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# Shoulder tendon characteristics in disabled swimmers in high functional classes – Preliminary report

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ABSTRACT

*Objective:* To characterize disabled swimmers in comparison to an able-bodied swimmers for (1) supraspinatus tendon thickness, (2) subacromial space and (3) occupation ratio.
*Design:* Cross-Sectional Study.
*Setting:* Research laboratory.
*Participants:* Disabled swimmers with upper (DSw-Upper) ($n = 8$) and lower (DSw-Lower) ($n = 7$) extremity disorders. The DSw-Upper were classified in sports class S7-S8, while DSw-Lower in S9-S10. The control group had 15 able-bodied swimmers.
*Main outcome measures:* Ultrasound images of (1) supraspinatus tendon in short axis and long axis, (2) subacromial space, and (3) occupation ratio.
*Results:* A thicker supraspinatus tendon in short axis was observed in DSw-Upper versus C-Sw ($p = 0.012$) and DSw-Upper versus DSw-Lower ($p = 0.018$); and in long axis for DSw-Upper versus CSw ($p = 0.0001$), and DSw-Upper versus DSw-Lower ($p = 0.002$). There was a greater occupation ratio in DSw-Upper versus DSw-Lower in short axis ($p = 0.013$) and long axis ($p = 0.035$).
*Conclusions:* The present study showed a thicker supraspinatus tendon and greater occupation ratio with the tendon occupying more of the subacromial space that may predispose upper extremity disabled swimmers to tendon disorders such as subacromial impingement syndrome. Ultrasound examination can be used to assess shoulder tendon characteristics and the relationship to the subacromial space, to determine potential for injury and training load monitoring.



## 1. Introduction

Swimmers are required to perform multi-faceted shoulder movements in 1 or more of 4 swim strokes; freestyle, butterfly, backstroke, and breaststroke. During each stroke, the shoulder is required to move through an arc of elevation with humeral rotation, and some degree of scapular protraction. For example, in the freestyle stroke during the pull-through phase, the scapula is protracted while the humerus is adducted and internally rotated (Johnson, Gauvin, & Fredericson, 2003). These scapular and humeral positions have been associated with rotator cuff tendon impingement, theoretically contributing to shoulder pain in swimmers (Struyf, Tate, Kuppens, Feijen, & Michener, 2017; Yanai & Hay, 2000; Yanai, Hay, & Miller, 2000).

Epidemiologic studies have reported the incidence of shoulder injuries and pain in disabled swimmers (Weiler, Van Mechelen, Fuller, & Verhagen, 2016). During the Paralympic Games in London 2012, disabled swimmers had one of the highest incidence rates of injury (Willick et al., 2013). Moreover, it has been showed, that the shoulder was the most injured anatomical region of the body. Polish Paralympics swimmers had one of the highest injury rates in relation to other Polish athletes (Beijing 2008–13.1%; London 2012–9%) (Gawroński, Sobiecka, & Malesza, 2013). Disabled swimmers may be exposed to potentially higher shoulder overload, that may result in greater shoulder injuries (Ferrara &

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Peterson, 2000; Klenck & Gebke, 2007).

Findings from several studies suggest that intrinsic and extrinsic factors may affect shoulder biomechanics during swimming, leading to the development of shoulder pain (Struyf et al., 2017; Tovin, 2006). Yanai et al. (2000) investigated swimming stroke mechanics during freestyle swimming and reported that impingement occurred during 24,8% of the stroke time based on arm position. This finding suggests a high potential for impingement, without considering the supraspinatus tendon thickness and relationship to the subacromial space. Shoulder pain in swimmers is theorized to be commonly associated with impingement of the supraspinatus tendon in the subacromial space, called “swimmer's shoulder” (Bak, 2010; Struyf et al., 2017; Tovin, 2006).

Diagnostic ultrasound is a reliable technique used to investigate tendon characteristics (Del Baño-Aledo et al., 2017; Leong, Tsui, Ying, Leung, & Fu, 2012a; Michener, Subasi Yesilyaprak, Seitz, Timmons, & Walsworth, 2015). The measurement of the supraspinatus tendon thickness and acromiohumeral distance (AHD) was previously used to assess those with suspected impingement syndrome and rotator cuff tendinopathy (Braman, Zhao, Lawrence, Harrison, & Ludewig, 2014; Leong, Tsui, Ng, & Fu, 2016; Leong, Tsui, Ying, Leung, & Fu, 2012b; Michener et al., 2015; Rodeo, Nguyen, Cavanaugh, Patel, & Adler, 2016; Tucker, Armstrong, Gribble, Timmons, & Yeasting, 2010) and rotator cuff tears (De Jesus, Parker, Frangos, & Nazarian, 2009; Naqvi, Jadaan, & Harrington, 2009). The relationship between the supraspinatus tendon thickness and subacromial space has not been investigated in swimmers, either with or without the presence of shoulder pain and disability. Michener et al. (2015) used the supraspinatus tendon occupation ratio to understand the mechanism of subacromial impingement of the tendon. Reduced subacromial space has been associated with improper scapular positioning (Silva, Hartmann, De Souza Laurino, & Biló, 2010), and alterations in abnormal shoulder kinematics (Blache, Gillet, Selin, Sevrez, & Rogowski, 2018; Kibler et al., 2013), and deficits in scapular muscle activation (Matzkin, Suslavich, & Wes, 2016).

The characteristics of supraspinatus tendon thickness and subacromial space may provide crucial foundational knowledge to enable the prevention and treatment of shoulder pain in disabled swimmers. The aim of this study was to compare disabled swimmers with upper and lower extremity disorders to an able-bodied swimmers group to characterize (1) supraspinatus tendon thickness, (2) subacromial space, and (3) supraspinatus tendon thickness as a percentage of subacromial space. We hypothesized that the supraspinatus tendon would be larger, the subacromial space would be smaller, and the tendon would occupy a greater proportion of the subacromial space in disabled swimmers with upper extremity disorders.

## 2. Methods

### 2.1. Participants

Subjects ($n = 30$) participated in this study were disabled swimmers with upper (DSw Upper) ($n = 8$) and lower (DSw-Lower) ($n = 7$) extremity disorders. The control group (CSw) consisted of 15 able-bodied swimmers. DSw-Upper and DSw-Lower were recruited from Para Swimming Polish Team and Para-Swimming section, while CSw from college swimming team. Two were elite Para-swimmers, including Summer Paralympic Games (Rio de Janeiro 2016) and international-level (World Cup, European Championship, World Championship) participants. The CSw group participated in college and national competitions, with National Cup and Championship medalists. To be included, DSw-Upper and DSw-Lower met the following inclusion criteria: 1) Para-swimming classification and categories, and 2) training experience ($\leq$8 years). The CSw inclusion criterion was training experience ($\leq$8 years). Exclusion criteria for both disabled swimming groups and control group were shoulder pain at rest, positive impingement sign (positive Neer's test), painful arc during active arm elevation and a full-thickness rotator cuff tear.

All disabled swimmers were classified to high functional classes (from S7 do S10). A lower start class (expressed in classification points) indicates more functional limitation in the locomotor system than a higher class (World Para Swimming, 2018). DSw-Upper were classified in S7-S8 class. The S7 class includes swimmers obtained point score 191-215, with paralysis of one arm and birth defect of upper extremity, while the S8 class with one arm amputation (point score: 216-240). In this group, swimmers had single upper extremity amputation above elbow and dysmelia. DSw-Lower were classified in S9-S10 class. The S9 class is dedicated for swimmers obtained 241-265 points, with joint restrictions in one lower extremity or with lower extremity amputation, while the S10 for swimmers with minimal physical impairments (point score: 266-285) (World Para Swimming, 2018). In this group, swimmers had an amputation of one lower extremity below knee, restriction of mobility in hip joints and club foot. All subjects in DSw-Lower and CSw group were right-handed, and all participants in the DSw-Upper group had a disabled right shoulder.

The participant were adults aged between 19 and 22 years (DSw-Upper), 18–22 years (DSw-Lower) and 23–24 years (CSw) (Table 1). The greatest swimming experience had CSw and DSw-Lower ($11 \pm 1$ and $10 \pm 1$ years respectively), while the smallest DSw-Upper ($9 \pm 2$ years). Both disabled groups trained 6 times a week, while control group 10 times a week. All of the participants competed in freestyle and butterfly swimming events. None of the participants reported shoulder pain, any history of pain and impingement syndrome in the prior 6 weeks.

The sample size was calculated using G*Power software (version 3.1.9.2; Kiel University, Kiel, Germany) (Faul, Erdfelder, Lang, & Buchner, 2007) with an expected medium effect size ($f^2 = 0.35$) for changes in the ultraasonographic parameters within groups, an alpha level of 0.05, and power (1-$\beta$) of 0.80. The power calculation indicated 8 participants per group were necessary. This small simple size is caused by a small population of disabled swimmers.

The study was explained, the participants read and sign an informed consent form approved by the Senate Research Ethics Committee (project identification code: 26/2016; date of approval: 13.10.2016) and was conducted ethically according to the principles of the World Medical Association Declaration of Helsinki.

### 2.2. Experimental procedure

Sonography was performed using a Honda HS − 2200 (Honda, Japan) ultrasound scanner with a 7.5 (6.0–11.0) MHz linear array transducer (HLS − 584 M, Honda, Japan) in grey scale B-mode. The settings of the ultrasound system were standardized for all the participants and kept constant during all measurements. Ultrasound images were obtained by a single examiner.

In all groups the ultrasound examination was obtained for right shoulder, including: (1) supraspinatus tendon in short axis, (2) supraspinatus tendon in long axis and (3) subacromial space, defined by the acromio-humeral distance (AHD). From these 3 images, the supraspinatus tendon thickness was measured on the short and long axis images, the linear distance of the subacromial space via the AHD, and tendon thickness expressed as a percentage of the subacromial space (occupation ratio).

#### 2.2.1. Supraspinatus tendon thickness in short and long axis

The participant was seated with their back against a low back

**Table 1**
General characteristics of the participants.

| Variables | DSw-Upper (n = 8) | DSw-Lower (n = 7) | C-Sw (n = 15) |
|---|---|---|---|
| Age [years] | 20 ± 3 | 21 ± 4 | 23 ± 1 |
| Gender | | | |
| Male [n] | 4 | 3 | 8 |
| Female [n] | 4 | 4 | 7 |
| Height [cm] | 174.8 ± 5.6 | 178.4 ± 3.3 | 185.3 ± 3.2 |
| Weight [kg] | 66.5 ± 4.8 | 64.5 ± 6.6 | 80.2 ± 2.5 |
| Shoulder ROM | | | |
| Flexion [°] | – | 164.0 ± 1.5 | 167.7 ± 2.2 |
| Scapula Plane Elevation [°] | – | 158.2 ± 4.6 | 162.0 ± 3.7 |
| Hand grip strength [kg] | – | 41.4 ± 4.1 | 49.7 ± 6.4 |

chair. The arm was placed posteriorly with the palmar side of the hand on the superior aspect of the iliac wing, with the elbow flexed and directed posteriorly. During supraspinatus-short axis scanning the linear transducer was placed on the anterior aspect of the shoulder, and placed perpendicular to the supraspinatus tendon and just anterior to the anterior-lateral margin of the acromion. The transducer was moved medial and lateral and rocked to ensuring the biceps tendon was visualized (Jacobson, 2011). Three positions along the tendon were measured for thickness in millimeters (mm) at 10, 15 and 20 mm lateral to the reference point of the superior and lateral point of hyperechogenicity of the biceps tendon. The tendon borders were defined inferiorly as the first hyperechoic region above the anechoic articular cartilage of the humeral head, and the hyperechoic superior border of the tendon before the anechoic subdeltoid bursa. The three measures (10 mm, 15 mm and 20 mm) were averaged for a single measure of tendon thickness (Fig. 1) (Cholewinski, Kusz, Wojciechowski, Cielinski, & Zoladz, 2008; Michener et al., 2015).

During supraspinatus-long axis scanning the linear transducer was placed on the anterior aspect of the shoulder, just off the acromion oriented approximately 45° between the sagittal and frontal planes to obtain a longitudinal view of the supraspinatus. The probe was then moved anterior and lateral until the most distal end of the supraspinatus tendon was visualized just proximal to the greater tuberosity. The supraspinatus tendon in longitudinal view was a beaked-shaped structure with fibrillar pattern and regular margins. The probe was rocked back and forth to ensure the transducer was perpendicular to the supraspinatus tendon (Jacobson, 2011). Three measurements of tendon thickness were taken at 5, 10, and 15 mm proximal to the attachment of the tendon to the reference point of the greater tuberosity. The tendon borders were defined inferiorly as the first hyperechoic region above the anechoic articular cartilage of the humeral head, and the hyperechoic superior border of the tendon before the anechoic subdeltoid bursa. The three measures (5 mm, 10 mm and 15 mm) were averaged for a single measure of tendon thickness (Fig. 2) (Tsai et al., 2007).

*2.2.2. Acromiohumeral distance (AHD)*

AHD was examined in seated position with their back against a low back chair. The arm was placed by their side, with the forearm resting on the thigh, and both feet flat on the floor. The linear transducer was placed on the anterior-lateral aspect of the acromion (Jacobson, 2011). The subacromial space was measured as the linear distance between the edge of the superior aspect of the humeral head and the inferior aspect of the acromion, defined as the AHD (Fig. 3) (Michener et al., 2015).

*2.2.3. Supraspinatus tendon thickness as a percentage of subacromial space (occupation ratio)*

Mean tendon thickness was expressed as a percentage of the mean AHD using the formula below to define the occupation ratio in both the short and long axis views (Michener et al., 2015).

$$\%\,ratio = \left[\frac{\textit{SST tendon thickness}}{\text{Subacromial space}}\right] \times 100 \text{ SST} = \text{supraspinatus tendon}$$

*2.3. Statistical analysis*

SPSS 18 statistical software (SPSS Inc., Chicago, Ill) was used for data analysis. The Kruskal-Wallis test was used to compare the three participant groups because the data was not normally distributed (alpha set at 0.05). When a significant main effect was determined with the Kruskal-Wallis test, post-hoc comparisons between groups was performed using the Mann-Whitney *U* test with an adjusted Bonferroni correction ($p = 0.05$).

Effect sizes were calculated by dividing the mean difference between group comparison/standard deviation. Effect size interpretation used was 0.20–0.49 as small, 0.50–0.79 as medium, and large effects are considered greater than or equal to 0.80 (Cohen, 1988).

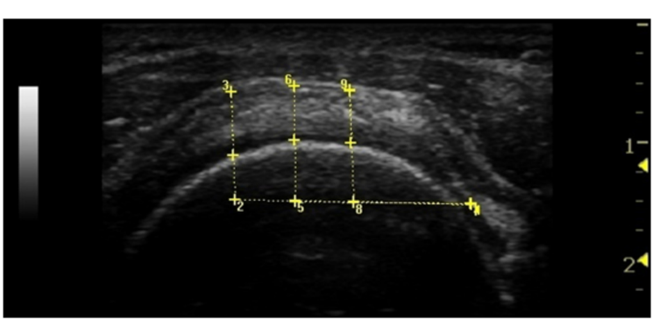

**Fig. 1. Supraspinatus tendon thickness in the short-axis**. The average of three tendon thickness measures (10, 15 and 20) mm lateral to the biceps tendon.

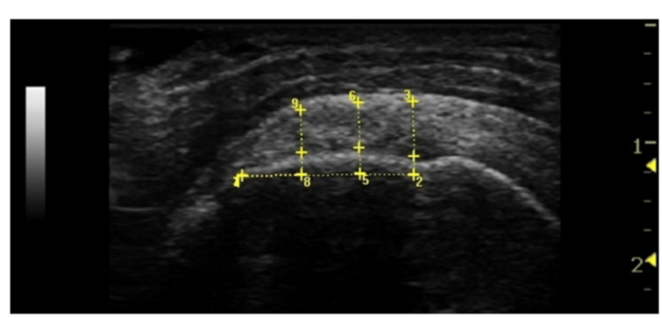

**Fig. 2. Supraspinatus tendon thickness in the long-axis**. The average of three tendon thickness measures (5, 10 and 15) mm lateral to the greater tuberosity.

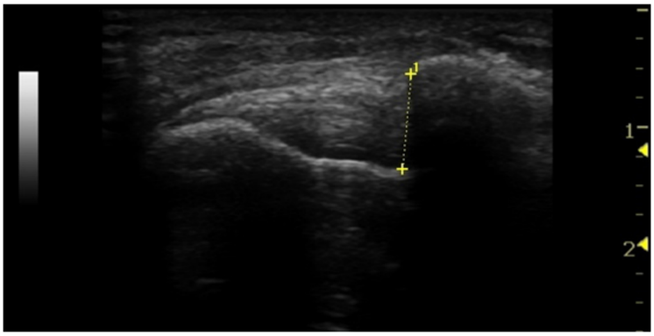

**Fig. 3. Acromiohumeral distance.** The linear distance between aromial tip and humeral head.

## 3. Results

Intra-rater test-retest reliability of the supraspinatus-short axis [ICC(3.2) = 0.98; MDC90 = 0.4 mm; SEM = 0.05]; supraspinatus-long axis [ICC(3.2) = 0.97; MDC90 = 0.5 mm; SEM = 0.05]; AHD [ICC(3.2) = 0.99; MDC90 = 0.2 mm; SEM = 0.05] and occupation ratio [ICC(3.2) = 0.96; MDC90 = 0.6 mm; SEM = 0.08] revealed excellent reliability and acceptable measurement error in a pilot study of n = 15 participants.

Table 2 provides the mean values of the supraspinatus thickness and AHD parameters for the 3 groups. The Kruskal-Wallis test revealed a significant main effect for supraspinatus-short axis ($p = 0.020$), supraspinatus-long axis ($p < 0.0001$), occupation ratio for the supraspinatus-short axis ($p = 0.039$), and occupation ratio for the supraspinatus-long axis ($p = 0.035$). There was no significant main effect for the AHD measure ($p = 0.247$).

Post-hoc testing using the Mann-Whitney *U* test with Bonferroni correction showed significant thicker supraspinatus-short axis in the DSw-Upper when compared to the C-Sw [mean difference = 0.4 mm (95%CI: 0.2, 0.8); effect size = 0.54; p = 0.012], and in the DSw-Upper as compared to the DSw-Lower [mean difference = 0.4 mm (95%CI: 0.1, 0.8); effect size = 0.57; p = 0.018]. The supraspinatus-long axis in the DSw-Upper was thicker as compared to the C-Sw [mean difference = 0.6 mm (95%CI: 0.3, 0.8); effect size = 0.76; p = 0.0001] and thicker in the DSw-Upper as compared to the DSw-Lower [mean difference = 0.6 mm (95%CI: 0.3, 0.6); effect size = 0.88; p = 0.002]. Post-hoc testing demonstrated that there was a greater occupation ratio for the supraspinatus-short axis and supraspinatus-long axis in the DSw-Upper as compared to the DSw-Lower [mean difference = 7.7%, (95% CI: 2.1, 13.3); effect size = 0.64; p = 0.013; mean difference = 7.0%, (95% CI: 2.5, 11.4); effect size = 0.70; p = 0.035, respectively]. Additionally, differences between groups for AHD were not significant.

## 4. Discussion

Two important findings were observed in this study. First, a 5.8% and 11.5% thicker supraspinatus tendon (in short and long axis respectively) was observed in the DSw-Upper group. Second, a 7.7% greater occupation ratio in the short axis was found in DSw-Upper as compared to DSw-Lower. The supraspinatus tendon thickness differences indicate an intrinsic change in the supraspinatus tendon. Tsui et al. (2007) showed increased supraspinatus tendon vascularity in those with tendinopathy. Moreover, the presence of increased vascularity within the tendon was associated with a reduced subacromial space.

Repeated loading of tendons and associated rotator cuff muscles may lead to greater vascular changes in overhead athletes. Prior studies have found a thicker supraspinatus tendon in those with shoulder impingement syndrome (5.6–8.1 mm) in comparison to a control group (6.0–6.9 mm) (Cholewinski et al., 2008; Leong et al., 2012b; Michener et al., 2015). Swimmers in our DSw-Upper group had a thicker supraspinatus tendon, and this tendon occupied a greater amount of the subacromial space. The overall effect size was 0.54 and 0.57 for supraspinatus-short axis, as well as, 0.76 and 0.88 for supraspinatus-long axis in DSw-Upper vs. C-Sw and DSw-Upper vs. DSw-Lower group, respectively. Large effect sizes were obtained for supraspinatus-long axis, suggest a strong degree of practical significance. These findings may indicate that these swimmers are predisposed to the development of shoulder pain related to impingement of the supraspinatus tendon in the subacromial space.

In our study, we examined swimmers with upper extremity disabilities as single upper extremity amputation above elbow and phocomelia. Phocomelia causes deformations and structural changes in the shoulder, which may lead to dysfunctional shoulder movement patterns. Our results showed a thicker tendon in DSw-Upper, which may indicate overload changes in the supraspinatus tendon. The tendon thickness may be related to kinematic changes in the shoulder that are caused by the upper extremity disorder. Prior studies have observed decreased trapezius, serratus anterior and deltoid muscle activity in swimmers with impingement syndrome during different phases (Struyf et al., 2017; Tovin, 2006). These muscle imbalance may be responsible for altered scapular motion and decreases in the subacromial space (Page, 2011).

The supraspinatus thickness in relation to the subacromial space (occupation ratio) was used to describe the relationship between supraspinatus tendon within the subacromial space. In this study, there was a 7.7% greater tendon occupation of the subacromial space in DSw-Upper as compared those with DSw-Lower. The greater occupation ratio in DSw-Upper may be lead to compression of the supraspinatus tendon and increased tendon vascularity (Tsui, Leong, Leung, Ying, & Fu, 2017). In a previous report, the occupation ratio in subjects with impingement were $61.7 \pm 10.3\%$ and $54.2 \pm 7.9\%$ in control group (Michener et al., 2015). The overall effect size was 0.64 for occupation ratio from the supraspinatus-short axis for DSw-Upper vs. DSw-Lower group. A 22.5% greater occupation ratio in swimmers should be considered with about 4000 strokes during a training, causing shoulder dysfunctions (Tovin, 2006). Greater occupation ratio in C-Sw than in DSw-Lower

**Table 2**
Supraspinatus tendon thickness, acromiohumeral distance mean and standard deviations in 3 groups: disabled-upper extremity, disabled-lower extremity, and able-bodied swimmers.

| Variables | DSw-Upper (n = 7) | DSw-Lower (n = 7) | C-Sw (n = 15) |
|---|---|---|---|
| SST-short axis [mm] | $6{,}9 \pm 0{,}4^{a,c}$ | $6{,}5 \pm 0{,}1^{c}$ | $6{,}5 \pm 0{,}3^{a}$ |
| SST-long axis [mm] | $5{,}2 \pm 0{,}2^{a,c}$ | $4{,}6 \pm 0{,}1^{c}$ | $4{,}6 \pm 0{,}3^{a}$ |
| AHD [mm] | $8{,}3 \pm 0{,}4$ | $8{,}5 \pm 0{,}3$ | $8{,}0 \pm 0{,}6$ |
| SST-short axis ratio to AHD [%] | $84{,}2 \pm 5{,}9^{c}$ | $76{,}5 \pm 2{,}9^{c}$ | $81{,}1 \pm 8{,}0$ |
| SST-long axis ratio to AHD [%] | $63{,}1 \pm 4{,}7^{c}$ | $56{,}1 \pm 1{,}6^{c}$ | $58{,}3 \pm 7{,}7$ |

Legend: SST: Supraspinatus Tendon; AHD: Acromiohumeral distance.
Significant differences ($p \leq 0{,}05$) between groups: a - DSw-Upper and C-Sw, b - DSw-Lower and C-Sw. c - DSw-Upper and DSw-Lower.

could be related to numbers of training. Swimmers participating in C-Sw train more, than DSw-Lower (4 times a week). In this group observed also the smallest AHD, which is less (~2 mm) than in subjects with subacromial implement (Michener et al., 2015).

The swimmer's shoulder may lead to a greater supraspinatus tendon thickness as a result of an increase in resistance loads and a chronic effect of exercise (0.5 and 1 million arm cycles per year). This increase in tendon thickness may also be related to the changes in flexibility and stiffness around the shoulder and the trunk reported in swimmers (Struyf et al., 2017), as well as associated with the decreased subacromial space (Bak, 2010). The swimming stroke may also relate to the cause of increased tendon thickness because the supraspinatus tendon has an increased chance of impingement due to arm positions during the freestyle stroke (Yanai & Hay, 2000).

There were no differences in the subacromial space (AHD) in this study. In prior studies of healthy (non-painful) overhead athletes, Maenhout, Van Eessel, Van Dyck, Vanraes, and Cools (2012) reported a larger AHD on the dominant side (9.4–9.7 mm) and a smaller AHD in elite tennis players (8.8 mm) by Silva et al. (2010), which is consistent with the disabled swimmers in this current study (8.3–8.5 mm). However, training may lead to changes that affect the AHD, as Silva et al. (2010) reported the AHD is smaller in tennis players as compared to those who do not play tennis. During elevation a reduction in AHD is expected, as demonstrated by Hinterwimmer et al. (2003) from 30° to 120° elevation. A reduction in the subacromial space may be caused by an imbalance of the muscles stabilizing scapula, as well as altered scapular motion (Kibler et al., 2013; Silva et al., 2010). Freestyle swimming requires a combined movement consisting of scapula protraction and elevation, along with humeral abduction and internal rotation. This movement could induce overload to the scapular muscles leading to scapular muscle imbalance and altered control. A reduction in subacromial space may suggest increased compression of the supraspinatus tendon during swimming. Changes in the AHD and shoulder tendon characteristics may also be a result of upper extremity disorders in the disabled swimmers group. Both the DSw-Upper and DSw-Lower groups may have altered muscle activity during swimming as compared to able-bodied swimmers.

Diagnostic ultrasound may be a useful tool to assess shoulder tendon characteristics and their relationship to the subacromial space to determine the potential for injury and monitoring effects of training load. Moreover, in suspected cases of unspecific shoulder pain and subacromial impingement, diagnostic ultrasound may aid in the identification of the mechanisms related to the swimmer's pain. A limitation of this study is the evaluation of the AHD and tendon with the arm in low elevation angles. Swimmers typically have shoulder pain during high shoulder elevation angles. Future studies should include evaluation of tendon and AHD during higher angles of shoulder elevation. Moreover, dynamic analysis of shoulder motion using ultrasonography and kinematics could aid the identification of mechanisms associated with swimmer's shoulder pain. We did not assess strength in shoulder external and internal rotation. Evaluation of shoulder rotational strength could elucidate the impact of training volume and the supraspinatus tendon thickness. Finally, studies of swimmers with shoulder pain should include assessments of rotator cuff and scapular muscle function to aid the understanding of the development of shoulder pain.

The present study was limited by the number of disabled swimmers. The sample size was low, but the medium effect sizes suggest that the changes in shoulder tendon characteristics were important. However, disabled swimmers are a small selected group, and we examined elite disabled swimmers. Another limitation is the results are not generalizable to all swimmers with disabilities, because disabled swimmers are heterogeneous and may also have additional nervous system disorders (i.e. cerebral palsy). The cross-sectional nature of the study does not infer causation. Thus, future studies should consider prospective cohort design with multiple longitudinal assessments.

## 5. Conclusions

The present study showed for the first time that disabled paralympic swimmers, those with arm amputations and defects (e.g. phocomelia), have alterations in shoulder tendon characteristics and potential mechanism of impingement risk with a greater tendon occupation of the subacromial space (occupation ratio). Specifically, those swimmers had a thicker supraspinatus tendon and a greater occupation ratio, with the tendon occupying more of the subacromial space as compared to disabled swimmers with lower extremity disorders and able-bodied swimmers. This may be associated with tendon vascularity, altered kinematics and specifics of the sport. Additional research on athletes with and without pain is clearly needed to determine the relationship between tendon characteristics and subacromial space, and the development of shoulder pain related to potential impingement.

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## References

Bak, K. (2010). The practical management of swimmer's painful shoulder: Etiology, diagnosis, and treatment. *Clinical Journal of Sport Medicine, 20*(5), 386–390. https://doi.org/10.1097/JSM.0b013e3181f205fa.

Blache, Y., Gillet, B., Selin, J., Sevrez, V., & Rogowski, I. (2018). Scapular kinematics during scaption in competitive swimmers. *European Journal of Sport Science*. https://doi.org/10.1080/17461391.2018.1449893.

Braman, J. P., Zhao, K. D., Lawrence, R. L., Harrison, A. K., & Ludewig, P. M. (2014). Shoulder impingement revisited: Evolution of diagnostic understanding in orthopedic surgery and physical therapy. *Medical, & Biological Engineering & Computing, 52*(3), 211–219. https://doi.org/10.1007/s11517-013-1074-1.

Cholewinski, J. J., Kusz, D. J., Wojciechowski, P., Cielinski, L. S., & Zoladz, M. P. (2008). Ultrasound measurement of rotator cuff thickness and acromio-humeral distance in the diagnosis of subacromial impingement syndrome of the shoulder. *Knee Surgery, Sports Traumatology, Arthroscopy, 16*(4), 408–414. https://doi.org/10.1007/s00167-007-0443-4.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences. Statistical power analysis for the behavioral sciences. https://doi.org/10.1234/12345678.

De Jesus, J. O., Parker, L., Frangos, A. J., & Nazarian, L. N. (2009). Accuracy of MRI, MR arthrography, and ultrasound in the diagnosis of rotator cuff tears: A meta-analysis. *American Journal of Roentgenology*. https://doi.org/10.2214/AJR.08.1241.

Del Baño-Aledo, M. E., Martínez-Payá, J. J., Ríos-Díaz, J., Mejías-Suárez, S., Serrano-Carmona, S., & de Groot-Ferrando, A. (2017). Ultrasound measures of tendon thickness: Intra-rater, inter-rater and inter-machine reliability. *Muscles, Ligaments and Tendons Journal*. https://doi.org/10.11138/mltj/2017.7.1.192.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146.

Ferrara, M. S., & Peterson, C. L. (2000). Injuries to athletes with disabilities: Identifying injury patterns. *Sports Medicine, 30*(2), 137–143. https://doi.org/10.2165/00007256-200030020-00006.

Gawroński, W., Sobiecka, J., & Malesza, J. (2013). Fit and healthy paralympians - medical care guidelines for disabled athletes: A study of the injuries and illnesses incurred by the polish paralympic team in Beijing 2008 and London 2012. In *British journal of sports medicine* (Vol. 47, pp. 844–849). https://doi.org/10.1136/bjsports-2013-092298.

Hinterwimmer, S., Von Eisenhart-Rothet, R., Siebert, M., Putz, R., Eckstein, F., Vogl, T., et al. (2003). Influence of adducting and abducting muscle forces on the subacromial space width. *Medicine & Science in Sports & Exercise, 35*(12), 2055–2059. https://doi.org/10.1249/01.MSS.0000099089.49700.53.

Jacobson, J. A. (2011). Shoulder US: Anatomy, technique, and scanning pitfalls. *Radiology, 260*(1), 6–16. https://doi.org/10.1148/radiol.11101082.

Johnson, J. N., Gauvin, J., & Fredericson, M. (2003). Swimming biomechanics and injury prevention. *The Physician and Sportsmedicine, 31*(1), 41–46. https://doi.org/10.3810/psm.2003.01.165.

Kibler, W. B., Ludewig, P. M., McClure, P. W., Michener, L. A., Bak, K., & Sciascia, A. D. (2013). Clinical implications of scapular dyskinesis in shoulder injury: The 2013 consensus statement from the "scapular summit. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2013-092425.

Klenck, C., & Gebke, K. (2007). Practical management: Common medical problems in disabled athletes. *Clinical Journal of Sport Medicine: Official Journal of the Canadian Academy of Sport Medicine, 17*(1), 55–60. https://doi.org/10.1097/JSM.0b013e3180302587.

Leong, H. T., Tsui, S. S. M., Ng, G. Y. fat, & Fu, S. N. (2016). Reduction of the subacromial space in athletes with and without rotator cuff tendinopathy and its association with the strength of scapular muscles. *Journal of Science and Medicine in Sport*. https://doi.org/10.1016/j.jsams.2016.03.011.

Leong, H. T., Tsui, S., Ying, M., Leung, V. Y. fong, & Fu, S. N. (2012a). Ultrasound measurements on acromio-humeral distance and supraspinatus tendon thickness: Test-retest reliability and correlations with shoulder rotational strengths. *Journal of Science and Medicine in Sport*. https://doi.org/10.1016/j.jsams.2011.11.259.

Leong, H. T., Tsui, S., Ying, M., Leung, V. Y. fong, & Fu, S. N. (2012b). Ultrasound measurements on acromio-humeral distance and supraspinatus tendon thickness: Test-retest reliability and correlations with shoulder rotational strengths. *Journal of Science and Medicine in Sport, 15*(4), 284–291. https://doi.org/10.1016/j.jsams.2011.11.259.

Maenhout, A., Van Eessel, V., Van Dyck, L., Vanraes, A., & Cools, A. (2012). Quantifying acromiohumeral distance in overhead athletes with glenohumeral internal rotation loss and the influence of a stretching program. *The American Journal of Sports Medicine, 40*(9), 2105–2112. https://doi.org/10.1177/0363546512454530.

Matzkin, E., Suslavich, K., & Wes, D. (2016). Swimmer's shoulder: Painful shoulder in the competitive swimmer. *Journal of the American Academy of Orthopaedic Surgeons*. https://doi.org/10.5435/JAAOS-D-15-00313.

Michener, L. A., Subasi Yesilyaprak, S. S., Seitz, A. L., Timmons, M. K., & Walsworth, M. K. (2015). Supraspinatus tendon and subacromial space parameters measured on ultrasonographic imaging in subacromial impingement syndrome. *Knee Surgery, Sports Traumatology, Arthroscopy, 23*(2), 363–369. https://doi.org/10.1007/s00167-013-2542-8.

Naqvi, G. A., Jadaan, M., & Harrington, P. (2009). Accuracy of ultrasonography and magnetic resonance imaging for detection of full thickness rotator cuff tears. *International Journal of Shoulder Surgery*. https://doi.org/10.4103/0973.

Page, P. (2011). Shoulder muscle imbalance and subacromial impingement syndrome in overhead athletes. *International Journal of Sports Physical Therapy, 6*(1), 51–58. https://doi.org/10.1007/s11999-009-1124-z.ders.

Rodeo, S. A., Nguyen, J. T., Cavanaugh, J. T., Patel, Y., & Adler, R. S. (2016). Clinical and ultrasonographic evaluations of the shoulders of elite swimmers. *The American Journal of Sports Medicine*. https://doi.org/10.1177/0363546516657823.

Silva, R. T., Hartmann, L. G., De Souza Laurino, C. F., & Biló, J. P. R. (2010). Clinical and ultrasonographic correlation between scapular dyskinesia and subacromial space measurement among junior elite tennis players. *British Journal of Sports Medicine, 44*(6), 407–410. https://doi.org/10.1136/bjsm.2008.046284.

Struyf, F., Tate, A., Kuppens, K., Feijen, S., & Michener, L. A. (2017). Musculoskeletal dysfunctions associated with swimmers' shoulder. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2016-096847.

Tovin, B. J. (2006). Prevention and treatment of swimmer's shoulder. *North American Journal of Sports Physical Therapy : NAJSPT, 1*(4), 166–175. https://doi.org/10.1159/000089786.

Tsai, Y.-H., Huang, T.-J., Hsu, W.-H., Huang, K.-C., Li, Y.-Y., Peng, K.-T., et al. (2007). Detection of subacromial bursa thickening by sonography in shoulder impingement syndrome. *Chang Gung Medical Journal, 30*(2), 135–141.

Tsui, S. S. M., Leong, H. T., Leung, V. Y. F., Ying, M., & Fu, S. N. (2017). Tendon vascularity in overhead athletes with subacromial pain syndrome and its correlation with the resting subacromial space. *Journal of Shoulder and Elbow Surgery, 26*(5), 774–780. https://doi.org/10.1016/j.jse.2016.09.041.

Tucker, W. S., Armstrong, C. W., Gribble, P. A., Timmons, M. K., & Yeasting, R. A. (2010). Scapular muscle activity in overhead athletes with symptoms of secondary shoulder impingement during closed chain exercises. *Archives of Physical Medicine and Rehabilitation, 91*(4), 550–556. https://doi.org/10.1016/j.apmr.2009.12.021.

Weiler, R., Van Mechelen, W., Fuller, C., & Verhagen, E. (2016). Sport injuries sustained by athletes with disability: A systematic review. *Sports Medicine*. https://doi.org/10.1007/s40279-016-0478-0.

Willick, S. E., Webborn, N., Emery, C., Blauwet, C. A., Pit-Grosheide, P., Stomphorst, J., … Schwellnus, M. (2013). The epidemiology of injuries at the London 2012 paralympic games. *British Journal of Sports Medicine, 47*(7), 426–432. https://doi.org/10.1136/bjsports-2013-092374.

World Para Swimming. (2018). *World Para swimming classification rules and regulations*.

Yanai, T., & Hay, J. G. (2000). Shoulder impingement in front-crawl swimming: II. Analysis of stroking technique. *Medicine & Science in Sports & Exercise, 32*(1), 30–40. https://doi.org/10.1097/00005768-200001000-00006.

Yanai, T., Hay, J. G., & Miller, G. F. (2000). Shoulder impingement in front-crawl swimming: I. A method to identify impingement. *Medicine & Science in Sports & Exercise, 32*, 21–29. https://doi.org/10.1097/00005768-200001000-00005.