger multicenter studies are needed to validate normative stiffness values for shoulder structures and to establish SWE-based diagnostic criteria for the various stages of frozen shoulder.

Looking ahead, SWE holds significant promise not only as a **diagnostic tool** but also as a **biomarker** for therapeutic response. Its integration with machine learning algorithms could further enhance diagnostic accuracy and disease staging. In conclusion, SWE represents a valuable advancement beyond conventional imaging—offering objective, early, and dynamic insights into a complex and often elusive clinical condition.

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