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Predictors of shoulder injuries in female collegiate swimmers

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Predictors of shoulder injuries in female collegiate swimmers

by

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Dissertation
Doctor of Philosophy Program

Nova Southeastern University
College of Health Care Sciences
Physical Therapy Program

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Abstract

Competitive swimmers frequently injure their shoulders. The risk factors for shoulder injuries in competitive swimmers have not been clearly identified. The primary purposes of this study were to describe the characteristics of female collegiate swimmers at the onset of a swim season, identify the risk factors of shoulder injury in female collegiate swimmers, characterize the swim volume of female collegiate swimmers, and determine if swim volume is a predictor of shoulder injury.

A prospective longitudinal cohort multi-center design was utilized. Female collegiate swimmers [n=53, mean age=19.3+/- 1.2] from four NCAA Division II universities were recruited to participate in this study. Preseason screening data that included demographics and sport history, swimming characteristics, and a musculoskeletal assessment was collected on 106 shoulders. Participants completed a weekly survey to track exposure data over the course of the season. Shoulder injury data was also collected. A shoulder injury was defined as swimming-related shoulder pain that resulted in one or more limited or modified athletic practices or competitions.

Female swimmers reported a history of shoulder pain in 18/106 (17.0%) shoulders, and 14/106 (13.2%) of swimmers presented with obvious scapular dyskinesis at preseason. No differences in shoulder characteristics were found between swimmers with a history of shoulder pain and those without and those with obvious dyskinesis compared to those with normal scapular motion. There was a positive correlation between anterior glenohumeral laxity and shoulder external rotation range of motion ($r=0.37, p<0.001$) and total range of motion ($r=0.41, p<0.001$). A total of 14 new shoulder injuries were reported. Previous shoulder injury was the sole predictor of a new shoulder injury (B=7.4; p=0.001). Weekly training logs were collected for 34 participants (68 shoulders) for 16 weeks. The swimmers reported an average of 5.5 swim sessions/week, 4,099 yards swam/session, and 24,515 yards swam/week. Swim volume was not a predictor of new injury. The incidence rate for shoulder injury in this group of swimmers was 0.065 injuries per 100,000 yards swam.

Previous injury was the sole predictor of new shoulder injury in the group studied. Further research into the predictors of shoulder injury in female collegiate swimmers is warranted.

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Chapter One – Introduction

Introduction

Swimming is a popular activity in the United States at both the recreational and competitive level. However, swimming is commonly associated with shoulder injuries, with as many as 90% of competitive swimmers reporting shoulder pain at some point in their career.[1-11] Shoulder impairments such as scapular dyskinesis, glenohumeral laxity, deficits in shoulder muscle strength and endurance, and abnormal shoulder range of motion can lead to changes in shoulder performance during the large volume of overhead training that occurs over the course of a swim season. These impairments, occurring singularly or in combination, may be risk factors for the development of a shoulder injury during the course of a swim season.

The primary purposes of this study were to describe the swimming-related factors, shoulder joint factors, and shoulder muscle characteristics of female collegiate swimmers at the onset of a swim season, identify the risk factors of shoulder injury in female collegiate swimmers, characterize the swim volume of female collegiate swimmers, and to determine the usefulness of swim volume as a predictor of shoulder injury. Successful identification of the risk factors for shoulder pain in female swimmers will provide the necessary background knowledge to develop injury prevention strategies.

Statement of the Problem

Shoulder pain and swimming-related disability are a concern for competitive swimmers. Impairments associated with shoulder pain in swimmers has largely been examined in retrospective or cross-sectional cohort studies. Characteristics associated with shoulder pain that have been identified via retrospective research include: history of shoulder injury, insufficient strength or endurance in the shoulder musculature, laxity in the glenohumeral joint, pectoralis minor tightness, changes in glenohumeral range of motion values, and abnormal scapular position or motion commonly labeled scapular dyskinesis.[1,2,6,7,9,12-15] However, the retrospective nature of these studies does not allow for the identification of these factors as predictors of shoulder injury in swimmers. In addition, many of the previous studies have examined the impairment-related variables in isolation, limiting any inferences to a potential cumulative effect of the impairments.[1,2,6,7,9,12-15]

A limited number of prospective studies have investigated the risk factors for shoulder injury in collegiate swimmers.[8,10] Two prospective studies identified a history of shoulder injury as a risk factor for shoulder injury during the course of a season.[8,10] Additionally, Walker et al[8] identified a large amount as well as a deficit of glenohumeral external range of motion as predictors of shoulder injury during the course of a swim season. These prospective studies are limited as they did not evaluate the contribution of other shoulder impairment variables associated with shoulder injury.

The previously conducted prospective and retrospective research investigating the risk factors for injury in swimmers is limited. Scapular dyskinesis, glenohumeral laxity, abnormal shoulder range of motion, and muscular deficits may lead to a dysfunctional shoulder complex, shoulder pain and loss of function. Swimmers who present with a combination of these impairments may be unable to sustain the stresses associated with a competitive swim season and may be at a greater risk of injury.

The primary purposes of this study were to describe the swimming-related factors, shoulder joint factors, and shoulder muscle characteristics of female collegiate swimmers at the onset of a swim season, identify the risk factors of shoulder injury in female collegiate swimmers, characterize the swim volume of female collegiate swimmers, and to determine the usefulness of swim volume as a predictor of shoulder injury. The first set of research hypotheses are that there will be relationships between demographics, swimming-related factors, shoulder joint factors, and muscle characteristics in female collegiate swimmers at the onset of a swim season, there will be differences in shoulder characteristics in swimmers with a history of shoulder injury compared to those without and, and there will be differences in shoulder characteristics between swimmers with scapular dyskinesis and those without. The second research hypothesis is that there will be differences in swimming-related factors, shoulder joint factors, and muscle characteristics in female collegiate swimmers who develop a new shoulder injury compared to those who did not, and that those impairments will predict the onset of shoulder injury during the season. The third research hypothesis is that there will be differences in swim volumes between female collegiate swimmers who develop shoulder injury compared to those who did not, and that swim volume will predict the onset of shoulder injury. Successful identification of the risk factors for the development of shoulder pain in female swimmers will provide foundational knowledge for the development of an injury prevention program for swimmers.

Relevance and Significance

Shoulder injury or pain that interferes with training or the progression of training is a significant concern for competitive swimmers. This study is founded on the hypothesis that scapular dyskinesis, increased glenohumeral laxity, pectoralis minor tightness, scapular muscle strength deficits, rotator cuff strength deficits, shoulder endurance and stability deficits, shoulder range of motion values, a history of shoulder pain, and age of starting competitive swimming are risk factors for shoulder injuries in the collegiate swimmer. Theoretically, these impairments, when occurring in combination, create an unstable shoulder complex that is unable to sustain the high volume of training that occurs during the swim season. This cumulative effect is identified throughout this paper as the Shoulder Dysfunction Model. The results of this study will identify the usefulness of the Shoulder Dysfunction Model as a predictor of shoulder injuries in collegiate swimmers. The findings of this research will also serve as foundational knowledge for the development of future shoulder injury prevention programs for competitive swimmers.

The primary purposes of this study were to describe the demographics and physical characteristics in female collegiate swimmers at the onset of a swim season, identify demographics and physical characteristics that are risk factors of shoulder injury in female collegiate swimmers, to characterize swim volume of female collegiate swimmers, and to determine the usefulness of swim volume as a predictor of shoulder injury.

Research Questions

The study addressed research questions in three main areas:

1. What are the demographic and physical characteristics of female collegiate swimmers at the onset of a swim season?

   1.1 What are the descriptive characteristics of swimming-related factors, shoulder joint factors, and muscular deficits in female collegiate swimmers at the onset of a swim season?

   1.2 Are there relationships between shoulder joint factors and muscular deficits in female collegiate swimmers at the onset of a competitive swim season?

1.3 Are there differences in between shoulder joint factors and muscular deficits between the dominant and non-dominant shoulders of female collegiate swimmers?

1.4 Are there differences in shoulder joint factors and muscular deficits between swimmers with a history of shoulder injury and those without?

1.5 Are there differences in shoulder joint factors and muscular deficits between swimmers with scapular dyskinesis and those who do not?

2. What are the demographic and physical characteristics that are risk factors of shoulder injury in female collegiate swimmers?

2.1 Are there differences in swimming-related factors, shoulder joint factors, and muscular deficits between those who developed shoulder injury compared to those who did not?

2.2 Can swimming-related factors, shoulder joint factors, or muscular deficits predict shoulder injury in female collegiate swimmers?

3. What is the swim volume of female collegiate swimmers and is it a predictor of shoulder injury?

3.1 Is there a difference in swim volume in female collegiate swimmers who developed shoulder pain compared to those who did not?

3.2 Is swim volume a predictor of shoulder injury in female collegiate swimmers?

Definitions of Terms

Athlete Exposure – one athlete competing in one practice or competition

Glenohumeral Laxity– the amount of humeral head motion within the glenoid fossa as measured by a KT-1000 joint arthrometer

Injury Incidence Rate – number of injuries occurring per 100,000 yards swam

Modified Practice or Competition – a practice or competition when the yardage swam is decreased, swim strokes are modified, or the swimmer's training or competition is modified in any other way due to pain

Scapular Dyskinesis – abnormal scapular position and/or motion observed during dynamic shoulder flexion and/or abduction

Shoulder Injury – swimming-related shoulder pain that required the student-athlete to seek medical attention and resulted in at least one limited or modified athletic exposure

Shoulder Dysfunction – a combination of scapular dyskinesis, glenohumeral laxity, shoulder muscle strength, and/or shoulder muscle endurance deficits

Swimming Season – the duration of a championship segment of a collegiate swimming season, typically occurring between mid-September and mid-March

Summary

Shoulder injury is a frequent and significant concern for the competitive swimmer. The risk factors for shoulder injuries in swimmers have not been clearly identified in the literature. The purpose of this study was to describe the characteristics of female collegiate swimmers at the onset of a season, describe the possible predictors of shoulder injury in female collegiate swimmers, and to characterize the swim volume of female collegiate swimmers over the duration of a season and determine the usefulness of swim volume as a predictor of shoulder injury.

Chapter Two – Review of the Literature

Introduction

A large number of competitive swimmers present with shoulder injury during the course of a competitive swim season.[1-4,7-11,16,17] A historical overview of shoulder injuries in swimmers is presented followed by a review of shoulder injury rates in swimmers. A review of the literature regarding risk factors for shoulder injuries in swimmers is provided. The argument is then made for a new model for predicting shoulder injuries in competitive swimmers.

Historical Overview

Shoulder pain is a significant problem for the competitive swimmer, with up to 90% of competitive swimmers presenting with a history of shoulder pain.[1,2,12,14,16-19] Kennedy, Hawkins, and Krissoff[20] first presented the concept of "swimmer's shoulder" in 1978, and Jobe et al[21] expanded upon the concept in 1989. This original research in the area of shoulder pain in swimmers suggested a linear relationship between glenohumeral laxity, supraspinatus impingement, and shoulder pain. [20,21]

Although the source of shoulder pain in swimmers is most likely within the supraspinatus tendon, recent research indicates that glenohumeral laxity is not the sole predisposing factor for shoulder pain in swimmers.[6,7,14-17,22] Additional risk factors such as scapular dyskinesis, pectoralis minor tightness, muscle weakness, poor endurance of the glenohumeral or scapular stabilizers, and glenohumeral range of motion values may also play a significant role.[7,10,11,13-17,22-26]

Theory and Research Literature

Incidence and etiology of shoulder pain in swimmers

A review of the recent literature reveals a consistently high rate of shoulder pain and injury in swimmers, with 14-53% of swimmers reporting shoulder pain or injury during the course of any single season.[6-11,16,17] The majority of the swimming-related injuries discussed in the literature are chronic in nature, and many athletes continue to participate either fully or in some modified manner while in pain.[7,11] The high frequency of shoulder pain and injuries in swimmers may result in swimmers expecting to train through pain. [11]

Injury incidence rates in swimming are typically presented as the number of injuries per athlete exposures or as the number of injuries per 1,000 swim kilometers. An athlete exposure is defined as one athlete participating in one practice or competition. Injuries are typically reported as a painful event that interferes with training or competition or requires medical attention. Published injury incidence rates for swimming range from 2.12 to 5.50 injuries per 1,000 athlete exposures.[10,27,28] Likewise, an injury rate of 0.3 injuries per 1,000 km swam has been reported.[8] The cumulative training distance for a swim squad size of 20 swimmers over a 20 week season is 15,200 kilometers (6.4 km/session x 6 training sessions/week x 20 athletes x 20 weeks) resulting in a calculated estimate of 4.56 shoulder injuries per season for a team of 20 swimmers.[8,10,11,18,22,24,25]

In the swimming population, the shoulder, followed by the spine, are the most frequently injured body parts.[8,10,27,28] The majority of the injuries are of gradual onset, with subacromial impingement syndrome being the most prevalent diagnosis.[1,2,7,10,14,27-29]

The majority of swimmers complain of pain either anterior or anterolateral to the shoulder, with a significant number of swimmers presenting with positive impingement signs.[12,14,16,29] A study by Bak and Fauna[14] identified positive impingement signs in 80% of swimmers with shoulder pain, and an epidemiological study of swimmers conducted by Bansal et al[7] established positive impingement signs in 17% of the swimming population studied. Sein et al[29] reported a correlation between positive impingement signs and supraspinatus tendinopathy and also a correlation between supraspinatus tendon thickness and tendinopathy in swimmers.

The literature demonstrates a high rate of shoulder injuries in competitive swimmers. The research is fairly conclusive that the source of shoulder pain in swimmers is the supraspinatus tendon. The evidence is also highly suggestive that the pain is a result of mechanical impingement of the supraspinatus tendon. Identification of the risk factors for shoulder injuries in swimmers will be useful in recognizing athletes at risk for injury and will also be helpful in developing future injury prevention programs.

Risk factors for shoulder pain in swimmers

A number of studies have attempted to retrospectively establish the variables that are associated with shoulder pain in swimmers.[1,2,6,7,14,15,24,29,30] The variables identified through retrospective research include: scapular dyskinesis, glenohumeral laxity, glenohumeral range of motion, pectoralis minor muscle length, shoulder strength, shoulder endurance, a history of shoulder injuries, and the volume of swimming exposure.[1,2,6,7,14,15,24,29,30] A fewer number of studies have utilized a prospective approach in identifying predictors of shoulder injuries in swimmers.[8-10] Risk factors identified through previous prospective research include: athlete’s age when starting competitive swimming, a history of shoulder injuries, and glenohumeral range of motion.[8-10] Each of those variables and risk factors is explored in greater detail below.

Scapular dyskinesis as a risk factor for shoulder pain in swimmers

Normal scapular position and motion is essential for effective shoulder function. Scapular motion increases the total range of motion occurring at the shoulder girdle, promotes glenohumeral congruency, ensures optimal subacromial space, and provides an ideal length-tension relationship of the periscapular musculature. The scapula moves about three axes with three motions occurring in unison in the healthy shoulder. Upward and downward rotation occurs around an axis of rotation that is perpendicular to the plane of the scapula. Internal and external rotation occurs around a vertical axis through the plane of the scapula, and anterior and posterior tilt occurs around a horizontal axis in the plane of the scapula.[31-36]

Scapular dyskinesis is defined as abnormal scapular position and/or motion observed during dynamic shoulder flexion and/or abduction. Scapular dyskinesis can be identified through the presence of one or more of the following: medial border prominence during motion; abnormal anterior tilt or scapular elevation during arm elevation; and rapid downward scapular rotation during arm lowering.[32,33]

The primary muscular stabilization and control of the scapula occurs through a force couple generated through contractions of the serratus anterior, rhomboid major and minor, and the upper and lower trapezius muscles. The scapula upwardly rotates during humeral elevation, providing maximal space for the supraspinatus tendon under the acromion process. The upward rotation occurs via a force couple created through contraction of the serratus anterior and trapezius muscles.[23,35,37] The serratus anterior also produces the scapular posterior tilt and external rotation that occurs with humeral elevation while also stabilizing the medial border of the scapula.[35]

Previous research has established a relationship between serratus anterior weakness and decreased upward rotation of the scapula resulting in scapular dyskinesis.[25,37,38] In addition, serratus anterior strength and endurance deficits can lead to over-activation of the trapezius and rhomboid muscles in an effort to stabilize the scapula.[27,30,33] Changes in the scapular stabilization force couple may lead to scapular dyskinesis.

The concept of fatigue-induced scapular dyskinesis is worth considering.[22,23,26,39,40] Muscle fatigue associated with individual swim training sessions can lead to scapular dyskinesis, with as many as 82% of swimmers presenting with scapular dyskinesis following a training session.[22,23,25,26,40] Specifically, a decrease in upward scapular rotation during humeral elevation has been identified following a swim practice.[22,23,26] Tsai et al[39] also identified decreases in scapular posterior tilt, external rotation, and upward rotation following fatigue of the glenohumeral external rotators. The research supports poor muscular endurance and fatigue as causative factors for fatigue-induced scapular dyskinesis in swimmers.

Scapular dyskinesis has been associated with a variety of shoulder pathologies, including supraspinatus impingement, multidirectional instability, and rotator cuff injury.[33,37,38,41] Several studies have identified scapular dyskinesis in swimmers with painful shoulders.[14,15,23,42-44] However, this data was collected after the swimmers presented with shoulder pain; and therefore, it is difficult to ascertain if the dyskinesis was a result of the pain, if the dyskinesis was fatigue-induced, or if the dyskinesis was a predisposing factor for the shoulder pain. In a retrospective study, Tate et al[6] were not able to associate dyskinesis with shoulder pain, dissatisfaction, and disability in swimmers. Scapular dyskinesis, either present from the onset of the season or fatigue-induced, may be a predictive risk factor for shoulder injuries in competitive swimmers and should be included as a possible risk factor for shoulder injuries in swimmers.

Scapular dyskinesis can be identified clinically by observation or it can be measured with an inclinometer.[45-47] Both methods are reliable and valid measures of scapular dyskinesis.[45-47] The inclinometer technique measures static scapular position while the shoulder is forward flexed. The inclinometer is placed along the spine of the scapula, and the scapula position is assessed at rest, and at 60°, 90°, and 120° of arm elevation in the plane of the scapula.[47] The Scapular Dyskinesis Test is a clinical observation method of assessing dynamic scapular dyskinesis during weighted humeral flexion and abduction. Participants are rated as having Normal, Subtle Dyskinesis, or Obvious Dyskinesis as they perform five repetitions of resisted shoulder flexion and abduction. The reliability and validity of the Scapular Dyskinesis Test has been established.[45,46] The Scapular Dyskinesis has moderate interrater reliability ($k_w = 0.57$ for live raters and 0.54 for those viewing via videotape).[45] The validity of the Scapular Dyskinesis Test has been established by comparing visual analysis to 3-dimensional electromagnetic kinematic testing.[46] Differences in scapular and clavicle motion as measured with kinematic testing were noted for individuals classified as having normal scapular motion compared to those rated with obvious dyskinesis.[46]

Glenohumeral laxity as a predictor of shoulder pain in swimmers

Glenohumeral laxity is described as the amount of humeral head translation occurring at the shoulder joint, in comparison to joint instability which is a symptomatic increase in joint laxity.[34] Clinical practice suggests that swimmers develop glenohumeral hyperlaxity which leads to secondary supraspinatus impingement; however, this connection has not been fully made in the scientific literature.

Jobe et al[21], in 1989, described the potential relationship between anterior glenohumeral laxity and supraspinatus impingement. The authors describe the possibility for glenohumeral ligament attenuation as a result of repeated overhead activities. The ligamentous laxity that is induced by the repeated overhead activity increases the demands on the dynamic glenohumeral stabilizers as they struggle to maintain the humeral head centered within the glenoid cavity. The authors suggest weakness or fatigue in this muscle group may then lead to increased superior humeral head migration and secondary supraspinatus impingement.[21]

Several subsequent studies used clinical measures of laxity in support of Jobe's original theory.[2,7,14] In one of the early studies of laxity and shoulder pain in swimmers, McMaster et al[2] established a correlation between glenohumeral laxity, assessed with the Drawer Sign and Sulcus Test, and interfering shoulder pain in swimmers. Similar results were found in a study conducted by Bak and Fauno.[14] A more recent study identified glenohumeral laxity, measured through clinical exam, as a predictive factor for impingement syndrome in swimmers.[7]

Conversely, several recent studies have questioned the presence of glenohumeral laxity in swimmers.[13,18] Jansson et al[13] evaluated generalized joint laxity, shoulder laxity, and shoulder mobility in youth swimmers. The researchers assessed glenohumeral laxity with the Anterior Drawer and Sulcus Tests, two common clinical measures of glenohumeral laxity, and established no differences in laxity between swimmers and non-swimmers.[13] Additionally, advances in diagnostic technologies have allowed researchers to more accurately measure humeral head translation. Sonographic measures of glenohumeral mobility demonstrated no difference in glenohumeral laxity between swimmers and controls, and also no difference in glenohumeral mobility in swimmers with pain versus those without pain.[18]

The evidence remains unclear if swimmers present with increased glenohumeral laxity compared to non-swimmers. With increased laxity in swimmers, it is difficult to ascertain if the laxity is a result of the extensive time spent in the overhead position during training and competition, or if genetically lax individuals are predisposed to become better swimmers. Previous research is inconclusive if glenohumeral laxity is a predictor for shoulder injuries in swimmers; however, the evidence suggests it should be included in a prediction model.

Glenohumeral laxity can be assessed with clinical tests, self-report measures, or instrumented devices such as diagnostic ultrasound and joint arthrometers.[2,7,13,14,18,48] Clinical tests for glenohumeral laxity are well-known and relatively easy to perform; however, their usefulness in detecting laxity in swimmers is questionable.[13] Diagnostic ultrasound is a fairly new technique for health care providers and researchers. And while it likely provides an accurate assessment of laxity at the glenohumeral joint, it requires equipment that is not readily available to all clinicians. Joint arthrometers, commonly used for measuring laxity in the knee joint, can be also used for measuring glenohumeral laxity.[49,50] The arthrometer is placed on the proximal humerus and scapula and an anterior force is applied. The amount of anterior translation of the humeral head is then measured. This technique has excellent test-retest reliability (ICC=0.93; 95% CI, 0.81-0.98). [50] Previous research has reported a mean value for anterior translation at 67 N of force of 11 mm +/- 2 mm.[50]

Pectoralis minor muscle length as a predictor of shoulder injury in swimmers

Pectoralis minor tightness has been identified retrospectively as a potential risk factor for shoulder injury in swimmers.[6,30]. The pectoralis minor inserts onto the coracoid process of the scapula; therefore, tightness may lead to altered scapular position and/or altered scapular mechanics. Recent retrospective research by Tate et al[6] and Harrington et al[30] established shortness in the pectoralis minor as a risk factor for shoulder injury in swimmers. However, pectoralis minor length has not been studied prospectively as a risk factor for shoulder injury in swimmers.

The length of the pectoralis minor can be determined by measuring from the coracoid process to the fourth intercostal space adjacent to the sternum.[51] The distance is measured with a tape measure, caliper, or palpation meter with the pectoralis minor in both the relaxed and stretched positions. The pectoralis minor length is normalized by dividing the measured length by the participant's height and multiplying by 100.[6,51,52] Previously reported reliability and validity of a palpation meter for measuring pectoralis minor length is excellent (ICC=0.98–0.99, SEM=0.29–0.32 cm).[51]

Shoulder muscle strength and endurance deficits as predictors of shoulder injury in swimmers

The volume of training completed by competitive swimmers and the repeated overhead nature of the activity requires optimal strength and endurance of the scapulothoracic and glenohumeral muscles. Weakness, poor endurance, or poor neuromuscular control of the scapulothoracic stabilizers may result in scapular dyskinesis during a single training session or over the course of a competitive season. Similar muscular deficits in the glenohumeral stabilizers may lead to increased humeral head migration and secondary supraspinatus impingement.

The scapular stabilizers include the serratus anterior, rhomboid major and minor, upper, middle and lower trapezius, and the levator scapulae. The scapular stabilizers are utilized throughout all phases of the swimming stroke.[53] Several studies have specifically discussed the relevance of the serratus anterior during the swimming stroke.[26,43,53] The serratus anterior is initially active as it protracts the scapula as the hand enters the water. The serratus anterior then contracts again as it pulls the body forward against a stabilized scapula, propelling the swimmer through the water.[14] The serratus anterior is active during the entire swim stroke cycle and is therefore at risk for fatigue over the course of a practice, competition, and season.[43,53-55] Additionally, the importance of the serratus anterior in promoting normal scapula position and movement has been previously established in this paper.

Previous research has demonstrated changes in electromyographic (EMG) activity in the scapulothoracic muscles in individuals with shoulder pain.[19,43,44,55] Pink et al[43] conducted an EMG study of twelve shoulder muscles in swimmers with and without painful shoulders. Swimmers with shoulder pain demonstrated decreased upper trapezius activity at hand entry and decreased serratus anterior and teres minor activity during the pull-through phase. Other studies have shown increased upper trapezius activity and decreased lower trapezius and serratus anterior activity in patients with impingement signs.[37,56,57] A study by Cools et al [58]also revealed increased upper trapezius and middle trapezius latency times in patients with impingement signs.

Weakness and poor endurance in the glenohumeral external rotators may also lead to shoulder pain in swimmers. The external rotators function to center the humeral head within the glenoid cavity while the arm is in the overhead position. Strength or endurance deficits in these muscles in swimmers may lead to superior humeral head migration and subsequent supraspinatus impingement.[59] Previous research has identified a potential correlation between poor endurance of the glenohumeral external rotators and shoulder pain in swimmers.[24] Swim training primarily focuses on the internal rotators of the glenohumeral joint and therefore negatively impacts the ideal external to internal rotator strength ratio.[14,15,53] Several small studies have identified decreased external to internal glenohumeral rotator strength ratios in swimmers with painful shoulders.[14,15,42-44]

Additionally, the glenohumeral external rotators rely on the scapular retractors to stabilize the scapula as the external rotators contract. Fatigue in the muscles that retract the scapula has been shown to decrease the amount of torque generated by the glenohumeral external rotators.[42] The literature supports including scapular stabilizer strength values, glenohumeral strength values, and shoulder endurance and control values as potential predictors of shoulder injuries in swimmers.

Hand-held dynamometry is a common way of measuring muscle strength in both clinical and research settings. Participants are positioned in standard muscle testing position, with the dynamometer stabilized for the participant to perform a “make” test. A “make” test relies on the participant to perform a maximal isometric contraction compared to a “break” test which may be influenced by researcher/clinician strength.

Hand-held dynamometry is a reliable and valid measure of scapular stabilizer and glenohumeral strength.[60,61] A summary of previously established reliability and error measurements for handheld dynamometry of the shoulder is presented in Table 1.

Table 1 Reliability and error estimates for hand-held dynamometry of the shoulder

Muscle	Author	Reliability[a]	CI[b]	Mean SD[c] Range	SEM	MDC
Upper trapezius	Michener et al[60]	0.96	.91-.98	16.1-17.2 kg 7.1 kg 2.4-29.2 kg	1.6 kg	3.3
	Turner et al[61]	0.65-0.89	NR[d]	303.4 N 791.1 N NR	22.7-28.5 N	NR
Lower trapezius	Michener et al[60]	0.89	.89-.96	9.2-10.5 kg 6.0-6.3 kg 1.5-18 kg	0.9 kg	2.6 kg
	Turner et al[61]	0.69-0.77	NR	123.5 N 37.8 NR	9.9-13.9 N	NR
Serratus anterior	Michener et al[60]	0.94	.88-.97	15.2-15.3 kg 6.0-6.3 kg 2.5-27.2 kg	1.7 kg	3.6 kg
	Turner et al[61]	0.69-0.87	NR	187.3 N 59.3 N NR	15.9-21.7 N	NR
Supraspinatus	Kelly et al[62]	0.65	NR	NR	NR	NR
Teres minor and infraspinatus	Hayes et al[63]	0.92	.78-.98	NR	NR	NR
Subscapularis	Hayes et al[63]	0.85	.64-.96	NR	NR	NR

[a] Intrarater reliability, ICC value
[b] Confidence Interval (95%)
[c] Standard deviation
[d] Not reported

A limited number of techniques for measuring shoulder muscle endurance and control are presented in the literature. The Serratus Anterior Punch Test assesses endurance of the serratus anterior by having the participant perform repeated resisted scapular protraction until fatigue. The Serratus Anterior Punch Repetition Test has good reliability with a published ICC value of 0.75.[64] Shoulder muscle endurance and control can be measured with the Closed Kinetic Chain Upper Extremity Stability Test. The participant, in the push-up position, crosses her arms to the contralateral side as quickly as possible for 15 seconds, and the number of repetitions is counted. The reported test-retest ICC value for the Closed Kinetic Chain Upper Extremity Stability Test is 0.922.[65]

Glenohumeral range of motion values as a predictor of shoulder injury in swimmers

A variety of factors can lead to changes in glenohumeral internal and external range of motion values in overhead athletes. Swimmers differ from many other overhead athletes in the amount of time they spend in the overhead position. Numerous studies have researched potential associations between range of motion values and shoulder pain in swimmers.[6-8,15,24,30] A prospective study by Walker et al[8] identified swimmers in both high (>100°) and low (<93°) external range of motion groups at a higher risk of shoulder injury. Bansal et al[7] retrospectively identified decreased internal rotation and increased external rotation range of motion values in swimmers with impingement syndrome. Reduced internal rotation has also been identified in swimmers with shoulder pain, dissatisfaction, and disability.[6] The causes of the shift in rotation range of motion to increased external rotation and decreased internal rotation has been studied extensively in baseball players; however, research investigating similar range of motion changes in swimmers is relatively non-existent. Increases in external rotation range of motion may be due to laxity in the anterior and anteroinferior glenohumeral ligaments or bony changes to the humerus and/or scapula. Tight posterior capsular structures and/or bony changes may explain the decreases in internal rotation range of motion. The research is mixed regarding range of motion variables as a predictor of shoulder injuries in swimmers. However, enough evidence exists to include shoulder rotation range of motion values in the prediction model.

Shoulder range of motion can be measured with a goniometer or an inclinometer. Internal and external passive range of motion is measured in 90° of abduction. The reliability of an inclinometer for measuring rotation range of motion is excellent (ICC = 0.90-1.0, SEM=0.67-1.54°).[30]

A history of shoulder pain as predictor of shoulder injuries in swimmers

A history of previous shoulder pain and injury appears to be associated with subsequent shoulder injury.[6-10] Swimmers with a history of shoulder injury are between 2.1 and 4.1 more likely to develop a shoulder injury compared to those swimmers who do not have a history of shoulder injury.[8-10] It is difficult to establish a causal relationship between previous shoulder injury and future shoulder injuries. It is logical for the pain or injury to return if the initial injury is not treated properly, if the athlete returns to sport too soon, or if the causative factors are not properly addressed. The evidence exists that a history of shoulder injuries is predictive of future shoulder injuries, and therefore it is included as a variable in the prediction model.

Additional factors associated with shoulder injury in swimmers

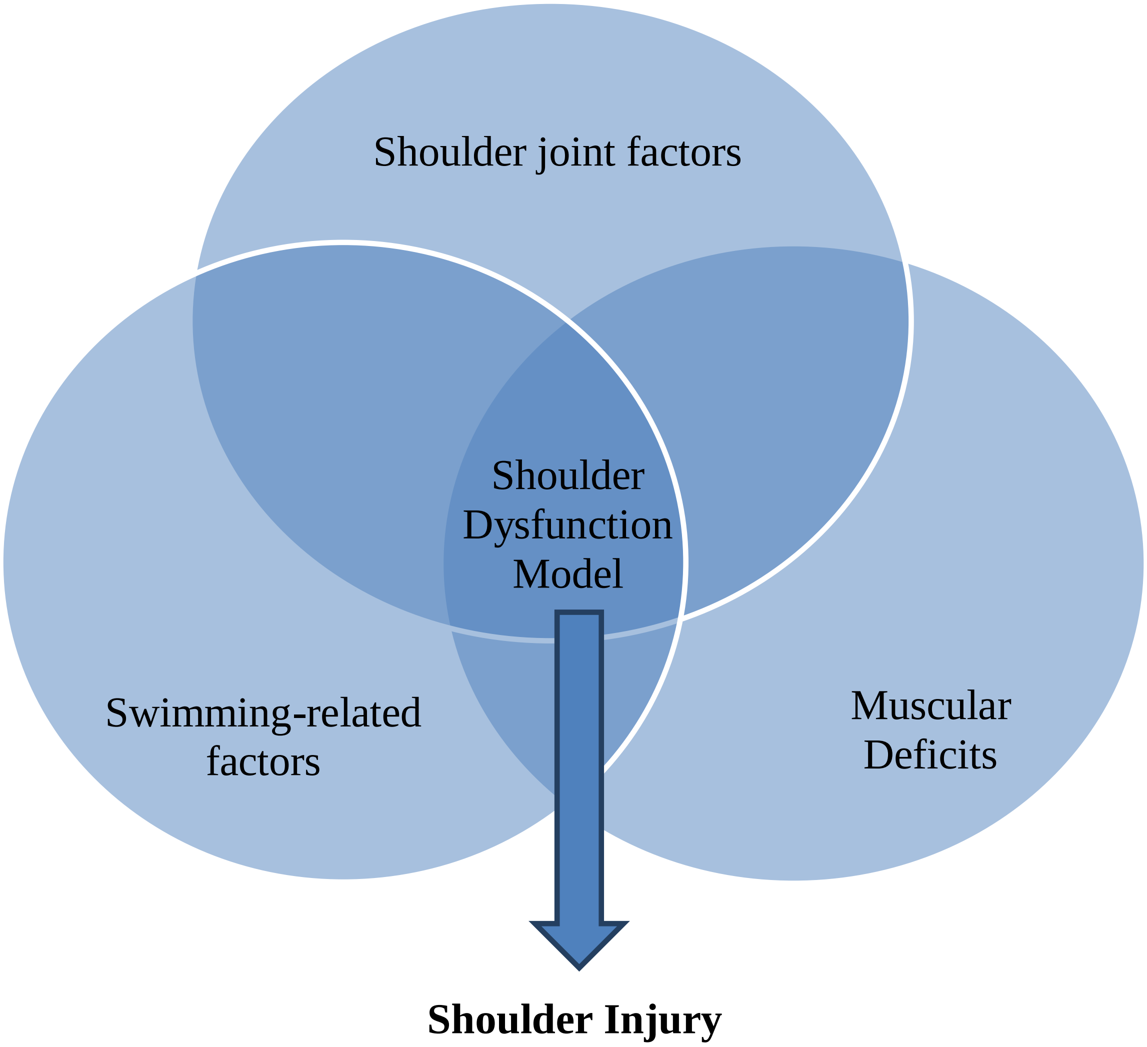
Several other variables have been associated with shoulder pain in swimmers, including the volume of training and the swimmer’s age at the time of starting training and competing.[6,9,29] Prospective research indicates a 13% decrease in injury likelihood for every year older in age the swimmer begins competitive training.[9] The swimmer's age when she began training and competing will be a risk factor included in the prediction model.

The relationship between the volume of training and injury rates is questionable. Previous research by Tate et al[6] discovered greater swimming exposure in swimmers who were positive for shoulder pain, dissatisfaction, and disability. Research has also correlated supraspinatus tendon thickness with the number of years the swimmer has competed.[29] However, in a prospective study of risk factors for shoulder pain in swimmers, Walker et al[8] reported the volume of swim training did not significantly alter injury rates and therefore concluded that swim training distance was not a significant predictor of shoulder injury. A retrospective analysis of swim training volume and shoulder injuries will be included as part of this study.

The Shoulder Dysfunction Model as a predictor of shoulder injury in swimmers

The cumulative effects of shoulder joint factors, muscular deficits, and swimming-related factors potentially creates a Shoulder Dysfunction Model, illustrated in Figure 1, that predisposes competitive swimmers to shoulder injuries over the course of a season. The combination of glenohumeral laxity, scapular dyskinesis, decreased strength and poor endurance of the scapulothoracic and glenohumeral stabilizers leads to decreased upward scapular rotation and/or superior humeral head migration during arm elevation. The likelihood of a shoulder injury in those athletes with Shoulder Dysfunction is then elevated due to the extensive time the swimming athletes spend in the arm overhead position during training. The risk factors of scapular dyskinesis, glenohumeral laxity, shoulder muscle strength deficits, and endurance and control deficits, when combined with thousands of swimming strokes per day over the course of swim season, may predispose the swimming athlete to shoulder injury.

Figure 1 Swimmers Shoulder Dysfunction Model



Summary of what is known and unknown

The rate of shoulder injuries in competitive swimmers is concerning. Swimmers spend a tremendous amount of time in the overhead position during training and competition; however, not all swimmers develop shoulder injuries. A limited number of studies have attempted to identify the predisposing factors for shoulder pain in swimmers, and even fewer studies have done so prospectively. Scapular dyskinesis, increased glenohumeral laxity, pectoralis minor tightness, scapular muscle strength deficits, range of motion changes, shoulder muscle strength deficits, and shoulder endurance and control deficits may lead to decreases in the subacromial space and decreased ability to maintain the humeral head centered within the glenoid cavity. Together, scapular dyskinesis, glenohumeral laxity, and weakness or poor endurance in the scapular stabilizers and glenohumeral external rotators may create a Shoulder Dysfunction Model that is able to predict shoulder injuries in swimmers.

Contribution to the field

Shoulder injuries are a common and debilitating condition for competitive swimmers. This study attempts to determine if scapular dyskinesis, glenohumeral laxity, pectoralis minor tightness, scapular muscle strength, rotator cuff strength, shoulder muscle endurance and control, range of motion, history of shoulder injury, and age when starting competitive swimming are predictors of shoulder injuries in swimmers. A better understanding of the risk factors for shoulder injuries in swimmers will assist clinicians in identifying swimmers at risk for injury and will also be useful in guiding future research into injury prevention and off-season training programs.

Summary

Shoulder injuries are a significant concern for the competitive swimmer. Previous attempts by researchers to identify the predisposing factors for shoulder injuries has either been conducted retrospectively or have not included all of the factors being investigated in this study. In theory, scapular dyskinesis, glenohumeral laxity, and decreased scapulothoracic and glenohumeral strength and endurance are occurring in unison to create a Shoulder Dysfunction Model that leads to shoulder injury. The identification of a prediction model for shoulder injuries in swimmers will be useful in identifying those athletes who are at risk for shoulder injuries and will also guide future research into injury prevention programs.

Chapter Three – Methods

Introduction

The study was designed to address three primary research questions. The first research aim was to describe the swimming-related factors, shoulder joint factors, and muscle characteristics of female collegiate swimmers at the onset of a swim season. The second research aim was to identify the risk factors for shoulder injury in female collegiate swimmers. The final research aim was to characterize swim volume of female collegiate swimmers, and to determine the usefulness of swim volume as a predictor of shoulder injury. A demographic and swim history questionnaire, as well as a musculoskeletal screening, was completed at the beginning of the swim season, and injury surveillance data and swim volume data was collected throughout the 2015-2016 women's collegiate swim season.

Research Methods

A prospective longitudinal cohort multi-center design was used to identify the risk factors for shoulder injuries in swimmers. Female collegiate swimmers (n=53 with n= 106 shoulders) were prospectively examined, and then followed for the competitive segment of a collegiate swim season. Participants were recruited from four women's swim teams at universities within the Pennsylvania State Athletic Conference (PSAC). All four universities compete at the NCAA Division II level. After providing consent, participants completed a demographic and swimming-related questionnaire and underwent a musculoskeletal assessment at the beginning of the season. A summary of the variables measured and their respective measurement techniques are presented in Table 2.

Table 2 Risk factors studied

Risk factor	**Measurement**
Scapular dyskinesis	Scapular Dyskinesis Test
Anterior glenohumeral laxity	KT-1000
Pectoralis minor length	Palpation meter
Scapular strength	Hand-held dynamometer values for upper trapezius, lower trapezius, and serratus anterior strength
Rotator cuff strength	Hand-held dynamometer values for supraspinatus, teres minor, infraspinatus, and subscapularis strength
Shoulder endurance and stability	Serratus Anterior Punch Repetition Test and the Closed Kinetic Chain Upper Extremity Stability Test
Shoulder range of motion	Passive internal and external glenohumeral passive range of motion measured with an inclinometer
History of shoulder pain	Preseason questionnaire
Age of swimmer at time of starting competitive swimming	Preseason questionnaire

Shoulder injury data and swim volume data was collected weekly with a web-based survey sent to the swimmers. A shoulder injury was defined as swimming-related shoulder pain that required the student-athlete to seek medical attention and resulted in at least one modified or missed athlete exposure. A modified athlete exposure was defined as a decrease in the yardage swam, event(s) swam, or training technique as result of shoulder pain.

Specific Procedures

Participants were recruited from the women's swim teams within the Pennsylvania Athletic Conference. An email to the swim coaches, athletic directors, and head athletic trainers was sent during the summer of 2015 informing those individuals of the general nature of the study and solicited their support. A follow-up email was sent to the coaches during August of 2015 to remind them of the study details and timeline. Preseason data collection occurred during September and October of 2015. The study details were presented to the entire swim team, and athletes were provided the option to participate and provide consent. Swimmers were excluded from the study if they were 1) under the age of 18, 2) unable to participate in the first day of practice due to shoulder injury, and 3) if they were currently being treated for a shoulder injury or have been within the past three months.

A web-based a-priori sample size calculator was used to determine the sample size required for a regression analysis that included nine predictors (http://www.danielsoper.com/statcalc3/calc.aspx?id=1). Using an effect size of 0.15, power level of 0.80, 9 predictors, and a probability level of 0.05, a sample size of 113 was required. This coincided with an estimated 10 participants per predictor for a total of 90 participants. Assuming a 10% dropout rate, a total of 125 swimmers were recruited. Each shoulder was considered an individual participant; therefore, 63 swimmers were recruited for participation. Due to hesitancy of coaches and swimmers to participate, 53 swimmers participated in the preseason screening.

The preseason data collection included a demographic and swimming-related questionnaire and a musculoskeletal screening. The swimming-related questionnaire collected information regarding the participant's age when she started competitive swimming, number of years of competitive swimming, preferred events and distance, amount and frequency of off-season training, typical swim training frequency, number of months per year they practiced, participation in other sports, and a history of previous shoulder pain. The demographic and swimming-related questionnaire can be found in Appendix 2.

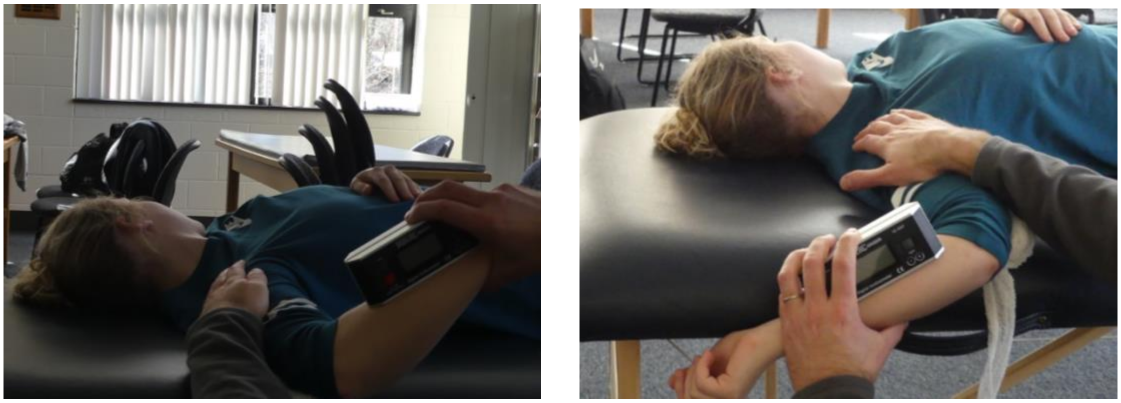
The musculoskeletal assessment included an evaluation of scapular dyskinesis, glenohumeral range of motion, glenohumeral laxity, pectoralis minor length, shoulder muscle strength, and shoulder muscle endurance. All data was collected bilaterally with a random selection of the side tested first and random sequence of testing.

Scapular dyskinesis was assessed with the Scapular Dyskinesis Test (SDT) described and validated by McClure et al.[45,46] Participants performed five repetitions of shoulder flexion and abduction with dumbbells in their hands. Participants weighing less than 68.1 kg used 1.4 kg (3 lb) dumbbells, and participants weighing more than 68.1 kg used 2.3 kg (5 lb) dumbbells. Participants stood two to three meters away from a tripod-mounted video camera for recording posterior views of the motion. Participants were instructed to lift their arms overhead into the flexion and abduction positions. The test motion was demonstrated to the participants, and the participants had the opportunity to practice each motion. Participants were instructed to perform each repetition at a speed of three seconds for each elevation and three seconds for each descent. Five repetitions were performed for both flexion and abduction. The test was videotaped from a posterior view for subsequent analysis. Each shoulder was rated as having either Normal/Subtle Dyskinesis or Obvious Dyskinesis. Normal was defined as no evidence of abnormality. Subtle dyskinesis reflected mild or questionable abnormality that may not be consistently present. Obvious dyskinesis includes strikingly clear and apparent abnormalities that are present on multiple trials.[45,46] The setup for the Scapular Dyskinesis Test can be found in Figure 2, and the Scapular Dyskinesis Test protocol can be found in Appendix 3.

Figure 2 Scapular Dyskinesis Test setup

Glenohumeral internal and external passive range of motion was measured with a digital inclinometer.[30] Participants were positioned supine with the shoulder abducted to 90°. The glenohumeral joint and scapula were stabilized to the table with the examiners hand. Two measures of passive internal and external rotation were completed, and the average was used for data analysis. The positioning for range of motion testing can be found in Figure 3, and the procedure for measuring range of motion can be found in Appendix 7.

Figure 3 Glenohumeral range of motion testing setup

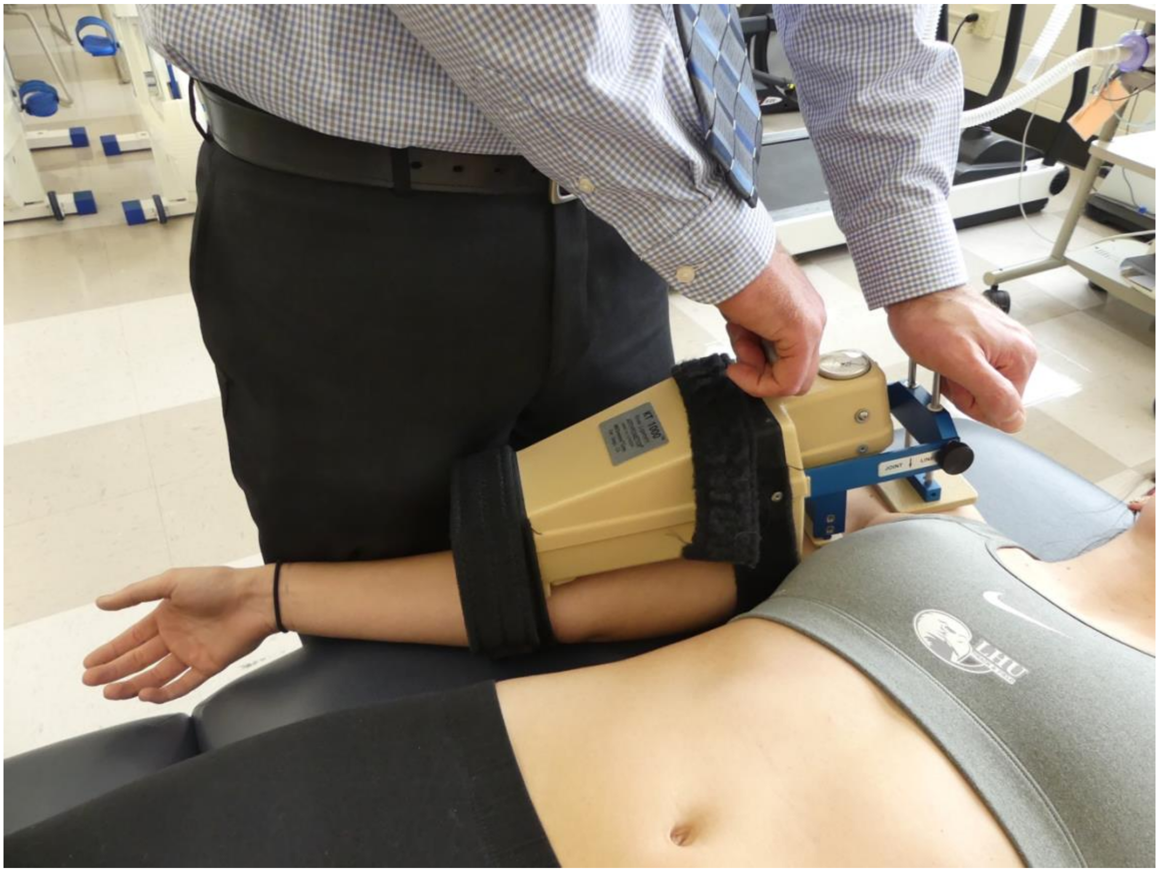


Passive internal rotation

Passive external rotation

Anterior glenohumeral laxity was evaluated using a KT-1000 joint arthrometer as described by Taylor and Bandy.[50] Participants were positioned supine with the shoulder abducted 20° and 0° of rotation, and the arm relaxed on the examination table. Once the participant was positioned correctly, the KT-1000 was positioned on the proximal arm with the tibia pad placed close to the glenohumeral joint line. The patella sensor pad was placed over the coracoid process of the scapula. The KT-1000 was stabilized with Velcro straps around the arm. Once the KT-1000 was positioned properly, the dial was set to zero. Three 67 N anterior forces were applied, ensuring the dial returned to 0 +/- 0.5 mm after each attempt. Participants were instructed to relax completely, and the amount of anterior translation was recorded for the two trials and averaged for data analysis. Positioning for the KT-1000 assessment can be found in Figure 3, and the protocol for measuring anterior laxity with the KT-1000 can be found in Appendix 4.

Figure 3 Anterior laxity testing setup



Pectoralis minor length was measured with the muscle in both the relaxed and stretched position. The distance from the coracoid process to the fourth intercostal space was measured using a palpation meter. Two measurements were taken on each side and averaged for data analysis. The pectoralis minor length technique is found in Figure 4, and the associated protocol can be found in Appendix 5.

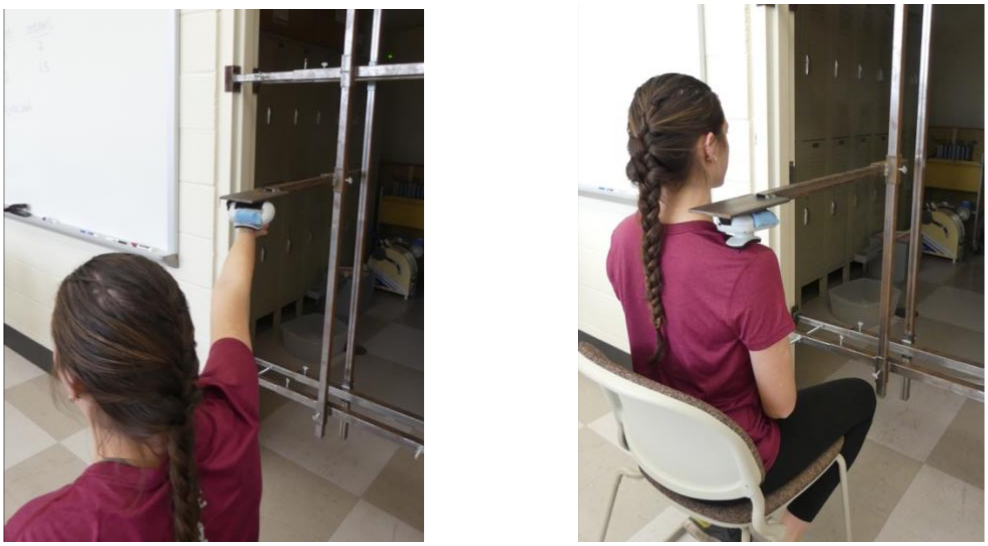
Figure 4 Pectoralis minor length testing setup

Resting position Stretched position

Strength for the shoulder and scapular muscles was evaluated with a hand-held dynamometer. Strength values of the serratus anterior, upper trapezius, lower trapezius, infraspinatus, teres minor, and subscapularis was collected. The participant’s body weight was also collected. For all measures, the distance from the joint axis to the dynamometer was recorded for calculating torque. Torque values were normalized for body weight by dividing the torque value by the subject’s body weight. The dynamometer was stabilized for each test, and a “make test” was used for assessing muscle strength. Participants were given the opportunity to practice each test where then instructed to provide maximal effort for two trials. The force output from the hand-held dynamometer was recorded for the two trials. The order of muscle testing was random. The specific protocol for the strength assessment is included in Appendix 6.

Participants were positioned seated with the arm abducted to 120° in the scapular plane to test the serratus anterior as described by Ekstrom et al.[66] The hand-held dynamometer was positioned at the participant’s radial styloid process and was stabilized to the wall. Participants were instructed to resist arm elevation during this test. The upper trapezius strength test was performed according to the technique described by Hislop et al.[67] Participants were seated with the hand-held dynamometer positioned over the acromion process. The dynamometer was stabilized by a device that was stabilized by a wall. Participants were instructed to elevate the scapula during this test. The serratus anterior and upper trapezius testing positions are illustrated in Figure 5.

Figure 5 Serratus anterior and upper trapezius strength testing position



Serratus anterior

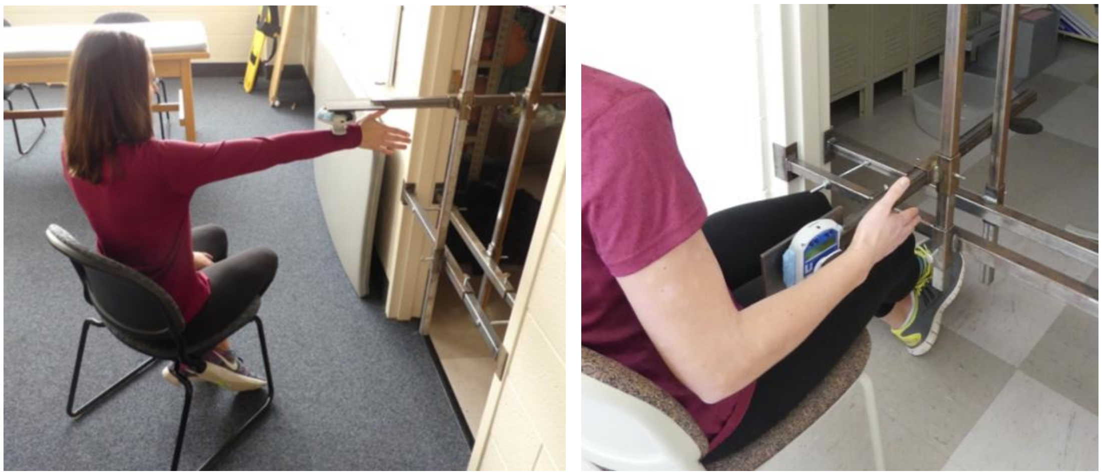
Upper trapezius

The lower trapezius muscle was tested with the patient prone, as described by Hislop et al.[67] The shoulder was abducted 140° and externally rotated. The dynamometer was placed over the lateral humeral epicondyle. Participants were instructed to retract and depress the scapula during this test. The lower trapezius testing position can be found in Figure 6.

Figure 6 Lower trapezius strength testing position

The supraspinatus was tested in 90° of humeral elevation with the shoulder in neutral rotation. The hand-held dynamometer pad was placed over the radial styloid process. The glenohumeral internal rotators and external rotators strength were tested with the participants seated with their arm at their side, the elbow flexed to 90°, and their forearm in a neutral position. The hand-held dynamometer pad was positioned between the ulnar and radial styloid processes and stabilized against a wall. Participants were instructed to either maximally internally rotate or externally rotate the shoulder. The supraspinatus and rotator testing positions can be found in Figure 7.

Figure 7 Supraspinatus and subscapularis strength testing position



Supraspinatus Subscapularis

The literature describes limited techniques for measuring shoulder muscle endurance. A common technique is to measure muscle endurance with an isokinetic dynamometer. However, isokinetic dynamometry testing is difficult in a multi-center study. Therefore, shoulder muscle endurance was measured with the Serratus Anterior Punch Repetition Test, and shoulder endurance and dynamic stability was measured with the Closed Kinetic Chain Upper Extremity Stability Test.[64,65] The endurance and stability protocol is found in Appendix 7.

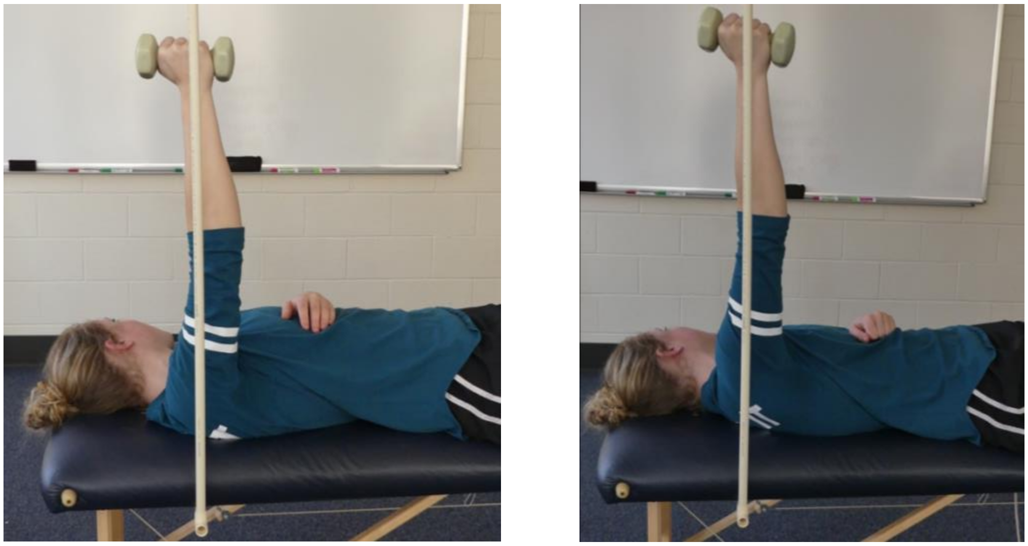
The Closed Kinetic Chain Upper Extremity Stability Test was performed with the participant in the push-up position. Two pieces of 1.5 inch-wide athletic tape were placed on the floor parallel to each other at a distance of 24 inches apart. The start position for this test was one hand on each piece of tape in the push-up position with the body as straight as possible. The participant moved one hand and touched the opposite line and then returned the hand to the original starting position. The same procedure was then repeated with the other hand. The participant was instructed to perform this motion as quickly as possible for 15 seconds. The average number of repetitions performed over two 15-second trials was recorded. The data was normalized by dividing the number of repetitions by the participant's height.[65] The position for Closed Kinetic Chain Upper Extremity Stability Test can be found in Figure 8.

Figure 8 Closed Kinetic Chain Upper Extremity Stability Test

Starting position Crossover position

The Serratus Anterior Punch Repetition Test was performed in the open kinetic chain serratus punch position. Participants used a dumbbell weight of 15% of their body weight when performing this test and performed the serratus punch maneuver at a rate of one repetition per second. A measuring device was placed beside the participant's arm. The measuring device provided the participant feedback in regards to keeping the arm in the 90° of shoulder flexion position and provided feedback regarding the amount of scapular protraction. The test ended when the participant reported fatigue, the participant was unable to keep the arm aligned with the measuring device, or the amount of protraction decreased more than one inch. The number of repetitions performed was recorded with a greater number of repetitions meaning greater muscle endurance. The positioning for the Serratus Anterior Punch Repetition Test can be found in Figure 9.

Figure 9 Serratus Anterior Punch Repetition Test



Starting position

Protracted position

Injury Surveillance

Participants were emailed a link to a web-based survey each week throughout the competitive swim season. Follow-up emails were sent after 24 hours if the participant did not complete the initial request. The survey included information regarding the number of training sessions that week, the number of competitions, the total number yards swam, if the athlete sustained a shoulder injury during the week, and the number of practices and competitions that were modified or missed due to injury. The weekly student-athlete survey is found in Appendix 9. All injuries were followed up with a survey to the team's athletic trainer for information regarding diagnosis, diagnostic imaging results, treatment, and confirming the number of missed or modified practices or competitions. The follow-up survey sent to the team athletic trainer can be found in Appendix 10.

Format for Presenting Results

Results are presented in three primary categories aligned with the aims of the study. The characteristics of female collegiate swimmers at the onset of a competitive swim season are presented first. The second section describes the potential predictors of shoulder injury in female collegiate swimmers. Finally, the swim volume of female collegiate swimmers over the duration of a season is presented along with its potential relationship to shoulder injury.

Resource Requirement

Data was collected at four universities within the Pennsylvania State Athletic Conference. A private room at each of the universities was needed for data collection. A portable examination table was utilized for data collection. A tripod and video camera was used for evaluating scapular dyskinesis. The author had access to a digital video camera, tripod, inclinometer, hand-held dynamometer, and palpation meter through his employing institution. The stabilization devices for the hand-held dynamometer was designed by the author and constructed by a local fabricator. A local physician's office provided access to the KT-1000 joint arthrometer. The demographic and swimming questionnaires, as well as the weekly injury surveillance questionnaire, was administered via a web-based survey platform available through the author's employing institution.

Reliability and Validity

Intra-rater reliability of the musculoskeletal screening was established with a pilot study. The screening measures included in the pilot study were the scapular and rotator cuff strength measures, shoulder endurance measures, glenohumeral range of motion testing, glenohumeral laxity testing, and pectoralis minor length evaluation.

Institutional review board approval was received prior to completing the pilot study. Participants were recruited through flyers and emails distributed on campus. The single inclusion criterion was 18-24 year-old females. Exclusion criteria included individuals who are currently being treated for shoulder pain or have been treated for shoulder pain within the past three months. Consent was obtained prior to the start of data collection. Participants were scheduled for two testing sessions, each 5-7 days apart. The sequence of testing events was randomized during each session. Participants' height and weight were recorded at the beginning of the testing session.

Pilot study data was entered into SPSS statistical software for analysis. As with the primary study, each shoulder was treated as an individual participant (*n*=30). Mean and standard deviation was calculated for each variable for each testing session. The Intraclass Correlation Coefficients ($ICC_{3,1}$) was calculated for each of the variables to establish intra-rater reliability. The Standard Error of the Measurement (SEM) and Minimal Detectable Change were also calculated.

Glenohumeral internal and external range of motion for both shoulders was measured with an inclinometer. Participants were positioned supine in 90 degrees of glenohumeral abduction. The scapula was stabilized while the glenohumeral joint was passively moved into maximal internal and external rotation. The inclinometer was aligned with the participant's forearm. Two trials were performed in each direction, and the mean was used for data analysis. The range of motion data can be found in Table 3.

Table 3 Glenohumeral range of motion reliability data

	Day 1		Day 2		Reliability		
	Mean	**SD**	**Mean**	**SD**	**ICC$_{3,1}$ (95% CI)**	**SEM**	**MDC**
Internal Rotation	75.1	8.5	76.1	8.7	.870 (.746, .935)	3.05	8.46
External Rotation	110.1	12.4	110.2	10.8	.945 (.888, .973)	2.90	8.03

Anterior glenohumeral laxity was measured with a KT-1000 joint arthrometer. Participants were positioned supine in 20 degrees of glenohumeral abduction. The KT-1000 was placed on the anterior arm with the tibial pad placed near the glenohumeral joint line, and the patella pad was placed over the coracoid process. The amount of anterior translation was measured when 67N of anterior force was applied. Two trials were performed on each arm, and the mean was used for data analysis. The laxity reliability data is presented in Table 4.

Table 4 Anterior glenohumeral laxity reliability data

	Day 1		Day 2		Reliability		
	Mean	**SD**	**Mean**	**SD**	**ICC$_{3,1}$ (95% CI)**	**SEM**	**MDC**
Anterior laxity	15.5	3.7	16.3	2.95	.796 (.608, .899)	1.67	4.62

Pectoralis minor length was measured with a PALM palpation meter. The distance from the coracoid process to the anteroinferior aspect of the 4th rib was measured to determine pectoralis minor length. The pectoralis minor length was measured in both the resting and stretched position. The stretched position was obtained by having the participant abduct her arm 90 degrees and place her forearm on a doorjamb. Participants were then instructed to turn her trunk away from the doorjamb without moving her feet. Two measures were taken for each position for each side, and the mean values were used for data analysis. Reliability data for pectoralis minor length measures can be found in Table 5.

Table 5 Pectoralis minor length reliability data

	Day 1		Day 2		Reliability		
	Mean	**SD**	**Mean**	**SD**	**$ICC_{3,1}$ (95% CI)**	**SEM**	**MDC**
Resting position	13.6	1.1	13.8	1.1	.865 (.714, .936)	0.41	1.13
Stretched position	16.5	1.47	16.7	1.3	.894 (.789, .984)	0.48	1.33

The strength of the upper trapezius, lower trapezius, serratus anterior, supraspinatus, infraspinatus/teres minor, and subscapularis was measured with a hand-held dynamometer. The specifics of the test positions can be found in Table 6. Participants performed a “make” test for each of the tests and the force output in kilograms was recorded. Two trials were performed for each test, and the mean was used for data analysis. Reliability values for the strength testing can be found in Table 7.

Table 6 Hand-held dynamometry test positions

Muscle	Participant Position	HHD Placement	Motion
Upper Trapezius	Seated with arm at side	Acromion process	Scapular elevation
Lower Trapezius	Prone with shoulder abducted 140° and externally rotated	Radial styloid process	Scapular retraction and depression
Supraspinatus	Standing with shoulder elevated to 90° in the scapular plane with thumb up	Radial styloid process	Humeral elevation
Serratus Anterior	Standing with shoulder elevated to 120° in the scapular plane with thumb up	Radial styloid process	Humeral elevation
Subscapularis	Seated with shoulder in neutral rotation and elbow flexed to 90°	Anterior wrist between styloid processes	Glenohumeral internal rotation
Infraspinatus / Teres Minor	Seated with shoulder in neutral rotation and elbow flexed to 90°	Posterior wrist between styloid processes	Glenohumeral external rotation

Table 7 Handheld dynamometry reliability data

	Day 1		Day 2		Reliability		
	Mean	**SD**	**Mean**	**SD**	**ICC$_{3,1}$ (95% CI)**	**SEM**	**MDC**
Upper trapezius	52.7	17.7	55.1	13.3	0.792 (.612, .895)	8.1	22.4
Lower trapezius	7.8	3.9	8.2	3.6	0.811 (.643, .905)	1.7	4.7
Serratus anterior	11.5	3.3	11.4	2.5	0.824 (.662, .912)	0.1	0.4
Supraspinatus	13.7	4.2	14.7	4.0	0.778 (.576, .889)	2.0	5.5
Subscapularis	19.5	5.8	19.4	5.7	0.928 (.854, .965)	1.6	4.3
Infraspinatus/ Teres minor	16.2	4.7	15.9	3.9	0.844 (.698, .922)	0.2	0.5

Shoulder stability and endurance was measured with the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) and the Serratus Anterior Punch Repetition Test (SAPRT). The CKCUEST was performed by placing two strips of athletic tape on the floor 24 inches apart. Participants placed their hands on the tape in either the pushup or modified pushup position. Participants were instructed to maintain that position while reaching their hand across their body and touching the contralateral strip of tape as many times as possible in 15 seconds. The SAPRT was performed with the participant supine and the shoulder elevated to 90 degrees. A dumbbell that was approximately 15% of the participant's body was placed in the participant's hand, and the participant was instructed to protract her scapula while maintaining elbow extension. A piece of PVC pipe was attached to the table to provide guidance for the participant while performing this exercise. The number of repetitions was recorded until one of the following events occurred: participant stopped due to fatigue, participant was unable to maintain the test position, or the distal arm fell out of alignment with the PVC pipe. Two trials were performed on each side, and the mean number of repetitions was used for data collection. The reliability values for the shoulder endurance and stability tests can be found in Table 8.

Table 8 Shoulder endurance and stability tests reliability data

	Day 1		Day 2		Reliability		
	Mean	**SD**	**Mean**	**SD**	**$ICC_{3,1}$ (95% CI)**	**SEM**	**MDC**
CKCUEST[a]	25.1	5.2	27.3	5.7	0.836 (.361, .942)	2.1	5.8
SAPRT[b]	24.7	7.0	25.2	6.5	0.855 (.720, .928)	2.7	7.4

Chapter Four – Results

Introduction

The results of the data analysis are presented in this chapter. The data is presented in three distinct areas. The characteristics of female collegiate swimmers at the onset of a competitive swim season is presented first. Descriptive statistics, correlations between variables, and differences in variables in swimmers with and without a history of shoulder injury and with and without scapular dyskinesis are presented. Second, the differences in variables between swimmers who developed a new shoulder injury and those who did not is presented, as well as predictors of shoulder injury in female collegiate swimmers. The final section presents swim volume data over a 16-week season and the usefulness of swim volume as a predictor of injury.

Data analysis

Data was analyzed using SPSS statistical software (Version 16.0). Descriptive statistics, ranges, means, and error measures were calculated for the characteristics of female collegiate swimmers at the onset of a competitive swim season. A Paired Samples *t* Test was used to evaluate differences in shoulder characteristics between the dominant and nondominant shoulder. Pearson Correlation Coefficients between preseason shoulder characteristics of continuous variables were calculated to determine relationships between those variables. A Mann-Whitney U test was utilized to determine differences in shoulder characteristics between swimmers who had a history of shoulder injury and those who did not and between shoulders with scapular dyskinesis and those who did not. The nonparametric Mann-Whitney U test was utilized due to the large differences in group sizes and a non-normal distribution of data.

Differences in preseason characteristics between swimmers who developed an in-season shoulder injury compared to those who did not was determined. A Mann-Whitney U test was utilized for continuous variables, and a Chi square test was used for dichotomous and categorical variables. Again, nonparametric tests were utilized due to a large difference in group sizes and a non-normal distribution of data. Characteristics found to be significant were entered into a binary logistic regression to determine their ability to predict shoulder injury during the season.

Training volume is reported for the duration of the season. Differences in total yards swam, average yards per practice, and average weekly yards at the time of injury for participants who developed shoulder injury were compared to the non-injured group at the corresponding time in the season utilizing an independent samples *t*-test. In order to compare swim volume at the time of injury, the group mean for the non-injured group at the corresponding point in the season was used for comparison. For example, if a swimmer sustained a shoulder injury during week 4 of the season, her total yards swam, average yards per practice, and average weekly yards were compared to the mean non-injured group values at the same point in the season.

Findings

Preseason demographic data, swim history data, and shoulder characteristics was collected from 106 shoulders (n=53 participants) from 4 universities. Preseason data and prevalence of in-season shoulder injuries is reported for 106 shoulders. A total of 34 swimmers completed the weekly training log for the season; therefore, swim volume data is presented for 68 shoulders.

Research Aim 1: Characteristics of female collegiate swimmers at the onset of a competitive swim season

Participant characteristics can be found in Table 9. The mean number of years of competitive swimming was 10.81. More swimmers reported preference for the freestyle stroke and middle-distance events (49.1% and 52.8%, respectively). Most commonly (24/53; 45%), participants were single-sport swimming athletes in high school.

Table 9 Female collegiate swimmer characteristics (n=53 participants)

	N	Mean	SD[a]
Age, y	53	19.3	1.2
Height, cm	53	167.6	6.0
Weight, kg	53	68.4	10.4
Years of competitive swimming, y	53	10.8	3.2
Age when starting competitive swimming, y	53	8.3	3.1
	Frequency	Percent	
History of shoulder injury	18	17.0%	
Number of high school sports[b]			
0	24	45.3	
1	14	26.4	
2	11	20.8	
3	4	7.5	
Total	53	100.0	
Preferred swim stroke			
Freestyle	26	49.1	
Breaststroke	13	24.5	
Butterfly	9	17.0	
Backstroke	5	9.4	
Total	53	100.0	
Preferred swim distance			
Sprint	19	35.8	
Middle	28	52.8	
Long distance	6	11.3	
Total	53	100.0	

[a] Standard deviation

[b] Excluding swimming

Descriptive statistics for the preseason musculoskeletal characteristics of 106 shoulders is presented in Table 10. Mean passive range of motion values for internal, external, and total motion were 99.50, 130.00, and 207.50 degrees, respectively. Mean anterior laxity, as measured by a KT-1000, was 16.9 mm. The mean normalized resting pectoralis minor length was 0.09, and the mean normalized stretched pectoralis minor length was 0.12. The normalized mean strength values for the rotator cuff and scapular stabilizer muscles can be found in Table 10. The normalized mean value for the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) was 0.26.

Table 10 Preseason shoulder joint and muscular characteristics of female collegiate swimmers

Variable	N	Min	Max	Mean	SD
Internal rotation ROM, deg	106	52.5	99.5	75.4	9.2
External rotation ROM, deg	106	91.0	130.0	108.9	9.4
Total ROM, deg	106	146.5	207.5	184.3	12.9
Anterior laxity, mm	106	10.5	23.0	16.9	2.5
Resting pec minor length	106	0.1	0.1	0.1	0.0
Stretched pec minor length	106	0.1	0.1	0.1	0.0
Upper trap strength	106	3.1	14.9	8.9	2.1
Serratus anterior strength	106	1.9	7.1	3.6	0.9
External rotation strength	106	1.5	4.9	2.7	0.7
Internal rotation strength	106	1.8	7.7	3.6	1.1
ER/IR strength ratio	106	0.5	1.3	0.8	0.1
Supraspinatus strength	106	2.2	8.0	4.4	1.1
Lower trapezius strength	106	1.3	4.3	2.8	0.6
Combined rotator cuff strength	106	5.9	18.7	10.6	2.6
Combined scapula strength	106	8.4	22.2	15.3	3.0
CKCUEST[a]	106	0.2	0.4	0.3	0.1
SAPRT[b]	106	13	44	26[c]	5.7

[a] Closed Kinetic Chain Upper Extremity Stability Test
[b] Serratus Anterior Punch Repetition Test
[c] Median value reported

Differences in preseason shoulder characteristics between the dominant and nondominant shoulder were calculated and are presented in Table 11. The dominant shoulder had significantly greater external rotation range of motion (110.3° ± 8.8° vs 107.3° ± 9.8°; $P = 0.001$) and total range of motion (185.3° ± 13.3° vs 183.2° ± 12.4°; $P = 0.039$). The dominant shoulder had significantly less anterior laxity (16.3mm ± 2.4mm vs 17.5mm ± 1.4mm; $P < 0.001$). The dominant serratus anterior (3.7 ± 0.1 vs 3.6 ± 0.1; $P = 0.018$) and external rotators (2.8 ± 0.1 vs 2.6 ± 0.1; $P = 0.009$) muscles were stronger than the nondominant. Serratus anterior endurance, measured via the Serratus Anterior Punch Repetition Test, was significantly greater in the dominant shoulder (28.0 repetitions ± 5.4 repetitions vs 25.0 repetitions ± 5.5 repetitions; $P < 0.001$).

Table 11 Preseason shoulder joint and muscular characteristics

Variable	N	Mean	SD	*P* Value	CI
Internal rotation ROM, deg					
Dominant	53	74.9	8.9	0.252	-2.7, 0.7
Nondominant	53	75.9	9.6		
External rotation ROM, deg					
Dominant	53	110.4	8.8	0.001	1.2, 4.8
Nondominant	53	107.4	9.8		
Total rotation ROM, deg					
Dominant	53	185.3	13.4	0.039	0.1, 4.0
Nondominant	53	183.2	12.4		
Anterior laxity, mm					
Dominant	53	16.3	2.4	0.000	-1.7, -0.6
Nondominant	53	17.5	2.4		
Resting pec minor length					
Dominant	53	0.1	<0.1	0.346	-0.0, 0.0
Nondominant	53	0.1	<0.1		
Stretched pec minor length					
Dominant	53	0.1	<0.1	0.304	-0.0, 0.0
Nondominant	53	0.1	<0.1		
Upper trap strength					
Dominant	53	9.0	2.2	0.153	-0.1, 0.5
Nondominant	53	8.8	2.0		
Serratus anterior strength					
Dominant	53	3.7	1.0	0.018	0.0, 0.2
Nondominant	53	3.6	0.9		
External rotation strength					
Dominant	53	2.8	0.7	0.009	0.0, 0.3
Nondominant	53	2.6	0.7		
Internal rotation strength					
Dominant	53	3.6	1.1	0.346	-0.1, 0.2
Nondominant	53	3.5	1.1		
ER/IR strength ratio					
Dominant	53	0.8	0.1	0.206	-0.0, 0.0
Nondominant	53	0.8	0.1		
Supraspinatus strength					
Dominant	53	4.4	1.1	0.109	-0.0, 0.2
Nondominant	53	4.3	1.1		
Lower trap strength					
Dominant	53	2.8	0.6	0.190	-0.0, 0.2
Nondominant	53	2.8	0.6		
SAPRT[d]					
Dominant	53	28.0	5.4	0.000	2.3, 3.8
Nondominant	53	25.0	5.5		

[a] SD, standard deviation

[b] Paired Samples *t* test

[c] 95% Confidence Interval

[d] Serratus Anterior Punch Repetition Test

Analysis were conducted to determine possible relationships between shoulder characteristics in female collegiate swimmers at the onset of the competitive swim season, and the associated correlation data is presented in Table 12. Positive correlations were present between many of the strength variables, with the strongest correlations being between supraspinatus and serratus anterior strength (r=.88, p<0.001), internal rotator and external rotator strength (r=.80, p<0.001), supraspinatus and internal rotator strength (r=.70, p<0.001), and internal rotator and serratus anterior strength (r=.70, p<0.001). There was also a positive correlation between anterior laxity and both external rotation range of motion (r=.37, p<0.001) and total range of motion (r=0.41, p<0.001).

Table 12 Correlation[a] between preseason shoulder joint and muscular characteristics

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Internal rotation range of motion	-																
2. External rotation range of motion	-.04	-															
3. Total range of motion	.69*	.70*	-														
4. Anterior laxity	.20*	.37*	.41*	-													
5. Resting pectoralis minor length	.12	-.01	.08	.03	-												
6. Stretched pectoralis minor length	.14	-.12	.01	.11	.75*	-											
7. Upper trapezius strength	-.35*	.08	-.19*	.07	.13	.13	-										
8. Serratus anterior strength	-.16	.09	-.05	.05	.27*	.20*	.48*	-									
9. External rotator (ER) strength	-.03	-.10	-.10	-.07	.24*	.18	.42*	.64*	-								
10. Internal rotator (IR) strength	-.03	-.09	-.09	-.05	.15	.14	.46*	.70*	.80*	-							
11. ER/IR strength ratio	.00	.00	.00	-.08	.10	.02	-.21*	-.24*	.09	-.49*	-						
12. Supraspinatus strength	-.22*	.03	-.13	.04	.32*	.32*	.49*	.88*	.67*	.70*	-.22*	-					
13. Lower trapezius strength	-.09	.00	-.07	-.11	.25*	.22*	.39*	.62*	.56*	.51*	-.08	.65*	-				
14. Combined rotator cuff strength	-.11	-.05	-.11	-.03	.27*	.24*	.51*	.84*	.89*	.93*	.27*	.89*	.64*	-			
15. Combined scapula strength	.31*	.08	-.16	.04	.22*	.19*	.92*	.76*	.60*	.64*	.24*	.74*	.66*	.74*	-		
16. CKCUEST[b]	-.34*	.12	-.16	-.03	-.03	-.03	.16	.30*	.15	.17	.05	.32*	.36*	.25*	.27*	-	
17. SAPRT[c]	-.23*	-.08	-.22*	-.08	.13	.21*	.29*	.34*	.19	.16	.01	.38*	.15	.28*	.34*	.17	-

[a] Pearson Correlation Coefficient
[b] Closed kinetic chain upper extremity stability test
[c] Serratus anterior punch repetition test
[*] $p < .05$

Differences in preseason shoulder characteristics were analyzed between swimmers who had a history of shoulder injury and those who did not. Swimmers reported experiencing previous shoulder injury in 18 shoulders (17%). A Mann-Whitney U test demonstrated no difference in preseason shoulder characteristics in swimmers who had a history of previous shoulder injury compared to those who did not. Results of the Mann-Whitney U test can be found in Table 13.

Table 13 Preseason shoulder joint and muscular characteristics

Variable	N	Median	Mean	SD	Mann-Whitney U	Sig.
Internal rotation ROM, deg						
Previous history	18	78.5	78.9	7.5	593.00	0.09
No history	88	74.5	74.7	9.4		
External rotation ROM, deg						
Previous history	18	111.0	109.4	8.9	741.50	0.67
No history	88	109.0	108.8	9.5		
Total rotation ROM, deg						
Previous history	18	191.3	188.3	12.3	625.50	0.16
No history	88	184.5	183.5	12.9		
Anterior laxity, mm						
Previous history	18	16.8	16.7	2.6	748.0	0.71
No history	88	17.5	17.0	2.4		
Resting pec minor length						
Previous history	18	0.1	0.1	<0.1	707.00	0.47
No history	88	0.1	0.1	<0.1		
Stretched pec minor length						
Previous history	18	0.1	0.1	<0.1	656.00	0.25
No history	88	0.1	0.1	<0.1		
Upper trap strength						
Previous history	18	9.1	8.5	2.0	696.00	0.42
No history	88	9.2	9.0	2.1		
Serratus anterior strength						
Previous history	18	3.6	3.7	0.9	754.00	0.75
No history	88	3.6	3.6	0.9		
External rotation strength						
Previous history	18	2.4	2.7	0.8	749.50	0.72
No history	88	2.7	2.7	0.7		
Internal rotation strength						
Previous history	18	3.3	3.5	1.0	709.50	0.49
No history	88	3.6	3.6	1.1		
ER/IR strength ratio						
Previous history	18	0.8	0.8	0.1	751.00	0.73
No history	88	0.8	0.8	0.1		
Supraspinatus strength						
Previous history	18	4.5	4.4	1.2	737.00	0.64
No history	88	4.3	4.3	1.1		
Lower trap strength						
Previous history	18	2.8	2.9	0.7	725.00	0.57
No history	88	2.7	2.8	0.6		
Combined rotator cuff strength						
Previous history	18	10.1	10.6	2.8	762.00	0.80
No history	88	10.4	10.7	2.6		
Combined scapular strength						
Previous history	18	15.8	15.1	2.9	772.00	0.87
No history	88	15.6	15.4	3.0		
CKCUEST[a]						
Previous history	18	0.2	0.3	0.1	746.00	0.89
No history	88	0.2	0.2	0.1		
SAPRT[b]						
Previous history	18	25	25.7	4.8	716.50	0.52
No history	88	26	26.7	5.8		

[a] Closed Kinetic Chain Upper Extremity Stability Test

[b] Serratus Anterior Punch Repetition Test

Differences in preseason shoulder characteristics were analyzed between swimmers who presented with obvious scapular dyskinesis compared to those who did not have dyskinesis or had subtle dyskinesis. A total of 14 shoulders (13%) presented with obvious scapular dyskinesis during the preseason screening. A Mann-Whitney U test demonstrated no difference in preseason shoulder characteristics in swimmers who presented with scapular dyskinesis compared to those who did not. Results of the Mann-Whitney test can be found in Table 14.

Table 14 Preseason shoulder joint and muscular characteristics

Variable	N	Median	Mean	SD	Mann-Whitney U	Sig.
Internal rotation ROM, deg						
Dyskinesis	14	75.5	76.0	7.9	625.50	0.86
No dyskinesis	92	75.8	75.3	9.5		
External rotation ROM, deg						
Dyskinesis	14	110.5	112.3	9.4	493.00	0.16
No dyskinesis	92	109.0	108.3	9.3		
Total rotation ROM, deg						
Dyskinesis	14	189.8	188.3	10.8	512.00	0.22
No dyskinesis	92	185.5	183.4	13.1		
Anterior laxity, mm						
Dyskinesis	14	17.3	17.2	2.5	631.50	0.91
No dyskinesis	92	17.5	16.9	2.5		
Resting pec minor length						
Dyskinesis	14	0.1	0.1	<0.1	519.00	0.24
No dyskinesis	92	0.1	0.1	<0.1		
Stretched pec minor length						
Dyskinesis	14	0.1	0.1	<0.1	525.50	0.26
No dyskinesis	92	0.1	0.1	<0.1		
Upper trap strength						
Dyskinesis	14	9.4	9.5	1.4	522.50	0.26
No dyskinesis	92	9.1	8.8	2.2		
Serratus anterior strength						
Dyskinesis	14	3.6	3.7	0.9	571.00	0.50
No dyskinesis	92	3.6	3.6	0.9		
External rotation strength						
Dyskinesis	14	2.6	2.6	0.5	637.00	0.95
No dyskinesis	92	2.7	2.7	0.7		
Internal rotation strength						
Dyskinesis	14	3.8	3.6	0.7	584.00	0.58
No dyskinesis	92	3.5	3.6	1.1		
ER/IR strength ratio						
Dyskinesis	14	0.7	0.7	0.1	522.00	0.26
No dyskinesis	92	0.8	0.8	0.1		
Supraspinatus strength						
Dyskinesis	14	4.7	4.7	1.3	534.00	0.31
No dyskinesis	92	4.3	4.3	1.1		
Lower trap strength						
Dyskinesis	14	2.8	2.9	0.6	569.00	0.48
No dyskinesis	92	2.7	2.8	0.6		
Combined rotator cuff strength						
Dyskinesis	14	11.1	10.9	2.1	567.00	0.47
No dyskinesis	92	10.3	10.6	2.7		
Combined scapular strength						
Dyskinesis	14	16.2	16.1	2.3	524.00	0.26
No dyskinesis	92	15.6	15.2	3.1		
CKCUEST[a]						
Dyskinesis	14	0.2	0.3	0.1	553.00	0.40
No dyskinesis	92	0.2	0.3	0.1		
SAPRT[b]						
Dyskinesis	14	23	25.1	7.5	474.00	0.11
No dyskinesis	92	27	26.7	5.4		

[a] Closed Kinetic Chain Upper Extremity Stability Test

[b] Serratus Anterior Punch Repetition Test

Research Aim 2: Describe the predictors of shoulder injury in female collegiate swimmers

All 106 shoulders were tracked for the duration of the season to establish injury data. An injury was defined as swimming-related shoulder pain that required the student-athlete to seek medical attention and resulted in at least one limited or modified athletic exposure. Shoulder injuries were self-reported by the student-athlete and confirmed through the university’s athletic trainer and coach. A total of 14 new shoulder injuries were reported over the 16-week period. Shoulder characteristics measured at preseason were compared between the injured and non-injured groups. No differences were noted in preseason shoulder characteristics between swimmers who developed shoulder pain and those who did not.

Table 15 Preseason characteristics for injured and non-injured groups

Variable	N	Median	Mean	SD	Mann-Whitney U	Sig.
Internal rotation ROM, deg						
Injured	14	73.8	73.2	9.1	549.50	0.38
Non-injured	92	76.0	75.7	9.3		
External rotation ROM, deg						
Injured	14	108.5	108.4	10.5	610.00	0.75
Non-injured	92	109.3	109.0	9.3		
Total rotation ROM, deg						
Injured	14	182.0	181.6	12.9	549.50	0.38
Non-injured	92	186.0	184.7	12.9		
Anterior laxity, mm						
Injured	14	17.8	17.1	3.6	588.50	0.60
Non-injured	92	17.3	16.9	2.3		
Resting pec minor length						
Injured	14	0.1	0.1	<0.1	553.00	0.40
Non-injured	92	0.1	0.1	<0.1		
Stretched pec minor length						
Injured	14	0.1	0.1	<0.1	610.50	0.76
Non-injured	92	0.1	0.1	<0.1		
Upper trap strength						
Injured	14	9.7	9.6	1.4	497.00	0.17
Non-injured	92	9.1	8.8	2.1		
Serratus anterior strength						
Injured	14	3.6	3.8	0.8	548.00	0.37
Non-injured	92	3.6	3.6	1.0		
External rotation strength						
Injured	14	2.6	2.6	0.6	601.50	0.69
Non-injured	92	2.7	2.7	0.7		
Internal rotation strength						
Injured	14	3.3	3.5	0.7	627.50	0.88
Non-injured	92	3.6	3.6	1.1		
ER/IR strength ratio						
Injured	14	0.7	0.7	0.1	517.00	0.24
Non-injured	92	0.8	0.8	0.1		
Supraspinatus strength						
Injured	14	4.5	4.6	0.9	532.00	0.30
Non-injured	92	4.3	4.3	1.1		
Lower trap strength						
Injured	14	2.8	2.9	0.6	589.00	0.61
Non-injured	92	2.7	2.8	0.6		
Combined rotator cuff strength						
Injured	14	10.2	10.6	1.9	613.00	0.77
Non-injured	92	10.4	10.6	2.7		
Combined scapular strength						
Injured	14	16.3	16.3	1.9	481.00	0.13
Non-injured	92	15.1	15.2	3.1		
CKCUEST[a]						
Injured	14	0.2	0.3	0.1	635.00	0.93
Non-injured	92	0.2	0.2	0.1		
SAPRT[b]						
Injured	14	27	27.1	4.1	598.00	0.67
Non-injured	92	26	26.4	5.9		

[a] Closed Kinetic Chain Upper Extremity Stability Test
[b] Serratus Anterior Punch Repetition Test

Participants were identified as having either Normal / Subtle Dyskinesis or Obvious Dyskinesis through the Scapular Dyskinesis Test. The scapular dyskinesis data is presented in Table 16. No differences in scapular dyskinesis were noted between participants who developed a shoulder injury and those who did not.

Table 16 Scapular dyskinesis data

			In-season shoulder injury			
			No	Yes	Total	Sig
Scapular dyskinesis	Normal/Subtle	Count	79	13	92	0.688
		Expected Count	79.8	12.2	92	
	Obvious	Count	13	1	14	
		Expected Count	12.2	1.8	14	
	Total	Count	92	14	106	
		Expected Count	92	14	106	

Swim history data is presented in Tables 17 and 18. No differences were noted in age when started competitive swimming, number of years of competitive swimming, and number of high school sports for swimmers who developed a shoulder injury compared to those who did not.

Table 17 Swimming history data

Variable	N	Mean Rank	Mann-Whitney U	Sig.
Age when starting competitive swimming				
Injured	14	54.29	633.00	0.92
Non-injured	92	53.38		
Years of competitive swimming				
Injured	14	51.07	610.00	0.75
Non-injured	92	53.87		

Table 18 Swim history data

			In-season shoulder injury			
			No	Yes	Total	Sig[a]
Number of high school sports[b]	0	Count	42	6	48	0.75
		Expected Count	42	6	48	
	1	Count	24	4	28	
		Expected Count	24	4	28	
	2	Count	20	2	22	
		Expected Count	19	3	22	
	3	Count	6	2	8	
		Expected Count	7	1	8	

[a] Likelihood ratio
[b] Excluding swimming

Previous shoulder injury data is presented in Table 19. A significant difference existed in the history of shoulder injury in swimmers who developed a shoulder injury compared to those who did not. A history of previous shoulder injury was entered into a binary logistic regression. The results can be seen in Table 20. Swimmers who have a previous history of shoulder injuries are over 7 times more likely (B=7.365; p=0.001) to develop another swimming-related shoulder injury.

Table 19 Shoulder injury history data

			In-season shoulder injury			
			No	Yes	Total	Sig[a]
History of shoulder injury	Yes	Count	11	7	18	.002
		Expected Count	16	2	18	
	No	Count	81	7	88	
		Expected Count	76	12	88	

[a] Fisher's Exact Test

Table 20 Binary logistic regression

							95% CI	
	B	SE	Wald	df	Sig	Exp(B)	Lower	Upper
Previous history	2.00	0.624	10.25	1	.001	7.364	2.17	25.00
Constant	-2.45	0.394	38.629	1	.000	0.086		

Research Aim 3: Characterize the swim volume of female collegiate swimmers and its relationship to shoulder injury

Weekly training logs were collected for a total of 68 shoulders over the course of 16 weeks. Swimmers reported the number of swim practices, number of dry land training sessions, number of competitions, and total yards swam for the week. The swimmers reported an average of 5.51, 2.13, and 0.38 swim practices, dry land training sessions, and competitions per week, respectively. On average, swimmers swam 24,514 yards per week, with an average of 4,099 yards per session. The swim volume data can be found in Table 21.

Table 21 Swim training volume for female collegiate swimmers

Swim training sessions per week[a]	Yards swam per swim training session[a]	Yards swam per week[a]	Dry land training sessions per week[a]	Competitions per week[a]	Total athletic exposures per week[a]
5.51	4,099	24,515	2.13	0.38	5.45

[a]Mean values are reported

Total yards swam, average yards per practice, and average weekly yards at the time of injury for participants who developed shoulder injury were compared to the non-injured group at the corresponding time in the season. The swim volume comparisons can be found in Table 22. No differences in swim volume were noted between the injured and non-injured groups.

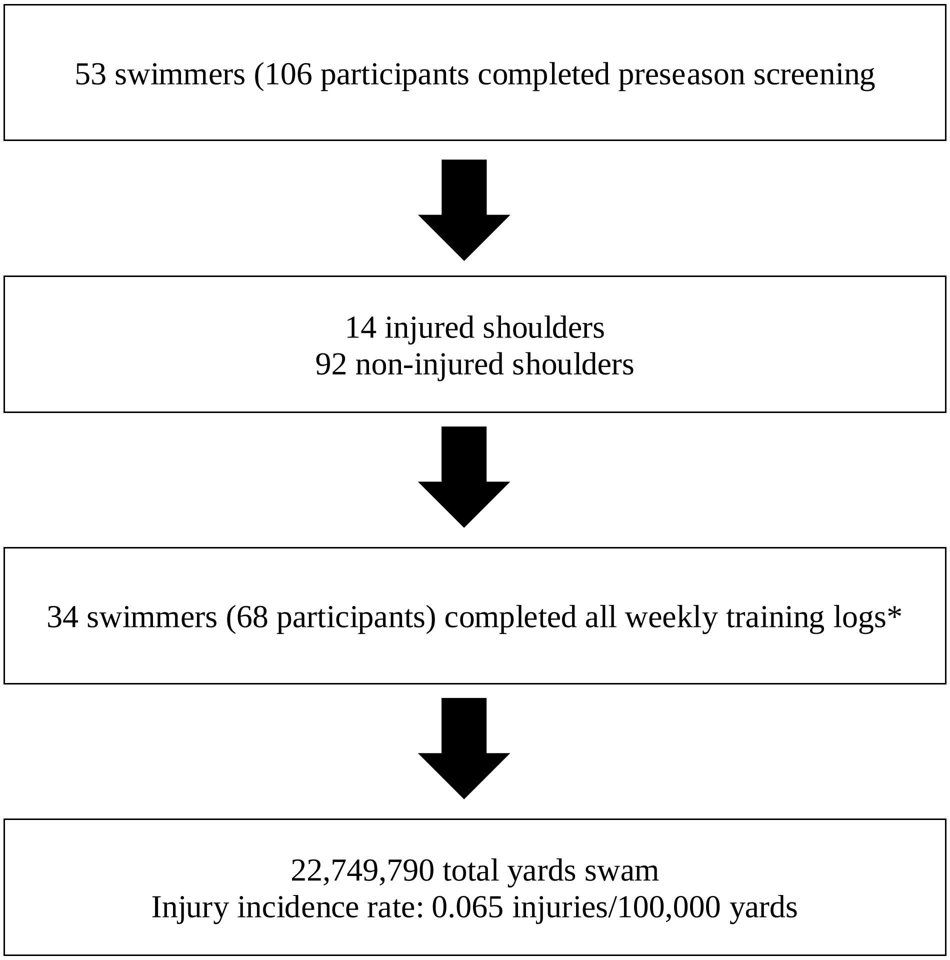
Table 22 Swim volume data

	N	Mean	SD[a]	*P* Value[b]	CI[c]
Total yards swam					
Injured group	14	71908.9	70502.6	.110	-11987.15, 1.65
Non-injured group	14	121170.5	86368.3		
Average yards swam per practice session					
Injured group	14	4137.5	613.4	.604	-486.20, 288.35
Non-injured group	14	4038.6	347.5		
Average weekly yards swam					
Injured group	14	20117.5	8859.3	.207	-1879.46, 8261.03
Non-injured group	14	23308.3	2586.9		

[a] SD, standard deviation
[b] Independent *t* test
[c] 95% Confidence Interval

A total of 14 new shoulder injuries were reported over the 16-week period as seen as Figure 10. The total yardage swam over the 16-week reporting period was 22,749,790 yards, for an injury incidence rate of 0.065/100,000 yards swam.

Figure 10 Incidence of shoulder injury in 4 collegiate women’s swim teams during 1 season



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* Includes all 14 injured shoulders

Summary of results

The first research aim of this study was to describe the characteristics of female collegiate swimmers at the onset of a season. There was a positive correlation between many of the strength values and a positive correlation between anterior laxity and external rotation range of motion and total range of motion. Differences in external rotation and total range of motion, anterior laxity, serratus anterior and external rotator strength, and serratus anterior endurance were detected when comparing the dominant and nondominant shoulder at preseason. No differences were noted in preseason shoulder characteristics in swimmers who had a history of shoulder injury compared to those who did not. Likewise, there were no differences in shoulder impairments in swimmers with obvious scapular dyskinesis compared to those with no dyskinesis or subtle dyskinesis.

The second aim of the study was to describe the potential predictors of shoulder injury in female collegiate swimmers. No differences were noted in shoulder impairments between swimmers who developed a shoulder injury compared to those who did not. In addition, there was no difference in swim history between swimmers who developed a shoulder injury compared to those who did not. A difference was noted in history of shoulder injury for swimmers who developed a shoulder injury compared to those who did not. Swimmers with a history of shoulder injury are 7 times more likely to develop an in-season shoulder injury compared those without a history of shoulder injury. The overall incidence rate of shoulder injury in this population was 0.065 injuries per 100,000 yards swam.

Finally, the study characterized the swim volume of female collegiate swimmers over the course of a season, and the usefulness of swim volume in predicting shoulder injury. No differences were noted in swim volume between swimmers who developed a shoulder injury and those who did not. Swim volume was not a predictor of shoulder injury in this population.

Chapter Five - Discussion

Introduction

A discussion of the data is presented in this chapter. The discussion is presented in three sections. A discussion of the characteristics of female collegiate swimmers at the onset of swim season is presented first, followed by a discussion of the predictors of shoulder injury in female collegiate swimmers. Finally, swim volume characteristics of female collegiate swimmers and its usefulness in predicting shoulder injury is discussed.

Discussion

Characteristics of female collegiate swimmers at the onset of a swim season

Demographic data, swimming history data, and preseason shoulder characteristics was collected on 106 shoulders of female collegiate swimmers. A positive correlation was noted between anterior glenohumeral laxity and external rotation (r= 0.37) and total rotation (r=0.41) range of motion. The mean anterior glenohumeral laxity, measured via joint arthrometer, was 17 mm (SEM=0.24) in the female swimming population included in this study. Previous research has indicated a mean anterior translation of 11 mm in a general population; however, this data was collected on a relatively small sample size (*n*=15) and included both male and female participants.[50] The mean anterior laxity in a general population collected as part of the pilot study for this project (*n*=30; females only) was 15 mm (SEM=1.67, MDC = 4.6). The anterior laxity in this group of collegiate female swimmers falls within the error range of the non-swimming female participants that were studied as part of the pilot study.

Glenohumeral stability at the end range of external rotation is provided by the inferior glenohumeral ligament complex, which tightens as the humeral head rotates.

Inferior glenohumeral laxity was not evaluated as part of this study. The correlation between anterior laxity and external rotation and total range of motion should not be construed as causation; however, it is plausible the positive correlation is due to lengthening of the anterior and inferior glenohumeral ligamentous structures. Further research is warranted to further explore the relationship between laxity and range of motion values in this population.

Positive correlations were also noted between various shoulder and scapular strength values, as expected. No other significant relationships between shoulder measurements at the onset of a swim season were noted. In the group of female swimmers studied, there are minimal relationships between shoulder variables at the onset of a swim season.

Differences were noted in preseason range of motion, strength, serratus anterior endurance, and laxity values compared bilaterally. The dominant shoulder had significantly greater external and total rotation range of motion, serratus anterior and external rotator strength, and serratus anterior endurance. The dominant shoulder had significantly less anterior laxity. Differences in impairments compared bilaterally could be attributed to more frequent use of dominant arm during activities in daily living. Additionally, breathing side during swim training could have an impact on some of the measures. Breathing side data was not collected as part of this study; however, it should be included in future risk factor research.

Of the 106 shoulders tested at preseason, a total of 18 (17%) presented with previous shoulder injury. This number is considerably smaller than previously-reported data; however, a precise definition of a previously-reported injury is often unclear or non-existent in the literature.[8-10] It is also difficult to ascertain if a previous injury was associated with an underlying risk factor, or if future injuries indicate inadequate treatment of the original injury. The results of this study indicate no differences in preseason shoulder joint factors and muscular characteristics between the swimmers who had a history of shoulder injury and those who did not.

Swimmers were evaluated for scapular dyskinesis at the onset of a swim season via the Scapular Dyskinesis Test. Swimmers were identified as having either normal/subtle dyskinesis or obvious dyskinesis. A total of 14 shoulders (13%) presented with obvious dyskinesis at the onset of a competitive swim season. The frequency of scapular dyskinesis in swimmers reported in previous research is between 9% and 37%.[14,23] Although previous research has correlated scapular dyskinesis with weakness and endurance deficits in the serratus anterior, no differences in preseason shoulder measures were noted between those who presented with scapular dyskinesis compared to those who did not.[25,37,38]

Predictors of shoulder injury in female collegiate swimmers

The 106 shoulders tested during preseason were tracked for injury throughout the swim season. Swimmers reported a total of 14 new shoulder injuries (13% of shoulders) over the 16-week season. This is on the low end of previous research which reports 14-53% of swimmers reporting shoulder pain or injury during the course of any single season.[6-11,16,17] Few studies have attempted to prospectively identify risk factors for shoulder pain in swimmers. None of the shoulder joint factors or muscular deficits were successful at identifying injury in female collegiate swimmers.

This study, as well as previous research, has investigated scapular dyskinesis, tested prior to activity, as a predictor of injury. However, it is certainly possible, especially in the overhead endurance athlete, that muscle endurance deficits may lead to fatigue-induced scapular dyskinesis during a training session. Previous research indicates an increase in prevalence in dyskinesis during an single training session.[23,68] The methods for evaluating shoulder and scapular muscle endurance are limited. Previous research does indicate a negative correlation between muscle endurance measured with an isokinetic dynamometer and shoulder pain in swimmers.[24] Future research should expand upon techniques for measuring shoulder and scapular muscle endurance, the relationship between muscle fatigue and scapular dyskinesis, and the role of fatigue-induced scapular dyskinesis in predicting injury.

Previous shoulder injury was the sole variable noted to be different in swimmers who developed a shoulder injury compared to those who did not. Swimmers with a previous shoulder injury are seven times more likely to sustain a future shoulder injury. A history of shoulder injury does not provide a clear explanation as a cause for future injury. One explanation for previous injury being a risk factor is that a previously unidentified risk factor exists in this population. No differences in shoulder impairments were noted between swimmers with a history of shoulder pain and those without, supporting the theory that previously unidentified risk factors or combinations of risk factors should be considered. The initial injury may not have been treated adequately which predisposed the athlete to future injury. Previous injury can be considered a non-modifiable risk factor; however, swimmers with previous shoulder injury can, and should be, made aware they are likely to sustain a future shoulder injury. Continued research with swimmers with a history of shoulder injury may provide a better understanding of the risk factors for injury.

Swim volume characteristics in female collegiate swimmers and its relationship to injury

Weekly training logs were collected from a total of 68 shoulders over the 16-week season. The swimmers provided a weekly report of the number of practices, number of competitions, number of dry land training sessions, and total swim yardage. No difference in swim volume was noted between swimmers who developed shoulder injury and those who did not. In this population of female collegiate swimmers, swim volume was not a predictor of shoulder injury.

The injury rate in the study population was 0.065 injuries/100,000 yards swam. The majority of previous swim injury research reported injury rates per athletic exposure with a published injury rate of 1.05-6.06 injuries per 1,000 athletic exposures.[10,27,28,69] However, the variability in yards swam per practice is problematic when the swim injury rate is presented as injuries per athletic exposure.[10,27,28,69] An injury rate presented as a number of injuries per distance swam may be a more useful representation for this population. A single previous study reported injury rate as the number of injuries per 1,000 km swam.[8] The study was conducted across several Australian swim clubs, and the authors reported a shoulder injury rate of 0.3 shoulder injuries per 1,000 km swam, which converts to 0.027 injuries per 100,000 yards swam. The shoulder injury rate for female collegiate swimmers appears to fall in a range of 0.027-0.065 injuries per 100,000 yards swam.

Implications

Shoulder injuries continue to be a concern for the competitive swimmer. Of the 106 shoulders investigated as part of this study, 14 (13%) developed a shoulder injury over the course of a 16-week swim season. A positive correlation was noted between anterior glenohumeral laxity and external rotation and total range of motion. The notion that swimmers are potentially sacrificing glenohumeral stability in exchange for range of motion is supported with these results. However, the anterior laxity and range of motion measurements are not predictors of injury. Of the variables measured in this study, the sole predictor of a new shoulder injury in female collegiate swimmers is a previous shoulder injury. Swimmers with a history of shoulder injury should be informed of their risk of future injury. Additionally, future research should focus on a more extensive assessment of risk factors in swimmers with a history of shoulder pain. Competitive swimmers spend a substantial amount of time in the overhead position over the course of a season. The swimmers in this study averaged over 4,000 yards per session and 5.5 swim sessions per week.

Recommendations

This study investigated characteristics of female collegiate swimmers at the onset of season, predictors of shoulder injury, and swim volume data over the course of a season and its usefulness as a predictor of injury. While an exhaustive literature review was completed in the search of possible predictors of shoulder injury in competitive swimmers, further research into injury predictors should continue. A relatively small number of measures of shoulder muscle endurance and stability are presented in the literature. A more robust measure of shoulder or scapular muscle strength deficits may more accurately predict shoulder injury in swimmers. Fatigue-induced scapular dyskinesis is also a potential concern for swimmers and should be investigated in further detail. The shoulder injury rate may warrant a larger sample size. With only 14 reported new injuries over the course of a season, it was statistically difficult to identify possible risk factors. A larger sample size with a group of swimmers from a wider variety of university sizes will provide increased generalizability.

Limitations and delimitations

A number of anticipated limitations were identified. Demographic, swimming information, and injury surveillance information was collected via surveys. It was assumed that all participants accurately and honestly responded to the questions. Swim volume was also self-reported weekly, and athletes may not have been able to accurately recall their training volume for the week. Injury information was self-reported by the swimmers and was confirmed by the university's athletic training and coaching staff.

The definition of an injury selected for this study was the definition frequently used in the injury surveillance literature. However, swimmers frequently train through pain without seeking medical treatment. A definition of injury that included a change in shoulder pain or a change in function may be more appropriate for this population.

Measuring glenohumeral laxity in the large number of participants required for a regression analysis poses a unique challenge. Orthopedic tests of laxity are common; however, they lack the specificity required for a regression analysis. Other measures of laxity such as ultrasound and diagnostic imaging are possible; however, the instruments are expensive and have limited applicability to daily clinical practice at this time. A joint arthrometer was selected for evaluating anterior glenohumeral laxity due to its clinical availability. Additionally, menstrual cycle data was not collected as part of this study. Hormonal influences on ligament length may have had an impact on anterior glenohumeral laxity measures and could also be a predictor of shoulder injury.

There are also limitations with the techniques used to measure muscle characteristics. The testing positions utilized may not have isolated specific muscles. Very few measures of shoulder muscle endurance and stability are described in the literature. The Upper Extremity Closed Kinetic Chain Stability Test and the Serratus Anterior Punch Repetition Test are included in this study as measures of shoulder endurance and stability.

Delimitations for the study have also been identified. A thorough review of the literature was conducted in order to identify the risk factors to include in this study, and the decision to include certain variables was based on previous research. However, other potential risk factors should be considered.

Injury rates between male and female swimmers are fairly consistent; however, only females were recruited for this study. Additionally, participants were recruited from NCAA Division II athletes from within the Pennsylvania State Athletic Conference. Results may not be generalizable to athletes outside of the study population. Training volume and techniques may vary depending on competition level and geographic location.

The time in the season when the injury occurred and the swim volume for the time of the season when the injury occurred was not included as a research aim. Swim volume has peaks and valleys throughout the season, and it is possible that there is an increased risk of injury during the peaks of training. Additionally, the intensity of the individual training session was not recorded. The data collected did not indicate if the injury occurred during training or during competition.

Future studies should investigate the impact of arm position during the recovery portion of the swim stroke on shoulder pain. The recovery portion of stroke places the shoulder in the position of impingement, and swimmers with alterations in arm position during the recovery phase may be more likely to develop injury. Future studies should also investigate the effort exerted during practice and its relationship to injury. A simple web-based application that asks swim volume and intensity at the end of each training session may provide additional training-related information that will be helpful in predictor shoulder injuries. It is unknown if swim training induces scapular dyskinesis, and if fatigue-induced scapular dyskinesis is results in shoulder pain in swimmers. Further study of fatigue-induced scapular dyskinesis in swimmers is warranted. Future research should also focus on techniques for measuring shoulder muscle endurance and neuromuscular control. Once these strategies are developed, researchers can utilize them to better evaluate the relationship between shoulder muscle endurance and neuromuscular control and shoulder pain in swimmers.

Summary

Introduction

Swimming is a popular activity in the United States at both the recreational and competitive level. A review of the recent literature reveals a consistently high rate of shoulder pain and injury in swimmers, with 14-53% of swimmers reporting shoulder pain or injury during the course of any single competitive season.[6-11,16,17] Published injury incidence rates for swimming range from 2.12 to 5.50 injuries per 1,000 athlete exposures.[10,27,28] Likewise, an injury rate of 0.3 injuries per 1,000 km swam has been reported.[8]

Kennedy, Hawkins, and Krissoff[20] first presented the concept of "swimmer's shoulder" in 1978, and Jobe et al[21] expanded upon the concept in 1989. This original research in the area of shoulder pain in swimmers associated swimming with glenohumeral laxity and suggested a linear connection between glenohumeral hyperlaxity, mechanical supraspinatus impingement and shoulder pain. [20,21] Although the source of shoulder pain in swimmers is most likely within the supraspinatus tendon, recent research indicates the risk factors are likely multifactorial instead of linear approach originally presented.[6,7,14-17,22] These additional risk factors, occurring in isolation or in combination, may also play a significant role in causing shoulder pain in competitive swimmers.

A number of studies have utilized retrospective designs in attempts to identify variables that are associated with shoulder pain in swimmers.[1,2,6,7,14,15,24,29,30] The variables associated with shoulder pain in swimmers, identified through retrospective research, include: scapular dyskinesis, glenohumeral laxity, glenohumeral range of motion, pectoralis minor muscle length, shoulder strength, shoulder endurance, a history of shoulder injuries, and the volume of swimming exposure.[1,2,6,7,14,15,24,29,30] A fewer number of studies have utilized a prospective approach in identifying predictors of shoulder injuries in swimmers.[8-10] Risk factors identified through previous prospective research include: athlete's age when starting competitive swimming, a history of shoulder injuries, and glenohumeral range of motion.[8-10]

The primary purposes of this study were to characterize female collegiate swimmers at the onset of a swim season, identify possible risk factors of shoulder injury in female collegiate swimmers, and to characterize the swim volume of female collegiate swimmers over the course of a season and its potential usefulness as a predictor of shoulder injury. Successful identification of the risk factors for shoulder pain in female swimmers will provide foundational knowledge for the development of injury prevention programs.

Methods

A prospective longitudinal cohort multi-center design was utilized. Female collegiate swimmers (n=53, mean age=19.3 +/- 1.2 yrs) from four NCAA Devision II universities were recruited to participate in this study. After providing consent, all participants completed a demographic and swimming-related questionnaire and also underwent a preseason musculoskeletal assessment. The swimming-related questionnaire collected information regarding the participant's age when she started competitive swimming, number of years of competitive swimming, preferred events and distance, amount and frequency of off-season training, typical swim training frequency, number of months per year they practiced, participation in other sports, and a history of previous shoulder pain. The musculoskeletal assessment included evaluation of scapular dyskinesis, glenohumeral range of motion, glenohumeral laxity, pectoralis minor length, shoulder muscle strength, and shoulder muscle endurance. All musculoskeletal data was collected bilaterally and in a random order.

Shoulder injury data and weekly swim volume data was collected over the course of a 16-week season via a weekly web-based survey sent to the swimmers. A shoulder injury was defined as swimming-related shoulder pain that required the student-athlete to seek medical attention and resulted in at least one modified or missed athlete exposure.

Results

Preseason demographic and swimming-related questionnaire data was collected from 53 female collegiate swimmers from 4 universities. Preseason musculoskeletal data was collected from 106 shoulders. Swim volume data for the course of the season is presented for 68 shoulders.

Research Aim 1: Demographic and physical characteristics of female collegiate swimmers at the onset of a competitive swim season

The mean number of years of competitive swimming was 10.8. Most participants (24/53, 45.3%) reported being a single sport athlete in swimming at the high school level. Female swimmers reported a history of shoulder pain in 18/106 (17.0%) of shoulders. Analysis were conducted to determine possible relationships between shoulder characteristics in female collegiate swimmers at the onset of the competitive swim season. A positive correlation existed between anterior laxity and both external rotation range of motion (r=0.37, p<0.001) and total range of motion (r=0.41, p<0.001).

Differences in shoulder joint and muscle characteristics were analyzed between swimmers who had a history of shoulder injury and those who did not. A Mann-Whitney U test demonstrated no difference in preseason shoulder joint and muscle characteristics in swimmers who had a history of previous shoulder injury compared to those who did not.

Differences in shoulder characteristics were analyzed between swimmers who presented with obvious scapular dyskinesis compared to those who did not have dyskinesis or had subtle dyskinesis. A total of 14 shoulders presented with obvious scapular dyskinesis at the onset of the season (13%). A Mann-Whitney U test demonstrated no difference in preseason shoulder joint and muscle characteristics in swimmers who presented with scapular dyskinesis compared to those who did not.

Research Aim 2: Describe the predictors of shoulder injury in female collegiate swimmers

All 106 shoulders were tracked for the duration of the season to establish injury data. An injury was defined as swimming-related shoulder pain that required the student-athlete to seek medical attention and resulted in at least one limited or modified athletic exposure. A total of 14 new shoulder injuries were reported over the 16-week period. Preseason shoulder joint and muscle characteristics were compared between the injured and non-injured groups. No differences were noted in preseason shoulder joint and muscle characteristics between swimmers who developed shoulder pain and those who did not. No differences were noted in age when started competitive swimming, number of years of competitive swimming, and number of high school sports for swimmers who developed a shoulder injury compared to those who did not. A significant difference existed in in the history of shoulder injury in swimmers who developed a shoulder injury compared to those who did not. A history of previous shoulder injury was entered into a binary logistic regression. Swimmers who have a previous history of shoulder injuries are over 7 times more likely to develop another swimming-related shoulder injury (B=7.4; p=0.001).

Research Aim 3: Characterize the swim volume of female collegiate swimmers and its relationship to shoulder injury

Weekly training logs were collected for a total of 68 shoulders over the course of 16 weeks. Swimmers reported number of swim practices, number of dry land training sessions, number of competitions, and total yards swam for the week. The swimmers reported an average of 5.51, 2.13, and 0.38 swim practices, dry land training sessions, and competitions per week, respectively. On average, swimmers swam 24,514 yards per week, with an average of 4,099 yards per session.

The total yards swam, average yards per practice, and average weekly yards at the time of injury for participants who developed shoulder injury were compared to the non-injured group at the corresponding time in the season. No differences in swim volume were noted between the injured and non-injured groups. The total yardage swam over the 16-week reporting period was 22,749,790 yards, for an injury incidence rate of 0.065/100,000 yards swam.

Discussion

A positive correlation was noted between anterior glenohumeral laxity and external rotation and total rotation range of motion. The mean anterior glenohumeral laxity, measured via joint arthrometer, was 17 mm (SEM=0.24) in the female swimming population included in this study. Previous research has indicated a mean anterior translation, when measured with a similar arthrometer, of 11 mm in a general population; however, this previously-reported data was collected on a relatively small sample size (*n*=15) and included both male and female participants.[50] The mean anterior laxity in a general population collected as part of the pilot study (*n*=15; females only) for this project was 15 mm (SEM=1.67, MDC = 4.6). The correlation between laxity and external rotation and total range of motion should not be construed as causation;

however, it is plausible the positive correlation is due to lengthening of the glenohumeral ligamentous structures.

No other significant relationships between shoulder measurements at the onset of a swim season were noted. In the group of female swimmers studied, there are minimal relationships between shoulder variables at the onset of a swim season.

Of the 106 shoulders tested at preseason, a total of 18 (17%) presented with previous shoulder injury. This number is considerably smaller than what has been previously reported; however, a precise definition of a previously-reported injury in the literature is often unclear or non-existent.[8-10] It is difficult to ascertain if a previous injury was associated with an unidentified risk factor, or if future injuries indicate inadequate treatment of the original injury. No differences in preseason shoulder characteristics were noted between the swimmers who had a history of shoulder injury and those who did not.

A total of 14 shoulders (13%) presented with obvious dyskinesis at the onset of a competitive swim season. Although previous research has correlated scapular dyskinesis with serratus anterior weakness and endurance deficits, no differences in shoulder measures were noted between those who presented with scapular dyskinesis compared to those who did not.[25,37,38]

Within the 106 shoulders tested during preseason, a total of 14 new shoulder injuries (13% of shoulders) were reported over the 16-week season. This is on the low end of previous research which reports 14-53% of swimmers reporting shoulder pain or injury during the course of any single season.[6-11,16,17] Of all the variables investigated, previous shoulder injury was the sole variable noted to be different in swimmers who developed a shoulder injury compared to those who did not. Previous shoulder injury is a predictor of future shoulder injury in female collegiate swimmers, with swimmers with a previous shoulder injury being seven times more likely to sustain a future shoulder injury. The clinical usefulness of previous injury as a risk factor is uncertain. The possibility of an unidentified risk factor exists in this population making them susceptible to injury, or it is possible the initial injury was not treated adequately which predisposes the athlete to future injury. Previous injury can be seen as a non-modifiable risk factor; however, swimmers with previous shoulder injury can and should be made aware they are likely to sustain a future shoulder injury.

No difference in swim volume was noted between swimmers who developed shoulder injury and those who did not. In this population of female collegiate swimmers, swim volume is not a predictor of shoulder injury.

The injury rate in the study population was 0.065 injuries/100,000 yards swam. The majority of previous swim injury research reported injury rates per athletic exposure.[10,27,28,69] Previously-reported shoulder injury rates range from 1.05-6.06 injuries per 1,000 athletic exposures.[10,27,28,69] However, the substantial variability in yards swam per practice causes concern when swim injury rate is presented as injuries per athletic exposure. A single previous study reported injury rate as the number of injuries per 1,000 km swam.[8] This research, conducted across several Australian swim clubs, reported a similar shoulder injury rate of 0.3 shoulder injuries per 1,000 km swam (0.027 injuries per 100,000 yards swam). The authors utilized a similar definition of shoulder injury as was used in this study. The injury rate appears to fall in a range of 0.027-0.065 injuries per 100,000 yards swam.

Appendix 1: General Data Collection Procedure

Participants will be recruited from women's swim teams at Universities within the Pennsylvania State Athletic Conference. Participants will be informed of the nature of the study and invited to participate. Data collection will begin upon participant completion of the appropriate Institutional Review Board documentation.

Supplies required:

- Scale
- Tape measure
- Stopwatch
- Portable exam table
- Dumbbell weights
- Digital video camera
- Tripod
- Metronome
- KT-1000 joint arthrometer
- Towel
- Hand-held dynamometer
- Inclinometer
- Palpation meter
- Athletic tape
- Two laptops for questionnaire completion and data entry
- Bag with slips for random selection of order of testing
    - Dyskinesis testing
    - Laxity testing
    - Pectoralis minor length testing
    - Strength testing
    - Endurance testing
- Bag with slips for random selection of order of HHD testing
    - Upper trapezius
    - Lower trapezius
    - Serratus anterior
    - Subscapularis
    - Teres minor/Infraspinatus
    - Supraspinatus
- Coin

Preseason screening data collection protocol

- Participants will be assigned a random number for identification purposes
- Participants will begin by completing the demographic and swimming questionnaire on a laptop.
- Participant's height and weight is recorded.
- Participants proceed with the data collection stations as randomly selected from the appropriate bag of slips.

- The order of side tested first for each of the data collection stations (if needed) will be determined by a coin toss.
- The order of the endurance tests will randomly be determined by coin toss.

In-season data collection protocol

- Participants will be emailed weekly a link to a web-based survey
- Survey reminders will be sent out every 24 hours if the participant does not complete the weekly survey
- Follow-up surveys will be emailed to the team's athletic trainer for injuries reported on the participants' weekly survey

Appendix 2: Demographic and swimming-related questionnaire

Demographic information:

Age: ___

Are you currently being treated for a shoulder injury?
___ Yes (1) ___ No (0)

Does a shoulder injury currently prevent you from practicing or competing fully without modifications for distance, stroke, or training techniques?
___ Yes (1) ___ No (0)

Dominant hand (which hand do you throw a ball with):
___ Right (1) ___ Left (0)

List all other sports have you competed for a full season in either at the high school or collegiate level.

________________ ________________ ________________

________________ ________________ ________________

Swimming information:
At what age did you begin competitive swimming? _____

How many years have you swam competitively? _____

What is your preferred swim stroke?
___ Freestyle (0) ___ Butterfly (1) ___ Breaststroke (2) ___ Backstroke (3)

What is your preferred swim distance?
___ Sprint (0) ___ Middle distance (1) ___ Long distance (2)

Please answer the following questions related to your off-season training
Swim training:
Number of **days per week** you typically swim? ___

Number of **hours per week** you typically swim? ___

Dry land training:
Number of **days per week** you typically participate in dry land training? ___

Number of **hours per week** you typically participate in dry land training? ___

Please answer the following questions related to your in-season training

Swim training:

Number of **days per week** you typically swim? ___

Number of **hours per week** you typically swim? ___

Dry land training:

Number of **days per week** you typically participate in dry land training? ___

Number of **hours per week** you typically participate in dry land training? ___

Swimming-related injury information:
Have you ever sustained an injury as a result of swim training or competition?

(**Injury** is defined as pain that required you to seek medical attention and resulted in at least one modified or missed practice or competition. A modified practice or competition is one where you swam decreased yardage, trained with a different swim stroke, or modified your training in any other way due to pain).

___Yes (1) ___ No (0)

If yes, Injury #1:

Body part injured: __________

Diagnosis: __________

Date of injury (month and year): __________

Total number of practices and competitions missed: __________

If yes, Injury #2:

Body part injured: __________

Diagnosis: __________

Date of injury (month and year): __________

Total number of practices and competitions missed: __________

If yes, Injury #3:

Body part injured: __________

Diagnosis: __________

Date of injury (month and year): __________

Total number of practices and competitions missed: __________

Appendix 3: Scapular Dyskinesis Test Protocol

Supplies required:
3lb and 5lb dumbbells
Digital video camera
Tripod

- Data collection will be performed with participant wearing appropriate clothing for visual inspection of the scapula.
- Scapular dyskinesis testing will be conducted bilaterally simultaneously.
- The tripod and video camera will be placed 2-3 m behind the participant at the height of the scapula
- Participants will be demonstrated the flexion and abduction motions and will have the opportunity to practice.
- A coin flip will determine if the participant performs abduction or flexion first.
- All test motions will be recorded for subsequent analysis.
- Participants will move through the full range of motion for flexion or abduction at rate of 3 seconds for the ascension phase and 3 seconds for the descent. Five repetitions will be performed for each flexion and abduction.
- Upon later review of the video, participants will be rated as “Normal,” “Subtle,” or “Obvious” dyskinesis.

Participant ID #: ____________

Right rating:	___ Normal (0)	Left rating:	___ Normal (0)
	___ Subtle (1)		___ Subtle (1)
	___ Obvious (2)		___ Obvious (2)

Appendix 4: KT-1000 protocol

Supplies required:

Examination table
KT-1000 Joint Arthrometer
Towel

- Side tested first will be determined by coin flip
- Participants will be positioned supine with the arm abducted 20° and no rotation, and the arm relaxed.
- KT-1000 will be positioned on the upper arm with the tibial pad close to the glenohumeral joint line.
- The patella pad will be placed over a towel on the coracoid process of the scapula.
- The KT-1000 is stabilized with the Velcro straps around the arm.
- Once the KT-1000 is positioned properly, the dial will be set to zero.
- Three 67 N anterior forces are applied, ensuring the dial returns to 0 +/- 0.5 mm after each attempt.
- The amount of anterior translation is recorded for two trials.

Participant ID #: ____________

Right side:	Left side:
_____ Trial 1	_____ Trial 2
_____ Trial 2	_____ Trial 2
_____ Mean	_____ Mean

Appendix 5: Pectoralis minor length protocol

Supplies required:
Palpation meter

- Side tested first will be determined by coin flip
- Distance from the coracoid process to the 4th intercostal space adjacent to the sternum is measured
- Resting distance will be measured first followed by distance in stretch position

Participant ID #: ____________

Right side:	Left side:
Resting	Resting
______ Trial 1	______ Trial 2
______ Trial 2	______ Trial 2
______ Mean	______ Mean
Stretch	Stretch
______ Trial 1	______ Trial 2
______ Trial 2	______ Trial 2
______ Mean	______ Mean

Appendix 6: Hand-held dynamometry protocol

Protocol for Handheld Dynamometry (HHD) for testing the strength of the Upper Trapezius, Lower, Trapezius, Serratus Anterior, Supraspinatus, Infraspinatus/Teres Minor, and Subscapularis muscles

Supplies required:

Handheld dynamometer
Universal goniometer
Masking Tape
Armless chair with straight back
Stopwatch
Scale
Measuring tape
HHD Wall Mounting Apparatus

HHD Wall Mounting Apparatus

- An apparatus for mounting the HHD to the wall was fabricated to maximize stabilization of the HHD, and therefore maximum accuracy and reliability of the measure.
- The apparatus was constructed in a manner for it to be attached to a doorway. The apparatus is adjustable for height and distance from the doorway.
- To compensate for the curved side of the HHD, small wedges of foam were attached to the handheld dynamometer and the corresponding flat piece of the stabilizing apparatus.

Initial Procedures

- Record participant’s height in meters with a measuring tape and weight in pounds with a scale. Both measurements will be made with the participant standing without shoes. This data will be used to normalize force measurements. Mean participant force output will be divided by participant weight (converted to kg) in order to have numbers useful for comparison between participants of different size.
- Order of the strength tests will be determined by drawing labeled, folded pieces of paper from a bag.
- All participants will be tested bilaterally. Limb to be tested first will be randomized by coin toss.

Participant Instructions

- Position the patient according the specific muscle testing instructions listed below.
- Tell the participant, “This (indicating HHD) is used to measure muscle force. When I tell you to, I want you to hold your arm like this (demonstrate the position about to be tested). I will place the apparatus that is connected to the dynamometer on your arm like this (demonstrate accordingly). When I ask you

to, push against the HHD until I say stop, which will be about 4 seconds. Keep trying to push as hard as you can for the 4 seconds. We will be doing two trials in each position (to get an average) with 30 seconds in between each trial and position. If you need more than 30 seconds please tell me." Position HHD apparatus as appropriate. Once the apparatus is aligned correctly on the participant's arm and secured to the doorframe instruct the participant to begin pushing. Say to participant "push…push…push." Proceed as follows with this test.

- A make test is performed by asking the participant to push as hard as they can against the apparatus for the given test position. Participants will be encouraged to apply the maximum force within their pain tolerance and can stop at any time.
- For each test, the dynamometer on the apparatus will be aligned so that the resistance is in exactly the opposite direction of the direction of motion being resisted.
- Two trials will be performed for each muscle test, taken sequentially. The participant will be allowed to rest for 30 seconds between the two trials.
- The average of two trials will be used for data analysis.
- For all tests, a bad/unacceptable trial is one that includes one or more of the following:
    - Trial lasts less than 4 or exceeds 6 seconds
    - Improperly placed HHD
    - HHD settings are not as described above
    - Participant states they did not give best effort during the trial
    - Participant does not maintain proper positioning
    - Administrator fails to properly position participant
    - Participant does not follow instructions
    - Randomization of trial sequence is compromised
    - Randomization of arm selection in healthy participants is compromised
    - The HHD apparatus is loosened or compromised for any reason
- A good/acceptable trial is defined as anything not included above

Participant ID #: ____________

Participant weight: ________

Participant height: ________

Procedure: Upper trapezius, resisted scapular elevation

- Instruct participant to sit in an armless chair with his or her back flush to the back of the chair, feet flat on the floor approximately shoulder width apart, and sitting with neutral posture. To obtain a neutral posture, the participant will be asked sit with his or her back straight, shoulders rolled back, and ears aligned over shoulders and hips.
- Measure the distance in cm from C7 spinous process to the acromion process of the side being tested. Record this measurement.
- Tell participant “during this test, I want you to lift your shoulder blade as if you are trying to raise your shoulder to your ear.” Demonstrate scapular elevation and have participant practice the motion.
- The stabilizing apparatus is placed behind the patient, and adjust the HHD apparatus and center the HHD pad on the acromion process.
- Explain the test instructions as described above.
- Examiner instructs the participant to begin to apply pressure to the HHD in the direction of scapular elevation. A stopwatch will be used to time 4 seconds. Instruct the patient to stop pushing after approximately 4 seconds.
- Record findings before clearing the HHD.
- Repeat for 2 trials with 30 second of rest between

Distance: _____ *Trial 1:* _____ *Trial 2:* _____ *Mean:* _____

Procedure: Lower trapezius, resisted scapular retraction and depression

- Position patient prone on the exam table. The cervical spine should be in a neutral position. The extremity being tested will be abducted 140° and externally rotated to thumb pointing towards the ceiling.
- Measure the distance in cm from the inferior angle of the scapular to the lateral epicondyle of the humerus. Record this measurement.
- Tell participant “during this test, I want you to pull your shoulder blade back and down.” Demonstrate scapular retraction and depression and have participant practice the motion.
- The stabilizing apparatus is placed inferior to the patient’s arm. Adjust the HHD apparatus and center the HHD pad on the lateral humeral epicondyle.
- Explain the test instructions as described above.
- Examiner instructs the participant to begin to apply pressure to the HHD in the direction of scapular retraction and depression. A stopwatch will be used to time 4 seconds. Instruct the patient to stop pushing after approximately 4 seconds.
- Record findings before clearing the HHD.
- Repeat for 2 trials with 30 second of rest between

Distance: _____ *Trial 1: _____* *Trial 2: _____* *Mean: _____*

Procedure: Serratus anterior, resisted arm abducted above 120°

- Position patient seated in the chair. Position in the arm in 120° of abduction in the scapular plane with the elbow fully extended position.
- Measure the distance in cm the superior angle of the scapula to the radial styloid process. Record this measurement.
- Tell participant "during this test, I want you to raise your arm over your head." Demonstrate abduction and have participant practice the motion.
- The stabilizing apparatus is attached to the wall. Adjust the HHD apparatus and center the HHD pad on the superior aspect of the radial styloid process.
- Explain the test instructions as described above.
- Examiner instructs the participant to begin to apply pressure to the HHD in the direction of abduction. A stopwatch will be used to time 4 seconds. Instruct the patient to stop pushing after approximately 4 seconds.
- Record findings before clearing the HHD.
- Repeat for 2 trials with 30 second of rest between

Distance: _____ *Trial 1: _____* *Trial 2: _____* *Mean: _____*

Procedure: Infraspinatus and Teres Minor, resisted ER at neutral rotation

- Instruct participant to sit in an armless chair with his or her back flush to the back of the chair, feet flat on the floor approximately shoulder width apart, and sitting with neutral posture. To obtain a neutral posture, the participant will be asked sit with his or her back straight, shoulders rolled back, and ears aligned over shoulders and hips.
- With the participant in position as described in "Participant Instructions," have them hold the arm of interest at their side at 0 degrees of elevation, elbow bent to 90 degrees, and humerus internally rotated 45 degrees. Verify that the forearm is parallel to the ground as described above. Align the forearm with a premeasured piece of tape on the floor to determine IR.
- Measure the distance from the tip of the olecranon process to the midpoint between the radial and ulnar styloid processes. Record this measurement.
- Tell participant "during this test, I want you to keep your elbow at your side and push with your forearm so that it works like a door on a hinge." This motion (ER) will be demonstrated. The administrator will use one hand to stabilize the participant's arm on the lateral side of the elbow. Have participant practice the motion.
- Adjust the height of the HHD apparatus and center the HHD pad on the posterior aspect of the forearm between the radial and ulnar styloid processes.
- Explain the instructions for the test to the participant, as described above.

- Examiner instructs the participant to begin to apply pressure to the HHD. A stopwatch will be used to time 4 seconds. Instruct the patient to stop pushing after approximately 4 seconds.
- Record findings before clearing the HHD
- Repeat for 2 trials with 30 second of rest between

Distance: _____ *Trial 1:* _____ *Trial 2:* _____ *Mean:* _____

Procedure: Supraspinatus

- With the participant in the position as described in "Participant Instructions," have them hold the arm of interest at their side at 90 degrees of elevation in the scapular plane and the thumb up.
- Tell participant "during this test, I want you to raise your arm in the overhead direction." This motion (elevation) will be demonstrated. Have participant practice the motion.
- Measure the distance from the tip of the acromion process to the radial styloid process. Record this measurement.
- Adjust the height of the HHD apparatus and position the pad of the HHD on the radial styloid process.
- Explain the instructions for the test to the participant, as described above.
- Examiner instructs the patient to begin to apply pressure to the HHD in the direction of elevation. A stopwatch will be used to time 4 seconds. Instruct patient to stop pushing after approximately 4 seconds.
- Record findings before clearing the HHD
- Repeat for two trials with 30 seconds of rest between

Distance: _____ *Trial 1:* _____ *Trial 2:* _____ *Mean:* _____

Procedure: Subscapularis

- With the participant in the position as described in "Participant Instructions," have them hold the arm of interest at their side at 0 degrees of elevation, elbow bent to 90 degrees, and the forearm held in neutral. Verify that the forearm is parallel to the ground as described above. Use a visual estimate to determine neutral position.
- Tell participant "during this test, I want you to keep your elbow at your side and push with your forearm so that it works like a door on a hinge." This motion (IR) will be demonstrated. The administrator will use one hand to stabilize the participant's arm on the lateral side of the elbow. Have participant practice the motion.
- Measure the distance from the tip of the olecranon process to the midpoint between the radial and ulnar styloid processes. Record this measurement.
- Adjust the height of the HHD apparatus and position the pad of the HHD on the most anterior aspect of the forearm, centered between the radial and ulnar styloid processes.

- Explain the instructions for the test to the participant, as described above.
- Examiner instructs the patient to begin to apply pressure to the HHD in the direction of IR. A stopwatch will be used to time 4 seconds. Instruct patient to stop pushing after approximately 4 seconds.
- Record findings before clearing the HHD
- Repeat for two trials with 30 seconds of rest between

Distance: _____ *Trial 1:* _____ *Trial 2:* _____ *Mean:* _____

Appendix 6: Endurance testing protocol

Supplies required:

- 1.5 inch athletic tape
- Tape measure
- Stopwatch
- Various dumbbells
- Metronome

General Procedure:

- The order of endurance tests (Closed Kinetic Chain Upper Extremity Stability Test and the Serratus Anterior Punch Repetition Test) is determined by coin toss.
- The order of side tested first with the Serratus Anterior Punch Repetition Test is determined by coin toss.

Closed Kinetic Chain Upper Extremity Stability Test Procedures

- Two parallel strips of tape 36 inches of tape are placed on the floor.
- Participants assume the push-up position with each hand on one of the strips of tape.
- Participants lift one hand, reach across their body and touch the other tape strip, and return to the starting position. The same process is repeated for the other hand. It does not matter which hand the participant starts with.
- Participants are instructed to complete as many touches as possible within 15 seconds.
- A touch is defined as the hand touching the opposite line. The number of touches in 15 seconds is recorded.
- Two trials, with a 45 second rest between each trial, are completed.

Participant ID #: ____________

Trial #1: _____ *Trial #2:* _____ *Mean:* _____

Serratus Anterior Punch Repetition Test Procedures:

- Patient is positioned supine on the exam table.
- A dumbbell closest in weight to 15% of the participant's body weight is used for this test.
- The side tested first is determined by coin toss.
- The participant grasps the dumbbell. The shoulder is flexed to 90° with the elbow fully extended.
- The metronome will be set at rate of 60 beats per minute (1 beat per second).
- Participants will perform scapular protraction and retraction at a rate of one complete cycle per second.
- The measuring device is placed alongside the participant's arm for feedback in regards to maintaining 90° of shoulder flexion and also the amount of protraction.

- The participant will perform as many repetitions as possible, until one of the following conditions is met:
    - Participant reports fatigue
    - Participant is unable to maintain their arm aligned with the measuring device
    - The amount of protraction decreases more than 1”
- Two trials, with a 45 second rest between each trial, are completed.

Participant ID #: ____________

Trial #1: _____ *Trial #2:* _____ *Mean:* _____

Appendix 7: Range of motion protocol

Supplies required:

Exam table
Inclinometer

Procedure:

- Patient is positioned supine on exam table and shoulder is abducted 90°
- Side tested first and direction (external versus internal) tested first will be determined by coin toss
- Arm is passively rotated in appropriate direction while humeral head and scapula are stabilized to prevent substitution
- Inclinometer is placed on along radius/ulna and measurement is recorded
- Two trials are recorded for both internal and external rotation range of motion

Participant ID #: ____________

Right internal rotation
Trial #1: _____ *Trial #2:* _____ *Mean:* _____

Right external rotation
Trial #1: _____ *Trial #2:* _____ *Mean:* _____

Left internal rotation
Trial #1: _____ *Trial #2:* _____ *Mean:* _____

Left external rotation
Trial #1: _____ *Trial #2:* _____ *Mean:* _____

Appendix 8: Weekly survey sent to swimmers

A link to the weekly survey will be sent via email to all participants. Reminder emails will be sent every 24 hours for participants who have not responded.

Participant ID #: ___________________

Number of swimming practices this week: _____

Number of dry land training sessions this week: _____

Total yardage swam this week: _____

Number of competitions this week: _____

A **<u>Shoulder</u> <u>Injury</u>** is defined as a swimming-related painful event that required you to **seek medical attention** and resulted in at least **one modified or missed practice or competition**. A modified practice or competition is one where you swam decreased yardage, trained with a different swim stroke, or modified your training in any other way due to pain.

Did you sustain a new shoulder injury this week (causing you to seek medical attention and missing or modifying a practice or competition)?

___ No (0) ___Yes (1)

If yes,

Body part injured: ___________

Side injured:
___ Right (1) ___ Left (0)

Number of missed practices this week due to injury (not swimming or training at all): _____

Number of modified practices this week due to injury (decreased yardage, different swim stroke, or modified your training in any other way due to pain): _____

Number of missed competitions this week due to injury (not swimming in any events in the competition): _____

Number of modified competitions this week due to injury (different events or distances): _____

Do you have a previously-reported injury causing you to seek medical attention and missing or modifying a practice or competition this week?

___ Yes (1)   ___ No (0)

If yes,

Number of missed practices this week due to injury (not swimming or training at all): _____

Number of modified practices this week due to injury (decreased yardage, different swim stroke, or modified your training in any other way due to pain): _____

Number of missed competitions this week due to injury (not swimming in any events in the competition): _____

Number of modified competitions this week due to injury (different events or distances): _____

Appendix 9: Follow-up survey sent to athletic trainers

A link to the weekly survey will be sent via email to all athletic trainers with swimmers reporting new or existing injuries. Reminder emails will be sent every 24 hours for athletic trainers who have not responded.

A **<u>Shoulder</u> <u>Injury</u>** is defined as a painful event that required the swimmer to **seek medical attention** and resulted in at least **one modified or missed practice or competition**. A modified practice or competition is one where she swam decreased yardage, trained with a different swim stroke, or modified her training in any other way due to pain.

Athlete's name: _______________

Diagnosis: _______________________

New injury or existing?
___ New (1)   ___ Existing (0)

Clinical tests performed and results: ____________________

Diagnostic tests performed and results: ____________________

Number of missed practices this week due to injury (not swimming or training at all): _____

Number of modified practices this week due to injury (decreased yardage, different swim stroke, or modified training in any other way due to pain): _____

Number of missed competitions this week due to injury (not swimming in any events in the competition): _____

Number of modified competitions this week due to injury (different events or distances): _____

Appendix 10: Swim Volume Data

	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**Week 9**	**Week 10**	**Week 11**	**Week 12**	**Week 13**	**Week 14**	**Week 15**	**Week 16**	**Avg**
Practices	5.33	5.79	5.75	6.03	6.65	6.25	5.94	6.58	5.61	3.65	6.45	6.03	6.18	2.26	2.16	7.50	5.51
Dry land	2.96	2.88	2.53	2.44	2.48	2.56	2.39	1.87	1.06	1.39	2.52	2.23	2.26	1.03	1.06	2.43	2.13
Competitions	0.00	0.04	0.56	1.06	0.77	0.69	0.81	0.10	0.94	0.16	0.10	0.03	0.39	0.03	0.03	0.40	0.38
Total yards	18306	22247	25955	27377	28298	30828	26157	29285	23720	16426	29785	26671	30684	9629	9619	37245	24515
Yards/session	3451	4031	4487	4741	4333	4855	4538	4386	4033	3559	4401	4208	5218	2347	2429	4564	4099

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