Comparison of ultrasound with electrodiagnosis of scapular winging: A prospective case control study

Sara Silkjær Bak a, Birger Johnsen a,b, Anders Fuglsang-Frederiksen a,b, Kaj Døssing c, Erisela Qerama a,b,*

a Department of Clinical Neurophysiology, Aarhus University Hospital, Palle Juul-Jensens Boulevard 16, Plan 2, J209, DK-8200 Aarhus N, Denmark
b Department of Clinical Medicine, Aarhus University Hospital, Palle Juul-Jensens Boulevard 82, Incuba/Skejby, Building 2, DK-8200 Aarhus N, Denmark
c Department of Orthopaedics, Viborg Regional Hospital, Heibergs Alle 4F Indgang F, Etage 3, 8800 Viborg, Denmark

Article info

Article history:
Accepted 28 September 2021
Available online 29 October 2021

Keywords:
Scapulae alatae
Scapular winging
Long thoracic nerve
Serratus anterior muscle
Brachial plexus
Spinal accessory nerve

Abstract

Objective: Compare high-resolution ultrasound (HRUS) and electrodiagnostic examination (EDX) in the diagnostic workup of patients with scapulae alatae.

Methods: 27 patients with scapulae alatae and 41 healthy subjects (HS) and underwent a standardized clinical examination (CEX), EDX and HRUS. We measured the thickness of the serratus anterior (SER), rhomboid major and trapezius muscles and the diameter of the long thoracic (LTN), dorsal scapular and spinal accessory nerves (SAN).

Results: Twenty patients showed medial winging and six patients showed lateral winging on CEX. One patient had both lateral and medial winging. In patients with medial winging, the SER muscle was thinner and the LTN diameter was larger on the symptomatic side compared with the asymptomatic side and with the dominant side in HS. In this group, both EDX and HRUS detected abnormalities of SER muscle/LTN with sensitivity of 65%, and with specificity of 100% and 57%, respectively. EDX and HRUS detected abnormalities of the trapezius muscle/SAN with sensitivity of 60% and 40%, and specificity of 91%, and 86% respectively. There was no significant difference between the two methods.

Conclusion: HRUS can contribute to the diagnostic workup of scapulae alatae by demonstrating atrophy of muscles and enlargement in nerve diameter.

Significance: HRUS supplements EDX in the diagnostic workup of scapulae alatae.

2021 International Federation of Clinical Neurophysiology. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

Scapulae alatae is an underreported and rare disorder, that leads to pain, reduced range of motion, with emotional and sometimes social consequences for the patients (Srikumaran et al., 2014; Tibaek and Gadsboell, 2015). It is caused by neuromuscular disturbance in the scapulothoracic stabilizer muscles; the most important are the serratus anterior muscle innervated by the long thoracic nerve (LTN), the rhomboid muscle innervated by the dorsal scapular nerve and the trapezius muscle innervated by the spinal accessory nerve.

Studies have found variable incidences. One study reported ten cases of serratus anterior muscle paresis from 20 orthopaedist practices in the University of Pennsylvania over a three- year period, but the article could not uncover the true incidence since the total number of patients was not presented (Gregg et al., 1979). Another study found 15 cases of isolated serratus anterior muscle

Abbreviations: BMI, Body mass index; CEX, Clinical examination; CI, Confidence interval; CT, Computer tomography; EDX, Electrodiagnostic examination; EMC, Electromyography; LTN, Long thoracic nerve; DSN, Dorsal scapular nerve; SAN, Serratus anterior nerve; SER, Serratus anterior muscle; MRI, Magnetic resonance imaging; NCS, Nerve conducting studies; HRUS, High – resolution ultrasound.

Corresponding author.

E-mail address: Erismont@rm.dk (E. Qerama).

https://doi.org/10.1016/j.clinph.2021.09.021
1388-2457/ © 2021 International Federation of Clinical Neurophysiology. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).
paresis in 7000 patients from their electromyographical laboratory (Fardin et al., 1978). The true incidence of scapulae alatae is, however, unknown and is likely to be higher than described in the literature as it is often unrecognised or misdiagnosed (Gregg et al., 1979; Srikumaran et al., 2014; Warner and Navarro, 1998). The Harvard Shoulder Service diagnosed fourteen patients with a winged scapula in a period of three years; previously eight of these patients had been misdiagnosed resulting in unnecessary treatments and operations (Warner and Navarro, 1998).

Long thoracic neuropathy and serratus anterior muscle paresis causes scapulae alatae with medial winging and can be either trauma-induced (Foo and Swann, 1983; Galano et al., 2008; Gregg et al., 1979) or due to inflammation (Bischel et al., 2008; Foo and Swann, 1983; Goodman et al., 1975; Sivan and Hassan, 2009; Van Eijk et al., 2016). In Seror et al., 2018 they found that 61 of 70 cases of scapulae alatae due to long thoracic nerve damage were diagnosed as a part of neuralgic amyotrophy (Seror et al., 2018). Dorsal scapular neuropathy causes lateral winging and the aetiology can be idiopathic, after heavy lifting above the head or merely repetitive overhead activities (Akgun et al., 2008; Sultan and Younis El-Tantawi, 2013), after dislocation of the shoulder (Jerosch et al., 1996), and as a complication to bracing scoliosis (Debeer et al., 2007). Spinal accessory neuropathy also causes lateral winging, and it is frequently caused by lymph node biopsies or neck surgery. Furthermore, it can have idiopathic aetiology, or be due to neuralgic amyotrophy or trauma. (Bigliani et al., 1996; Hammond and Danza, 1981; Seror et al., 2018; Teboul et al., 2004; Williams et al., 1996).

Scapulae alatae is often underdiagnosed or misdiagnosed (Srikumaran et al., 2014) and the diagnostic work-up of these patients can be difficult. Evaluation of the patients involves the collection of medical history, a thorough clinical examination (CEX), and an electrodiagnostic examination (EDX) such as nerve conduction studies (NCS) and electromyography (EMG) (Petrera and Trojaborg, 1984). Imaging such as radiographs, magnetic resonance imaging (MRI) or computer tomography (CT) may, in some cases, be useful in diagnosing scapulae alatae (Mohsen et al., 2006; Nguyen et al., 2016; Orth et al., 2012).

Patient cases where high resolution ultrasound (HRUS) has been used to visualise an atrophied muscle and an enlarged nerve have been described in the literature (Bodner et al., 2002; Coraci et al., 2016; Lieba-Samal et al., 2015; Lucchetta et al., 2014; Seok et al., 2014). In this regard, HRUS compared to CT and MRI has numerous advantages being fast, cost-effective, non-invasive and an easily accessible tool in the clinic. In a study from 2013, HRUS shows higher sensitivity and equivalent specificity compared to MRI in patients with mononeuropathies and brachial plexopathies (Zaidman et al., 2013).

Another advantage of HRUS is that it allows for guided EMG, where the examiner can visualize the needle when inserting it in the muscle. This ensures the correct placement of the needle in the muscle, may prevent inflicting damage on vessels and nerve structures and prevent causing pneumothorax (Kassardjian et al., 2016).

In this study we aimed to examine whether high resolution ultrasound (HRUS) can contribute in the diagnostic workup of scapulae alatae patients by measuring the thickness of the serratus anterior, rhomboid major and trapezius muscles and the diameter of the long thoracic nerve, dorsal scapular and spinal accessory nerves. Moreover, we wanted to correlate these HRUS findings with the EDX results.

2. Methods

2.1. Study design

The study was designed as a prospective and controlled study. The regional Committee on Biomedical research Ethics and the Danish Data Protection Agency granted permissions for the study. The study follows the guidelines on reporting results in diagnostic neuromuscular ultrasound (Hobson-Webb and Boon, 2013). For randomisation the website www.random.org and the app Randomizer+ (Jester Dev) was used.

2.2. Subjects

All subjects received written and oral information and signed a consent statement.

We invited 38 consecutive patients referred with a diagnosis of scapulae alatae to the Department of Neurophysiology, Aarhus University Hospital, Denmark between April 2018 and January 2019. Inclusion criteria were age 18 or older, clinical suspicion of scapulae alatae, and the ability to speak Danish. Patients with known myopathy (e.g. fascioscapulohumeral muscle dystrophy) or patients who were diagnosed with myopathy in the diagnostic workup were excluded. Other exclusion criteria were known acute mental illness or drug abuse. Twenty-seven patients were included (Fig. 1).

Forty-two healthy subjects who were at least 18 years old and able to speak Danish were recruited by http://www.forsoegsperson.dk/, by advertisement on Aarhus University and by advertisement on different departments of Aarhus University Hospital. We excluded one subject due to a diagnosis of rotator cuff syndrome; thus we included 41 healthy subjects in the study. Further details of this group are described elsewhere (Silkjær Bak et al., 2021).

2.3. Examinations

All patients went through an HRUS examination bilaterally followed by a standardized clinical examination (CEX) and a neurological examination, a collection of medical history, and an electrodiagnostic examination (EDX) of the symptomatic side. All healthy subjects went through an HRUS examination bilaterally and collection of general information. We performed EDX only patients, thus blinding was not possible. However, the EDX examiner studied all three muscles, regardless of the direction of the scapular winging. The HRUS examiner was aware of the subject status (patient vs healthy) when performing the US scan. Nevertheless, the HRUS examiner was unaware whether the patient had a lateral or medial winging and therefore did not know which muscle was most likely to be affected.

Lastly, when HRUS quantitative measurements on muscles and nerves were made, the examiner was blinded to patient vs healthy subject status as the images were anonymized and randomized.

2.3.1. CEX

We performed a standardized CEX prior to the EDX in order to establish a tentative clinical diagnosis of the scapulae alatae, which was used as a reference standard (Cohen et al., 2016). The CEX contained a static and a dynamic evaluation and the findings were plotted in a standardised form (Fig. 2). Based on a literature search (Lee et al., 2015; Martin and Fish, 2008; Meiningher et al., 2011) and expert opinion, we defined main and secondary criteria a priori for both a static and a dynamic examination. First, we performed a static examination with inspection of the scapula and the shoulder. We looked for lateral or medial displacement of the scapula and displacement upwards or downwards both for the shoulder and the scapula. Moreover, atrophy or hypertrophy was assessed. Then we performed a dynamic examination which included bilateral arm abduction, lowering the arms from forward position, resisted active external rotation and push-up against a wall. For these examinations we looked for accentuation of the winging. More-
**Fig. 1.** Flowchart of the recruitment and diagnostic work-up of the patients. SER: the serratus anterior muscle, TRAP: the trapezius muscle, RHOMB: the rhomboid major muscle, LTN: the long thoracic nerve, SAN: the spinal accessory nerve, CEX: clinical examination, EDX: electrodiagnostic examination. Flowchart for all patients referred with scapulae alatae. The upper section shows the included and excluded patients, the mid-section shows the distribution according to the CEX and the lower section shows the distribution according to the EDX. In the TRAP patient group 3 out of five patients would have been categorised as RHOMB patients as well, though this group was not included in the study.

**Fig. 2.** Instruction for the clinical examination of scapulae alatae patients. S: Serratus anterior muscle, T: Trapezius muscle, R: Rhomboid muscle. Table 1 involves two anatomical structures: the scapula and the shoulder. If the scapula was displaced laterally on the affected side the placement of the inferior angle of scapula compared to the superior angle of scapula was assessed as well. Table 2 involves hypertrophy and atrophy of different muscles. Table 3 involves 6 different examinations. The examiners looked at whether the winging was apparent during the respective examinations. Furthermore, the examiner ensured to note whether the winging appearing during the examination matched with winging due to serratus anterior muscle affection, trapezius muscle affection or rhomboid muscle affection.
over, difficulty in elevating the shoulders were noted as a sign of trapezius muscle affection.

Patients were classified in the specific groups (Fig. 1) when one main criterion and one secondary criterion of a given muscle were fulfilled. For example, a patient was classified to be in the group with serratus anterior muscle affection if he/she had a medial winging during static examination (main criterion) and upwards scapular displacement (secondary criterion). Likewise, a patient was classified to be in the group with trapezius muscle affection if he/she had lateral winging of the scapula during static examination (main criterion) and downwards scapular displacement (secondary criterion).

Furthermore, a neurological examination of the upper extremities was performed, including an assessment of sensory and motor function and examination of reflexes.

2.3.2. EDX

The EDX included NCS and EMG. We performed EDX with the Keypoint EMG-system version 2.33 (previously Medtronic, Skovlunde, now Alpine, Denmark). Two certified neurophysiologists (EQ, BJ) performed the examination using a standardized strategy. Shortly, the examination included EMG of the serratus anterior muscle, the rhomboid major muscle and all three parts of the trapezius muscle. We performed the NCS of the long thoracic nerve by stimulation at Erb’s point and the spinal accessory nerve by stimulation at regio collí lateralis and according to the department’s routine methods. NCS of the dorsal scapular nerve was not performed, since it was not part of the department’s routine methods and no normative data was available. EMG included recording of spontaneous activity at different locations for a period of up to 60 seconds per location and semiquantitative interference pattern analysis at maximal effort. For the serratus anterior muscle, the rhomboid major muscle and the middle and lower parts of the trapezius muscle the EMG needle placement was HRUS-guided.

For further examination of the brachial plexus the strategy followed the guidelines of the Danish Society of Clinical Neurophysiology, www.dskn.dk, developed by the Danish National Consensus Group (Fuglsang-Frederiksen and Pugdahl, 2011) including examination of sensory and motor nerves of the symptomatic part and a part of the brachial plexus adjacent to that. This included sensory and motor function of the median and ulnar nerve and motor function of the axillary nerve by stimulating at Erb’s point. We performed a quantitative analysis of the motor unit potentials in m. deltoideus of the symptomatic side by applying the technique described by Buchthal (Buchthal and Pinelli, 1953).

EDX was considered abnormal when minimum one abnormal finding (denervation activity in a muscle, prolonged distal motor latency of a nerve or chronic neurogenic findings of the EMG) was recorded.

2.3.3. HRUS examination

HRUS was performed with a Siemens ACUSON 1000 ultrasound machine with a high-frequency linear array transducer (18L6HD, 5 cm). The HRUS examination was done according to the protocol described in detail elsewhere (Silkjaer Bak et al., 2021). Shortly, the HRUS examination of muscles included bilateral images of the upper, mid, and inferior part of the trapezius muscle and the rhomboid major muscle with the probe placed medial to the scapula. For the first image of the upper trapezius muscle, the probe was placed between C7 and acromion in an oblique position. Hereafter, the probe was placed horizontally right below the spine of the scapulae for the image of the middle trapezius muscle and the rhomboid major muscle. For the image of the lower trapezius muscle, probe placement was next to the spinal column, with the lateral edge of the transverse process in the picture, in level with the inferior angle of the scapula.

The serratus anterior muscle was measured at three different levels right behind the post axillary line: with the second, third and fourth rib respectively from the armpit shown in cross section in the image. The HRUS examination of the nerves included bilateral images of the long thoracic nerve in three sites, the dorsal scapular nerve in one site, and the spinal accessory nerve in one site. For the long thoracic nerve, in the first site it was lying in or under the middle scalene muscle, for the second site, it was lying above the scalene musculature, and for the last site, it was running behind and hereafter lateral to the suprascapular nerve, above the scapular musculature and under the omohyoid muscle. The image of the DSN was with the nerve lying in the middle scalene muscle. The image of the spinal accessory nerve was taken in the posterior triangle on the neck, after it passes under or through the two heads of the sternocleidomastoid muscle and before it runs in or under the trapezius muscle.

HRUS was considered abnormal when minimum one of the measurements of muscle thickness was below the lower limit of the normative data or one of HRUS measurements of nerve diameter was above the upper limit of the normative data (Silkjaer Bak et al., 2021).

2.4. Data analysis

We used STATA 15.1 to perform statistical analysis. Mean ± 1.96 standard deviations were calculated for continuous data. Unpaired t-test with equal or unequal variance was used for group comparisons. Chi2 or Fisher’s exact test was used for more than two group comparisons. Bland-Altman plots (paired data) and SD-tests (unpaired data) were used for assumptions of normal distribution. The muscle data was analysed in a log-transformed form when a correlation was seen between the difference and the average in the Bland-Altman plots. The results were back-transformed and presented in their geometric form. When back-transforming a difference, the data are presented in ratios.

As a results, nerve diameter data is presented as differences between sides and muscle thickness data is presented as ratios between sides. A two-tailed p-value of < 0.05 was considered significant. Normal material for the ratio of muscle thickness between sides, difference in nerve diameter between sides and for linear multiple regressions for muscle thickness and nerve diameter taking into account age, sex, weight, height and hand dominance have been calculated using the 41 healthy subjects (82 sides). This is presented elsewhere (Silkjaer Bak et al., 2021).

For specificity and sensitivity, confidence intervals (CI), has been calculated using the website: https://www.medcalc.org/calc/diagnostic_test.php. A McNemar’s test was used to test difference in sensitivities and specificities.

3. Results

3.1. Demographics

Comparison of demographics between all patients and healthy subjects, and between patient subgroups and healthy subjects were performed (Table 1). No differences were found for sex, age, body mass index (BMI), height or weight.

3.2. CEX

Of 27 patients, 20 patients showed medial winging and six patients showed lateral winging on the static and/or the dynamic examination. Furthermore, one patient had lateral winging on the static examination but medial winging on the dynamic examination.

During static examination eight patients (30%) did not have a visible winging and they were classified using the dynamic exam-
The symptomatic side was significantly thinner than on the asymptomatic side at all three sites (Table 2). The thickness of the serratus anterior muscle on the symptomatic side of the patients was significantly larger than on the asymptomatic side at all three sites (Table 2).

The thickness of the serratus anterior muscle on the symptomatic side of the patients was significantly smaller than on the dominant side of the healthy subjects at the upper (p-value: 0.01), mid (p-value: 0.02) and lower level (p-value: 0.00) of the muscle (Fig. 3A). The diameter of the long thoracic nerve in the symptomatic side of the patients was significantly larger than the diameter on the dominant side of the healthy subjects at all three levels (LTN1 site (p-value: 0.03), LTN2 site (p-value: 0.03) and the LTN3 site (p-value: 0.01) (Fig. 3B).

The serratus anterior muscle thickness ratio between the asymptomatic and the symptomatic side in patients was larger than the ratio between the non-dominant and the dominant side in healthy subjects, both for the upper level (p-value: 0.01) and for the lower level (p-value: 0.00) of the serratus anterior muscle. No significant difference was found for the mid-level of the muscle (p-value: 0.051).

The difference in long thoracic nerve diameter between the symptomatic and the asymptomatic side in patients was larger than the difference between the dominant and the non-dominant side in healthy subjects, both for LTN2 (p-value: 0.01) and LTN3 (p-value: 0.04), but not for LTN1 (p-value: 0.06).

Atrophy of the serratus anterior muscle and an enlargement of the long thoracic nerve in a patient with medial winging can be seen in Fig. 4.

Four of the 20 patients with medial winging only showed an abnormal muscle thickness on US of the mid or lower level of the serratus anterior muscle and not at the upper level, whereas only one patient showed an abnormal muscle thickness on US of the upper level without the mid and lower level.

3.4.2. Patients with lateral winging and trapezius muscle affection in CEX (n = 5)

As the patient group with clinical trapezius muscle affection was small, we chose not to perform a statistical analysis. An overview of these patients is shown in Table 3. Here, the unclassified patients can also be seen.

3.5. Impact of combining HRUS and EDX

Using CEX as reference standard, in patients with medial winging and serratus anterior muscle affection, both EDX and HRUS was able to detect abnormalities in the serratus anterior muscle and/or long thoracic nerve in 13 out of 20 patients, with a sensitivity of 65%. For the remaining seven patients without serratus anterior muscle affection, the EDX showed no pathology in all seven patients; giving a specificity of 100%, whereas HRUS showed no pathology in four out of seven patients; giving a specificity of...
In the acute stage as the atrophy has not yet developed. Thus, one limitation of this study was the limited number of patients who did not allow for further sub-group analysis without compromising the strength of the statistical analysis. Larger studies are needed to further examine this group of patients.

4. Discussion

To our knowledge, this is the first prospective study to investigate the role of HRUS in the diagnostic workup of patients presenting with scapulae alatae. This is also the first study to correlate the electrodiagnostic findings with the HRUS measurements in this group of patients.

For the patients with clinical serratus anterior muscle affection, we found that HRUS measurements of muscle thickness and nerve diameter could differentiate between the symptomatic and asymptomatic side. This was also true for the measurements between these patients and the healthy subjects. A tendency towards EDX having a larger specificity for the patients with clinical serratus anterior muscle affection and a larger sensitivity and specificity for the patients with clinical trapezius muscle affection was seen, though this was not significant. Using EDX as the reference standard, we found that HRUS has a high sensitivity and a moderate specificity for the patients with serratus anterior muscle affection, whereas it has a moderate sensitivity and high specificity for patients with trapezius muscle affection.

Since the EDX was done HRUS guided in this study, it is possible that the sensitivity of the EDX would have been lower if we did not use HRUS for the purpose of needle positioning besides measuring the muscles and nerves.

To our knowledge, no other study has measured the serratus anterior muscle at different levels. We did this to ensure that we were able to examine the part of the muscle that would be affected in case not all parts were affected. Of the 20 patients with medial winging only one patient showed an abnormal muscle thickness on US of the upper level without the mid and lower level. This particular patient showed lateral winging on the CEX and a spinal accessory neuropathy on the EDX.

This study highlights the challenges in the diagnostic workup of scapulae alatae. To our knowledge, there does not exist a standardized way of clinically assessing the scapulae alatae patients. For the purpose of this study, we created a standardized CEX (Fig. 2) which included a static and dynamic examination. Using this CEX, we found that 30% of the patients did not have a visible winging during the static examination and 33% had an indistinct winging during the static examination. This makes the clinician dependent on knowing which dynamic examinations to use to reveal the winging. By using the dynamic examinations, we could separate the majority (26 out of 27 patients) patients in two distinct groups; one group with medial winging (20 patients) and one group with lateral winging (six patients). EDX was abnormal in only 63% of the included scapulae alatae patients, leaving 37% of the patients with no detectable abnormality in regard to the suspected diagnosis. Therefore, in the diagnostic work-up we chose to use the CEX as the gold standard.

5. Limitations

We were able to include 27 patients during the study period of ten months, which is a small number but rather acceptable taking into consideration the low incidence of the disease. Only five patients had a clinical trapezius muscle affection, thus, the sensitivity and specificity calculations were made on a poorer foundation than for the patients with clinical serratus anterior muscle affection (n = 20). The patient group has been diverse both in regard to aetiology and duration of symptoms. The limited number of patients did not allow for further sub-group analysis without compromising the strength of the statistical analysis. Larger studies are needed to further examine this group of patients.

HRUS was able to demonstrate muscle atrophy in patients as the duration of symptoms was long enough for atrophy to appear (mean 21.55 months (range 1 month–14 years for patients with medial winging and), and 50.00 months (range 9 months–10 years) in the patient group with lateral winging). Thus, one could expect that HRUS findings could be limited in patients in the acute stage as the atrophy has not yet developed.

A full randomization of which body side (left or right) the HRUS examination started with was not done. However, in the study, all

Table 2

| Muscle/nerve       | N (Asymptomatic side) | Mean (mm), 95% CI (Asymptomatic side) | N (Symptomatic side) | Mean (mm), 95% CI (Symptomatic side) | P-value |
|--------------------|-----------------------|---------------------------------------|----------------------|---------------------------------------|---------|
| SER Upper level    | 20                    | 5.4 [4.2, 6.5]                        | 20                   | 7.6 [6.1, 9.1]                        | 0.00    |
| SER Mid-level      | 20                    | 6.1 [4.6, 7.6]                        | 20                   | 8.8 [7.4, 10.2]                       | 0.02    |
| SER Lower level    | 20                    | 4.3 [3.1, 5.6]                        | 20                   | 7.0 [5.5, 8.4]                        | 0.00    |
| LTN1               | 19                    | 1.7 [1.6, 1.9]                        | 19                   | 1.5 [1.4, 1.7]                        | 0.05    |
| LTN2               | 19                    | 1.4 [1.3, 1.6]                        | 18                   | 1.2 [1.1, 1.3]                        | 0.01    |
| LTN3               | 14                    | 1.5 [1.3, 1.6]                        | 17                   | 1.2 [1.1, 1.3]                        | 0.02    |

* Not all nerves were found, therefore, for the nerves, it is specified how many that are included in the calculation.
* Significant difference.

LTN: Long thoracic nerve, SER: Serratus anterior muscle, S: symptomatic, A: asymptomatic

57%. Nevertheless, there was no significant difference between the sensitivities (p-value: 1.00) or the specificities (p-value 0.08) of the two methods.

Likewise, using CEX as a reference standard, in patients with lateral winging and trapezius muscle affection, the EDX was able to detect abnormalities in three out of five patients, giving a sensitivity of 60%, while HRUS was abnormal in two out of five patients, giving a sensitivity of 40%. For the remaining 22 patients without trapezius muscle affection, the EDX showed no pathology in 20 out of 22 patients, giving a specificity of 91%, whereas HRUS showed no pathology in 19 out of 22 patients, giving a specificity of 86%. Nevertheless, there was no significant difference between the sensitivities (p-value: 0.32) and specificities (p-value: 0.56) of the two methods.

Using the EDX findings as a reference standard, we found that for the patients with abnormal findings in the serratus anterior muscle or the long thoracic nerve on the EDX, HRUS showed pathology of the same structures in 11 out of 13 patients, giving a sensitivity of 85%, and for the patients with no pathology on the EDX, HRUS showed no pathology in nine out of 14 patients, giving a specificity of 64% (Table 4). For the patients with abnormal findings in the trapezius muscle and spinal accessory neuropathy on the EDX, HRUS showed pathology in 3 out of 5 patients, giving a specificity of 86%. Nevertheless, there was no significant difference between the sensitivities (p-value: 0.32) and specificities (p-value: 0.56) of the two methods.

We found that HRUS measurements of muscle thickness and nerve diameter could differentiate between the symptomatic and asymptomatic side. This was also true for the measurements between these patients and the healthy subjects. A tendency towards EDX having a larger specificity for the patients with clinical serratus anterior muscle affection and a larger sensitivity and specificity for the patients with clinical trapezius muscle affection was seen, though this was not significant. Using EDX as the reference standard, we found that HRUS has a high sensitivity and a moderate specificity for the patients with serratus anterior muscle affection, whereas it has a moderate sensitivity and high specificity for patients with trapezius muscle affection.
HRUS images were randomized and anonymized before the measurements of muscle thickness and nerve diameter were done.

In this study we excluded patients with a history of musculoskeletal disorders, muscle disease, cervical radiculopathy etc., thus, we believe our patients atrophy was caused by the neuropathy of the examined nerves. On the other side, although most of the patients were receiving physiotherapy and were active, we cannot exclude that inactivity may have played a role in the muscle atrophy.

The HRUS examiner was not blinded to the symptomatic side as this was often visible (70% had a visible winging during the static examination). This may have caused a possible selection bias and may have influenced the outcome of the HRUS scan. Nevertheless, the examiner was not aware which of the three possible muscles/nerves were affected.

Our CEX scheme, though standardised, was not validated in a larger group of patients and neither in healthy subjects. A larger study including an evaluation of intra- and inter examiner reliability is needed.

The differences in muscle thickness and nerve diameter found in this study are small, though significant. We do not believe that this is due to selection bias as the measurements were done
blinded. Moreover, the same trend is seen in all measured sites. We did not find any difference in intra-examiner measurements of any of the nerves in our previous study (Silkjaer Bak et al., 2021). Nevertheless, the limit of intra-examiner agreement was 0.1 mm, which is also the accuracy of the system. Thus, these data should be interpreted with caution and some uncertainty exits.

We did not apply a quantitative echo-intensity analysis in the study. As one study has shown, atrophied muscles have a higher echogenicity and this could have added more sonographic information about the affected muscles (van Alfen et al., 2018). On the other hand, we used ultrasound to guide EMG and that, we believe, increased the sensitivity of EMG in this study. Combining the evolving ultrasound technology with EDX methods and optimizing its clinical application alongside EDX, may help improving the work-up of the scapular winging.

Moreover, we examined only three muscles/nerves of the shoulder girdle as these are the muscles/nerves typically reported in the literature associated with a winged scapula. We cannot

**Table 3**
Overview of the seven patients with clinical trapezius muscle affection or unclassified winging.

| Patient          | US of muscles          | US of nerves                  | EDX               |
|------------------|------------------------|--------------------------------|-------------------|
| TRAP patient 1   | Normal TRAP            | Normal SAN                    | Normal            |
| TRAP patient 2   | Abnormal ratio and abnormal muscle thickness for all parts of the TRAP | The nerve on the symptomatic side was not enlarged, but it was not possible to follow the nerve from the scalene muscle to the trapezius muscle | Complete SAN lesion |
| TRAP patient 3   | Normal TRAP            | Normal SAN                    | Partial SAN lesion |
| TRAP patient 4   | Normal TRAP            | Normal SAN                    | Normal            |
| TRAP patient 5   | Abnormal ratio and abnormal muscle thickness for TRAP superior and mid, but only an abnormal ratio for TRAP inferior | Normal SAN | Normal |
| Unclassified patient - lateral winging | Normal TRAP | Normal | Normal |
| Unclassified patient - mixed winging | Normal SER | Normal | Normal |

EDX: electrodiagnostic examination, SAN: spinal accessory nerve, TRAP: trapezius muscle, US: ultrasound, LTN: Long thoracic nerve, SER: Serratus anterior muscle.
Table 4

| US      | EDX | Number of patients with abnormal results |
|---------|-----|------------------------------------------|
| +       | +   | 11                                       |
| +       | -   | 2                                        |
| -       | +   | 2                                        |
| -       | -   | 5                                        |

US: Ultrasound. EDX: Electrodiagnostic examination. CEX: Clinical examination. SAN: spinal accessory nerve, LTN: long thoracic nerve.

Table 5

| US      | EDX | Number of patients with abnormal results |
|---------|-----|------------------------------------------|
| +       | +   | 2                                        |
| +       | -   | 0                                        |
| -       | +   | 1                                        |
| -       | -   | 2                                        |

US: Ultrasound. EDX: Electrodiagnostic examination. CEX: Clinical examination.

Acknowledgments

We would like to thank the Lundbeck Foundation and the Foundation of the Maigaards ef. fru Lily Benthine Lunds Foundation for their financial support.

References

Akgun K, Aktas I, Terzi Y. Winged scapula caused by a dorsal scapular nerve lesion: a case report. Arch Phys Med Rehabil 2008;89(10):2017–20. https://doi.org/10.1016/j.apmr.2008.03.015

Biglami LU, Comporti CA, Duralde XA, Wolfe IN. Transfer of the levator scapulae, rhomboid major, and rhomboid minor for paralysis of the trapezius. J Bone Joint Surg Am 1996;78(10):1534–40.

Bischel OE, Hempling A, Rickert M, Loew M. Operative treatment of a winged scapula due to peripheral nerve palsy in Lyme disease: a case report and review of the literature. J Shoulder Elbow Surg 2008;17(6):e24–7. https://doi.org/10.1016/j.jse.2008.03.005

Bodner C, Harpt E, Gardet A, Kovacs P, Gruber H, Peer S, et al. Ultrasonography of the accessory nerve: normal and pathologic findings in cadavers and patients with iatrogenic accessory nerve palsy. J Ultrasound Med 2002;21(10):1159–63.

Buchthal F, Pinelli P. Action potentials in muscular atrophy of neurogenic origin. Neurology 1953(3):591–601.

Cohen JF, Korevaar DA, Altman DG, Bruns DE, Gatsonis CA, Hooft L, Irwig L, Levine D, Reitsma JB, de Vet HCW, Bossuyt PMM. STARD 2015 guidelines for reporting diagnostic accuracy studies: explanation and elaboration. BMJ Open 2016;6(11):e012799. https://doi.org/10.1136/bmjopen-2016-012799.

Coraci D, Romano M, Paolasso I, Santilli V, Padua L. A case of traumatic long thoracic nerve suffering: High-frequency ultrasound findings. Joint Bone Spine 2016;84(4):505–6. https://doi.org/10.1016/j.jbspin.2016.07.008.

Debeer P, Van Den Ende E, Meens P. Scapular winging: an unusual complication of bracing in idiopathic scoliosis. Clin Orthop Relat Res 2007;461:258–61.

Fardir P, Negrin P, Danishe R. The isolated paralysis of the serratus anterior muscle: clinical and electromyographical follow-up of 10 cases. Electromyogr Clin Neurophysiol 1978;18(5):379–86.

Foo CL, Swann M. Isolated paralysis of the serratus anterior. J Bone Joint Surg Br 1983;65-B(5):352–6.

Fuglsang-Frederiksen A, Pugdahl K. Current status on electrodiagnostic standards and guidelines in neuromuscular disorders. Clin Neurophysiol 2011;122(3):440–55. https://doi.org/10.1016/j.clinph.2011.06.025.

Galano G, Biglami LU, Ahmed CS, Levine WN. Surgical treatment of winged scapula. Clin Orthop Relat Res 2008;466(3):652–60. https://doi.org/10.1002/mus.20858.

Goodman CE, Kenrick MM, Blum MV. Long thoracic nerve palsy: a follow-up study. Arch Phys Med Rehabil 1975;56(8):352–8.

Gregg JR, Lahosky D, Harty M, Lofte P, Ecker M, DiStefano V, et al. Serratus anterior paralysis in the young athlete Retrieved from. J Bone Joint Surg Am 1979;61(6a):825–32. http://jbjs.org/content/61/6/825.long.

Hammond SR, Danta G. A clinical and electrophysiological study of neurogenically induced winging of the scapula. Clin Exp Neurol 1981;17:153–66.

Hobson-Webb LD, Boon AJ. Reporting the results of diagnostic neuromuscular ultrasound: an educational report. Muscle Nerve 2013;47(4):608–10. https://doi.org/10.1002/mus.24883.

Jerosch J, Castro WH, Geske B. Damage of the long thoracic and dorsal scapular nerve: clinical and electromyographical findings in two cases. Clin Neurophysiol 1978;18(5):379–86.

Lee S, Savin DD, Shah NR, Bronswick D, Goldberg B. Scapular Winging: Evaluation and Treatment: AAOS Exhibit Selection. J Bone Joint Surg Am 2015;97(20):1708–16. https://doi.org/10.2106/jbjs.o.02722.

Lieba-Samal D, Morgenbesser J, Moritz T, Gruber G, Bernathova M, Michaud J, Bodner G. Visualization of the Long Thoracic Nerve using High-Resolution Sonography. Ultraschall Med 2015;36(3):264–9. https://doi.org/10.1055/s-0034-1366084.

Lucchetta M, Pazzaglia C, Cacciavillani M, Riondato A, Lucchetta M, Pazzaglia C, Cacciavillani M, Riondato A, D’Ambrosio CM, Briani C, Padua L. A case of traumatic long thoracic nerve palsy of different etiology. Neurology 1984;34(8):1033–7.

Moro A, Fuglsang-Frederiksen A, Pugdahl K. Upper limb bracing in idiopathic scoliosis. Clin Orthop Relat Res 2007;461:258–61.

Nguyen C, Guerini H, Zauderer J, Roren A, Seror P, Lefevre-Colau MM. Magnetic resonance imaging of dynamic scapular winging secondary to a lesion of the accessory nerve. J Shoulder Elbow Surg 2016;25(6):e124–30. https://doi.org/10.1016/j.jse.2015.11.013.

Orth P, Anagnostakis K, Fritsch E, Kohn D, Madry H. Static winging of the scapula caused by osteochondroma in adults: a case series. J Med Case Rep 2012;6:363. https://doi.org/10.1186/1752-1947-6-363.

Petera JF, Troyajorg W. Conduction studies of the long thoracic nerve in serratus anterior palsy of different etiology. Neurology 1984;34(8):1033–7.

7. Presentations

Presented at the 17th European Congress of Clinical Neurophysiology, Warsaw, the 8th of June 2019.

Funding

The Lundbeck foundation [188,000 DK] and the Th. Maigaards ef. fru Lily Benthine Lunds Foundation of 1.6.1978 [15,000 DK] supported this work and they played no role in any of the aspects of the study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Clinical Neurophysiology 133 (2022) 48–57
