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Research article

Investigating The Association Between Supraspinatus Tendon Abnormality, Shoulder Pain and Isokinetic Strength in Elite Swimmers: A Cross-Sectional Study

Billy Chun Lung So [1,2]✉, Stan Cheuk Ting Lau [1], Wan Yu Kwok [1], Daniel Hon Ting Tse [1] and Siu Shing Man [1]
[1] Gait and Motion Analysis Laboratory, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Hong Kong; [2] Research Institute for Sports Science and Technology, The Hong Kong Polytechnic University, Hung Hom, Hong Kong

Abstract
Shoulder pain is common among elite swimmers due to the tremendous stress over shoulders during swimming. Supraspinatus muscle is one of the major prime movers and stabilizers of shoulder and is highly susceptible to overloading and tendinopathy. An understanding of the relationship between supraspinatus tendon and pain; and between supraspinatus tendon and strength would assist health care practitioners for developing training regime. The objectives of this study are to evaluate 1) the association between structural abnormality of supraspinatus tendon and shoulder pain and 2) the association between structural abnormality of supraspinatus tendon and shoulder strength. We hypothesized that structural abnormality of supraspinatus tendons positively associated with shoulder pain and negatively associated with shoulder muscle strength among elite swimmers. 44 elite swimmers were recruited from the Hong Kong China Swimming Association. Supraspinatus tendon condition was evaluated using diagnostic ultrasound imaging and shoulder internal and external rotation strength was evaluated by the isokinetic dynamometer. Pearson's R was used to study the correlation between shoulder pain and supraspinatus tendon condition and to evaluate the association between isokinetic strength of shoulders and supraspinatus tendon condition. 82 shoulders had supraspinatus tendinopathy or tendon tear (93.18%). However, there was no statistically significant association between structural abnormality of supraspinatus tendon and shoulder pain. The results showed that there was no association between supraspinatus tendon abnormality and shoulder pain and there was a significant correlation between left maximal supraspinatus tendon thickness (LMSTT) and left external rotation/ concentric (LER/Con) and left external rotation/ eccentric (LER/Ecc) shoulder strength ($p < 0.05$) while internal rotation/ external rotation (IR/ER) ratio can also be a significant predicator on LMSTT >6mm ($R^2 = 0.462$, $F = 7.016$, df = 1, $p = 0.038$). Structural change of supraspinatus tendon was not associated with shoulder pain, but could be a predictor on MSTT >6mm in elite swimmers.

Key words: Elite swimmers, supraspinatus tendon abnormality, shoulder pain, isokinetic strength.

Introduction

Shoulder pain is one of the most prevalent musculoskeletal symptoms presented by elite swimmers; it ranged from 40% to 91% as reported in previous studies (Bak & Faunø, 1997; Ciullo, 1986; Hawkins & Kennedy, 1980; McMaster, 1999; Rupp et al., 1995). Researchers suggested that pain could be attributed by the tremendous stress exerted on shoulders during training (Bak, 2010; Fredericson et al., 2009; Kennedy et al., 1978). As such, this kind of sports related injury were identified and the term 'swimmer shoulders' had been widely used in the past five decades (Kennedy et al., 1978). Recently, primary impingement and secondary impingement have also been introduced. Although researchers have investigated the risk factors causing secondary impingement in the past, few contributing factors of a moderate level of evidence had been identified. Those factors included namely competitive level, previous history of pain and injury, internal/external rotation ratio and clinical joint laxity and instability (Hill et al., 2015).

According to Sein et al (2010), the duration of swimming training (hours/week) ($r = 0.49$, $p < 0.01$) and swimming distance (distance/week) ($r = 0.39$, $p < 0.05$) had a significant and positive correlation with supraspinatus tendinopathy (Sein et al., 2010). Evidence showed that supraspinatus tendinopathy could be a major cause of shoulder pain presented in elite swimmers and this tendinopathy could be predisposed by huge amount of swimming training (Sein et al., 2010).

Similarly, researchers suggested that supraspinatus tendinopathy could be significantly correlated to the substantial repetitive loading during front crawling in swimming (Porter et al., 2020). Supraspinatus muscle is one of the rotator cuff muscles that works as a prime mover and stabilizer of shoulders, as well as responsible for securing the humeral head in the glenoid. Hence, supraspinatus muscles are more susceptible to overload injury which potentially resulted in tendinopathy (Jobe et al., 1989; Renström & Johnson, 1985; Soslowsky et al., 2000; Suzuki et al., 2020).

There have been a high prevalence rate of shoulder pain and supraspinatus tendinopathy among elite swimmers. Researchers suggested that asymptomatic sportsmen shoulders have similar pathological changes when compared to symptomatic non-sportsmen shoulders. Nevertheless, there were even more tendon structural pathological changes reported in asymptomatic sportsmen shoulders group (Connor et al., 2003; Fredericson et al., 2009). For instance, it has been reported that supraspinatus tendinopathy is the major cause of shoulder pain in a study evaluated the relationship between supraspinatus pathology and

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shoulder impingement sign among elite swimmers (Sien et al., 2010). However, a direct comparison between supraspinatus tendon (SST) structural changes in symptomatic shoulders and asymptomatic shoulders among elite swimmers was lacking in such study (Sein et al., 2010).

A reduced muscle strength of shoulder external and internal rotation has been recognized as a contributor to shoulder pain, and commonly presented in elite swimmers (Bak & Magnusson, 1997; Boettcher et al., 2020; Hegedus et al., 2012). In spite of that, evidence on the relationship between symptomatic swimmers' shoulder strength and supraspinatus tendon structural abnormality was lacking. Hence, to examine a relationship between swimmer's shoulder pain, strength and SST structure can be useful to establish a better understanding on shoulder pathology. An isokinetic strength test has been well-recognized and commonly adopted as a reliable, valid and quantifiable tool in measuring muscle strength (Habets et al., 2018). In particular, the internal and external shoulder rotator strength can be measured by peak torque (PT) in order to establish a correlation between strength deficit and structural abnormality. Previous studies suggested using shoulder rotational peak torque strength ratios (External rotation (ER)/Internal Rotation (IR) to measure overhead sports to investigate normative values. The results ranged from 0.66 to 0.75 while such results were not applicable to swimmers (Ellenbecker and Davies, 2000; Ellenbecker and Roeterert, 2003). There were other studies examined the shoulder peak torque strength ratios (IR/ER) of swimmers ranged from 0.39 to 0.66 (Gozlan et al., 2006; Olivier et al., 2008). Such difference in peak torque strength ratio (IR/ ER) can be contributed by the major propulsion movement during the acceleration phase of swimming was induced by internal rotators (Liaghat et al., 2018). Researchers also suggested that such a reduction in the ratio of shoulder internal and external rotators could be contributed by muscle imbalance, that is, external rotators were likely weakened and internal rotators were likely strengthened in elite swimmers. As a result, we adopted PT and external rotation/ internal rotation PT ratios to identify aforementioned relationship.

Upon reviewing the existing literature, we found that the relationship between SST structure, shoulder rotational strength and pain remain unknown. Not only without direct comparison between supraspinatus tendon structural changes in symptomatic shoulders and asymptomatic shoulders among elite swimmers, but also no investigation has been conducted in regards to the relationship between SST structural abnormality and symptomatic swimmers' shoulder rotational strength. Therefore, we aimed to evaluate the relationship (1) between SST structure and pain, (2) between SST structure and strength in order to benefit coaches, swimmers and healthcare professionals in understanding the clinical applications and relevant deficits for future rehabilitation planning.

We hypothesized that structural abnormality of supraspinatus tendon is positively associated with shoulder pain and negatively associated with shoulder muscle strength in elite swimmers.

Methods

Study design

This was a cross-sectional study. Assessors were responsible for supraspinatus structural examination with diagnostic ultrasound images and shoulder isokinetic strength assessment with isokinetic dynamometer respectively. Assessor 1 is a physiotherapist trained with advance diagnostic ultrasound imaging at shoulder region and had relevant clinical experiences in ultrasound scanning. Assessor 2 is a physiotherapist with clinical experience of using isokinetic dynamometer for examination or training for years. During the examination session, all results did not disclose to participants until all the assessments were finished. The workflow of this study is shown in Figure 1.

Participants

44 registered swimmers under Hong Kong China Swimmer Association were recruited from different swimming clubs according to the inclusion criteria. The inclusion and exclusion criteria are listed in Table 1.

The assessments were conducted in the Gait and Motion Analysis Laboratory of the Department of Rehabilitation Sciences of the Hong Kong Polytechnic University. All participants were informed about the background, procedure, potential benefits and side effects of this study. Written consent was obtained before data collection. This study was approved by the Human Subjects Ethics Subcommittee of The Hong Kong Polytechnic University (reference number: HSEARS20200828001).

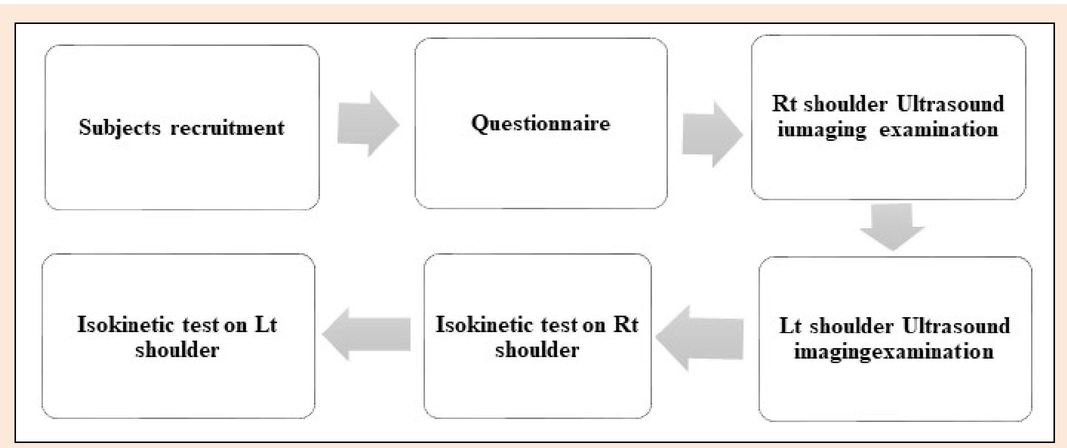

Figure 1. Study workflow.

Table 1. Inclusion and exclusion criteria

Inclusion Criteria	(1) At least 4 training sessions a week
	(2) More than 3,000 meters training distance per session, and
	(3) Participated more than 6 years competition
Exclusion Criteria	(1) Any history of shoulder fracture, dislocation or surgery
	(2) Recent injury of shoulder in the past 3 months

Each swimmer was asked to complete a questionnaire regarding demographics, anthropometric features, year of competition, major competition strokes and any injury history of shoulder etc. before assessment started.

Outcome Measures

Diagnostic ultrasound imaging

Ultrasound imaging is a reliable tool to evaluate the supraspinatus tendinopathy, especially in grading fibrillar disruption and detecting neovascularity. The interrater reliability in Kappa Statistic is moderate to excellent (Kappa statistic, k = 0.60 - 0.96) (Ingwersen et al., 2016). Additionally, an excellent result was obtained in measuring tendon thickness (Interclass correlation coefficient = 0.85 - 0.90). Likewise, the sensitivity and specificity of detecting full thickness tears were 0.95 and 0.96 respectively; and partial thickness tears were 0.72 and 0.93 respectively (95% Confidence Interval). The sensitivity and specificity of confirming tendinopathy were 0.67 - 0.93 and 0.88-1.00 respectively. The sensitivity and specificity of detecting calcifying tendonitis was 1.00 and 0.85 - 0.98 respectively (Ottenheijm et al., 2010). The high sensitivity and high specificity results implied that ultrasound imaging is capable to rule out actual pathological changes upon doing the tests.

In full thickness tear, we searched for non-visualization of the supraspinatus tendon due to the complete retraction of the tendon underneath the acromion or when there is retraction of the tendon with added sign including deltoid herniation, bursal thickening and excessive fluid (Teefey et al., 2000).

In partial thickness tear, we examined (1) minimal flattening of the bursal surface of supraspinatus or (2) hypoechoic and mixed hyperechoic and hypoechoic defect cross reference at the longitudinal plan and transverse plane at the articular surface of supraspinatus (Teefey et al., 2000).

In shoulders without full/ partial thickness tears, the evaluation continued to assess supraspinatus for the presence of tendinopathic changes. The assessor repeated taking the posterior to anterior scan with the transducer placed longitudinally on the supraspinatus tendon. Abnormal tendon structure (ATS) was defined as the presence of supraspinatus tendon with hypoechogenicity or altered fibrillar disruption (Ingwersen et al., 2016) (Figure 2). Tendon hypoechogenicity was defined as iso-echogenicity and hypo-echogenicity of the supraspinatus when compared to the deltoid muscle (Ingwersen et al., 2016). Altered fibrillar pattern was defined as loss of complex fibrillar pattern of the supraspinatus tendon.

Supraspinatus tendon could be classified as ATS with either partial/ full thickness tears or tendinopathic changes. In the absence of partial/ full thickness tear and the absence of tendinopathic change, the supraspinatus tendon was classified as a normal tendon.

Another outcome measure from ultrasound image on SST was the maximal supraspinatus tendon thickness (MSTT). In transverse view of SST at rotator cuff tendon internal, assessor measured the MSTT. First, assessor identified the long head of biceps. Then, maximal tendon thickness was obtained at 5mm and 10mm posterior to edge of the biceps tendon. Next, average values of two measurements were used as MSTT end result {Barrett et al., 2016). Researcher suggested that supraspinatus tendinopathy could be defined as MSTT >6 mm in non-sportsmen populations (Arend et al., 2014).

Isokinetic strength

An isokinetic strength is measured when the length of the muscle changes with a constant muscle contraction velocity. An isokinetic dynamometer could be used to measure muscle strength and found to be a reliable tool (Interclass correlation coefficient = 0.72 - 0.94) (Habets et al., 2018). Previous studies had also assessed the rotator cuff strength with isokinetic shoulder internal rotation (IR) and external rotation (ER) in overhead sports (Land et al., 2017). In that study, isokinetic concentric and eccentric shoulder IR and ER strength were measured in terms of peak torque (unit: Nm), as well as the ratio of ER/IR. Peak torque was defined as the maximum torque produced by the shoulder at any point of the range of motion and it was taken to represent the strength values (Perrin, 1993). In our study, the average peak torque value was normalized against each participant's own body weight (unit: Nm/kg) for analyzing purpose (Land et al., 2017).

Procedures

Diagnostic ultrasound imaging evaluation was conducted at the start of the study followed by the isokinetic strength examination. In these two assessments, both shoulders of each participant were tested separately.

Figure 3. Supraspinatus tendon evaluation using diagnostic ultrasound image.

Supraspinatus tendon evaluation with diagnostic ultrasound imaging

The SST was evaluated during the ultrasound examination (Figure 3). In order to expose SST for examination as described in American Institute of ultrasound in Medicine Practice guideline for the performance of a shoulder

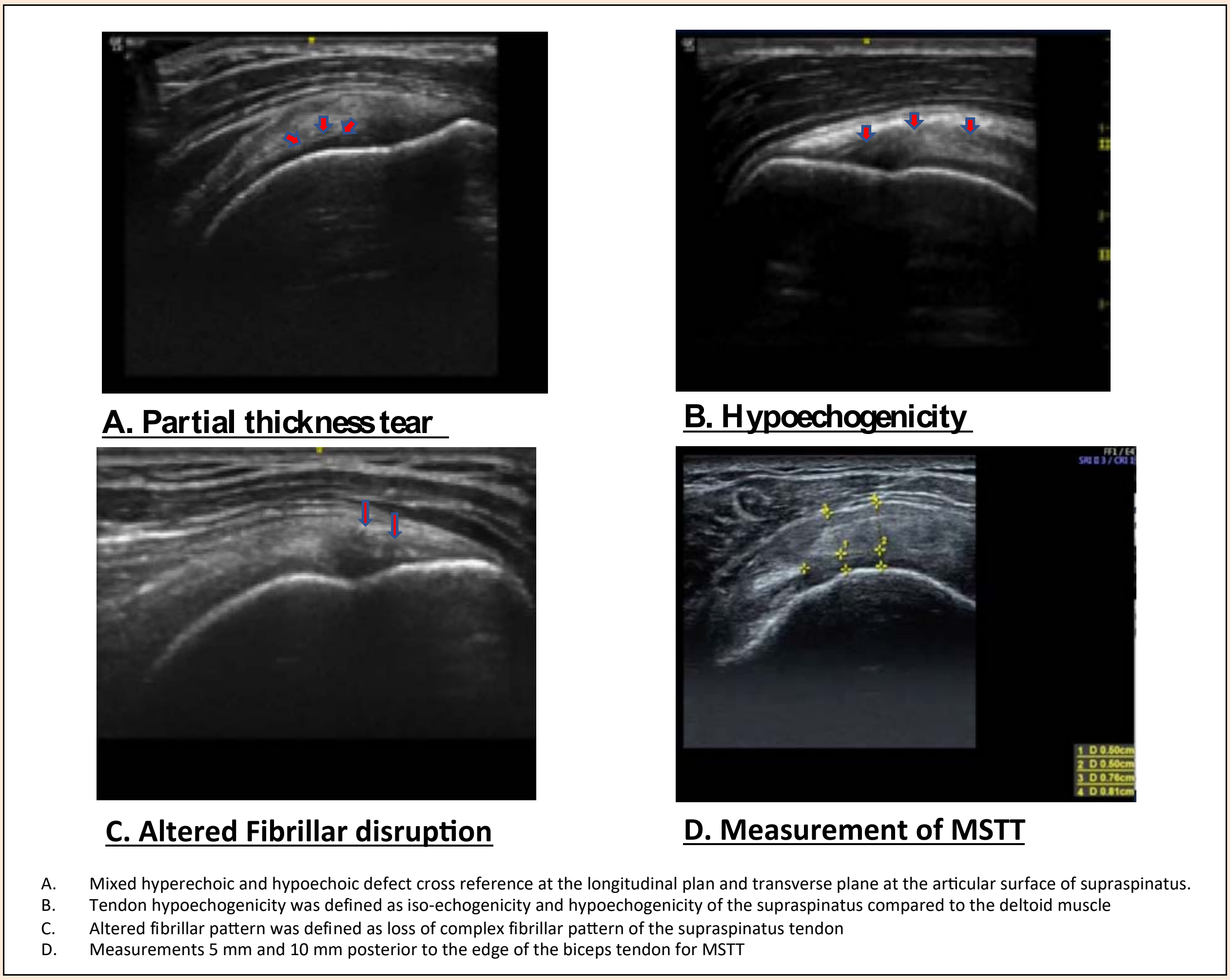

Figure 2. Supraspinatus tendinopathy/tear features in diagnostic ultrasound imaging.

ultrasound examination, participants were asked to extend the arm and internally rotate the shoulder, with the palm placed on the iliac wing ((AIUM), 2003).

A Diagnostic Ultrasound Scanner (Logiq e, GE Healthcare) was utilized for assessing the signs of tendinopathy in SST. A linear transducer of 5.0-13.0MHz was selected for examinations (Sein et al., 2010). Other ultrasound scanner parameters, such as gain control, time gain compensation controls, focal zones and frequency selection, were all selected by the assessor.

Shoulder rotation isokinetic strength assessment with isokinetic dynamometer

A Cybex Norm isokinetic dynamometer (Lumex, Inc., Ronkonkoma, New York, USA) was used to evaluate the IR and ER strength of swimmer shoulders. The setup of the isokinetic test was shown in Figure 4. The isokinetic test for shoulder muscle was performed in seated. The trunk of the participants was stabilized by the chest and pelvis straps. The glenohumeral joint (GHJ) was positioned at 45 degrees of abduction and 30 degrees of forward flexion. The elbow joint of the participants was fixed at 90 degrees of flexion and the forearm should be in neutral supination-pronation position. The axis of the dynamometer was aligned with the longitudinal axis of the humerus through the olecranon. During the assessment, the testing arm of participants held the handle of the test adapter and the other one grasped the stabilizing handle (Aguado-Henche, 2018; Jobe et al., 1989). It was suggested that less discomfort would be experienced by participants with a lower risk of shoulder anterior instability and subacromial impingement (Stickley et al., 2008).

Figure 4. Isokinetic test of shoulder strength by isokinetic dynamometer.

During the isokinetic test, both concentric (Con) and eccentric (Ecc) contractions of shoulder internal rotation (IR) and external rotation (ER) were assessed. Concentric contractions of IR and ER were tested first. Previous researches have shown that interclass correlation coefficients for IR and ER peak torque at 60 degrees/second in the scapular plane were high. The kappa value of IR was ranged from 0.82 to 0.86, and the kappa value of ER from 0.70 to 0.76 (Wilk and Arrigo, 1993).

The isokinetic test was performed at a speed of 60 degrees/second, through the range of 90 degrees, from 45 degrees of IR to 45 degrees of ER, since testing the strength at a relatively slow velocity could reduce the artefacts (Yildiz et al., 2006). Five submaximal contractions trials were first performed so that the participants could familiarize with the movements. After one-minute break, five maximal contractions were performed during testing session. Assessment of eccentric contractions of IR and ER were performed with the same procedure after two minutes rest. Standardized verbal encouragement was given by assessor one during the test. Bilateral shoulders were tested with the same procedures.

Statistical analysis

Means and standard deviations (S.D.) were calculated for age, height, weight, years of competition, total training sessions, training distance, as well as the average peak torque per body weight of isokinetic strength. The software SPSS 26.0 (International Business Machines Corporation, U.S.A.) was used to run statistical tests with threshold p-value of 0.05. A normality test has been used to check the sampling distribution. Pearson's r correlation (2 tailed) tests were performed to evaluate the correlations between (1) shoulder rotation strength or ER/IR ratio in isokinetic strength of shoulders and SST condition. and (2) shoulder rotation strength or ER/IR ratio and maximal supraspinatus thickness. Analysis of the both sides of the shoulder was conducted separately. Linear regression was used to predict the MSTT from ER/IR ratio in isokinetic strength of shoulders. The current study showed that the incidence of impingement findings had no significant difference between genders. Therefore, the statistical analysis is done with mixed genders.

Results

Demographics

44 swimmers were recruited (32 males and 12 females) in our study. Mean age was 21.48(±4.18) years. Average training sessions among swimmers were 7.40(±3.26) per week, training distance was 4407(±1195) meters per session and competitive years were 11.35(±2.95) years. 38 swimmers were right handedness and the same 38 swimmers with right preferential breathing side. 88 shoulders were examined, 26 shoulders were symptomatic and 62 shoulders were asymptomatic. The demographic and anthropometric data were listed in Table 2.

Ultrasound images

The results obtained from ultrasound scanning were summarized in Table 3. There were 18.18% of supraspinatus tendons showed partial thickness tear, 88.64% supraspinatus tendons showed altered fibrillary pattern and 54.55% supraspinatus tendons showed hypoechogenicity. 93.18% supraspinatus tendons were classified as tendinopathy (abnormal tendon structure), whereas only 6.82% of supraspinatus tendons were classified as normal. The mean of maximal supraspinatus thickness (MSTT) was 6.61(±1.04) mm in 88 shoulders and shoulders with maximal supraspinatus thickness > 6.0mm were 71.59% (Table 3).

Supraspinatus tendon structure versus pain

91.94% asymptomatic swimmers with abnormal tendon structure and 96.15% symptomatic swimmers with abnormal tendon structure (Table 3). Likewise, asymptomatic swimmers with maximal supraspinatus thickness more than 6.0mm were 69.84%; and symptomatic swimmers with maximal supraspinatus thickness more than 6.0mm were 64.0% (Table 3).

There was no significant association between supraspinatus tendon structure and shoulder pain ($p = 0.474$). Similarly, no significant association was found between maximal supraspinatus thickness and shoulder pain ($p = 0.178$).

Shoulder isokinetic strength

All swimmers' shoulders were tested and the results of concentric and eccentric contraction of both shoulder

Table 2. Demographic and anthropometric data of participants.

Characteristics of Swimmers		
Number of Swimmers	**Male**: 32, **Female**: 12 **32 are front crawl swimmers**	
Right Handedness	N=38	
Left Handedness	N=6	
Preferential breathing to Right side	N=38	
Preferential breathing to Left side	N=6	
Symptomatic Shoulders	N=26	
Asymptomatic Shoulders	N=62	
	Mean	**Standard Deviation**
Age	21.48	4.18
Height (m)	1.72	0.08
Weight (kg)	68.38	14.92
Competitive years	11.35	2.95
Swimming training (session/wk)	7.40	3.26
Training distance (m/session)	4406.82	1194.98

Table 3. Summary of supraspinatus tendon condition of participants.

	Total	Percentage
Full thickness tear	0	0.00%
Partial thickness tear	16	18.18%
Altered fibrillar pattern	78	88.64%
Tendon hypoechogenicity	48	54.55%
Normal tendon Structure	6	6.82%
Abnormal tendon structure (ATS)	82	93.18%
Asymptomatic with ATS	57	91.94%
Symptomatic with ATS	25	96.15%
MSTT>= 6mm	63	71.59%
MSTT< 6mm	25	28.41%
Asymptomatic with MSTT >= 6mm	44	69.84%
Symptomatic with MSTT >= 6mm	16	64.00%
	Mean	**Stand Dv**
Mean of MSTT (mm)	0.66	0.10

ATS: Abnormal tendon structure; MSTT: maximal supraspinatus tendon thickness. Unit: mm: millimeter.

internal rotation and external rotation were obtained. The mean of concentric internal rotation (Con IR) and eccentric internal rotation (Ecc IR) were 0.68 ± 0.14 and 0.74 ± 0.14 (Nm/kg) respectively. The mean of concentric external rotation (Con ER) and eccentric external rotation (Ecc ER) were 0.27 ± 0.08 and 0.36 ± 0.10 (Nm/kg) respectively. Mean ratio of Ecc ER/Con IR was 0.54 (± 0.11) and mean ratio of Con ER/Con IR was 0.40 (± 0.09). The mean and standard deviation of isokinetic strength were presented in Table 4.

Supraspinatus tendon versus shoulder strength (abnormal tendon structure vs isokinetic rotation strength)

The mean value of concentric internal rotation and eccentric internal rotation were larger in normal tendon group. However, those were not significant. For the mean eccentric internal rotation, similar results were shown between abnormal tendon structure group and normal supraspinatus tendon structure group (Table 5).

On the other hand, a significant correlation was found between left maximal supraspinatus thickness >6mm and left ER/Con ($r = 0.635$, $p = 0.02$) and left ER/Ecc ($r = 0.584$, $p = 0.036$) (Table 6). However, no significant association was found between maximal supraspinatus thickness and IR/Con or IR/Ecc.

Supraspinatus tendon versus shoulder strength ratio (ER/IR ratio in isokinetic strength)

The strength ratios of normal tendon were 0.66 ± 0.12 (Ecc ER/Con IR), 0.48 ± 0.08 (Con ER/Con IR), 0.43 ± 0.12 (Con ER/Ecc IR) and 0.59 ± 0.18 (Ecc ER/Ecc IR) (Table 7). The strength ratios of abnormal tendon were 0.53 ± 0.11 (Ecc ER/Con IR), 0.40 ± 0.09 (Con ER/Con IR), 0.37 ± 0.11 (Con ER/Ecc IR) and 0.48 ± 0.13 (Ecc ER/Ecc IR) (Table 7).

Table 4. Mean and standard deviation of isokinetic shoulder rotation strength results (n = 88.)

	mean (nm/kg)	standard deviation (nm/kg)
Con IR	0.68	0.14
Ecc IR	0.74	0.14
Con ER	0.27	0.08
Ecc ER	0.36	0.10
	Ratio	**Ratio**
Ecc ER/ Con IR	0.54	0.11
Con ER/ Con IR	0.40	0.09
Con ER/ Ecc IR	0.37	0.11
Ecc ER/ Ecc IR	0.49	0.13

Con: Concentric; Ecc: Eccentric; ER: External rotation; IR: Internal Rotation.

Table 5. Mean values of shoulder rotation strength by SST condition.

Tendon condition		Con IR (Nm/kg)	Ecc IR (Nm/kg)	Con ER (Nm/kg)	Ecc ER (Nm/kg)
Normal tendon (N=6)	Mean	0.67	0.76	0.32	0.45
	Standard Deviation	0.16	0.10	0.11	0.14
ATS (N=82)	Mean	0.68	0.74	0.27	0.36
	Standard Deviation	0.14	0.14	0.08	0.10

Con: Concentric; Ecc: Eccentric; ER: External rotation; IR: Internal Rotation; ATS: abnormal tendon structure

Table 6. Correlation between MSTT and shoulder rotational strength.

		Con IR	Ecc IR	Con ER	Ecc ER
LMSTT	Pearson’s Correlation	0.442	.431	0.635 *	0.584*
	Sig. (2-tailed)	0.131	0.142	0.02	0.036
RMSTT	Pearson’s Correlation	0.255	0.077	0.388	0.346
	Sig. (2-tailed)	0.476	0.833	0.268	0.328

Con: Concentric; Ecc: Eccentric; ER: External rotation; IR: Internal Rotation; df: degree of freedom; Sig.: significance probability; LMSTT: Left maximal supraspinatus tendon thickness; RMSTT: Right maximal supraspinatus tenson thickness

Table 7. **Mean values of shoulder rotation strength ratio by SST condition**

Tendon Condition		Ratio (Ecc ER/ Con IR)	Ratio (Con ER/ Con IR)	Ratio (Con ER/ Ecc IR)	Ratio (Ecc ER/ Ecc IR)
Normal Tendon	Mean	0.66	0.48	0.43	0.59
	Std. Deviation	0.12	0.08	0.12	0.18
ATS	Mean	0.53	0.40	0.37	0.48
	Std. Deviation	0.11	0.09	0.11	0.13

Con: Concentric; Ecc: Eccentric; ER: External rotation; IR: Internal Rotation; ATS: abnormal tendon structure; std. deviation: standard deviation

Table 8. **Linear regression between MSTT and ER/IR ratio.**

		R	Adjusted R square	F value	Sig.
LMSTT>6mm LMSTT<6mm	Linear Regression	0.734*	0.462	7.016	P=0.038
RMSTT>6mm	Linear Regression	0.254	-0.169	0.277	P=0.627
RMSTT<6mm		0.073	-0.492	0.011	P=0.927

ER: External rotation; IR: Internal Rotation; Sig.: significance level; MSTT: maximal supraspinatus tendon thickness.

Simple linear regression was used to predict the maximal supraspinatus thickness from IR/ER ratio in isokinetic strength. It showed that ER/IR ratio is a significant predicator on left maximal supraspinatus thickness (R^2 = 0.462, F = 7.016, df = 1, p = 0.038). IR/ER ratio accounted for 46% of the variance of left maximal supraspinatus thickness (Table 8). However, there was no association between right maximal supraspinatus thickness and shoulder ER/IR ratio when taken maximal supraspinatus thickness > 6mm as a diagnostic criterion for supraspinatus tendon tendinopathy.

Discussion

We hypothesized that structural abnormality of SST is associated with shoulder pain and negatively associated with shoulder muscle strength in elite swimmers. In this study, the results showed that (1) there was no association between SST abnormality and shoulder pain and (2) there was a significant correlation between LMSTT and L ER/Con and LER/Ecc shoulder strength ($p < 0.05$) while ER/IR ratio can also be a significant predicator on LMSTT > 6mm.

This study showed that majority of the elite swimmer's shoulders were presented with supraspinatus tendinopathy (93.18%). A high prevalence of supraspinatus tendinopathy was found in our study and was consistent with other studies (Celliers et al., 2017; Dischler et al., 2018; Sein et al., 2010; Suzuki et al., 2020). Some of the authors studied shoulder structural abnormalities using MRI imaging among elite swimmers and revealed 46.7% to 69% prevalence of supraspinatus tendinosis (Celliers et al., 2017; Dischler et al., 2018; Sein et al., 2010; Suzuki et al., 2020). Our results revealed a higher prevalence rate than those studies (93.18% vs 46.7% to 69%). It might due to the fact that not only SST tendinosis was included, but also SST tendon changes, such as AF. Nonetheless, their findings were close to our results of defining MSTT >6mm as SST tendinopathy which contained 71.59% in all elite swimmers. Suzuki et al. (2020) has also found the prevalence of SST tendinosis was significantly higher among the swimmers (75%) than the age-matched control group (17.5%)(Suzuki et al., 2020). Our current study agreed with Suzuki et al. (2020) that swimmers were susceptible to develop SST tendinosis and SST tendinopathy.

Supraspinatus tendon structure vs pain

We found a non-significant association between supraspinatus abnormality structural changes and shoulder pain (p = 0.474); and non-significant association between MSTT and shoulder pain (p = 0.176). Our result agreed with Brasseur et al. (2004) that no relationship was found between current pain and the presence of a supraspinatus tendinopathy in sportsmen performing overhead sports (Brasseur et al., 2004). The lack of association between pain and supraspinatus tendon abnormality can be explained by the fact that swimmers' shoulder pain could be caused by various shoulder pathologies, including labral damage, shoulder laxity, neuropathy from nerve entrapment and anatomic anomalies (Matzkin et al., 2016). Similarly, other studies (Fredberg & Bolvig, 2002; Khan et al., 1997; Leung & Griffith, 2008) recruited asymptomatic athletes had also revealed tendinosis or tears in their patellar/Achilles tendons. All these findings supported a poor relationship between tendon structural abnormalities and pain. Therefore, shoulder pain is not the best indicator for shoulder tendinopathy among swimmers. Also, ATS was identified among the majority of asymptomatic swimmers (93.18%), and there was a substantial portion of asymptomatic shoulder with MSTT > 6.0mm (69.84%). Hence, most of the asymptomatic swimmers have different level of supraspinatus tendon pathologies.

Supraspinatus tendon structure versus strength

Our results showed that the shoulder mean Con IR strength (0.68+/-0.14) Nm/kg was greater than mean Con ER strength (0.27+/-0.08) Nm/kg. Similar results were revealed in the study conducted by Bak and Magnusson (IR: 0.57-0.74Nm/kg, ER: 0.37-0.49Nm/kg) (Bak & Magnusson, 1997). This could be explained by the shoulder IR was the major muscle for propulsion movement during the acceleration phase of swimming (Liaghat et al., 2018).

Our findings had showed that a significant correlation was found between left MSTT > 6mm and L ER/Con (r = 0.635, p =0.02) and L ER/ Ecc (r = 0.584, p = 0.036)

(Table 7). However, no significant association was found between MSTT and IR/Con or IR/Ecc.

This could be explained by the role of supraspinatus muscle in shoulder movement in swimming. Besides initializing shoulder abduction and external rotation, SST can also act as a stabilizer working together with trapezius, rhomboids and middle and anterior deltoid during recovery phase of front crawl stroke (Pink et al., 1991). Different level of SST pathologies might cause weaker ER and lead to shoulder instability which could be a potential cause of symptoms. On the contrary, the role of different rotator muscles in front crawl swimming could be another cause of this finding. An imbalance of ER/IR of shoulder will alter swimming pattern and cause difference in dynamic instability.

Our results of association between MSTT and shoulder muscle isokinetic strength in this study were in lined with other studies. Such result agreed with MacDermid et al. (2004) about the association between rotator cuff pathology and strength. They revealed that the shoulder internal and external rotation strength were significantly decreased in the group with rotator cuff pathology ($P < 0.05$). However, Zanca et al. (2011) has also found that IR strength of athletes with shoulder impingement was less (0.47 0.49Nm/kg) than the group without shoulder impingement (0.51 - 0.53Nm/kg) Bujalance-Moreno et al. (2019). It may probably due to their findings were based on shoulder impingement but not SST structure.

There was previous study investigated the relationship between ultrasound image and muscle strength in elite swimmers' shoulders. Those studies reported that 83.8% of 90 subjects with ultrasound abnormal findings in rotator cuff muscles were significantly weaker in all shoulder muscle strength (Jigami et al., 2018). That is in congruent with our findings despite they measured shoulder muscle strength with a hand-held dynamometer (HHD) instead of isokinetic dynamometer. Besides of the limitation of HHD in testing moving limbs, Muff et al. (2016) has also suggested that HHD is not a valid option for strength ratio assessment (Muff et al., 2016). Whereas, we found that there was a specific association between supraspinatus tendon abnormality and shoulder Ecc ER strength in swimmers with ultrasound evaluation and isokinetic dynamometer. A more precise and specific finding is warranted to help clinicians to optimize the understanding of "swimmers' shoulder".

Clinical implications

Our results suggested that supraspinatus tendon abnormalities were identified among the majority of asymptomatic swimmers. Ultrasound imaging might serve as a prime prognostic or screening tool for both symptomatic and asymptomatic swimmers for early identification of tendon abnormalities before high intensity swimming training. Since pain is a subjective and complex entity, and can be perceived differently between individuals, asymptomatic swimmers prone to develop high risk of tendon tendinopathy. Thus, early detection of tendon abnormality in elite swimmer's shoulders is crucial to prevent future rotator cuff tendons damages. Therefore, future longitudinal studies with long follow-up should be considered to investigate how well the current asymptomatic tendon abnormality would predict the development of future symptoms.

Since ER/IR ratio is identified associating with supraspinatus tendon abnormality; pre-season training can focus more on the shoulder rotation program to prevent sports injury in elite swimmers' shoulders. Furthermore, the training program can target on eccentric strength of shoulder external rotators although the target ratio of ER/IR needs further investigations. The isokinetic shoulder strength to predict the risk for supraspinatus tendinopathy for swimmers is also warranted for future study.

Limitation of study

The SST of participants were unknown prior this study which has led to a different number of subjects for comparisons among the groups. Moreover, this research examined the supraspinatus tendon only. Studies on other rotator cuff muscles like infraspinatus and subscapularis muscles could also be conducted in the future since those muscles also contributed to shoulder IR and ER in overhead swimming.

Conclusion

This study showed that majority (93.18%) of elite swimmer's shoulders examined presented with supraspinatus tendinopathy. There were 91.94% asymptomatic swimmers with ATS and 96.15% symptomatic swimmers with ATS. Meanwhile, 71.59% of shoulders had MSTT > 6.0mm. Asymptomatic swimmers with MSTT more than 6.0mm were 69.84% and symptomatic swimmers were 64.0% respectively. Based on the statistical analysis, we conclude that there was no significant association between SST structure and shoulder pain.

The mean Ecc ER strength of the group with ATS (0.36+/-0.10 Nm/kg) was significantly less than that of the group with normal SST (0.45+/- 0.14 Nm/kg) ($p = 0.033$). We found that there was a significant negative association between ATS and ER/IR ratio in Ecc ER/con IR ratio ($p = 0.005$) and con ER/con IR ratio. ($p = 0.020$).

As a result, early detection of supraspinatus tendon structural changes with the use of ultrasound imaging in swimmers is warranted to help healthcare practitioner or coaches to design a precise training program and rehabilitation protocol for tendon injury preventions.

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Key points

- Coaches and practitioners may take advantage of the effectiveness of a single limb body-weight conditioning activity, such as, i.e., alternating leg bounds as a part of pre-competition warm- ups to enhance subsequent performance without needing specific equipment.
- The effectiveness of conditioning activity exercises appears to be force-vector specific, i.e., vertical drop jumps improve vertical jump performance, while horizontal drop jumps enhance sprint and change of direction performance.
- The effects of single limb conditioning activity on the contralateral limb have not been thoroughly examined. However, the limited evidence shows that the post-activation performance enhancement effect is mainly local.

AUTHOR BIOGRAPHY

Billy Chun Lung SO
Employment
Assistant professor from Department of Rehabilitation Sciences in The Hong Kong Polytechnic University
Degree
PhD
Research interests
Ergonomics in work safety and health, aquatic therapy in anterior cruciate ligaments injuries and swimming performance enhancement and evaluation.
E-mail: billy.so@polyu.edu.hk

Wan Yu KWOK
Employment
Ph.D. student from Department of Rehabilitation Sciences in The Hong Kong Polytechnic University.
Degree
MSc
Research interests
Sports performance and biomechanical evaluation of athletic performance.
E-mail:wan-yu-aryu.kwok@connect.polyu.hk

Daniel Hon Ting TSE
Employment
Physiotherapist and former Hong Kong SAR Swimming Team representative.
Degree
BSc
Research interests
Swimming performance enhancement and evaluation, and also anterior cruciate ligaments injuries and aquatic physiotherapy
E-mail: httse@polyu.edu.hk

	**Stan Cheuk Ting LAU** **Employment** Physiotherapist in Hong Kong Sanatorium & Hospital **Degree** MSc **Research interests** Manual therapy **E-mail:** cheukting.lau@hksh.com
	**Siu Shing MAN** **Employment** Postdoctoral Fellow from Department of Rehabilitation Sciences in The Hong Kong Polytechnic University **Degree** PhD **Research interests** Biomechanial Evaluation, Health and Safety **E-mail:** ss1man@polyu.edu.hk

✉ **Dr. Billy Chun Lung So**
Assistant Professor, ST506, Ng Wing Hong Building, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Chine