Current Rehabilitation Applications for Shoulder Ultrasound Imaging

Previous estimates indicate that over 20% of the population has activity-limiting shoulder pain. In this population, detriments to quality of life and function make it necessary to explore the best available means of informing clinical practice. Physical therapists traditionally rely on a variety of physical examination procedures to determine pathoanatomic and impairment-based diagnoses; however, many of these procedures lack the adequate diagnostic accuracy and relevant prognostic indicators to sufficiently drive clinical decision making. To supplement these procedures, clinicians and researchers have explored the capabilities of ultrasound imaging to inform and augment clinical practice. There is a mounting body of evidence to support the effectiveness of ultrasound imaging in the clinical evaluation of certain musculoskeletal conditions, most notably low back pain. Likewise, several ultrasound applications are emerging for clinical evaluation in persons with shoulder pain. Considering this recent growth of literature, summary and critical review of these applications may be helpful to guide physical therapists in understanding the applications of these techniques.

SYNOPSIS: The available body of knowledge on shoulder ultrasound imaging has grown considerably within the past decade, and physical therapists are among the many healthcare professionals currently exploring the potential clinical integration of this imaging technology and the knowledge derived from it. Therefore, the primary purpose of this commentary was to review the recent evidence and emerging uses of ultrasound imaging for the clinical evaluation of shoulder disorders. This includes a detailed description of common measurement techniques along with their known clinimetric properties. Specifically provided are critical appraisals of the existing measures used to estimate soft tissue and bony morphology, muscle contractile states, and lean muscle density. These appraisals are intended to help clinicians clarify the scope of physical therapy practice for which these measurement techniques are effectively utilized and to highlight areas in need of further development. J Orthop Sports Phys Ther 2015;45(5):394-405. Epub 27 Jan 2015. doi:10.2519/jpos.2015.4232

KEY WORDS: rehabilitation, rotator cuff, ultrasonography

Investigators have proposed the use of ultrasound imaging to quantify anatomic regions, tissue morphology, contractile states, and muscle integrity at the shoulder. Conceptually, the information provided through these applications may guide therapeutic interventions and potentially impact clinical outcomes through appropriately targeted interventions. However, prior to the large-scale implementation of ultrasound imaging, it is imperative to understand the clinimetric properties and limitations of these measurement techniques. Therefore, the purpose of this article was to (1) review common shoulder ultrasound imaging techniques of relevance to physical therapists, (2) critically appraise their clinimetric properties, and (3) discuss their potential clinical applications.

BONY RELATIONSHIPS

The bony architecture of the glenohumeral joint permits a wide range of motion to occur at the shoulder. Some postulate that this unique morphology and exceptional range of motion may contribute to injury by placing excessive stress on the local anatomy during functional activities, like throwing and overhead work. Recently, in-

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Investigators have documented the use of ultrasound imaging to quantify humeral torsion and acromiohumeral distance. Two measures suspected of being related to patient symptoms.

Humeral Torsion

Current evidence indicates that injury prevalence is higher among overhead athletes with shoulder range-of-motion deficits of their dominant throwing shoulder. Specifically, glenohumeral internal rotation deficits greater than 20° and total rotation range-of-motion deficits (external rotation combined with internal rotation) greater than 5° have been identified as possible risk factors for the development of shoulder and elbow injuries. Recent consensus holds that these deficits are the result of both bony and soft tissue adaptations that occur with repeated exposures. The difficulty facing rehabilitation clinicians lies in determining the contributions of bony morphology, as traditional goniometric measures fail to discriminate between bony architecture and the influence of soft tissue restriction. The ability to account for bony versus soft tissue influence on shoulder range of motion may aid clinicians in directing the appropriate interventions to the shoulder region.

By definition, humeral torsion represents the relative difference of osseous rotation between the proximal and distal articular surfaces of the humerus (FIGURES 1A and 1B), and has been shown to significantly influence shoulder rotation range of motion. Most non-throwing individuals display a relative torsion of approximately 20° to 30° from proximal to distal surfaces, which develops throughout skeletal maturity and is influenced by the arm’s natural carrying angle. In skeletally immature overhead athletes, however, the stresses placed on the humerus with throwing are postulated to retard the natural development of humeral torsion, a condition known as “humeral retrotorsion.” This contention has been supported in numerous studies of throwing athletes who commonly display humeral retrotorsion on their throwing side compared to the non-throwing side and other non-throwing athletes.

Ultrasound is specifically used to calculate humeral torsion by aligning the apices of the greater and lesser tuberosities and measuring the corresponding forearm angle (FIGURE 1B). Whiteley and colleagues demonstrated that the reliability of this measure is greatly improved with the use of a probe-mounted inclinometer to ensure proper orientation to the biceps groove, while also firmly aligning an inclinometer to the ulnar diaphysis to obtain the corresponding forearm angle (ONLINE VIDEO available at www.jospt.org). Rehabilitation specialists investigating these measurement techniques report acceptable intrarater and interrater reliability (intraclass correlation coefficient [ICC] > 0.90) for measurements made in healthy individuals and overhead athletes (TABLE 2). In previous work, the reliability of ultrasound measurements appears to be superior to those from computed tomography (CT). In that study, the difference between the measurements made with ultrasound and CT was approximately 6.3°, which the authors contend might have been less had the CT method been more reliable.

Although there are existing links between humeral torsion and range-of-motion risk factors, there are several questions that remain unanswered. Specifically, side-to-side range-of-motion differences do not have a direct 1-to-1 relationship with the side-to-side difference in humeral torsion. Myers and colleagues reported an average coefficient of determination (R²) of 0.64 for the relationship between humeral torsion and range-of-motion differences, which, though clearly impactful, does not account for the remaining variability in glenohumeral range of motion. Anecdotally, this discrepancy is most likely attributable to soft tissue mobility of the shoulder musculotendinous and capsuloligamentous anatomy. To date, there are no studies or imaging procedures to objectively quantify the influence of the soft tissue structures.

Despite the need for future development, ultrasound imaging of humeral torsion may provide useful information to inform therapeutic treatment. For instance, athletes who display shifted but equal values in their total rotation range of motion are considered to have primary alterations in humeral morphology, due to the preservation of total rotational range of motion between sides. In contrast, athletes who display deficits in total rotation range of motion (greater than 5°) from throwing to nonthrowing sides are postulated to have added soft tissue mobility limitations. Therefore, the utilization of ultrasound torsion measures may help to confirm the contribution of bony morphology to range-of-motion limitations.
deficits, thus allowing for tailored treatment and range-of-motion goals. Future studies are needed to collectively account for all of the potential mediating factors of these range-of-motion deficits and to shed further light on the clinical utility of this ultrasound method.

**Acromiohumeral Distance**

While the etiology, pain-generating factors, and level of tissue involvement of rotator cuff disease are debatable, there is literature to suggest that acromiohumeral distance is associated with the presence and magnitude of rotator cuff tears. To quantify the dimensions of the subacromial space, investigators have utilized radiographs, magnetic resonance imaging (MRI), and ultrasound imaging to specifically determine acromiohumeral distance. Acromiohumeral distance is operationally defined as the shortest linear distance between the most inferior aspect of the acromion and the adjacent humeral head.

A majority of the available evidence indicates that acromiohumeral distance is greater than 7 mm in asymptomatic individuals. Decreased values have been related to large rotator cuff tears, superior migration of the humeral head, and poor surgical outcomes. Specifically, recent work shows that the level of humeral elevation at which the rotator cuff becomes vulnerable to extrinsic impingement, originally described by Neer, is much lower than previously believed. Consequently, from 60° to 120° of elevation ("painful arc" of motion), the rotator cuff tendons have likely moved medially beyond the anterior-in-

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<td>Unknown</td>
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Abbreviations: CT, computed tomography; ICC, intraclass correlation coefficient; MDC, minimal detectable change; MRI, magnetic resonance imaging; SEE, standard error of the regression estimate; SEM, standard error of the measurement.

The superior aspect of the acromion and are no longer susceptible to extrinsic impingement. Therefore, ultrasound imaging, to measure acromiohumeral distance in this patient population, might be considered during active contraction and for up to 60º of glenohumeral elevation to assess the relationship of this anatomic region to extrinsic impingement.

Ultrasound imaging measurement of acromiohumeral distance is obtained with the transducer oriented in the scapular plane and placed on the lateral aspect of the acromion to capture both the acromion and the superior portion of the humeral head (FIGURES 2A and 2B). Note that the 2-dimensional characteristics of this measure are not necessarily representative of the specific location(s) or the entire volume of this region, where extrinsic impingement is postulated to occur. Despite these limitations, there are studies to support the reliability<sup>26</sup> and validity<sup>2,27</sup> of this measurement technique (TABLE 2).

Warranting further investigation are the relationships between acromiohumeral distance and functional improvements with the application of therapeutic interventions. In a preliminary study by Desmeules et al<sup>16</sup> of patients with shoulder pain receiving physical therapy, a strong positive correlation ($r = 0.86$, $P = .01$) was detected between increased acromiohumeral distance and function following 4 weeks of treatment. These results are far from definitive, as this sample of just 20 patients (7 with subacromial impingement and 13 healthy controls) highlights the need for more high-quality studies to confirm these relationships. However, serial tracking of acromiohumeral distance may provide an additional clinical indicator of functional improvement and is indeed worthy of further investigation.

Perhaps more specific to therapeutic applications, physical therapists have used ultrasound imaging to examine the influence of extrinsic factors on acromiohumeral distance. Research suggests that acromiohumeral distance increases with improvements in posture,<sup>26</sup> scapular position,<sup>26</sup> posterior shoulder flexibility, and glenohumeral internal rotation range of motion.<sup>26</sup> A comparative study by Kalra et al<sup>26</sup> that included healthy individuals and individuals with rotator cuff disease showed that those who assumed an upright posture displayed a statistically
significant increase in acromiohumeral distance of 1.2 mm (95% confidence interval: 0.3, 2.0) on ultrasound imaging. However, that study was unable to detect differences between those with and without rotator cuff disease, indicating a current measurement limitation.\textsuperscript{26}

Similarly, manual facilitation of the scapula into a more externally rotated and posteriorly tilted position (scapular assistance test) increased acromiohumeral distance (mean ± SD, 2.1 ± 1.1 mm) in both healthy participants and individuals diagnosed with shoulder impingement.\textsuperscript{26} The authors\textsuperscript{26} propose that rehabilitation strategies aimed at improving scapular position and neuromuscular control may effectively increase the subacromial space. However, once more, the investigators were unable to detect a difference between the healthy and the impingement groups, which calls into question the true sensitivity of acromiohumeral distance to diagnose and differentiate the presence of rotator cuff disease. Considering these results, measures of acromiohumeral distance in individuals with rotator cuff disease merit further investigation to determine their scope within clinical practice.

Maenhout et al\textsuperscript{26} assessed the comparative effectiveness of shoulder stretching for improving range-of-motion deficits and its influence on acromiohumeral distance within a group of healthy overhead athletes. The results indicated that posterior shoulder stretching increases acromiohumeral distance (mean ± SD, 0.6 ± 0.1 mm) while improving range-of-motion deficits in athletes displaying glenohumeral internal rotation deficits.\textsuperscript{26} Though these acromiohumeral distance gains proved statistically significant, more data are needed to determine the amount of improvement that could be functionally and clinically significant for various populations with shoulder pathologies, as this represents a key gap in the available literature. Nonetheless, this preliminary evidence does highlight the ability of ultrasound imaging to detect changes in acromiohumeral distance induced by improving poor posture, forward scapular position, and glenohumeral internal rotation range-of-motion deficits.

MUSCULOTENDINOUS CHARACTERISTICS

Recent techniques have been published quantifying muscle (1) thickness, (2) volume, (3) cross-sectional area, (4) fiber bundle length, (5) pennation angle, and (6) contractile density.\textsuperscript{27,46} While the evidence is generally limited, these emerging techniques offer the potential to impact clinical practice through repeated assessment of musculotendinous characteristics,\textsuperscript{27,46} muscle atrophy,\textsuperscript{27,48} and treatment effects over time.\textsuperscript{25,37,42} The following summarizes ultrasound techniques recently used to quantify the morphology and contractile characteristics of muscles within the shoulder girdle.

Muscle Thickness

Altered scapular movement patterns and muscle activation deficits are commonly observed in individuals with shoulder pain and dysfunction.\textsuperscript{12,50,51,55,58} As a consequence, strengthening of the scapulothoracic musculature is clinically recommended to improve scapular position and dynamic control of the shoulder complex during overhead movement.\textsuperscript{11,12,46,50} Recently, physical therapists have studied the ability of ultrasound imaging to reliably obtain measures of scapular muscle thickness for quantifying muscle integrity and providing preliminary evidence to support potential biofeedback applications.\textsuperscript{14,46,50-52} In particular, the evidence demonstrating the ability of ultrasound to assess scapular muscle thickness of the serratus anterior and lower and middle trapezius muscles is growing,\textsuperscript{4,14,46-52} with studies describing promising measurement techniques and reporting adequate clinimetric properties for clinical utilization.

The role of the serratus anterior in shoulder function has been well documented with electromyography\textsuperscript{25,29,44,52} and motion analysis.\textsuperscript{50,54} In general, participants with shoulder pain commonly display deficits in serratus anterior muscle activity compared to healthy individuals,\textsuperscript{14,50} which is thought to be clinically significant, as the serratus anterior is the only scapulothoracic muscle to contribute to each of the desired scapular movements during overhead elevation (upward rotation, posterior tilting, and external rotation).

The existing data reported by Day and Uhl\textsuperscript{14} and Talbott and Witt\textsuperscript{41,42} indicate that ultrasound imaging is able to detect differences in muscle thickness between resting and active states but not between active and resistive states, which implies a measurement limitation of this technique as a biofeedback tool. In light of these results and the paucity...
of evidence, ultrasound imaging is currently recommended for discrimination between resting and active states, not graded levels of serratus anterior muscle activation. This emphasizes the need for future work to investigate the utility of ultrasound imaging as a sensitive measure of muscle activation biofeedback. Furthermore, additional study is needed to examine the relationship between muscle thickness of the serratus anterior and function within various symptomatic populations.

By comparison, the published data are slightly more robust for the measurement of the lower trapezius muscle.\textsuperscript{14,66-68,90} Reports\textsuperscript{66-68} suggest an average ± SD resting thickness of approximately 3.1 ± 0.8 mm in healthy individuals, using measurement techniques that have good reliability (ICC\textsubscript{agg} = 0.96; standard error of the measurement, 0.20 mm)\textsuperscript{60} and fair validity compared to those made with MRI (r = 0.77),\textsuperscript{68} when measured 3 cm lateral to the edge of the T7-8 spinous process (FIGURE 3). However, to our knowledge, only one comparative study has investigated the difference in lower trapezius muscle thickness between healthy individuals and those with mild shoulder pain (an average score on the Disabilities of the Arm, Shoulder and Hand questionnaire of 12/100), with the results indicating no detectable differences between groups. We recommend that future investigations include further validation studies, for example, to compare MRI measurements in different patient populations, prior to applying these measurements in clinical practice.

Generally speaking, there are insufficient data to guide clinicians in the objective measurement of middle trapezius muscle characteristics, as Bentman et al.\textsuperscript{1} reported only moderate reliability (ICC\textsubscript{agg} = 0.67; standard error of the measurement, 1.0 mm) of muscle thickness measurements using ultrasound imaging. Considering these values, we recommend further research to develop a more reliable method of capturing middle trapezius muscle thickness. Furthermore, validation of these methods should be performed using cadaveric specimens, MRI, and/or CT.

Rotator Cuff Tendon Thickness
Prospective research indicates that asymptomatic individuals with a documented tendon tear have a high likelihood of becoming symptomatic.\textsuperscript{69} Physical therapists\textsuperscript{6} examined the use of ultrasound imaging to obtain normative measures of supraspinatus tendon thickness in a group of healthy college students and laborers (TABLES 1 and 2). These investigators reported an average supraspinatus tendon thickness of 6.6 mm, with an acceptable test-retest mean ± SD difference in measurements of 0.24 ± 0.37 mm when measured from the base of the greater tuberosity of the humeral head, where the tendon is clearly distinguished from the darker muscle belly by its classic bright-white appearance and fibrillar pattern (FIGURE 4).

In healthy individuals, side-to-side comparison of supraspinatus tendon thickness shows a negligible mean difference of 0.1 mm, suggesting that thickness asymmetry as measured with ultrasound is an abnormal finding.\textsuperscript{6} This contention was later supported by Joensen et al.,\textsuperscript{26} who reported that patients diagnosed with unilateral supraspinatus tendinopathy displayed greater tendon thickness on their symptomatic side. These authors\textsuperscript{36} also reported clinical findings of decreased muscle strength and palpable tenderness when supraspinatus tendon
thickness was more than 15% greater than the asymptomatic side (positive predictive value, 0.94). Considering these results, tendon thickness measured by ultrasound may be a useful clinical indicator of tendon integrity and/or staging of pathology. The serial tracking of tendon thickness throughout the course of therapeutic care may also provide additional insight into patient progress and prognosis. However, despite these promising relationships, ultrasound assessment of rotator cuff tendon thickness requires further evidence of measurement reliability and validity to support its clinical use (TABLE 2). We recommend that research further establish these clinimetric properties prior to performing longitudinal studies and the influence of these measurements on prognosis and clinical decision making.

Muscle Volume

Deltoid muscle performance is critical to shoulder function and can be compromised in the event of trauma or surgery. In some groups, as many as 42% of individuals with an episode of anterior shoulder dislocation sustain an axillary nerve injury that may result in marked deltoid muscle atrophy and decreased shoulder function.\(^6\) Deltoid muscle performance is also critical in the nonoperative management of individuals with full-thickness rotator cuff tears and postoperative outcome for candidates of reverse total shoulder arthroplasty.\(^7\) With these considerations in mind, measures of deltoid morphology may be valuable in determining a patient’s functional capacity.

Audenaert and colleagues\(^1\) studied the validity of ultrasound imaging to assess deltoid muscle volume in cadaveric samples by comparing ultrasound-derived measures to the values obtained with a fluid-displacement method (TABLE 2). By using the following formula to derive the muscle volume from measurements of length, height, and thickness, ultrasound imaging demonstrated high criterion validity (\(r = 0.98\)) with volumetric water displacement: volume = (length \times height)/2 \times thickness.

In vivo ultrasound imaging estimates of deltoid muscle volume were also shown to be strongly associated (\(r = 0.89, P<0.001\)) with isokinetic peak shoulder abduction torque, which may be related to functional performance.\(^1\) Despite these promising comparisons, this method presents practical challenges for clinical integration. Specifically, the length and width of the deltoid can be difficult to measure, as the field of view of most ultrasound imaging systems fails to capture each of these components in their entirety. An extended field-of-view function, which is rarely a standard feature on most commercial devices, is necessary to capture these morphologic characteristics without postprocessing software. To avoid this technical challenge, we recommend future investigation into the associations of deltoid muscle thickness with functional performance measures.

Rotator Cuff Muscle Atrophy and Cross-sectional Area

Rotator cuff atrophy is associated with chronic rotator cuff disease and poor shoulder function.\(^24,25,84\) In addition, significant atrophy is negatively associated with tendon reparability and positively associated with the size of supraspinatus tears.\(^19,72\) Due to these relationships, rehabilitation programs are often tailored...
to improve rotator cuff muscle strength and endurance. To assess the integrity of the rotator cuff and presence of muscle atrophy, ultrasound images are obtained in a manner similar to the scapular “Y” method previously established for CT and MRI (FIGURE 5A). With the suprascapular notch serving as a standardized landmark, images are obtained within the short axis of the supraspinatus muscle to visualize the contents of the supraspinal fossa. Occupation ratios are calculated using 2 ellipses, the first capturing all contents within the supraspinal fossa and the second capturing only the hypoechoic (dark) supraspinatus muscle (FIGURES 5B and 5C). These 2 images are used to estimate the relative proportion of muscle atrophy, with lower values indicating greater muscle atrophy. High correlations (r = 0.90) have been reported between ultrasound imaging and MRI measurements of atrophy of the supraspinatus (TABLE 2), providing preliminary evidence of measurement validity.

Similar imaging methods have been used to calculate cross-sectional area of the supraspinatus and infraspinatus muscles in healthy individuals. Supraspinatus cross-sectional area is estimated with the probe oriented perpendicular to the muscle’s line of action (short axis) at a standardized location centrally located between the medial border of the scapular spine and the lateral acromion. An ellipse is then drawn around the hypoechoic supraspinatus muscle to estimate the muscle’s cross-sectional area. Physical therapists investigating cross-sectional area have reported acceptable reliability (ICC = 0.98; standard error of the measurement, 0.26 mm²) with these methods (TABLE 1). While studies support the relationships between ultrasound and MRI for measuring rotator cuff atrophy, there are no existing studies confirming the relationships of ultrasound-derived measures to upper extremity function or prognosis. We therefore recommend that investigators examine the relationships between ultrasound measurement of muscle atrophy and functional performance in patients with rotator cuff disease.

The reliability of the measurement of infraspinatus cross-sectional area (TABLE 1) in a group of healthy overhead athletes was documented by Oyama and colleagues using 3 measurement points within a standardized template (FIGURES 6A and 6B). The authors also observed that changes in infraspinatus cross-sectional area occurred concurrently with a decrease in shoulder internal rotation and horizontal adduction range of motion over a 24-hour period following an eccentric rotator cuff-fatiguing protocol. The authors proposed mechanisms of increased vasodilation, cellular permeability, and inflammatory markers to explain the changes in cross-sectional area and losses in glenohumeral range of motion. Notwithstanding a lack of knowledge of the specific cellular mechanisms, this measurement may be of potential use in clarifying the influence of exercise on muscle cross-sectional area and shoulder range of motion. Specifically, cross-sectional area may provide a sensitive measure of potential tissue adaptations occurring with exercise/activity. Yet, prior to clinical implementation, future studies are needed to validate the measurement technique (TABLE 2), along with the temporal changes that occur following functional activity (ie, throwing or exercise).

**Fatty Infiltration**

Fatty infiltration is strongly related with rotator cuff atrophy and is considered to be an irreversible sequela of severe rotator cuff disease that is associated with poor surgical and functional outcomes. The measurement of fatty infiltration is determined by estimating the density of hyperechoic fibroadipose bundles invested between the perimysium of the muscle. By adapting Goutallier and colleagues’ original 4-part classification system of fatty infiltration, Strobel et al introduced a 3-part classification system to be used with ultrasound imaging, based on the relative density of tissue appearance. Ultrasound imaging of fatty infiltration is categorized by comparing the echogenicity and structural organization of the rotator cuff with the superficial deltoid and trapezius muscles. These muscles provide a gradient standard for the assessment and severity of fatty infiltration of the underlying rotator cuff. Qualitative echogenicity comparisons are classified as grade 0, isoechoic (normal); grade 1, mildly hyperechoic (mild infiltrate); or grade 2, markedly hyperechoic (marked infiltrate). Recent studies have reported high rater agreement (supraspinatus, \( \kappa = 0.76 \); infraspinatus, \( \kappa = 0.67 \) ) and sensitivity (13 of 15) of ultrasound when compared to assessment using MRI. Not surprisingly, rater agreement for this measure also appears to improve (\( \kappa > 0.83 \) ) when using dichotomized classification systems.
Fiber Bundle Length and Pennation Angle

In addition to quantifying gross muscle morphology, the assessment of intrinsic contractile tissue characteristics may provide valuable information, as these properties have been shown to directly influence muscle performance.46-47 The supraspinatus muscle serves as a unique example of this characteristic when considering its intrinsic tendon and contractile properties, thought to be responsible for withstanding multidirectional load demands.39 Researchers using conventional ultrasound imaging to perform morphologic study of the supraspinatus report that the muscle is not uniformly continuous and consists of anterior and posterior regions, which are further subdivided into superficial, middle, and deep portions.41 These investigations include descriptions of fiber bundle length and pennation angles, which may provide insight into the initiation and propagation of rotator cuff tears.

More recently, preliminary data derived from ultrasound studies have shown that individuals with supraspinatus tears have fiber bundle lengths and pennation angles that are significantly decreased in comparison to those of healthy controls.62 However, at this time, it is unknown whether fiber bundle length or pennation angle can be changed with either conservative or surgical therapeutic interventions. Future investigations should be performed to determine whether these associations are observable and to further clarify the role of tracking muscle fiber lengths and angles in informing clinical practice.

FUTURE CONSIDERATIONS

The use of ultrasound imaging holds the potential to help guide more targeted treatment and prevention interventions through the assessment of tissue characteristics. In turn, targeted treatment may lead to improved patient outcomes. Assessments of tissue morphology and muscle biofeedback are of particular interest for rehabilitation clinicians, as these techniques may be used to track temporal changes throughout the patient’s rehabilitation care.

The utilization of ultrasound imaging to measure muscle thickness as a form of biofeedback has proven to be an effective treatment strategy in individuals with low back pain35,71,83,89; however, there are no existing data to support this current application at the shoulder. Future studies are needed to determine the relationships of scapulothoracic muscle thickness with clinical examination findings and patient-reported outcomes, as well as the efficacy of biofeedback for the treatment of shoulder pain.

SUMMARY

Based on the current body of literature, it is likely that the impact of ultrasound imaging for the management of shoulder dysfunction has yet to be realized. There is growing evidence to support the continued development of techniques and applications of ultrasound imaging for potential integration into physical therapy practice. In general, while the current data are promising, more high-quality studies are needed to fully determine the potential of ultrasound imaging to help in the diagnosis, prognosis, and treatment of a variety of shoulder conditions.

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