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Altered Functional and Structural Measures in Masters Swimmers With Shoulder Pain and Disability

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Context: Supraspinatus tendinopathy and shoulder pain are common in competitive youth swimmers. However, no researchers have investigated clinical and structural factors contributing to shoulder pain and disability in masters-level swimmers.

Objective: To (1) determine the prevalence of shoulder pain and disability in masters-level swimmers; (2) identify the most provocative special tests for shoulder pain; and (3) determine if shoulder clinical and tissue-specific measures, training variables, and volume varied between those with and those without shoulder pain, dissatisfaction, and disability.

Design: Cross-sectional study.

Setting: Collegiate swimming facilities.

Patients or Other Participants: Thirty-nine adult masters-level swimmers.

Main Outcome Measure(s): Demographics, training, and pain and disability ratings using the Penn Shoulder Score and Disability of Arm, Shoulder, and Hand sports module were surveyed. Swimmers underwent a clinical examination that consisted of passive range of shoulder motion, posterior shoulder endurance test, and supraspinatus tendon structure and posterior capsule thickness. One-way analyses of variance were used to compare demographic, clinical, and structural findings between those with significant (positive) pain, dissatisfaction, and disability (+PDD) and those without (negative) pain, dissatisfaction, and disability (–PDD).

Results: Pain was reported by 15% of participants at rest, 28% with normal activities (eating, dressing), and 69% with strenuous activities (sports); 50% reported disability. The +PDD group had less shoulder internal rotation (10°) and less external rotation (8°) and completed less yardage per day and per year. Differences were noted in supraspinatus tendon structure between the +PDD and –PDD groups.

Conclusions: Masters swimmers with pain and disability were able to self-limit yardage, which was likely the reason they recorded less yardage. The reduced shoulder motion (internal and external rotation) without posterior capsule differences may be due to rotator cuff muscle and tendon restrictions; the supraspinatus tendon structure may reflect degeneration caused by previous overuse that resulted in pain.

Key Words: tendinopathy, tendon organization, range of motion

Key Points

- The Jobe empty can test was the most provocative shoulder test for masters-level swimmers.
- Of the masters swimmers, 5% reported swimming-related disability and 69% reported pain with sport participation.
- Masters swimmers with significant shoulder pain, dissatisfaction, and disability had less shoulder internal and external rotation range of motion and displayed altered supraspinatus tendon structure. They swam fewer yards than their less symptomatic counterparts.

It is estimated that more than 3 million individuals swim on competitive teams in the United States.[1] The repetitive nature of training has been associated with a high rate of shoulder pain; the reported prevalence ranged from 40% to 91%.[2–4] In addition, the combination of training volume plus the load on the shoulder during swimming can lead to both clinical and tissue-specific adaptations, ultimately resulting in symptoms. Clinical differences between swimmers with and those without shoulder pain and disability include decreased shoulder strength and range of motion (ROM) and reduced shoulder or core endurance, whereas tissue-specific adaptations include reduced pectoralis minor length.[4] However, other tissue-specific alterations, such as posterior capsule hypertrophy and supraspinatus tendon structure, have not been examined. Posterior capsule hypertrophy and increased stiffness have been demonstrated in the shoulders of baseball players but have not been examined in swimmers.[5,6] A tight and hypertrophied posterior capsule can decrease glenohumeral internal rotation.[5] In addition, a tight posterior capsule in cadaver shoulders was shown to shift the humeral head in an anterior-superior direction during internal rotation,[7] which could increase subacromial impingement during the hand entry–early catch and recovery phases of the freestyle stroke.[8] Over time, this repetitive compression could lead to rotator cuff degeneration and tearing.

The supraspinatus tendon has often been identified as a cause of pain and disability in swimmers who were diagnosed with impingement or supraspinatus tendinopathy or tears (or a combination of these). Researchers[3,9] suggested that the development of tendinopathy in swimmers was volume induced and stemmed from chronic repetition during practices, over a season, and throughout years of swimming. Interestingly, no authors have demonstrated structural changes to the supraspinatus tendon in masters swimmers. In addition, due to the abundance of shoulder special tests, clinicians often struggle with the best pain-provocation test in swimmers.

Therefore, the objectives of our investigation were to (1) determine the prevalence of shoulder pain and disability in masters-level swimmers; (2) identify the most provocative special tests for shoulder pain in masters swimmers for future use in screening programs; and (3) determine if shoulder clinical and tissue-specific measures, training variables, and volume vary between those with and those without shoulder pain, dissatisfaction, and disability.

METHODS

Research Design

A cross-sectional design was used to examine the objectives. The independent variables were the positive pain and disability (+PDD) group versus the negative pain and disability (–PDD) group. The dependent variables were glenohumeral ROM, endurance, posterior capsule thickness (PCT), and supraspinatus tendon structure.

Participants

A total of 39 swimmers, consisting of 20 men (age = 52 ± 11 years old, height = 182 ± 5 cm, mass = 84.9 ± 10.5 kg) and 19 women (age = 41 ± 12 years old, height = 168 ± 8 cm, mass = 67.9 ± 11.1 kg) from 3 teams currently participating or practicing in a US Masters Swimming program, completed this cohort study. All details of the investigation were orally explained to the swimmers before data collection, and they read and signed an informed consent form that was approved by the institutional review board, which approved all procedures. Participants then filled out a general health history questionnaire, which was used to assess eligibility for the research. Swimmers who had shoulder surgery in the past 6 months were excluded from the investigation. Data collection occurred at the swimming team's local pool before swimming practice and consisted of completion of a written survey, a clinical examination, and ultrasound imaging of the PCT and supraspinatus tendon structure. All measures were obtained bilaterally.

Pain, Dissatisfaction, and Disability

The health history questionnaire addressed demographics, shoulder injury history, quantity of swim training, and other sport and training information. In addition, the pain and satisfaction sections of the Penn Shoulder Score were used to determine pain levels at rest, with normal activities, and with strenuous activities, and the Disability of the Arm, Shoulder and Hand (DASH) sports module identified swimming-related disability. These self-report measures were also used to stratify participants into the +PDD or –PDD group based on previous research.[4,10] Swimmers were included in the +PDD group if they met 2 criteria: (1) A score of $<$35 of 40 points on the Penn Shoulder Score pain and satisfaction subsection; and (2) a DASH sports module score of $\geq$6 points, which indicates at least mild difficulty in 3 of the 4 areas or moderate or severe difficulty or inability in at least 1 of the 4 areas.

Clinical Examination

To assess participants for current symptoms, the clinical examination consisted of the following tests: Neer and Hawkins impingement,[11] infraspinatus (external-rotation resistance), painful arc, drop arm,[11] Jobe empty can,[12] and infraspinatus external-rotation lag sign.[13] In addition, if the empty can test was positive for pain (rated 1 to 10 on a numeric pain-rating scale) or weakness, it was repeated with the scapular reposition test,[14] and any symptom alteration was documented. If a painful arc was present, a modified scapular assistance test[15] was performed to determine if pain decreased. The tests were performed by an experienced licensed physical therapist.

Glenohumeral Range of Motion

Glenohumeral internal rotation (IR) and external rotation (ER) were measured using a digital inclinometer (PRO 360 Digital Protractor, SmartTool Technologies) as previously described.[16] The participant was positioned supine, with the arm in 90° of shoulder abduction and the scapula stabilized manually by the examiner to isolate glenohumeral motion. The digital inclinometer was placed on the ulnar side of the forearm to record both IR and ER. For all passive ROM measures, a licensed physical therapist stabilized the scapula and passively moved the shoulder into position while a second examiner recorded the inclinometer value. The physical therapist was blinded to the inclinometer values. Measurements were repeated 3 times and averaged. We established the SEMs for IR and ER on athletically active adults as 3.01° and 3.75°, respectively (unpublished data).

Glenohumeral horizontal adduction (HADD) was measured according to Myers et al.[17] The participant was positioned supine, with the dominant arm in 90° of shoulder flexion. He or she was then instructed to perform bilateral scapular retraction while the examiner passively stabilized the scapula with 1 hand and moved the shoulder into HADD with the other hand, maintaining neutral humeral rotation until a firm end-feel was identified. A second examiner placed the inclinometer on the lateral aspect of the arm and aligned it with the humerus. We determined that the SEM for HADD ROM in a reliability study was 4.0° (unpublished data).

Posterior Shoulder Endurance

For the posterior shoulder endurance test (PSET), the participant was positioned prone on a plinth with the testing arm hanging off the edge of the plinth in a relaxed position as described by Moore et al.[18] In this position, he or she held a dumbbell equaling 2% of body weight (rounded to the nearest 0.5 lb [0.23 kg]). A movable clamp placed on a vertically oriented metal rod was adjusted to a height that would limit shoulder HADD to 90° (Figure 1). The

Figure 1. Patient position during the posterior shoulder endurance test.

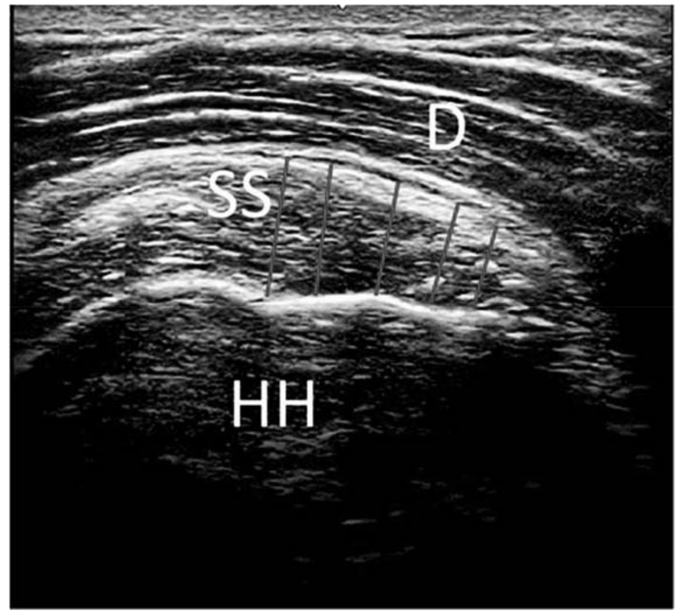

Figure 2. Representative ultrasound image of the supraspinatus tendon (SS), humeral head (HH), and deltoid (D). Vertical lines represent measurement locations along the supraspinatus tendon footprint.

participant was then asked to move the shoulder into HADD until contacting the clamp and hold that position for 1 second before lowering back to the starting position. This was continued at a cadence of 30 beats per minute (controlled by a metronome). The test was continued until the participant demonstrated any of the 3 signs of fatigue: (1) inability to hold the arm at the top of the arc for the required duration (1 second), (2) compensation with elevation of the entire upper torso, or (3) inability to continue.

Posterior Capsule Thickness

The PCT was measured using ultrasound as previously described and validated.[5] The participant was positioned upright in a chair with the arm at the side and forearm resting on the thigh. The examiner positioned a 15-MHz linear transducer (LOGIQ e, GE Healthcare) on the posterior shoulder, visualizing the glenoid labrum, humeral head, rotator cuff, and *posterior capsule* (defined as the tissue immediately lateral to the tip of the labrum between the humeral head and rotator cuff). A standard B-mode image was captured, and the PCT was measured using ImageJ software (National Institutes of Health); the SEM for this technique was 0.2 mm.[5]

Supraspinatus Tendon Structure

Supraspinatus tendon structure was measured using ultrasound as described previously.[16] The participant was positioned upright in a chair in the modified Crass position. The examiner positioned the 15-MHz linear transducer on the anterior shoulder to obtain a longitudinal view of the supraspinatus tendon. The transducer was then moved anteriorly and posteriorly across the tendon until the center of the tendon was identified, and an image was saved. The examiner moved the transducer anteriorly from the center position until a clear view of the anterior portion of the supraspinatus tendon was available, and an image was saved. Last, the examiner went back to the center region of the tendon and then moved posteriorly until a clear view of the posterior portion of the supraspinatus tendon was present, and an image was saved.

Supraspinatus Tendon Image Analysis

The 3 ultrasound images from each shoulder were analyzed by the same examiner using custom MATLAB software (The MathWorks, Inc). For each image, the examiner identified the supraspinatus footprint and placed vertical lines at the most medial and lateral aspects of the footprint. Next, a vertical line was drawn in the middle of the existing lines. Finally, 2 remaining vertical lines were placed, bisecting both the medial and lateral 2 lines. This created 5 vertical lines throughout the supraspinatus footprint. Care was taken to include only the thickness of the supraspinatus tendon and to keep the vertical lines perpendicular to the longitudinal collagen bundles observed as hyperechoic lines (Figure 2).

We then applied a 1-dimensional (1-D) fast Fourier transform (FFT) to the resulting intensity-versus-length data from each line. The results were used to determine the spatial frequency at peak spectral power, termed the *peak spatial frequency* (PSF), and the banding period (distance between peaks). The PSFs and banding periods for all 5 lines were averaged for each image, and then this value was averaged across all 3 images (anterior, center, and posterior) for each tendon. Because collagen bundles were responsible for increased intensity on the ultrasound image,[19] the PSF was inversely related and the banding period was directly related to the spacing between collagen bundles. By averaging across the proximal-to-distal and the anterior-to-posterior borders of the supraspinatus, the PSF and banding period represented the average spacing between collagen bundles throughout the thickness and volume of the supraspinatus footprint. Our SEM for this technique was 0.08 peaks/mm (unpublished data). We

Table 1. Demographics, Swimming Frequency, and Yardage Between +PDD and −PDD Groups With Associated *P* Values and Cohen D Effect Sizes

Variable	Group +PDD	Group −PDD	*P* Value	Effect Size
Sample size, No.	13	26		
	Mean ± SD			
Age, y	49.3 ± 11.3	45.8 ± 12.9	.4	0.289
Body mass index	24.6 ± 3.4	25 ± 3.1	.8	0.123
Years on team	21.2 ± 14.5	25 ± 14	.4	0.267
Months swimming each year	11 ± 1.3	11.4 ± 1.3	.4	0.308
Days swam/wk	2.8 ± 0.9	3.3 ± 1.2	.2	0.471
Hours swam/wk	3.8 ± 1.8	4.5 ± 1.7	.2	0.4
Yards swam/d	2846 ± 773	4224 ± 2248	.04[a]	0.82
Yards swam/y	90 323 ± 44 217	167 585 ± 101 064	.013[a]	0.991

Abbreviations: +PDD, positive pain, dissatisfaction, and disability; −PDD, negative pain, dissatisfaction, and disability.

[a] Difference between groups ($P \leq .05$).

measured tendon thickness at the center line for each ultrasound image and averaged the anterior, center, and posterior images for a representative average tendon thickness.

Statistical Analysis

To assess objective 1, descriptive data were computed for all variables and used to determine the prevalence of shoulder pain and disability among all swimmers. Objective 2 was evaluated by calculating the frequency of the pain-provocation tests. In addition, the effect of the scapular reposition test on symptom alteration in those with a positive Jobe empty can test and the effect of the modified scapular assistance test on symptom alteration in those with a painful arc were determined. For objective 3, a χ^2 test was used to compare the +PDD and −PDD groups' frequency of pool- and land-based training variables. Next, we calculated an age- and involved-arm-control matched 1-way analysis of variance to compare the +PDD and −PDD groups' demographics, ROM, posterior shoulder endurance, PCT, and supraspinatus tendon structure. For the +PDD group, if the participant had bilateral pain, the data from the more painful shoulder were used; if the participant had unilateral pain, the painful shoulder data were used for analysis. Last, Cohen *d* effect size was calculated for all variables.

RESULTS

Descriptive and Training Data

As described in the Methods section, participants were categorized based on their responses to the Penn and DASH scales, resulting in 13 +PDD and 26 −PDD participants. The groups did not differ by age, body mass index, years swimming, months swimming per year, days or hours of swimming per week (Table 1), or any of the land-based training variables (Table 2), except for yards per day ($P = .04$, Cohen $d = 0.82$) and yards per year ($P = .013$, Cohen $d = 0.991$).

Table 2. Land-Based Training of Swimmers in the +PDD and −PDD Groups

Training Variable	Group, % +PDD	Group, % −PDD	*P* Value
Dry land	8	12	.7
Participant in other sports	8	12	.7
Weight training	31	62	.07
Triathlon	0	19	.09
Running	23	42	.2

Abbreviations: +PDD, positive pain, dissatisfaction, and disability; −PDD, negative pain, dissatisfaction, and disability.

Provocation Tests and Pain and Disability

The frequencies of positive special tests for the right and left shoulders for the 39 swimmers are shown in Table 3. The percentages of swimmers with pain rated ≥1 at rest, with normal activities, and with strenuous activities in the Penn Shoulder Score, as well as swimming-related disability on the DASH sports module are reported in Figure 3. The mean pain ratings under the same conditions are shown in Figure 4.

Posterior Shoulder Endurance and Range of Motion

The PSET performance did not differ between the +PDD and −PDD groups ($P = .1$, Cohen $d = 0.548$). However, +PDD swimmers had a 10° decrease in passive IR ($P = .009$, Cohen $d = 0.919$) and an 8° decrease in ER ($P = .02$, Cohen $d = 0.824$), resulting in an 18° decrease in the total

Table 3. Positive Special Shoulder Tests

Provocative Test	Shoulder, % Positive Right	Shoulder, % Positive Left
Neer	15.3	13.1
Hawkins	12.8	18.4
Infraspinatus external-rotation resistance	7.6	5.1
Painful arc	2.5	12.8
Scapular assistance (% of those with + painful arc with a decrease in pain or significant increase in elevation range of motion with modified scapular assistance test)	100 (1/1)	80 (4/5)
Drop arm	0	0
Jobe empty can	48.7	56.4
Scapular reposition (No. with + Jobe empty can test and decreased pain with this test)	63.1 (12/19)	77.2 (17/22)
External-rotation lag sign	2.5	0
Presence of at least 1 positive test	53.8	61.5

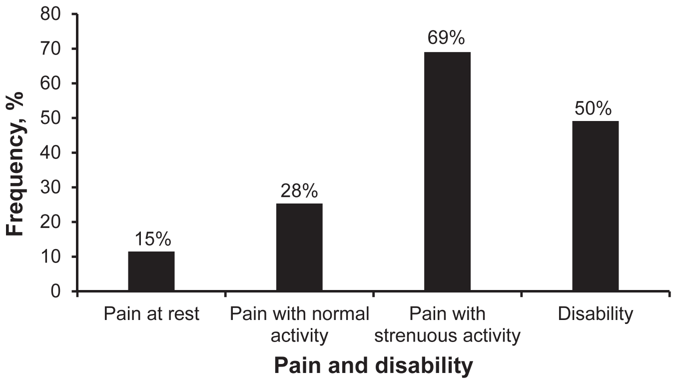

Figure 3. Frequency (%) of swimmers with a pain rating of ≥1 at rest, with normal activities, and with strenuous activities as well as swimming-related disability. Data were collected from the Penn Shoulder Score and the Disability of Arm, Shoulder and Hand (DASH) sports module.

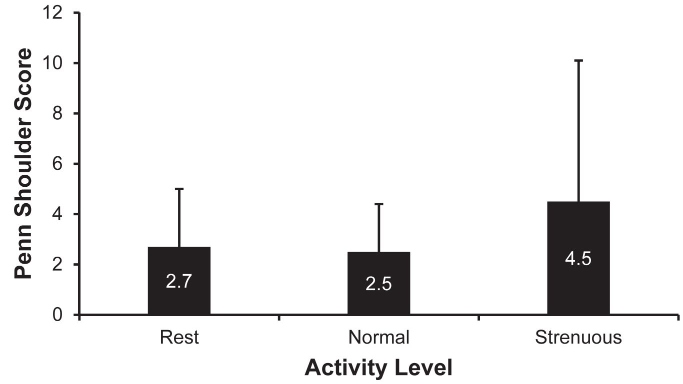

Figure 4. Self-reported pain ratings (mean ± SD) of swimmers at rest, with normal activities, and with strenuous activities. Data were collected from the Penn Shoulder Score.

arc of motion ($P = .001$, Cohen $d = 1.325$) when compared with the −PDD group. Consistent with this, the +PDD group had 8° less HADD ($P = .04$, Cohen $d = 0.586$; Table 4).

Posterior Capsule Thickness

No difference was present between the +PDD and −PDD groups for PCT ($P = .3$; Figure 5).

Supraspinatus Tendon Structure

The PSF increased ($P = .02$, Cohen $d = 0.943$) and banding period decreased ($P = .01$, Cohen $d = 1.21$) in the +PDD group compared with the −PDD group. Tendon thickness did not differ between groups ($P = .9$, Cohen $d = 0.042$; Table 5).

DISCUSSION

Provocation Testing

We found that most participants had signs of subacromial pain syndrome: 53.8% (21 of 39) and 61.5% (24 of 39) had at least 1 positive provocation test on the right and the left sides, respectively. The Jobe empty can test was the most provocative test; it was positive for pain and/or weakness in 91.1% (41 of 45) of symptomatic cases and was improved in 63.1% (12 of 19 on the right) and 77.2% (17 of 22 on the left) of these cases with the scapular reposition test during subsequent empty can testing. These data suggest that clinicians performing screening examinations of masters swimmers should incorporate the empty can test into their protocol. The Hawkins test was the next most provocative test, followed by the Neer test. Although the majority of swimmers' symptoms with a positive painful arc were reduced when the test was repeated using the modified scapular assistance test, symptom provocation with the painful arc test was low, so conclusions should not be drawn due to the small sample size.

Pain and Disability

Our results demonstrated that pain was experienced by 15% of masters swimmers with rest, 28% with normal activity, and 69% with strenuous activities. Previous researchers[4] who investigated symptoms across the life-spans of competitive swimmers determined that pain was present in 19% of female masters swimmers with rest, 19% with normal activity, and 64% with strenuous activities as indicated in the Penn Shoulder Score. Interestingly, in an earlier study,[4] 19% of female masters swimmers had +PDD using the same criteria, compared with 33% of male and female masters swimmers in our current study, in which 51% of swimmers were male, which would imply a higher prevalence of symptoms in males. Wymore and Fronek[20] did not find a difference in shoulder function between male and female collegiate swimmers using Kerlan-Jobe Orthopaedic Clinic scores, and we are not aware of any other authors who compared shoulder pain or function between male and female adult swimmers; therefore, the effect of sex on symptoms requires further exploration. Another possible explanation for the higher prevalence of pain and disability in our current work is that the mean age of swimmers was 5 years older than in the previous

Table 4. Glenohumeral Range of Motion and Posterior Shoulder Endurance Between +PDD and −PDD Groups

Variable	Group, Mean ± SD		P Value	Effect Size (Cohen d)
	+PDD	−PDD		
Glenohumeral range of motion, °				
External rotation	90.1 ± 8.7	98 ± 10.4	.02[a]	0.824
Internal rotation	26 ± 12.2	36.5 ± 10.6	.009[a]	0.919
Total motion	116.1 ± 11.1	134.5 ± 16.2	.001[a]	1.325
Horizontal adduction	74 ± 15.5	81.8 ± 10.7	.04[a]	0.586
Posterior shoulder endurance test, repetitions	29.8 ± 15	40.7 ± 23.8	.1[a]	0.548

Abbreviations: +PDD, positive pain, dissatisfaction, and disability; −PDD, negative pain, dissatisfaction, and disability.

[a] Difference between groups ($P \leq .05$).

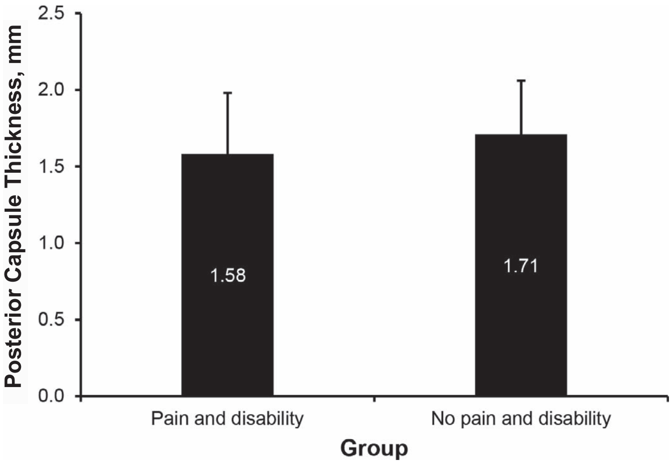

Figure 5. Posterior capsule thickness (mean ± SD) between the positive pain, dissatisfaction, and disability and the negative pain, dissatisfaction, and disability groups.

investigation. Given that shoulder tendinopathy is commonly related to both intrinsic factors (eg, age) and extrinsic factors (eg, external loading), the differences in age and exposure may explain the findings. In a previous report,[4] the mean years swam were 15 and 22 for the +PDD and –PDD groups, respectively, compared with 21 and 25, respectively, in the current investigation. It is surprising that in both studies, the +PDD group had fewer years of swimming participation than their less symptomatic counterparts, although the difference was not significant. This leads one to consider the role of intrinsic factors (eg, age) in symptom production.

Demographics Including Pool- and Land-Based Training

We did not find differences between the +PDD and –PDD groups when comparing age, body mass index, years on team, hours swam per week, or months swimming each year. However, the groups differed regarding the yardage swam per day and yardage swam per year. The +PDD group swam an average of 2846 yards per day, compared with 4224 yards per day for the –PDD group. Therefore, the –PDD group swam on average 1378 yards more than the +PDD group. Consistent with this, the –PDD group swam on average 77 262 more yards per year than the +PDD group. This is the opposite relationship than was found in youth swimmers, as greater swimming exposure in time and yardage was associated with shoulder pain and supraspinatus tendinopathy.[3] Although youth swimmers may be required to complete the training program provided by their coaches to maintain their status on the team, masters swimmers can normally self-regulate their yardage as programs are generally less rigorous and allow for individual variations in training volume.

Posterior Shoulder Endurance Test and ROM

No differences in the PSET were observed between the +PDD and –PDD groups. We used the method described by Moore et al,[18] which involved repeated lifting and lowering of a dumbbell. This method was time consuming, and we did not feel it was strenuous enough to adequately assess endurance in this population of athletes, which could explain our lack of group differences.

In a swimming population, we suggest use of the static-hold method of the PSET because it may better replicate the sustained loading of posterior shoulder muscles during freestyle swimming.[21] Differences were demonstrated in ROM measures between the +PDD and –PDD groups. The +PDD group had a mean 10° less IR and 8° less ER for a total of 18° less total ROM. Consistent with this was a 7.8° reduction in HADD in the +PDD group compared with the –PDD group. Given the loss of IR and ER ROM and HADD, restrictions appeared to be present in the soft tissue (latissimus dorsi, posterior rotator cuff, deltoid, and pectoral muscles) of the shoulder. However, it was also possible that the motion loss may have been due to humeral retroversion (which was not measured) or muscle guarding due to pain. One set of researchers[22] noted an association between swimming volume and humeral retroversion in adolescent swimmers (approximately 12 years old); yet this adaptation occurred during skeletal immaturity and there was no way of knowing the participants' swimming volume at that time. It should also be acknowledged that no swimmer complained of pain during ROM assessment and the investigator did not perceive muscle guarding at the time of testing.

Posterior Capsule Thickness

We did not find a difference in PCT between +PDD and –PDD groups. Previous researchers[16] and we demonstrated decreased glenohumeral IR ROM in swimmers. Thickness adaptations in the posterior capsule have been implicated in the clinical presentation of IR ROM deficits in swimmers but as of this writing have not been examined. Among baseball players, increased PCT was identified in the dominant arm, which was linked to IR ROM deficits and increased posterior capsule stiffness.[5,6] Yet the mechanics and stress caused by throwing and swimming are known to be very different and likely explain why the PCT results varied between these sports.

Table 5. Supraspinatus Structure in the +PDD and –PDD Groups With Associated *P* Values and Cohen D Effect Sizes

Supraspinatus Tendon	Group, Mean ± SD: +PDD	Group, Mean ± SD: –PDD	*P* Value	Effect Size (Cohen *d*)
Spatial frequency, peaks/mm	1.75 ± 0.09	1.65 ± 0.12	.02[a]	0.943
Banding period, mm	0.63 ± 0.03	0.68 ± 0.05	.01[a]	1.21
Thickness, mm	5.97 ± 1.07	6.02 ± 1.3	.9	0.042

Abbreviations: +PDD, positive pain, dissatisfaction, and disability; –PDD, negative pain, dissatisfaction, and disability.

[a] Difference between groups ($P \leq .05$).

Supraspinatus Tendon Structure

When examining the supraspinatus tendon, we observed no group differences in tendon thickness. Earlier authors[23] demonstrated increased tendon thickness in swimmers with upper extremity disabilities compared with those who had lower extremity disabilities and a control group of healthy swimmers. An examination[9] of National Collegiate Athletic Association Division II swimmers also revealed increasing tendon thickness with years of experience. These results suggested that the increased tendon thickness may predispose swimmers to subacromial impingement. Our lack of differences may have reflected the ability of the +PDD masters swimmers to limit their yards due to shoulder symptoms. As stated before, we found that the +PDD group swam fewer yards per day and per year. Previous investigators[9,23] recruited highly competitive collegiate swimmers who were not able to limit their yardage per day or per year.

Regarding supraspinatus tendon structure, we noted that swimmers in the +PDD group had increased PSF and a decreased banding period compared with the –PDD group. To our knowledge, we are the first to objectively measure supraspinatus tendon structure in swimmers using a custom algorithm. This algorithm relied on the collagen fascicles imaged with diagnostic ultrasound in the long-axis view to objectively quantify the tendon structure. Earlier authors used semiquantitative measures to identify tendinopathy in swimmers, which involved a scoring system based on the visual appearance of the tendon. Sein et al[3] determined that tendinopathy was related to swimming volume, and Rodeo et al[24] related tendinopathy to symptoms in swimmers. Previous researchers assessed tendon structure in other tendons and populations using a similar algorithm (2-D FFT) to ours (1-D FFT). Kulig et al[25] evaluated the PSF in both the patellar and Achilles tendons and compared dancers with pain or no pain. No differences were present between groups in either tendon. Kulig et al[26] examined the patellar tendon in volleyball players and compared those with and those without symptoms. The symptomatic group had a lower PSF, which they suggested indicated tendon disorganization. In our population of masters swimmers, PSF was increased in the +PDD group. Several factors likely explain these differences. First, we used a 1-D FFT to measure PSF; therefore, our analysis was specific to the longitudinal axis of the tendon. Because tendons are loaded longitudinally during function, our analysis quantified the collagen in the direction that was most important to function.[27] Second, we assessed the supraspinatus tendon, which, because of the design of the glenohumeral joint, experienced different loading environments than the patellar tendon and, as a result, produced different adaptations.[28,29] Last, our criteria to establish pain and disability involved the use of 2 patient-reported outcome measures whose reliability had been established. These criteria may have been more sensitive than those used by Kulig et al.[26] Basic science tendon research indicated that an increase in PSF may suggest tendon disorganization. Derwin and Soslowsky[27] assessed mousetail tendon fascicle characteristics in immature, adult, and adult MovI3 transgenic mice. They found a relationship between mean collagen fibril diameter and fascicle stiffness and maximal load. Specifically, mechanically weaker fascicles contained large numbers of fibrils that were smaller in diameter, while mechanically stronger fascicles contained smaller numbers of fibrils that were larger in diameter. Although our measurements were at the tendon and fascicle level versus the fascicle and fibril level in the mouse study, we believe we were seeing a similar mechanism of adaptation. The +PDD group had increased PSF and a decreased banding period, which could have been due to large numbers of fascicles that were smaller in diameter. According to Derwin and Soslowsky,[27] this would be characteristic of a mechanically weaker tendon that could fail at lower maximum loads, thereby placing these swimmers at greater risk for tendon tears.

Limitations

We used the repetitive lift-and-lower version of the PSET instead of the static hold, which we felt would better replicate the sustained loading of the posterior shoulder muscles during freestyle swimming. Another limitation was that we did not know the swimmers' previous swimming volumes, which could have influenced the adaptations. In addition, we were unsure if the +PDD group limited their yardage due to pain or external factors (skill, performance, conditioning, etc).

CONCLUSIONS

Similar to youth swimmers, masters swimmers exhibited a high prevalence of shoulder pain and disability. However, unlike youths, masters swimmers with pain and disability swam less yardage, perhaps due to self-imposed limitations or inadequate physical conditioning for the repetitive training. Swimmers in the +PDD group displayed reduced shoulder motion in HADD, IR, and ER without PCT differences. This reduction in mobility may have been due to rotator cuff muscle-tendon restrictions given that we did not observe a group difference in PCT, and the supraspinatus tendon structure may have reflected degeneration caused by cumulative overuse, resulting in pain.

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