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ORIGINAL ARTICLE

Study on the effects of arm abduction angle and cushion support during sonographic examination on the stiffness of supraspinatus muscle of sonographers using shear wave elastography

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Abstract

Objectives: The incidence of work-related musculoskeletal disorder remains high in sonography. The aims of this study are to determine the changes in muscle stiffness with different arm abduction angles, and to investigate the effect of cushion support on reducing muscle load in the supraspinatus when sonographers scan with the arm abducted to different angles.

Methods: This is a prospective crossover study. Twenty-three healthy female subjects aged between 20 and 23 years were included. Subjects were instructed to simulate performing standardized abdominal ultrasound scans. The changes in muscle stiffness of supraspinatus, measured as shear modulus, at rest and at 30°, 45°, and 60° arm abduction angles with and without cushion support were evaluated using shear-wave elastography. Styrofoam support was used for the cushion support.

Results: Mean shear moduli of supraspinatus were 27.77 ± 5.84 kPa at rest and 41.63 ± 7.09 kPa, 63.88 ± 14.43 kPa, and 89.76 ± 16.55 kPa for 30°, 45°, and 60° arm abduction respectively, which corresponds to 53%, 116% increase in muscle stiffness when scanning arm abducted from 30° to 45° and 60° ($p < .001$). After applying cushion support, shear moduli dropped to 24.04 ± 5.60 kPa, 31.98 ± 6.06 kPa, 37.47 ± 5.61 kPa for arm abducted to 30°, 45°, and 60° respectively ($p < .001$). The muscle stiffnesses between 30° abduction without support and 60° abduction with support had no significant difference ($p > .05$).

Conclusions: Muscle stiffness of supraspinatus increased with increasing arm abduction angle during ultrasound scanning. Utilizing cushion support underneath the arm was effective in reducing muscle stiffness in supraspinatus. Our results provide scientific justification on postural modifications for sonographers.

KEYWORDS
ergonomics, musculoskeletal diseases, occupational safety, ultrasonography

1 | INTRODUCTION

Work-related musculoskeletal disorders (WRMSD) are chronic problems that result from frequent usage of muscle and tendons without enough resting time. WRMSD has been reported in sonography in the 1980s.[1] However, the prevalence of WRMSD remains high despite ergonomic guidelines were established for sonographers.[2,3] Over 80% of the sonographers perform ultrasound scanning duty in pain as reported and the time from the start of employment to symptom onset is five years on average and as early as only six months.[3,4]

Shoulder injury presented in 84% of the reported cases and is the commonest injury with the most severe pain suffered.[4–6] The symptoms could range from itchiness, stiffness to sharp pain over the site of injury.[4] The primary driver of shoulder injury in sonography could be prolonged arm abduction throughout an examination and deprived rest time due to high workload.[4] Three mechanisms for shoulder injury were suggested by Village and Trask, including the mechanical compression of the supraspinatus tendon, reduced perfusion to rotator cuff muscle due to high intramuscular pressure (IMP), and damage in muscle fibers caused by muscle overload. Without adequate rest time, these microtears are difficult to be repaired and therefore accumulate into injury.[7] Physiologically, supraspinatus is responsible for nearly half of the shoulder torque produced during active arm abduction up to 90° and is the most vulnerable rotator cuff muscle in people working with repetitive arm abduction.[8,9]

Treatment of WRMSD for sonographers usually has a poor outcome because sonographers are exposed to the same hazard when returning to workplaces.[5] When sonographers are willing to perform scanning duty in pain, 20% of the reported cases end up with career-ending injuries.[10] Therefore, this issue not only affects sonographers themselves but also the healthcare system. It was found that years of experience was positively correlated with the prevalence of WRMSD and therefore, the field of sonography keeps losing the most experienced sonographers.[3] New and inexperienced sonographers may not be able to detect subtle pathology and eventually turn the price paid by the patients. Therefore, sufficient effort should be made to address this issue.

Resting and stretching during regular breaks are proved to be effective in the reduction of WRMSD.[11] Yet, sonographers face an increasing daily patient load and more lengthy scanning time per patient.[12] Coupled with existing labor shortage, it is hard to achieve sufficient rest time for sonographers and less than half of the sonographers could take two breaks per working day.[4,6] Therefore, while fatigue alleviation is less feasible, the focus of the present study is on the modification of ergonomics for sonographers to minimize muscle load so as to minimize exposure to WRMSD.

Sonographers are recommended not to abduct their arm over 30° during scanning in the existing guidelines.[2] However, a study revealed that sonographers abduct their arms more than the recommended angle in 67% of examination time and even exceed 45° in almost half of the examination time on average.[7] One underlying reason could be, as revealed by a survey in 2016, sonographers prioritized efficiency in obtaining high-quality images over a good working gesture.[13]

Although minimizing abduction of scanning arm could reduce exposure to WRMSD, factors including examination site, patients' size, and position of targeted organs also cause arm abduction unavoidable.[14] Therefore, apart from recommended shoulder abduction angles, more ways to eliminate the risk of WRMSD in the shoulder should be investigated.

To the best of our knowledge, most of the previous research addressing WRMSD in general focused on arm abduction in overhead work, in which the experiment design did not fit the job nature of sonographers. Research specific to sonographers has long been limited to surveys and observational studies with little effect in providing sufficient scientific proof of the mentioned risk factors and solutions in the guideline. A study by Murphey and Milkowski evaluating sonographic scanning posture has shown a significant reduction in muscle activity with the use of cushion support by using surface electromyography (EMG).[15] However, their study carries limitations. First, additional stress brought by the weight of the ultrasound probe and the downward force applied through the transducer, which is a unique risk factor of WRMSD in sonographers, were not taken into account.[16] Second, the effectiveness of arm support was only investigated for 30° arm abduction in their study. Third, surface EMG detected signals over the right suprascapular fossa not specific to supraspinatus and its accuracy was also challenged by other researchers because its signal could be interfered by many factors other than muscle activity.[17] In contrast, shear wave elastography (SWE) has a promising role in evaluating soft tissue elasticity in which acquired shear modulus information is co-registered with

B-mode ultrasound to provide anatomic specificity. It has also reported that SWE has excellent reliability and repeatability in studying muscle elasticity.[18] By using SWE, stiffness of supraspinatus could be acquired directly and analyzed individually. The muscle becomes stiffer when it contracts with higher force. To the best of our knowledge, no research studies have examined the stiffness of supraspinatus during active arm abduction by SWE.

To fill the knowledge gap, the aims of the present study are to demonstrate how arm abduction increases the stiffness of supraspinatus and to investigate the effectiveness of cushion support in reducing muscle load at three typical arm abduction angles using SWE. It was hypothesized that (1) muscle stiffness in supraspinatus increases with arm abduction angles when sonographers work with arm unsupported, and that (2) cushion support is able to reduce the muscle stiffness of supraspinatus caused by arm abduction. The clinical significance of this study is to demonstrate the importance of minimizing arm abduction angle and provide alternatives for sonographers to adopt for reducing risk to WRMSD.

2 | MATERIALS AND METHODS

2.1 | Subject recruitment

Ethical approval was obtained from the Human Subjects Ethics Sub-committee of the authors' institution, before the commencement of this research. All participants gave their written consent before the study. Twenty-five healthy females aged from 20 to 23 years (mean age = 20.3) were recruited in this study. All subjects are right-handed. The inclusion criteria were (1) young females aged between 18 and 30, (2) with normal clinical status. The exclusion criteria were (1) high body mass index (BMI ≥25),[19] and (2) with previous injuries or disease at and near their shoulder region. Basic demographic data of the subjects, including age, height, body weight, and physical activity were collected.

Subject recruitment was limited to young females to avoid the effect of confounding variables due to gender difference and age; most importantly, the difference in muscle composition between gender and the age-related dysfunction of the elastic fiber of the tissue.[20,21] The inclusion criteria would not significantly reduce the beneficiaries of our study because, first, around 85% of the sonographers are female. Second, the earliest time of symptom onset in sonographers is within the first year of their career with prevalence surged from 45% to 72% in the first three and ten years, respectively.[22]

2.2 | Experimental settings

This was a prospective crossover study to investigate the acute effect of arm abduction angles and cushion support on the stiffness of supraspinatus in sonographers. The experiment was conducted under the simulation of sonographer's scanning gestures (Figure 1).

Two independent variables, arm abduction angles and the use of cushion support, were included in the research. Arm abduction angles were set to three levels, 30°, 45°, and 60°, which are typical sonographer scanning positions.[7] For standardization of study protocol, participants' right side was examined. Measurements were taken with and without cushion support for each arm abduction angle.

Participants were asked to sit upright and grip an ultrasound transducer with their right hand. Except for baseline measurement, participants were instructed to flex their elbow at 90° horizontal to the floor and forearm pronated to simulate sonographer performing an abdominal ultrasound scan, which is the commonest requested ultrasound examination.[23] In addition, participants were instructed to give a downward force of 7.9 N through the ultrasound transducer, which is the mean force used to scan patients with normal BMI and is proved to be independent for job experience.[24] To maintain a constant downward force given through the ultrasound transducer, an electronic balance (SF-400, yousheng, Jiangxi, China) was placed underneath a plastic pillow inside a plastic bag to simulate the slippery surface of patient's body with ultrasound gel. Tasks were standardized to each participant by real-time monitoring of arm abduction angle with a digital protractor (DXL360, Walmeck, Yunnan, China) mounded to their arms. The acceptable range of sustained angle was ±3 as suggested by Palmerud's research.[25] Since the effect of forward flexion is not the focus of this study, participants were asked to keep their shoulders at coronal plane. Arm support used in this research was made by placing a polystyrene foam (22 cm (L) × 15 cm (W) × 7.2 cm(H)) underneath the elbow and the proximal part of forearm (Figure 1).

Arm abduction angles above 60° were not investigated in this study for several reasons. First, supraspinatus was found to be pushed further away from the skin surface and its SWE signals became very weak when trapezius contracted to a certain diameter at arm abduction angles above 60° in our trial. Second, it is not common for sonographers to abduct their arms above 60° owing to quick onset of fatigue.[14] Angles above 60° were therefore of less clinical interest in this study.

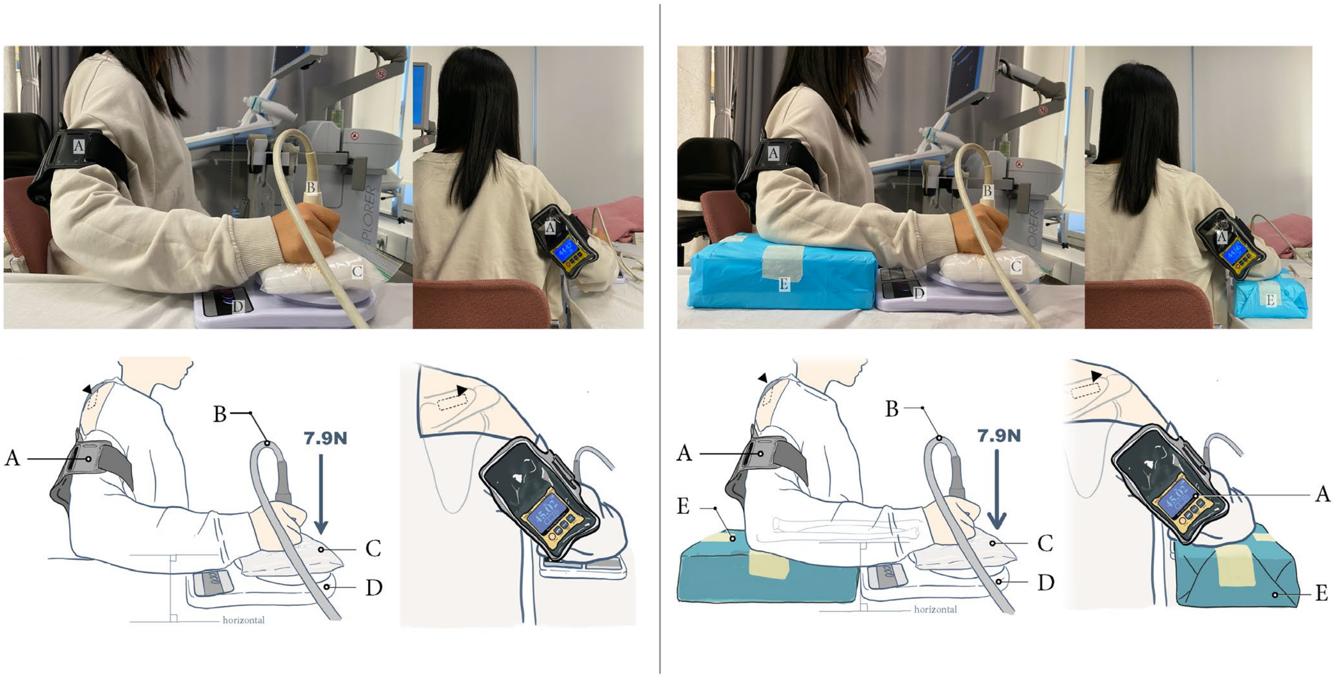

FIGURE 1 The experiment setup for simulation of sonographer's scanning gestures at 45° arm abduction with (right) and without (left) cushion support. ▼ in the diagram indicates the scanning site for data measurement. (A) Arm band with a digital protractor inside. (B) Abdominal ultrasound probe (not connected to the ultrasound system). (C) A small-sized pillow made with plastic bag. (D) An electronic balance to monitor constant downward force applied. (E) Cushion support made by polystyrene foam with blue sheet cover

2.3 | Ultrasound units and equipment

An Aixplorer ultrasound scanning system (SuperSonic Imagine, Aix- en-Provence, France) with a 4 to 15 MHz linear-array transducer was used to assess muscle stiffness by acquiring shear modulus in kilopascal (kPa).

2.4 | Data collection

The location of the scanning site was set to the center of the supraspinatus fossa for supraspinatus muscle belly. Supraspinatus was initially identified using B-mode ultrasound with the probe placed slightly superior to the scapular spine. The probe was then inclined to parallel with the muscle fiber, avoiding muscle anisotropic effect.[26] Supersonic shear imaging mode was activated using the musculoskeletal preset. As supraspinatus is inferior to trapezius, penetration mode was chosen to increase beam penetration power.

A shear wave elastography acquisition box of 1 cm × 1 cm indicating the region of interest (ROI) was placed next to the intramuscular tendon (Figure 2). Elastic muscle modulus measurements were taken after at least 10 s to attain steady measurement with the transducer placed with light pressure to avoid any deformation of the muscle thickness.[27] Within the acquisition box, two QBox™ with a diameter of 3 mm were used to take measurement. The areas that visually demonstrated maximum and minimum average elastic moduli were selected. QBox™ was kept slightly away from the boundary of the color signals to avoid counting no-signal areas in the measurement. The two values were then averaged into one single value.

Stiffnesses of the supraspinatus were measured with arm rest aside and in three arm abduction angles with and without cushion support. The location of the transducer was marked on the skin to ensure constant measuring site at different conditions, including (1) 30° arm abduction without support, (2) 30° arm abduction with support, (3) 45° arm abduction without support, (4) 45° arm abduction with support, (5) 60° arm abduction without support, and (6) 60° arm abduction with support. Participants were exposed to all six conditions in a random sequence. All measurements were performed by one trained investigator to avoid inter-observer variability.

Data were measured immediately after positioning before the onset of fatigue. Measurements were repeated three times for each test condition and separated by a one-minute rest to eliminate the accumulation of muscle fatigue.[28]

2.5 | Statistical analysis

Shapiro–Wilk test and Mauchly's test were used to test the normality and specificity of the data collected.

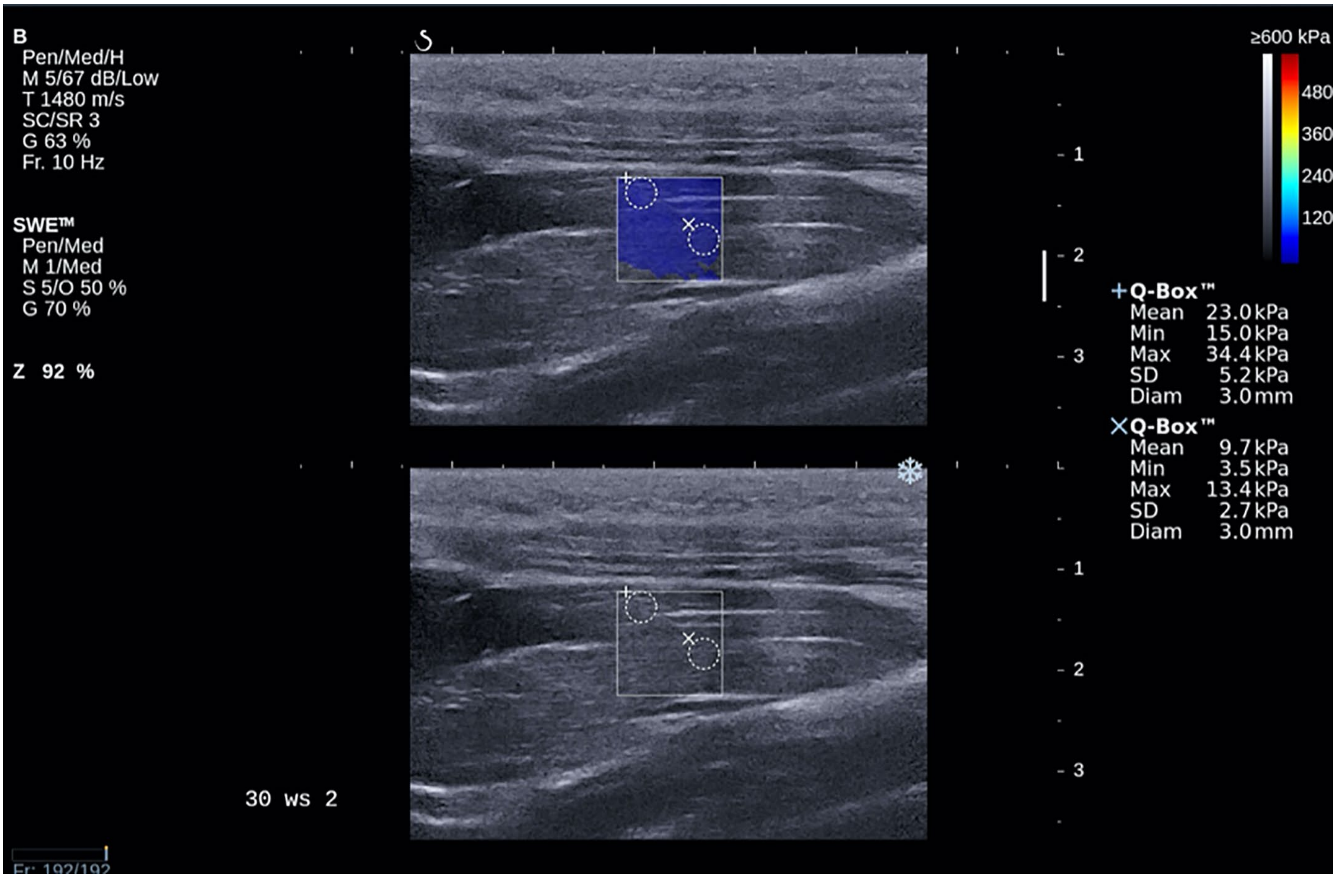

FIGURE 2 A shear wave elastogram of the right supraspinatus taken from one participant. The image shows a region of interest of 1 cm^2 with two Qbox™ of 3 mm put over the areas with maximum and minimum mean shear modulus measurement. Among different data listed on the right side of the image, mean shear modulus, which represent the averaged shear modulus within the 3 mm circle, was recorded for each Qbox™ measurement

Greenhouse–Geisser adjustments were made when the sphericity assumption was not met. The intraclass correlation coefficient ($ICC_{3,k}$) was used to test the intra-observer reliability for the three repeated measurements in each condition.

Two-way repeated measure ANOVA was performed to test the effects of arm abduction angles and cushion support on the stiffness of supraspinatus. When a significant interaction effect was identified between abduction angle and cushion support, multiple t-tests with Bonferroni correction were used to compare the effect of two variables. The alpha level was set at $p < .05$ throughout. All analyses were conducted using the Statistical Package of Social Science Software (SPSS) (IBM Corporation, Armonk, NY).

3 | RESULTS

Two participants who exhibited abnormal baseline measurement were excluded from the study, thus a total of 23 participants was included in the analysis.

$ICC_{3,k}$ among six sets of data ranged from 0.79 to 0.97, indicating good reliability. Mean shear moduli from three repeated measurements of all participants were averaged and expressed as mean ± standard deviation for each condition in Table 1. *p*-values for two-way repeated ANOVA test and post-hoc tests were summarized in Tables S1 and S2, respectively.

3.1 | Effect of arm abduction angles

The averaged shear modulus against arm abduction angles for all participants are shown in overall and individually in Figure 3A,B. Without cushion support, significant differences were noted between all three arm abduction angles ($p < .001$). The result showed a 54% and 116% increase in muscle stiffness in supraspinatus at 45° and 60° when compared with 30° abduction correspondingly. With the use of cushion support, a slight increase in stiffness in supraspinatus was noted with abduction angles but was not significant except for the comparison between 30° and 60° ($p < .001$).

3.2 | Effectiveness of the use of cushion support

Cushion support led to a significant decrease in the stiffness of supraspinatus at three abduction angles (Table 1). Figure 4A,B show the change in shear modulus measured before and after using cushion support. A similar trend is seen in all participants. The mean shear modulus after using cushion support dropped by 42%, 50%, and 58% for arm abducted to 30°, 45°, and 60°, respectively. The effect of cushion support was significant at all abduction angles tested ($p < .001$).

A significant ordinal interaction effect was found between arm abduction angles and cushion support ($F(1.362, 29.975) = 58.771, p < .001$) (Tables S1 and S2). In Figure 4A, cushion usage has the highest effectiveness in reducing muscle stiffness at 60° abduction.

4 | DISCUSSION

4.1 | Interpretation of findings

4.1.1 | Effect of arm abduction angles

To address the first hypothesis of the present study, our result shows that increased arm abduction angle during ultrasound scanning increases muscle stiffness of supraspinatus without using cushion support. This indicates higher muscle load in supraspinatus when sonographers perform ultrasound scan with their arm abducted to a larger angle.

While no existing reports measured active shear modulus of supraspinatus, our results are in good agreement with other research studying arm abduction by using other techniques. In Järvholm's research, IMP was measured

TABLE 1 Mean shear modulus (in kPa) measured at different arm positions and its percentage reduction achieved through the application of cushion support

Shear modulus (kPa) (Mean ± SD)				% of reduction in shear modulus after the use of cushion support
Rest	**Arm abduction angles**	**Without support**	**With support**	
27.77 ± 5.84	**30°**	41.63 ± 7.09	24.04 ± 5.60	42%
	45°	63.88 ± 14.43	31.98 ± 6.06	50%
	60°	89.76 ± 16.55	37.47 ± 5.61	58%

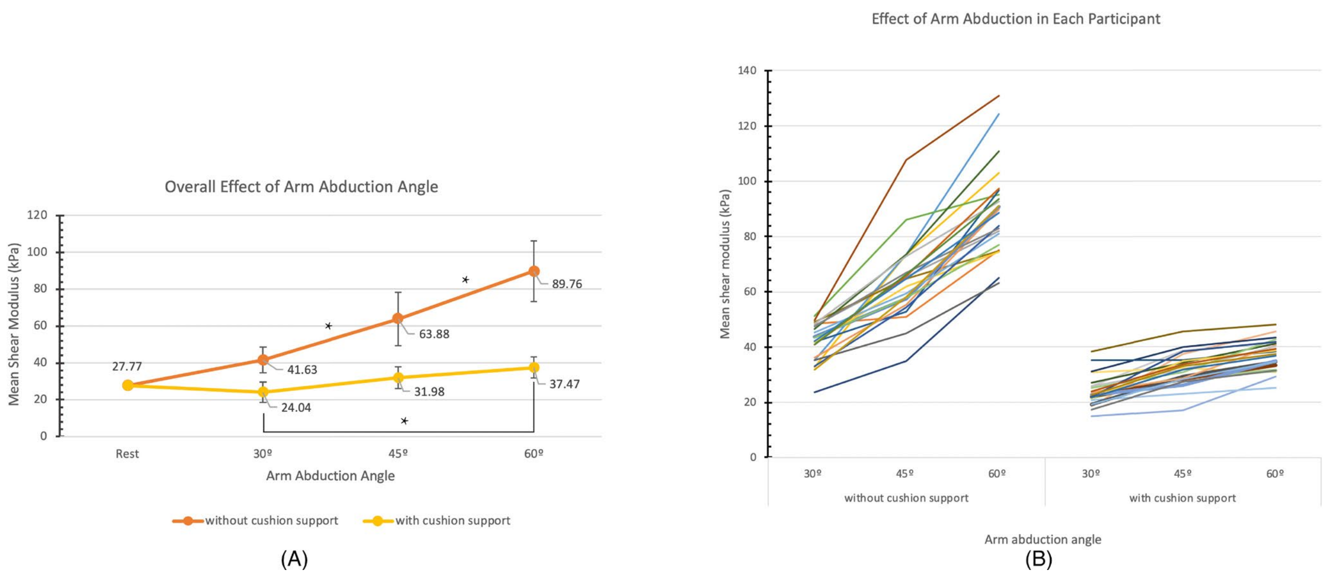

FIGURE 3 Line graphs show the effect of arm abduction on muscle stiffness of supraspinatus. (A) Overall mean shear modulus and standard deviation measured as at rest and during 30°, 45° and 60° arm abduction with (yellow line) and without cushion support (orange line). Error bars are the standard deviation of each tested condition. (B) Averaged shear modulus measured at 30°, 45°, and 60° arm abduction with and without cushion support in each participant. Each line represent data set of one participant in both conditions of cushion support. Asterisk indicates a significant difference between two settings

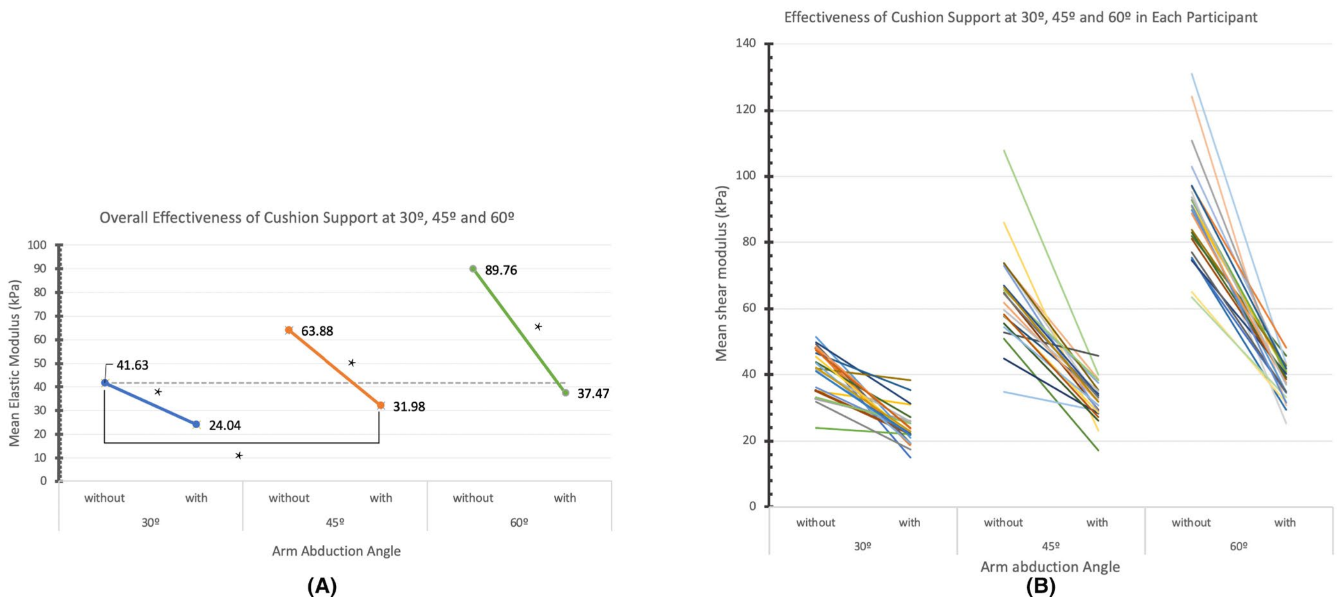

FIGURE 4 Line graphs show the effectiveness of cushion support at 30°, 45°, and 60° arm abductions. (A) Overall result with grey dash line representing shear modulus measured at recommended arm position (30°) in the existing guideline for sonographers (B) separated lines for individual participants. Asterisk indicates a significant difference between two settings

continuously from 0° to 90° arm abduction with a catheter inserted into the supraspinatus, and a constant increase in IMP was shown between 30° and 90° arm abduction.[8] IMP reveals muscle mechanical properties by muscle shortening and was found to correlate to shear modulus.[29] Similar results were also found in other studies.[30,31] In Murphey and Milkowski's research, the muscular activities of rotator cuff muscles were compared between 30° and 75° arm abduction during ultrasound scanning by using surface EMG. Reducing arm abduction angle from 75° to 30° as recommended was shown to result in a 46% reduction in muscle activity.[15] The reduced muscle activity can help to minimize muscle fatigue.

In our study, a comparable result was found with a 54% reduction in muscle stiffness when arm abduction changed from 60° to 30°. This could be explained by the role of supraspinatus as a supporter and stabilizer the arm during abduction. To exert its functions, supraspinatus sits and runs along the supraspinatus fossa with its tendon extends laterally and inserts down to the greater tuberosity of the humerus. Supraspinatus accounts for half of the shoulder torque present at the glenohumeral (GH) joint from 0° to 90°.[8] The role of supraspinatus as a first-class lever during ultrasound scanning with arm abducted is demonstrated in Figure 5.[32] When the scanning arm is abducted away from the body trunk with the elbow flexed, the moment arm of the force system increases. This generates a greater shoulder torque that requires higher muscle force from supraspinatus to hold the arm position. Moreover, supraspinatus also acts to stabilize the humeral head at GH joint against

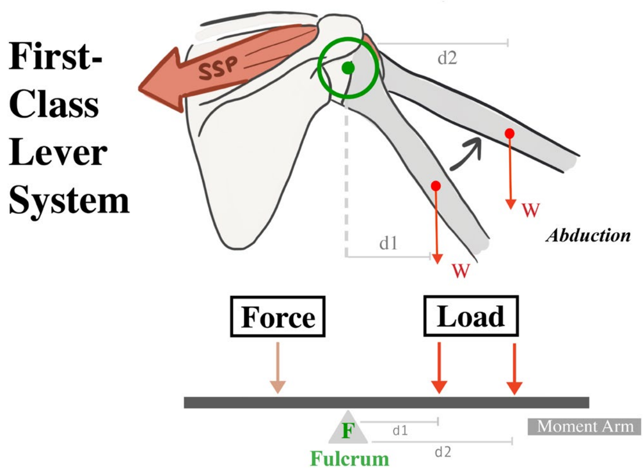

FIGURE 5 First-class lever system of supraspinatus with arm abduction. Moment arm increases with arm abduction angles, leading to larger shoulder torque at the GH joint. In first-class level system, fulcrum is placed in between the load and force where, Force = muscle force produced by supraspinatus contraction; Fulcrum = the GH joint; Load = weight of abducted arm and transducer; Moment arm (d1, d2) = perpendicular distance from axis to the line of action of force which increase with arm abduction

the pull of gravity and as an antagonist to neutralize the dislocating effect brought by activation of other muscles.[33,34] The downward force applied during ultrasound scanning is mainly contributed by triceps for extension of elbow, together with latissimus dorsi (LD) and pectoralis major (PM) for internal rotation of the shoulder.

Supraspinatus forms antagonistic relationships with LD and PM during shoulder internal rotation.[34,35] The downward force applied at a larger abduction angle involves more action from internal rotation. This results in a higher ratio of LD and PM in force-generation, causing additive muscle load to supraspinatus.

When sonographers keep their arm abducted during scanning, their supraspinatus is performing isometric contraction. This type of muscle contraction was reported to cause higher IMP than concentric contraction.[36] Histologically, muscle fiber can be subdivided into myofibril. Sarcomere is the contractile unit of myofibril running longitudinally one another. It consists of contractive proteins that overlap when activated to form cross-bridges for contraction.[37] Since cross-bridge has a spring-like property, its formation contributes to active muscle stiffness.[38] Based on this mechanism, larger arm abduction angle requires stronger shoulder muscle contraction to compensate the greater shoulder torque generated at the GH joint. More cross-bridges are therefore formed in the supraspinatus which increases muscle stiffness.

Despite the mild difference in angle selection between studies, the slight difference in stiffness reduction could also be attributed to different techniques and experiment setting used. SWE used in our study was found to be more sensitive than surface EMG in detecting muscle tension.[22] SWE is also superior in anatomical specificity without involving signals from other neighboring muscles that were also recruited in arm abduction. Besides, the role of supraspinatus in performing downward maneuver was not considered in their study. These, all together, led to lower muscle contraction intensity required in their setting and thus the effect of arm abduction was slightly underestimated.

When possible, sonographers are recommended to minimize arm abduction during work. This could be achieved by instructing patient to lie closer to the sonographer. For patients with larger body size, elevating the chair or lowering the examination couch could help. However, rearranging patient position and equipment to create a good ergonomic scanning might not always be possible and is highly dependent on the availability of adjustable equipment in the scanning site, especially during bedside scanning.[15] Patients' poor health conditions might cause difficulties in repositioning them. Therefore, this study also investigated the effectiveness of cushion support in reducing stiffness of the supraspinatus during scanning.

4.1.2 | Effectiveness of the use of cushion support

Our research shows a significant reduction in muscle stiffness at all arm abduction angles tested when cushion support is used. When the scanning arm is supported, supraspinatus is recruited less to support the entire weight of the abducted arm and the transducer. Thus, using cushion support could effectively reduce the muscle load to the supraspinatus added by arm abduction.

For the reduction in muscle stiffness after using cushion support at 30° arm abduction, our result aligned with Murphey and Milkowski's research, yet, with difference in percentage reduction between studies.[15] In their research, the use of cushion support at 30° arm abduction led to a 78% decrease in muscle activity measured by EMG. In the present study, similar trend was seen but only a drop of 42% in muscle stiffness was measured after the use of cushion support. This difference suggests the effect of downward transducer compression maneuver during ultrasound scanning on supraspinatus should not be neglected. The higher the arm is abducted, the greater the required counteracting force from supraspinatus. It is believed that cushion support has a limited effect in reducing the required counteracting force which explains the slight increase in muscle stiffness with enhancing arm abduction angles even when the scanning arm was supported (Figure 3).

Considering our second hypothesis, the drop in the shear modulus measured after using cushion support for all arm abduction angles in the present study was able to show a significant effect of cushion support on reduction in muscle stiffness when the scanning arm was abducted to a higher level (Figure 4). For arm abduction angles of 30° and 45°, our result showed that muscle stiffness measured with cushion support is significantly lower than that of the recommended position (30° arm abduction) without cushion support. For 60° arm abduction, utilizing cushion support leads to 58% reduction in muscle stiffness. The resulting mean muscle stiffness measured (37.47 kPa) was comparable to that measured at the recommended position of 30° arm abduction (41.63 kPa) with no significant difference found ($p = 1.00$). We believed that using cushion support at 60° arm abduction is equivalent to keeping arm abduction at 30° but unsupported.

To summarize, our study showed the effectiveness of cushion support in reducing muscle stiffness when scanning with arm abducted between 30° and 60°. Therefore, cushion support could act as an alternative when arm abduction is unavoidable. Support used in our research could also be modified into a vertical arm support as suggested in Coffin's research, which has greater flexibility to increase the possibility of using arm support during ultrasound scanning.[5]

While the use of cushion support was found to be helpful in reducing supraspinatus stiffness and potentially minimizing WRMSD, sonographers should still be reminded not to abduct their scanning arm over 60° even with cushion support. As suggested by Village and Trask, impingement of the supraspinatus tendon between the greater tuberosity and the glenoid rim happens when arm abduction exceeds 60°.[7] This triggers another mechanism of shoulder injury in which mechanical compression impairs perfusion to the tendon, causing tendon degenerative changes even muscle load is reduced.[7]

Lower muscle stiffness was revealed in supraspinatus at 30° with cushion support than that with arm rest aside. Yet, this result did not attribute to the muscle contraction. Supraspinatus' insertion onto the greater tubercle of humerus makes it run inferiorly when arm is resting against the body trunk. Based on previous research, supraspinatus has its own length-tension property and its tendon is pulled when the arm is at rest. Passive muscle stiffness develops when supraspinatus is elongated and was demonstrated to decrease with arm abduction in supraspinatus in the study done on cadaveric shoulders.[39] However, the effect of passive stiffness was masked by the involvement of active contraction at higher angles in our study.

4.2 | Limitations and recommendations

There were limitations in our study. Participants in this study were all young, sthenic to hypostenic (mean BMI = 19.3) females. The penetration of SWE is limited to a certain depth and highly influenced by the presence of subcutaneous fat. The result may not be applicable to sonographers who are senior or male, or with different body size. To avoid lengthy sessions per participant, the acute effect of isometric arm abduction, instead of induced muscle stiffness after prolonged isometric contraction, was investigated.

Although the main beneficiary of this study accounts for a large percent of the sonographers, extended study including subjects from both genders and from different age groups are recommended. In addition, to have better simulation, prolonged sustained arm abduction should be considered to demonstrate the muscle stiffness induced by isometric contraction at different arm positions.

4.3 | Clinical applications

Up to date, the assessments of the WRMSD in sonographers have been primarily focusing on the survey and qualitative research. However, identifying salient risk factors is also an important step for developing effective ergonomic training for sonographers. While existing research is rich enough to tell the urgency for immediate response, our result could provide scientific evidence of the risk factors and perform educational implication. We also investigated the effectiveness of cushion support in compensating the effect of arm abduction which could serve as an alternative way to reduce the risk of WRMSD in sonographers.

4.4 | Conclusion

In conclusion, this study showed a significant increase in supraspinatus stiffness when sonographers abduct their arm from 30°, 45°, and 60° during ultrasound examination. Our result showed a significant reduction in supraspinatus stiffness when the scanning arm is supported at all arm abduction angles tested. The largest reduction percentage was 58% at 60° arm abduction angles, leading to measured supraspinatus stiffness even lower than that measured at the recommended 30° abduction with the scanning arm unsupported. These results provide scientific justification on postural modifications for sonographers.

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AUTHOR CONTRIBUTIONS

WKY, LMW, LMH, CCH, MSH, NCH, and YTCM conceived the research idea and design. WKY, LMH, LMW, CCH, and NCF collected the data. CCH and MSH analyzed the data. WKY, LMW, and LMH drafted and revised the manuscript. YTCM critically reviewed the important intellectual content of the manuscript, and approved the final version of the manuscript.

DISCLOSURE

Approval of the research protocol: This study was approved by the Human Subjects Ethics Sub-committee of the Hong Kong Polytechnic University.

Informed Consent: We explained the study protocol to participants and obtained their written consent.

Registry and the Registration No. of the study/trial: N/A.

Animal Studies: N/A.

Conflict of Interest: The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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