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BASIC SCIENCE

Changes in clinical measures and tissue adaptations in collegiate swimmers across a competitive season

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Background: Competitive swimmers incur shoulder pain and injury. Physical characteristics such as shoulder range of motion (ROM) and endurance and tissue adaptations such as posterior capsule thickness (PCT) may be risk factors in addition to high training volume.
Hypothesis/Purpose: 1) To identify the most provocative special test and prevalence of positive special tests for shoulder impingement tests in a group of collegiate swimmers, (2) to assess shoulder pain and disability, internal rotation (IR) and external rotation, and horizontal adduction (HADD) ROM and posterior shoulder endurance longitudinally over a competitive collegiate season, and (3) determine if there is a relationship between swimming yardage, supraspinatus tendon organization, and PCT.
Methods: Thirty Division III swimmers were tested poolside at the beginning (T1), middle (T2), and end (T3) of their season. Dependent variables included pain and disability, shoulder ROM, Posterior Shoulder Endurance Test (PSET) value, and PCT. Analyses of variance with follow-up *t* tests compared measures over time, and Pearson correlation coefficients were performed.
Results: Despite increased swimming yardage, disability was reduced from T1 to T3 ($P = .003$). There was a reduction in bilateral IR and HADD ROM from T1 to T3. PSET values increased on the right from T1 to T3 ($P = .014$). There was a significant positive correlation between swimming yardage at T1 and T2 and PCT at T3 ($P = .034$, $P = .028$).
Conclusion: A loss of shoulder IR and HADD was observed across the season concurrent with less swimming-related disability, which may indicate a favorable adaptation. Improved PSET scores over the season is consistent with prior research linking endurance and less pain and disability.
Level of Evidence: Level II
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Keywords: Swimming; injury prevention; shoulder; athletic training; physical therapy; range of motion; endurance

A recent survey of National Collegiate Athletic Association swimmers found that 29.5% reported they were competing with arm trouble and 18.2% reported themselves as currently injured.[40] The same authors also examined mean functional scores of swimmers using the Kerlan-Jobe Orthopaedic Clinic Shoulder and Elbow score and found their scores to be lower than those from athletes participating in other overhead sports and, in fact, similar to those seen in injured athletes in these sports. They also found that

This study was approved by Arcadia University Institutional Review Board (study no. 15-08-03).

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swimmers competing for 11 or more years had lower functional scores than those competing for 10 years or less, suggesting a cumulative effect of swimmers' training on shoulder pain.[40] The growing participation of National Collegiate Athletic Association swimmers as well as the prevalence of shoulder pain and reduced shoulder function in comparison to other athletes warrants further investigation.

High training volume in terms of yardage and hours swum has been shown to predict supraspinatus tendinopathy in swimmers aged 13-25 years, with magnetic resonance imaging revealing 69% tendinopathy, 19% labral tears, 13% acromioclavicular joint arthritis, and 6% rotator cuff tears in elite Australian swimmers.[28] Rodeo et al[26] performed diagnostic ultrasonography on the shoulders of 42 US Olympic swimmers aged 15-41 years and found similarly high rates of pathology, including supraspinatus and infraspinatus tendinopathy in 96% and rotator cuff tears in 22%. Biceps and subscapularis pathology have also been cited as sources of injury in competitive swimmers as a result of repetitive shoulder loading during training.[7] In addition to training volume, certain physical characteristics that develop in overhead athletes may contribute to pathology. In throwers, changes have been found across the season that predispose to injury.[21] Myers et al[21] found that throwers with clinically diagnosed shoulder impingement had significantly reduced glenohumeral internal rotation (IR) and horizontal adduction (HADD) compared with asymptomatic throwers. A thickening of the posterior band of the inferior glenohumeral capsule has been associated with glenohumeral IR deficit[31,35] and was found in a series of professional baseball pitchers with rotator cuff and labral tears.[34] In collegiate baseball players, the posterior capsule was thicker on the dominant arm, and thickness was negatively correlated with IR.[35] In high school baseball and softball players, Shanley et al[29] found that those with a glenohumeral rotation deficit of 25° were 4.5 times more likely to incur shoulder injury. In a prospective study, Wilk et al[39] found that pitchers with insufficient shoulder external rotation (ER) were 2.2 times more likely to be placed on the disabled list for shoulder injury and 4 times more likely to require shoulder surgery. These studies highlight the need to identify shoulder adaptations and changes in shoulder mobility as a result of repetitive use to potentially develop shoulder pain prevention programs for swimmers.

In a group of 18 collegiate swimmers, Dischler et al[8] found an association between supraspinatus tendon thickness measured by ultrasonography and years of competitive swimming. In addition to increased thickness, the tendon's mechanical properties (measured with shear wave elastography) were reduced in more experienced swimmers, leading the authors to conclude that those with longer swimming careers may be increasing their risk of rotator cuff pathology. Given that swimming is one of the few sports that athletes can enjoy throughout their life and the findings of declining tendon properties with training, it is important to identify potential impairments that might be mitigated with prevention measures to allow these athletes long-term sport participation. Other factors potentially related to injury, such as shoulder muscular endurance, posterior capsule thickness (PCT), and mobility of the shoulder have not been investigated longitudinally to determine if changes in swimmers' physical characteristics over the training season are associated with pain and swimming-related disability. If adverse changes are found to occur during a training season, appropriate interventions could be implemented to reduce swimmers' risk of injury. Therefore, the purpose of our study was 3-fold: (1) to identify the most provocative special test and prevalence of positive special tests for shoulder impingement in a group of collegiate swimmers; (2) to assess shoulder pain and disability, IR and ER, and HADD ROM and posterior shoulder endurance longitudinally over a competitive collegiate season; and (3) determine if there is a relationship between swimming yardage, supraspinatus tendon organization, and PCT.

Methods

Participants

Thirty collegiate swimmers aged 18 or older from a Division III university volunteered for participation in this study. Swimmer demographics can be found in Table I. All participants signed a written informed consent.

Procedures

A repeated measures design of 30 collegiate swimmers was used at 3 testing sessions: the first occurred during the third week of the season (T1), the second occurred week 8 at midseason (T2), and the final occurred at week 20 of the 22-week season. Formal college practice was not held from week 13 through the middle of week 15 because of the winter holiday break. All testing sessions occurred during the team's regularly scheduled practices. At the initial testing session, swimmer demographics and training information were obtained using a survey. The pain and satisfaction sections of the Penn Shoulder Score and the sports subsection of the Disabilities of the Arm, Shoulder, and Hand (DASH) were used to quantify pain, satisfaction, and swimming-related disability. These measures have been used in prior swimming research.[11,32] A shoulder examination was performed on each swimmer that included the following special tests: painful arc, Jobe empty can, Neer, Hawkins, and infraspinatus test (resisted ER with the arm adducted to the side in neutral rotation). If there was a painful arc, the modified scapular assistance test was performed,[24] and if weakness and/or pain were provoked with the Jobe empty can test, then the scapula reposition test[33] was performed. After survey completion, swimmers rotated through 3 stations where they were evaluated by the research team, which consisted of a physical therapist with more than 25 years of clinical experience who performed ROM measures and special

Table I Demographics of participants

Variables	Male	Female	Combined
Participants, n	17	13	30
Age, yr	19.8 ± 1.1	19.4 ± 1.0	19.6 ± 1.1
Hours/week of swimming	14.9 ± 6.1	15.3 ± 3.9	15.1 ± 5.2
Months/yr of swimming	7.9 ± 2.1	9.7 ± 2.2	8.7 ± 2.3
Years of competitive swimming experience	9.9 ± 3.7	12.7 ± 2.3	11.1 ± 3.4
Previous shoulder pain, %	58.8	69.2	63.3

Unless otherwise noted, values are mean ± standard deviation.

tests, an athletic trainer with more than 10 years' experience using diagnostic ultrasonography who performed posterior capsule and supraspinatus measurements, and trained doctoral physical therapy students who recorded data and completed the Posterior Shoulder Endurance Test (PSET). Test-retest reliability was established on 13 athletically active individuals (7 male and 6 female) with a mean age of 24 ± 2.1 years, who reported participation in 4.8 ± 2.9 hours of exercise per week. Standard error of measurement for ER, IR, and HADD ROM, PSET result, and supraspinatus tendon organization was 3°, 4°, 4°, 0.6 seconds, and 0.10 peaks/mm, respectively.

Range of motion

Passive shoulder IR, ER, and HADD were assessed using a Precise Digital Level/Protractor digital (Precise Tool & Gage Co. Inc., Preston, WA, USA). For IR and ER, the participant was supine in 90° of shoulder abduction and 90° of elbow flexion. A rolled towel was placed beneath the humerus to maintain the arm in the frontal plane for more muscular individuals. The examiner palpated and stabilized the coracoid process and spine of the scapula for measuring the IR and ER, which were taken before movement of the scapula to assess glenohumeral motion. The inclinometer was placed on the proximal one-third of the forearm in line with the ulnar styloid process and olecranon.[5] For HADD, the shoulder was passively elevated to 90° of shoulder flexion. The participant was then asked to maximally retract, "squeeze," his or her scapulae together, and the tester used the thenar eminence of her hand to stabilize the lateral border of the scapula while passively moving the arm into maximal horizontal abduction while maintaining neutral shoulder rotation. The inclinometer was placed on the distal humerus along the midline over the flat aspect of the triceps tendon. Two ROM measures were taken for each position. A trained doctoral student placed the inclinometer and recorded all values, with the therapist blinded to the measures. The measures were averaged for data analysis.

Posterior Shoulder Endurance Test

Muscular endurance was measured using the isometric version of the PSET as described by Day et al.[6] Lying prone, participants were asked to actively elevate their arm to the horizontal position at a 135° angle ("Y" position), at which time a moveable clamp placed on a vertically oriented metal rod was adjusted to mark the point at which the radial aspect of the wrist contacted the horizontal rod, indicating full elevation. The swimmer then lowered his or her arm and the examiner passively elevated the arm into the Y position to ensure that end-range motion was achieved. The test was then performed with the swimmer lifting and holding a 0.90-, 1.36-, or 1.81-kg dumbbell (2% of body weight) while the examiner recorded the hold time using a stopwatch (Fig. 1). The test began when the swimmer's wrist contacted the clamp and stopped when the arm no longer contacted the bar or bodily substitution occurred, such as trunk rotation.

Ultrasonographic measures of PCT and supraspinatus tendon organization

PCT was measured using ultrasonography as previously described and validated.[35] The subject 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, LOGIQe (GE Healthcare, Wauwatosa, WI), 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 (Fig. 2, *a*). A standard B-mode image was captured, and the PCT was measured using ImageJ software (National Institutes of Health, Bethesda, MD, USA). Intratester and test retest standard error of measurement for this technique were found to be 0.2 and 0.2 mm, respectively.

Supraspinatus tendon organization was measured using ultrasonography. The subject was positioned upright in a chair with his or her hand placed on the ipsilateral posterior hip with the humerus in extension and ER (modified Crass position). The examiner positioned the 15-MHz linear transducer (LOGIQe) on the anterior shoulder to observe a longitudinal view of the supraspinatus tendon (Fig. 2, *b*). The transducer was then moved anterior and posterior across the tendon until the center of the tendon was determined and an image was saved. The examiner then moved the transducer anterior from the center position until a clear view of the anterior portion of the supraspinatus tendon was determined and an image was saved. Lastly, the examiner went back to the center region of the tendon and then moved posterior until a clear view of the posterior portion of the supraspinatus tendon was determined and an image was saved.

Data analysis

Analyses of variance with repeated measures on time were used to assess longitudinal changes of self-report of pain per the Penn Shoulder Score and swimming-related disability using the DASH sports score. Follow-up *t* tests were performed to compare the 3

Figure 1 Image demonstrating the patient position and equipment setup for the Posterior Shoulder Endurance Test (PSET).

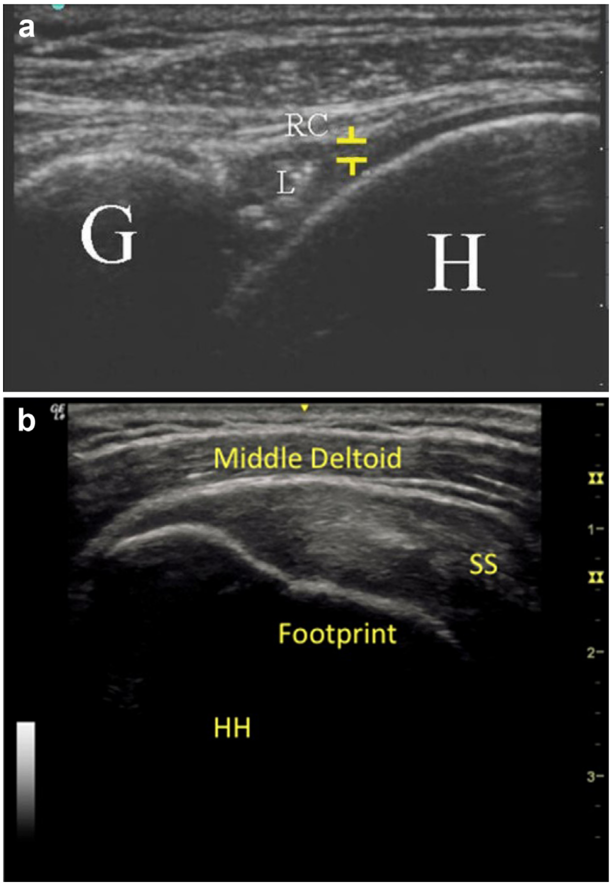

Figure 2 (a) Ultrasonographic image of posterior capsule thickness shows the calipers (yellow brackets, posterior capsule), the glenoid (G), humeral head (H), labrum (L), and the rotator cuff (RC). Reprint from Thomas et al,[35] with permission from Elsevier. (b)Ultrasonographic image of longitudinal view of supraspinatus tendon (SS), middle deltoid, footprint, and humeral head (HH).

time points: T1, T2, and T3. Because of the multiple comparisons performed, a Bonferroni correction was performed that adjusted the alpha level to 0.016. Pearson correlation coefficients were performed to assess the relationship between training volume and clinical and tissue adaptations.

The 3 ultrasonographic images from each supraspinatus tendon were analyzed by the same examiner using custom MATLAB software with a method similar to that of Kulig et al.[16] Both methods analyze the spatial frequency of the hyperechogenic ‘‘bands’’ seen in ultrasonographic images of tendons, which have been shown to relate to bundles of collagen.[25] For each image, the examiner identified the supraspinatus footprint and placed a vertical line at the most medial aspect of the footprint and at the lateral aspect of the footprint. Next a vertical line was created in the middle of the already created lines. Finally, 2 remaining vertical lines were created bisecting both the medial and lateral 2 lines. This created a total of 5 vertical lines throughout the supraspinatus footprint. Care was taken to only include the thickness of the supraspinatus tendon and to keep the vertical lines perpendicular to the longitudinal collagen bundles observed as hyperechoic lines. The spectral power (of echogenicity) over the length of each line was then determined using a 1D fast-Fourier transform, from which the spatial frequency at peak spectral power (peak spatial frequency [PSF]) was determined. The PSF is the inverse of the spacing between collagen fascicles, such that as spatial frequency increases, the spacing between fascicles (hyperechogenic bands on the ultrasonographic image) decreases. PSF was calculated for each of the 5 vertical lines within each of the 3 (anterior, center, posterior) images and averaged for a given tendon. As a result, the PSF for a given tendon relates to the spacing of collagen fascicles averaged across the volume of the supraspinatus tendon footprint (anterior-through-posterior for 3 images, and medial-to-lateral through the 5 lines).

Results

Thirty subjects were included in the study. Because of the nature of the longitudinal study design, 5 subjects had incomplete data. During statistical analysis, any subjects with incomplete data were not included for that particular dependent variable. Table II contains the percentage of positive shoulder special tests at each time period. Table III contains the mean Penn Shoulder Score pain and satisfaction total score and the DASH sports score for each of the testing sessions. Table IV contains the mean swimming yardage, ROM, and PSET values for each of the testing sessions throughout the competitive season. Table V contains the tendon organization data. Figures 3 and 4 demonstrate the correlation of yardage and PCT at time point 3.

Discussion

Symptom provocation tests

Our first objective was determining which shoulder special test would be the most provocative. We found the Jobe

Table II Percentage of positive clinical tests performed at the beginning (T1), middle (T2), and near end (T3) of competitive collegiate swimming season

Clinical tests	T1		T2		T3	
	L	R	L	R	L	R
Jobe empty can	52	55	28	31	30	48
SRT	93	94	88	100	63	77
Hawkins-Kennedy	21	38	7	31	22	26
Neer	17	24	0	7	4	15
Painful arc	14	17	10	7	7	11
SAT	75	100	100	100	100	100
Infraspinatus	10	7	10	10	7	7

SRT, Scapula Reposition Test; *SAT*, Scapular Assistance Test.

Table III Pain and disability ratings at the beginning (T1), middle (T2), and near end (T3) of competitive collegiate swimming season

Variable	T1	T2	T3	*P* value
Penn Shoulder Score*	31.2 ± 6.0	32.5 ± 6.5	32.2 ± 6.0	.1 .6 .2
DASH sports module†	6.83 ± 3.2	5.9 ± 2.8	5.16 ± 2.7§	.2 .2 .003§
% of swimmers with pain at rest‡ (mean pain rating ± SD)	37 (0.6 ± 1.2)	24 (0.7 ± 1.4)	22 (0.5 ± 1.1)	
% of swimmers with pain with normal activities‡ (mean pain rating ± SD)	53 (1.4 ± 1.7)	45 (1.1 ± 1.6)	52 (1.2 ± 1.6)	
% of swimmers with pain with strenuous activities‡ (mean pain rating ± SD)	97 (4.1 ± 2.3)	79 (3.1 ± 2.3)	96 (3.4 ± 2.1)	

DASH, Disabilities of the Arm, Shoulder, and Hand; *SD*, standard deviation.
* Pain and satisfaction subscales. Scores range from 0 to 40, with 40 indicating no pain and high satisfaction of shoulder function.
† Scores range from 4-20, with 4 indicating no difficulty performing sport.
‡ Pain level ≥1/10.
§ Significant change between T1 and T3 ($P < .05$).

empty can test to be the most provocative, with positive findings in 27% to 52% of swimmers. Given this finding, athletic trainers and physical therapists screening swimmers for shoulder injury should consider using this test. An additional finding was the effect of symptom alteration tests on shoulder pain. The scapula reposition test reduced pain and/or increased strength in 62%-100% of swimmers' shoulders with a positive Jobe empty can test, and the scapular assistance test reduced pain in 75%-100% of shoulders with a painful arc. These findings highlight the potential contribution of altered scapular mechanics on swimmers' shoulder symptoms. Further studies are needed to determine the effect of scapular rehabilitation techniques in shoulder pain prevention or treatment programs.

Pain, satisfaction, and swimming-related disability

The pain and satisfaction subsection totals of the Penn Shoulder Score did not reveal a change over the season, remaining stable despite fluctuating yardage over the season. Given the increase in yardage from T1 to T2, it was hypothesized that the swimmers' pain levels would increase because increased training volume (ie, yardage) has been associated with increased pain and tendon pathology[13,28,32]; however, this was not observed. The mean pain levels were less than 2 at rest and during normal activities of daily living with ranges between 3.1 ± 2.3 to 4.1 ± 2.3 throughout the season during swimming. These values are the means from all subjects tested; however, 96.29% of swimmers experienced some level of pain with swimming at T3. Hibberd and Myers[13] found that most competitive swimmers believed that shoulder pain is normal and should be tolerated to complete practice; therefore, our findings of relatively low pain ratings are not surprising. Because shoulder pain can elicit activation failure of the rotator cuff, resulting in decreased force output,[30] it is possible that pain adversely affects swimming performance. In addition, swimming-related disability as measured by the DASH Sports Module did not change at midseason when the yardage increased. Interestingly, the swimming-related disability demonstrated a decrease from T1 to T3. This

Table IV Swimming distance (m), ROM, and PSET values at the beginning (T1), middle (T2), and near end (T3) of competitive collegiate swimming season

Variable	T1	T2	T3	P value
External rotation, degrees				
Left	83 ± 12	92 ± 13*	91 ± 10†	.014* .9 .005†
Right	98 ± 12	96 ± 14	98 ± 11	.7
Internal rotation, degrees				
Left	44 ± 12	36 ± 11	28 ± 8†,‡	.035 .004‡ .0001†
Right	36 ± 11	29 ± 9*	23 ± 10†,‡	.0001* .009‡ .0001†
Horizontal adduction, degrees				
Left	87 ± 10	79 ± 9*	74 ± 8†,‡	.0001* .011‡ .0001†
Right	84 ± 11	74 ± 9*	74 ± 7†	.0001* .0001†
PSET value, s				
Left	7.9 ± 5.7	12.0 ± 11.5	15.0 ± 14.0	.020 .022 .018
Right	9.5 ± 10.7	14.0 ± 14.4	16.6 ± 15.2†	.023 .069 .014†
Distance, m	6312 ± 523	6823 ± 941*	5863 ± 906†,‡	.001* .0001‡ .02†

ROM, range of motion; PSET, Posterior Shoulder Endurance Test.
Values are mean ± standard deviation.
* Significant change between T1 and T2 ($P < .017$).
† Significant change between T1 and T3 ($P < .017$).
‡ Significant change between T2 and T3 ($P < .017$).

Table V Banding frequency of supraspinatus tendon at the beginning (T1), middle (T2), and near end (T3) of competitive collegiate swimming season

Arm	T1	T2	T3	P value
Left, peaks/mm	1.58 ± 0.12	1.59 ± 0.14	1.54 ± 0.13	.4
Right, peaks/mm	1.55 ± 0.15	1.55 ± 0.11	1.54 ± 0.15	.9

Values are mean ± standard deviation.

result may suggest that favorable training conditions were employed throughout the season to allow the swimmers to adapt to the variable load over the season. Although our study did not investigate specific exercises employed in dry land training, our survey revealed that 100% of swimmers participated in a formal dryland program provided by an experienced athletic trainer. Several studies have suggested strengthening exercises for scapular and posterior cuff muscles and stretching for pectoral muscles to address the muscle imbalances and flexibility deficits that have been reported to occur as a result of swim training.[1,12,15,18] In addition to dryland training, rate of distance progression is another aspect that could play a role in reducing the reported disability. The National Athletic Trainers' Association recommends that training distance should only increase by 10% each week to permit adequate tissue

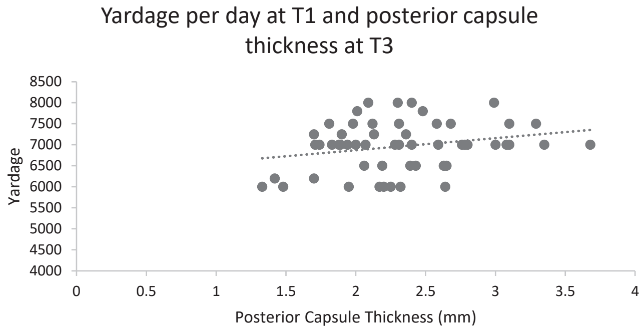

Figure 3 Relation between T1 yardage per day and T3 posterior capsule thickness.

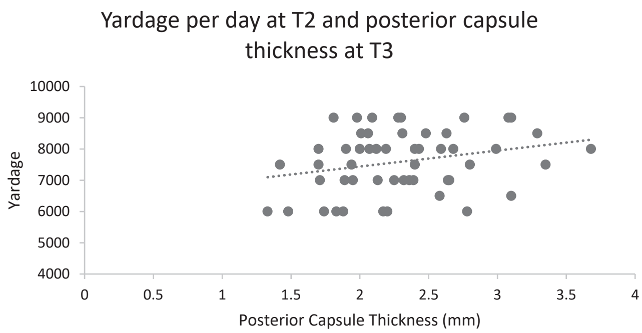

Figure 4 Relation between T2 yardage per day and T3 posterior capsule thickness.

adaptation.[37] Unfortunately, the current study did not measure weekly training volume, but future studies should measure weekly training volume to identify loading progression. One additional possibility for the lack of change in pain throughout the season may be a desensitization of pain receptors or the central nervous system integrating those signals. Naugle et al[22] in a meta-analytic review found that aerobic exercise had a hypoalgesic effect that was also dose dependent for both the intensity and frequency, which could explain our results; however, additional research investigating pain sensitivity throughout the season is needed.

Range of motion and PCT

Swimmers exhibited a reduction in IR and HADD ROM throughout the season. Glenohumeral range of motion (IR and ER) has only been examined longitudinally in one other study, of which the authors are aware. Thomas et al[36] examined glenohumeral ROM at preseason and postseason in high school swimmers and tennis and volleyball players. They did not find any changes in IR throughout the season in swimmers but did find significant decreases in ER. The lack of decreasing IR throughout the season in the Thomas et al[36] study may center around the amount of training, which was not reported, and the younger age of the participants. Two possible explanations for our finding of decreased IR over the swim season are posterior capsule tightness/thickness and/or posterior rotator cuff muscle tightness.[10] Thomas et al[35] originally identified that PCT correlated with glenohumeral IR in a group of healthy collegiate baseball players. Several authors have examined healthy college baseball players and found that PCT/stiffness measured by elastography was correlated with IR ROM deficits.[14,31,35] Our study examined PCT via ultrasonography at T3 and found significant correlations between swimming yardage at T1 and T2 and thickness of the posterior capsule, with swimmers completing higher yardage having thicker posterior capsules. This may indicate adaptive changes in the posterior capsule due to repetitive shoulder motion. However, because baseline values of PCT were not performed, we cannot conclude that the thickness changed over the course of the season. Because of methodological limitations, there is currently no method to isolate the posterior rotator cuff muscles to determine if the reduction in IR was the result of tightness of the posterior rotator cuff muscles.

It is difficult to determine the biomechanical effect of reduced shoulder IR on swimming. Interestingly, swimming-related disability decreased from T1 to T3. In throwers, glenohumeral IR deficit of 25° or greater increased the risk of injury by 4.5 times.[29] Additionally, throwers who lacked 20° of IR or more compared with the nonthrowing shoulder had an increased risk for shoulder injury.[2] In collegiate baseball players, pain was associated with a decreased total arc of motion and IR of the dominant shoulder compared with players without shoulder pain.[27] Contrary to the results of studies in athletes participating in other overhead sports in regard to the relation between decreased IR and increased injury, our findings show that our swimmers did not have a change in pain and actually had a decrease in swimming disability despite a significant decrease in IR over the season. Therefore, it is possible that the IR and/or HADD motion loss might be a positive adaptation in our swimmers. Yanai and Hay,[41] using 3-dimensional videography, have identified characteristics of the freestyle stroke that place swimmers at a high risk for impingement. Two of the 3 characteristics that were identified—a large amount of IR during the pull phase and a late initiation of ER during the recovery phase—could potentially be remediated by having greater shoulder ER, that is, a loss of IR during these phases of the stroke. In addition to the reduction of IR possibly being advantageous during freestyle swimming to reduce impingement, we also found a reduction in the frequency of positive provocation tests when comparing T1 to T2 and T3. If a loss of IR was negatively influencing shoulder symptoms, then a greater frequency of pain provocation testing at T2 and T3 would be expected. Given the unexpected findings of the loss of IR and HADD ROM without a concurrent increase in pain, disability, or pain provocations tests, further studies are needed to determine the effect of shoulder motion on stroke biomechanics, pain, and performance.

With respect to shoulder ER, our swimmers initially began with reduced ER on the left compared with the right, but the left ER ROM increased by T2 and was maintained at T3. Asymmetry in shoulder ROM may be related to some swimmers using asymmetric or unilateral breathing patterns. Besides the initial left ER ROM, the ER values remained stable throughout the season. In a prospective cohort study by Walker et al,[38] investigators looked at the incidence of shoulder pain in competitive swimmers and associated risk factors. Their results revealed that high and low shoulder ER, as defined by $\geq$100° or <93°, respectively, placed swimmers at significant risk for shoulder pain and injury compared with midrange ER. Our highest reported disability via DASH occurred at T1, with the mean ER being 83° on the left, which may support the Walker et al suggestion that there may be an optimal ER ROM that reduces risk for shoulder injury.

Posterior shoulder endurance

As can be seen in Table IV, the PSET values increased from T1 to T3 on the right with a trend toward increasing endurance on the left. Matthews et al[19] have found that a competitive swim season favors the development of greater strength and endurance of the internal rotators over the external rotators because of the freestyle stroke mechanics and recommend a compensatory strength training program. Given this propensity for stronger internal rotators as the season progresses, we hypothesize that swimmers' dryland training may have counteracted the effect of the freestyle stroke and facilitated the improved posterior musculature endurance throughout the season. Therefore, the increase in posterior shoulder endurance may have had a protective effect on swimmers' shoulders in preventing pain exacerbation because fatigue of the rotator cuff has been identified to cause superior humeral head migration and potential subacromial impingement.[3,4]

The time to task failure (TTF) of our swimmers was significantly shorter than that of Evans et al,[9] who used similarly aged subjects in their EMG study of muscular endurance using the PSET. Their female TTF was 49.2 $\pm$ 2.5 seconds and their male TTF was 59.6 $\pm$ 2.4 seconds at the 135° position. The maximum mean TTF values in our study were 13 $\pm$ 7 seconds on the left and 14 $\pm$ 9 seconds on the right with male and female values combined. Evans et al[9] excluded persons with shoulder pain from their study, and in our study 96% of swimmers at T1 and T3 had shoulder pain. As noted previously, pain can cause activation failure, which may be one explanation for the significantly lower TTF values in our study. Also, although Evans et al[9] measured hours of upper body weight training and shoulder function using an outcome measure, these results were not reported, so the effect of fatigue due to training and subjects' shoulder function cannot be compared between the Evans study and ours.

The PSET was first described by Moore et al,[20] in which participants were positioned prone with the shoulder horizontally abducted to 90° and lifted 2% of their body weight repetitively at a rate of 30 beats per minute. We used this technique in a previous study of swimmers and found that it was not time efficient. In addition, during the main swimming stroke, freestyle, the shoulder is never adducted to neutral as in the "lowered" position of the original PSET, which would essentially allow a rest period for the posterior shoulder musculature. Therefore, we chose to modify the original technique with a sustained arm elevation position. We used the 135° abduction or "Y" position because of its similarity with the arm entry position in freestyle. This isometric hold version proved to be both time efficient for the clinician and sensitive to change over time on the right in our group of collegiate swimmers.

Supraspinatus tendon organization

We examined supraspinatus tendon organization throughout the season, and no significant differences were observed. To our knowledge, this is the first study to examine tendon organization longitudinally with diagnostic ultrasonography. One previous study used similar methods to measure organization in a group of individuals with subacromial pain syndrome compared with a control group.[23] They did not find any group differences in supraspinatus organization. Only 1 study examining the patellar tendon in symptomatic and asymptomatic volleyball players have identified difference in this metric.[17] Our results of no changes over the season are supported with our pain and disability results as pain was not changed and disability decreased. Because there were no changes in these parameters, it is not likely that the collagen organization would have adapted. Research is currently being conducted to assess tendon organization in other populations and those with increased symptoms.

Conclusion

Collegiate swimmers' pain, swimming-related disability, shoulder pain provocation testing, PSET, and ROM were measured at 3 time points over a swimming season. Although there was a significant increase in distance swum from the beginning to the middle of the season, there was no increase in pain or swimming-related disability as expected because of the increased training load. Examining the effect of training on physical characteristics across the competitive season, there was a significant increase in PSET values, which may have mitigated imbalances in shoulder IR and ER. Finally, significant reductions in HADD and IR ROM were seen across the season. Although a loss of IR has been associated with shoulder injury in other overhead athletes, further studies are needed to determine if these could be favorable adaptations in swimmers that may provide protection from stroke biomechanical issues contributing to impingement.

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