Shoulder Tendon Injuries in Swimmers: Risk Factors, Treatment, and Prevention

Introduction

Swimming is a popular form of exercise and sport that can be performed throughout the lifespan and across of wide spectrum of recreation to elite competition. According to *USA Swimming*, the governing body for competitive swimming in the United States, over 327,000 athletes were registered as active members in the sport's organization in 2019.[1] This number primarily focuses on athletes under the age of 18, while another estimated 25,000 athletes compete at the collegiate level and 70,000 compete at the master's level (over the age of 18).[2, 3] These athletes propel themselves through pools and open bodies of water primarily through use of the upper extremities for 6,000 to 10,000 meters per day, often performing two practices per day with only 1-2 rest days per week, year round.[4] Given the average distance covered per practice session, and an average stroke count of 8-10 strokes per 25m lap, swimmers perform an average of 30,000 rotations per shoulder during each week of training.[4] This places significant stress on the musculoskeletal tissues of the glenohumeral joint and shoulder girdle, thus placing the athlete at increased risk for shoulder injury. The term "Swimmer's Shoulder" has been used to describe anterior shoulder pain felt by swimmers after training, and may be due to muscle soreness or soft tissue pathology, such as tendinitis, instability, impingement, or labral tears.[4] This paper will explore the biomechanics of the overhead freestyle/front crawl stroke, discuss symptoms and clinical presentations of swimmers with tendinous shoulder injuries, and suggest treatment and prevention strategies for swimmers.

Tendon tissue is comprised of strong, stiff collagenous fibrils that are oriented in parallel with its associated muscle belly and the long axis of the bone.[5, 6] At rest, these fibers have a crimped or "slacked" appearance, and this slack is taken up with longitudinal tensile stress.[5] In the face of excessive frequencies of loading, this tendon tissue becomes disorganized, collagen content is reduced, and mucoid ground substance formation is increased, thus reducing the strength and stiffness of the tendon.[5] This chronic degeneration and disorganization of tendon tissue is referred to as *tendinosis,* whereas the acute inflammatory process of tendon damage is called *tendinitis*, and general tendon pathology is considered *tendinopathy.* These weakening factors can be brought upon through increased compression (such as beneath the coracoacromial arch), frictional abrasion against (also possibly occurring beneath the coracoacromial arch), and excessive magnitude and duration of loading.[5-6] The supraspinatus and long head biceps tendons are commonly involved in tendinosis injuries in swimmers due to the high volume of training and biomechanical loading on the tissues during the overhead stroke.[4, 7] Careful attention must be paid to the frequency, magnitude, duration, and biomechanics of the swimmer's upper extremity loading during the overhead freestyle stroke in swimming.

Biomechanics of the Freestyle Stroke

The overhead stroke performed in the freestyle stroke can be broken down into 5 parts: the glide phase, early pull-through, mid-pull-through, late pull-through, and recovery. During the glide part of the stroke, the hand enters the water with the arm above and lateral to the head. If the center of the head and longitudinal axis of the body is 12:00 on a clock face, the right hand should enter at the 1:00 position, while the left hand enters at the 11:00 position. In this phase, the upper trapezius, and serratus anterior act to stabilize the scapula as it upwardly rotates to allow for humeral head clearance in the glenoid.[4]

The early pull-through phase occurs at maximal forward reach at the end of the glide phase, when the hand initiates a downward motion and the humerus reaches approximately 90 degrees of forward flexion. Internal rotation, adduction, and extension of the shoulder occurs in this phase, and the pectoralis major and teres minor create a force couple to accomplish these glenohumeral actions.[4] The mid-pull-through phase occurs when the athlete's forearm is pointing toward the floor, serving as an "anchoring point" over which the body is pulled through the water. In this phase, the pectoralis major, latissimus dorsi, and serratus anterior work to propel the body forward.[4] The late pull-through phase occurs from approximately 90 degrees of shoulder flexion to the point at which the hand exits the water, near the athlete's hip. At this stage of the stroke cycle, latissimus dorsi activity increases to accomplish glenohumeral extension, and works with the subscapularis to accomplish glenohumeral internal rotation.[4]

As the extremity moves into the recovery phase, the hand exits the water with slight elbow flexion, the glenohumeral joint moves into greater extension and abduction, while the scapula upwardly rotates, bringing the arm overhead to restart the cycle when the hand enters the water again. The posterior and middle deltoid work with the supraspinatus to extend and abduct the humerus, while the rhomboids retract the scapula in preparation for full body rotation as the contralateral limb progresses through the pull cycle.[4] At this time, the upper trapezius and serratus anterior work together to upwardly rotate the scapula, and the anterior deltoid fires to flex the shoulder in order to complete the recovery phase and initiate the next pull cycle.[4] A breakdown of muscle activity throughout the phases of the stroke cycle can be found in Figure 1, attached in the Appendix. At completion of recovery and initiation of the hand entry/glide phase, the athlete's trunk rotates approximately 45 degrees to allow for proper performance of the contralateral upper extremity stroke, while maintaining neutral head and neck position and a 6-beat flutter kick.

With poor technique or biomechanical error, each of these phases has potential to contribute to injury of the soft tissues in the shoulder girdle, such as the tendons of rotator cuff musculature and labrum. The most common presentations of incorrect biomechanics are dropped elbow position at any point in the pull-through or recovery phasing, midline crossing at hand entry/glide, or lateral placement of the hand during hand entry and glide.[7] In the early- and mid-pull through phases, a dropped elbow results in external rotation at the glenohumeral joint, placing the propulsive musculature at a mechanical disadvantage.[7] This requires greater magnitude of loading in order to accomplish the same task, placing the muscle and tendon tissues at greater risk for injury. During the late pull-through and recovery phases, a dropped elbow results in increased time internal rotation, horizontal adduction, and flexion position, which creates increased risk for subacromial impingement, and therefore compression and frictional abrasion at the supraspinatus tendon.[7] Improper positioning of the elbow at these stages of the stroke cycle can also contribute to incorrect hand entry position, thus creating inappropriate positioning of the extremity during the glide phase. With increased glenohumeral internal rotation during the glide and early pull-through phases, the long head biceps tendon experiences increased magnitude and duration of loading, which may damage the tendon tissue as well as increase stress at the attachment site of the anterior glenoid labrum.[7] A full description of stroke phasing biomechanics and associated injuries due to incorrect biomechanics of the stroke can be found in the Appendix in Table I.[4, 7-8]

Sport specialization, especially at an early age may increase risk of tendinopathies and other injuries due to overuse, potential for maladaptive musculoskeletal development, and earlier incidence of burnout.[9] This is applicable both to early single-sport specialization in general, as well as early stroke-specific specialization within the sport of swimming. All four competitive strokes (freestyle, butterfly, backstroke, and breaststroke) have associated risks for injury due to differences in biomechanics and muscle recruitment.[4] Specializing in one over the other early in a competitive career may create additional risk for shoulder injury.[4] However, freestyle is the most commonly practiced stroke, which is why it is the focus of this paper and much of the available literature. For additional details about the other strokes, readers are directed to the article by Heinlein et al.[4]

Symptoms and Clinical Presentation

Shoulder pain is fairly common among swimmers, with 47% of swimmers age 10-18, 66% of senior swimmers, and 73% of elite swimmers reporting a history of shoulder pain at some point in their swimming career.[4] The term “swimmer’s shoulder” has been coined to describe generalized shoulder pain among these athletes. Common symptoms reported by those with Swimmer’s Shoulder include: shoulder pain that gradually increases while swimming, pain during periods of rest, tenderness to palpation, aggravation of symptoms during sleep, especially on the involved side.[10]

These symptoms are often chronic in nature, especially in elite athletes who train at high volumes and senior athletes who have a great number of years spent participating in the sport.[4, 7, 10] Often, shoulder pain results from inappropriate firing of muscular force couples that contribute to and/or result from incorrect biomechanics of the phases of the stroke. It is unclear whether altered stroke mechanics are the cause of pain or the result of pain, as many athletes report some baseline level of soreness in the shoulder complex.

Impingement occurs at the shoulder when the greater tuberosity of the humerus and the acromion and/or the coracoacromial ligament create a narrowing of the subacromial space and therefore infringe upon the soft tissues in the subacromial space.[11] In one study of elite swimmers, the impingement position at the shoulder was demonstrated for 24.8% of the entire stroke, 14.4% of which occurred during the propulsive pull-through phases, and 10.4% occurring during the recovery phase.[4, 11] With the high volume of training and therefore number of strokes performed on a regular basis in elite swimmers, spending a quarter of their training time in loaded impingement positions places the soft tissues at risk for injury, specifically the supraspinatus tendon.

Due to the increased time spent in the impingement position, the supraspinatus tendon of swimmers is at greater risk of thickening and therefore increased presentation of subacromial impingement. With an increase in hours and yardage swum per week, the risk for supraspinatus tendinopathy, and the volume of training can be considered a direct and significant contributor to the changes in this tendon and presentation of shoulder pain.[7] Tendon thickening may increase the compressive and frictional forces on the tissue in the subacromial space, furthering tissue damage and tendinitis/tendinosis presentation.

Clinical presentation may vary for swimmers with shoulder pain. Because subacromial impingement is a common occurrence in these athletes, they may demonstrate a positive Neer, Hawkins-Kennedy, Empty Can, or Painful Arc test.[12] Pain and poor stroke biomechanics may also be due to muscle overuse in an attempt to stabilize in the presence of joint laxity. Some literature suggests that increases in internal and/or external rotation range of motion (ROM) at the shoulder may contribute to pain in the shoulders of swimmers.[13] Laxity may have ligamentous or capsular origin, which may be assessed via Apprehension-Relocation testing, with a positive test indicating joint laxity and possible muscular overuse for compensatory purposes.[4, 12-13] There is also literature that discusses a reduction in internal and/or external rotation ROM may contribute to shoulder pain in swimmers, as reduced ROM may alter the biomechanics of the stroke and therefore effect muscular recruitment throughout the different phases.[13] Generally imbalanced muscular force couples may also be the culprit for shoulder pain and tendinous injuries, as these may result in altered biomechanics throughout the stroke thus perpetuating inappropriate muscle recruitment and mechanical stress on the tissues.[4, 7-8, 10]

Additional literature suggests that impairments at other points in the kinetic chain may be responsible for pathology at the shoulder. In young overhead athletes, fatigued periscapular musculature and weak core musculature may contribute to shoulder dysfunction and impaired biomechanics of the overhead motion.[14] While this reasoning is generally accepted for overhead throwing athletes, similar principles can be applied to swimmers. Core musculature plays a role in body stability in the water and the body roll portion of the stroke, and fatigue may impact extremity positioning any phase of the stroke cycle.

In addition to special tests and clinical measures for ROM and strength, utilizing patient-reported and performance-based outcome measures can provide information about the individual's functional and sport-specific outcomes related to their pain. Lowered scores on measures such as the QuickDASH, Numeric Pain Rating Scale, and the Simple Shoulder Test are relevant outcome measures with generally excellent psychometric properties that can provide information about the athlete's pain and functional limitations.[15-16] It is also likely that impaired sport participation and performance may contribute to psychosocial dysfunction, as sport participation is often a source of social support, recreational outlet, and self-concept. Incorporation of a relevant quality of life or psychosocial assessment, such as the Rotator Cuff Quality of Life or Short Form-12 may be helpful measures for monitoring of these areas.[17-18]

Treatment Strategies

As with most tendinous injuries, time and rest are required for adequate healing and recovery of the tissue. Ice and NSAIDs in the acute phase can help manage pain, swelling, and damage to the tissue, but physical therapists are not likely to see injuries in this phase in the clinic. One recommended protocol for clinical management of chronic tendinosis includes rest, activity modification and/or redirection, heat to promote tissue extensibility, transverse friction massage to reduce adhesions in the tissue, controlled yet heavy loading of the involved tissue, stretching, and ice as needed for symptom management.[19] Return to sport, in this protocol is based on a reduction in length tenderness to palpation, which should be measured at evaluation and each subsequent re-evaluation.

General swimmer-specific rehabilitation often focuses on scapular stabilization, neuromuscular re-education for shoulder musculature, postural re-education, and core strength.[8] These are excellent areas to address in when providing rehabilitative care to swimmers with any musculoskeletal condition, as improvements in these areas will promote adequately balanced muscle groups and appropriate activation of muscles during the various phases of the overhead stroke. Additional methods for protecting the rotator cuff musculature include prevention of superior humeral migration through scapular stabilization, proximal muscle coordination, and cessation of activity prior to fatigue during training and rehabilitation.[4]

A yardage-based protocol is recommended by Spigelmen et al, with 2 phases. The key criterion for return to sport in a swimmer include near elimination of pain in the involved shoulder complex and full active extension and external range of motion in the glenohumeral joint.[8] Phase one of this protocol includes several drill techniques to train appropriate biomechanics of the stroke phasing, with small increases in yardage to prevent re-injury.[8] Phase two incorporates interval training to build muscular and cardiovascular fitness, while increasing the yardage in larger increments as tolerated by the athlete.[8] Fins and zoomers are two pieces of equipment commonly utilized in swimming training that can be used during this recovery protocol. Paddles, pull buoys, and kick boards are other common pieces of training equipment, but utilization should be delayed until later stages of the protocol. A description of equipment types, uses, and contraindications can be found in Table 2 of the attached Appendix. It is important to educate the swimmer and their coach about this protocol, including progression criteria and signs for reduction in training. Pain, discomfort, and soreness beyond that of exercise-related muscle soreness indicate a decrease in training is necessary and a re-evaluation of stroke mechanics would be indicated. A full description of this return to sport protocol can be found in Table 3 in the Appendix. Progression through the protocol should be based on the athlete's symptoms, clinical presentation, and biomechanics of the stroke, not just the suggested timeline.

As with any patient case, rehabilitation must focus on the individual's functional and sport-specific impairments, tailoring the interventions to their needs and interests. Working with the patient and coaching staff to identify gaps in training and needs for return to sport can help treat current injuries, and work toward prevention of injuries later in their athletic career.

Prevention Strategies

Similar principles can be applied to prevention as discussed for treatment methods. Balanced strength and coordination of all shoulder and periscapular musculature, as well as core stability will help promote adequate force couples and biomechanics throughout the stroke cycle. Incorporating drills that break down the phases of the stroke can help maintain proper biomechanics as well. Several common drills can be implemented to promote proper form, such as high elbow position during recovery, proper hand entry position, trunk control during body roll, and early to middle phases of pull through. These drills draw attention to each phase of the stroke, and provide the opportunity for coaches to give additional feedback to swimmers about the positioning and phasing of their strokes. Full details about these strokes can be found in table 4 the in the Appendix.[8]

Additional preventative exercises suggested in the literature include use of TRX Suspension training to promote balanced core and rotator cuff musculature and reduce risk for shoulder injury in swimmers.[10] Unilateral and bilateral active ROM and compound upper and lower extremity exercises provide a unique challenge to the core and shoulder musculature that may improve strength, cardiovascular endurance, posture, and ROM.[10] The TRX Suspension system allows the athlete to control the resistance depending on the angle of incline between their body and the floor. This allows for easy adjustment of loading based on the individual's strength, mobility, and goals. Some examples of appropriate TRX exercises for swimmers include pushups, M/T/Y rows, back rows, and squats. Picture demonstration of these exercises can be found in table 4 of the Appendix.[20] In general, strengthening exercises should challenge a variety of muscle groups and promote neuromuscular control as well as strength. Both open-and closed-kinetic chain activities can be beneficial for improving internal and external rotation torques at the shoulder, which may be an effective area of focus for prevention of swimmer's shoulder injuries.[21] Open chain exercises, however, demonstrated greater effects in swimmer's when compared to closed chain exercises, perhaps due to the demands for greater neuromuscular control during complex open chain activities.[21] Examples of open chain activities include resisted glenohumeral external rotation, resisted glenohumeral internal rotation, dumbbell pectoral fly, and reverse dumbbell fly. Examples of closed chain activities include pushups with varied hand placement/grips, scapular dips, and crab walks.

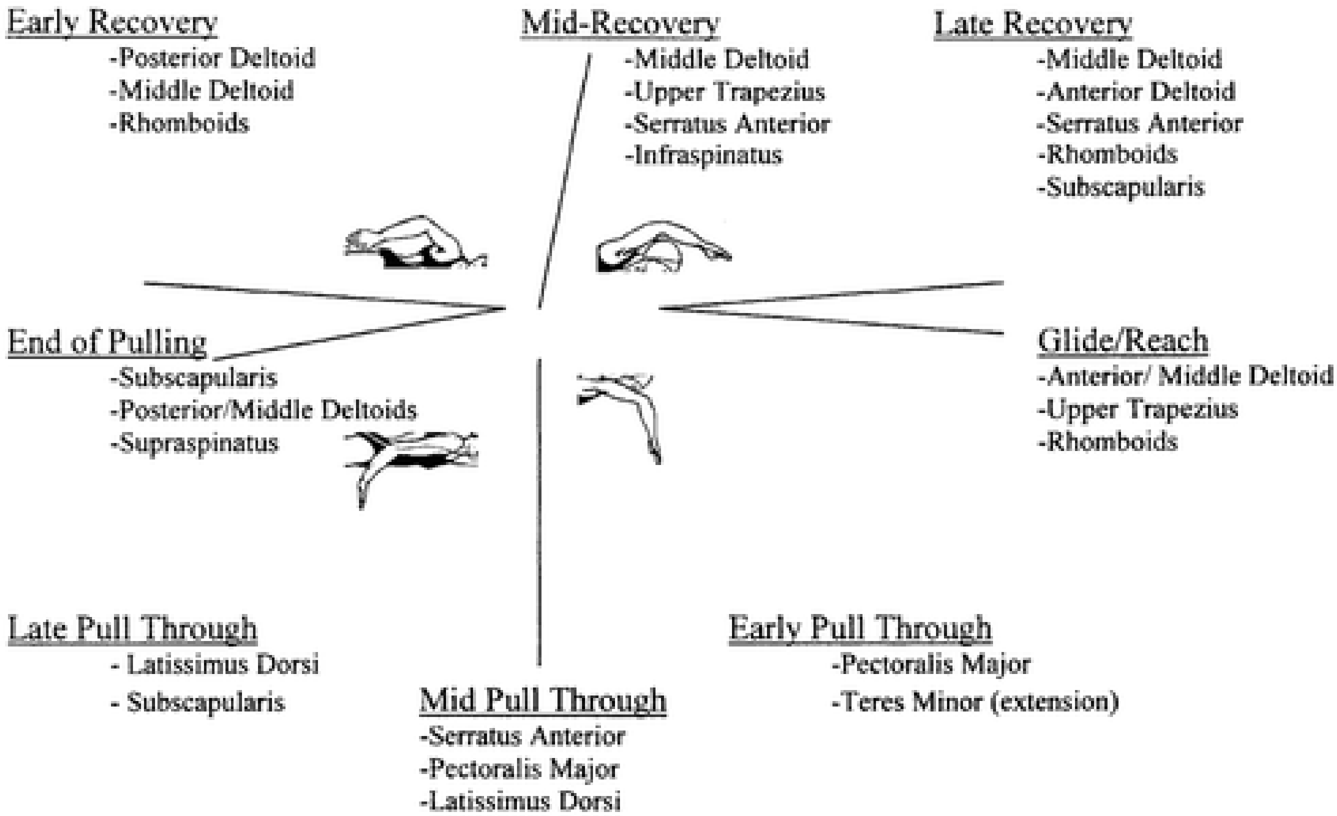
Finally, more consistent stretching and periscapular muscle strengthening protocols across swimming organizations can reduce the risk for injury as athletes move through various competition levels and phases of their swimming career. While core strengthening and cross training (weight lifting, running, cycling, yoga, etc) are commonplace at the elite level, periscapular-specific strengthening and stretching protocols are inconsistent and generally do not follow recommendations in the current research.[22] Pectoralis major, long head biceps, latissimus dorsi, and rotator cuff musculature may hold increased tension and reduce the available ROM to the athlete for functional and sport specific activities. Incorporation of a stretching and strengthening program for this commonly tight musculature in swimmers may reduce the risk of injury to shoulder soft tissues.

Conclusion

The frequency, magnitude, and duration of loading of shoulder and periscapular musculoskeletal tissues during training places swimmers at increased risk for chronic injury. Shoulder pain is very common in swimmers of all ages and competition levels, and may result from poor stroke mechanics, inappropriate muscle engagement and force couples during the stroke, glenohumeral instability, and/or limited range of motion. Increased frequency and magnitude of loading on tendinous tissues increased the likelihood of degeneration and disorganization, which may lead to chronic tendinosis, specifically in the supraspinatus tendon. These injuries can be treated with rest, activity modification such as drill work for improved stroke mechanics, periscapular, shoulder, and core strengthening, neuromuscular control, and heating and stretching of tight soft tissues to promote extensibility. Subacromial impingement and supraspinatus tendinosis can be prevented through adequate strengthening of upper extremity and core musculature, stretching of frequently tight musculature, cross training to vary loading patterns, avoiding early specialization, and maintaining appropriate stroke mechanics throughout training and competition. The athlete and coach must be educated about the importance of these principles for injury management and prevention for swimmers of all ages and competition levels.

Appendix

Figure 1: Muscle Activity by Phase Throughout the Overhead Freestyle Stroke



Heinlein et al.[4]

Table I: Correct and Incorrect Biomechanics and Associated Risks for Injury

Phase of Stroke	Correct Biomechanical Features	Common Incorrect Biomechanical Features	Common Pain and Injury Presentation due to Incorrect Biomechanics
Hand Entry/Glide	Hand enters the water in front of and lateral to the head, but medial to the shoulder Finger-first or 5th-digit-first entry	Hand enters too far lateral or crosses the midline of the body Thumb-first entry	Increased risk for impingement of the anterior shoulder (Neer impingement testing position); reduced anterior and middle deltoid, upper trapezius, and rhomboid activity Increased stress at the biceps attachment to the anterior labrum
Early pull-through	Elbow kept higher (toward the surface) than the hand	Dropped elbow (below hand)	External rotation increased, creating mechanical disadvantage of propulsive musculature
Mid-pull-through	Elbow kept higher than the hand, points laterally	Dropped elbow (below hand)	External rotation increased, creating mechanical disadvantage of propulsive musculature Reduced serratus anterior activity, increased rhomboid activity, resulting in reduced upward rotation and protraction of the scapula
Late pull-through	Elbow points laterally, hand and forearm pull in a straight line when moving toward the surface	S-shaped line of pull through of forearm and hand, horizontal adduction, crossing the midline of the body Early hand exit to avoid extremes of internal rotation	Increased time in horizontal adduction, flexion, and internal rotation of the glenohumeral joint (similar to Hawkins Kennedy testing position) increasing risk for impingement injury Inappropriate force coupling, reduced propulsion at the end of pull through, lengthened recovery time
Recovery	Flexed elbow, kept higher than the hand throughout recovery	Dropped elbow (equal to or below the hand)	Improper entry position, the water creates an upward force on the humerus, which increases superior translation of the humeral head

			and increased risk for subacromial impingement. Reduced anterior deltoid activity, limiting forward flexion and contributing to lateral hand entry position.
		Nearly full extension of the elbow	Increased moment arm and mechanical stress on the rotator cuff musculature
	Body roll of approximately 45 degrees along the longitudinal axis	Body roll less than or greater than approximately 45 degrees	Excessive body roll can contribute to midline crossover in the hand entry/glide phase. Inadequate body roll can contribute to lateral arm position at hand entry/glide, creating additional mechanical stress at the shoulder.
All Phases	Head and cervical spine in neutral position	Cervical extension, resulting in eyes-forward position	Impingement of scapulothoracic motion

Adapted from tables and discussion from Heilmein et al[4], Virag et al[7], and Spigelman et al[8].

Table 2: Equipment Used in Competitive Swimming Training

Tool	Name	Indications	Contraindications
	Kickboard	Used to practice kicking only. Commonly used in semi-prone position with arms maximally flexed at the shoulder and head out of the water. Creates increased lumbar lordosis.	Shoulder injuries, spondylolysis
	Pull Buoy	Used to practice upper extremity stroke only. Placed between the legs to provide buoyancy to the lower body and prevent kicking.	Shoulder tendinitis/tendinosis, elbow or forearm pain or pathology
	Fins	Used to increased propulsion and speed of the stroke. Increase the length of the leg (moment arm) and surface area of the feet).	Acute ankle injuries, knee pain, hip pain (relative)
	Zoomers	Used to increase leg strength. Allow for rapid leg motion to increase forward propulsion. Increase surface area of the feet, but are shorter than fins.	Acute ankle injuries, knee pain, hip pain (relative)
	Paddles	Used to slow the speed of pulling, but build strength while pulling. Increase the surface area of the hand. Comes in various sizes.	Shoulder injury or pain, improper stroke technique

Adapted from Spigelman et al.[8]

Table 3: Return to Swimming Protocol (distances are represented in yards, equipment referenced is described in *Table 2* above)

	Phase I		Phase II & Return to Team Training		
	Week 1: 1000-1500	Week 2: 1500-2200	Week 3: 2200-3000	Week 4: 2800-3900	Week 5: 3500-4700+
Warm Up	300-400	600-700	700-900	900-1100	1000-1200
Drills	Stroke technique using drills (300-500)	Stroke technique using drills (400-600)	Stroke technique using drills at the beginning and end of practice (600-700)	Incorporate drills at the beginning and end of practice (700-900)	All drills incorporated at the end of the training session (800-1000)
Kick	With fins or zoomers, no kickboard. Kick on side or back. Can be performed with arms at sides or in streamline position if pain free (400-600)	With fins or zoomers, no kickboard. Kick on side or back. Can be performed with arms at sides or in streamline position if pain free (500-900)	With fins or zoomers, no kickboard. Kick on side or back. Can be performed with arms at sides or in streamline position if pain free (700-900)	With fins or zoomers, kickboard if pain free. Kick on side or back. Can be performed with arms at sides or in streamline position if pain free (700-900)	Kick with kickboard if pain free, or kick in streamline position on side or back with arms at sides. Fins and zoomers optional (700-900).
Intervals	None	None	1 set at 70% effort level, 1 set ~10 sec slower than regular practice pace (200-500)	Gradually increase number of sets. Maintain correct stroke technique throughout (500-1000)	Start on interval 5-10 seconds slower than pre-injury practice pace. Progress toward pre-injury pace gradually. Maintain correct stroke technique throughout (800-1300)
Pull Set	None	None	None	None	Start pull set conservatively (200-300), increasing yardage in 300yd increments as tolerated. Do not use paddles. Stop if pain or discomfort noted.
Rest between Repe-titions	20-30 seconds	10-20 seconds	10-15 seconds between repetitions. 5-10 seconds rest between intervals. Longer duration = longer rest period	10-15 seconds between repetitions. 5-10 seconds rest between intervals. Longer duration = longer rest period	5-15 seconds between repetitions. 3-10 seconds between intervals. Longer duration = longer rest period

Progress-ion Criteria	1. Pain free 2. Proper stroke technique during drills per coach assessment (high bent elbow recovery, 4-6 beat kick, symmetrical body roll)	1. Pain free 2. Proper stroke technique during drills per coach assessment (high bent elbow recovery, 4-6 beat kick, symmetrical body roll)	1. Pain free during and after training 2. Ability to maintain proper stroke technique at end of training session 3. No shoulder pain during interval work	*Criteria to join team* 1. Pain free during and after training session 2. Ability to maintain proper stroke technique 3. No pain or discomfort during interval work	1. Completely pain free 2. Maintain proper stroke technique throughout 3. Complete pull work without pain 4. No discomfort or pain during interval work

Adapted from Spigelman et al.[8]

Table 3: Swimming Drills for Focused Technique Training

Drill	How to Perform	Focus of Drill	Phase of Stroke Cycle
Fingertip Drag	Face directed toward bottom of the pool, torso rotates about longitudinal axis. During the recovery phase, fingertips are dragged along the water surface	Promotes high, flexed elbow recovery, symmetrical body roll	Recovery
Shoulder, Head, Enter	Focus on high, flexed elbow recovery during freestyle. During recovery, athlete taps fingertips to axilla, then head, then enters the water at 1:00 clock face position	Promotes high, flexed elbow recovery, symmetrical body roll, proper hand entry	Recovery, hand entry
6/6	Swimmer is positioned on their side with their deep-side arm over their head (ear to bicep). Perform 6 kicks on one side, take 3 freestyle strokes, 6 kicks on the opposite side	Promotes symmetrical body roll, high elbow recovery	Recovery, hand entry, early pull through, body roll
Left Arm, Right Arm	Perform 3 freestyle strokes on the left side, hand enters at 11:00 on clock face, while maintaining a 6-beat kick. Repeat on right side	Proper hand entry, flexed elbow recovery, symmetrical body roll	Hand entry, early pull through

Flutter Kick on Side	Deep-side arm over their head (ear to bicep), keep the core engaged and maintain straight body position	Core strength	Early pull through, late pull through
Catch Up	Exagerrate recovery and catch phased of stroke. Left arm catches up to right arm at hand entry. Maintain 6-beat kick	Promotes proper hand entry	Hand entry
Fist	Perform all phases of the stroke with hand in fist position. Focus on rotation of torso and high elbow position during early pull phase of stroke	Appreciate sensation of “feeling the water” with hand and forearm as one unit	Early pull through, late pull through
4 Strokes Backstroke, 4 Strokes Freestyle	Perform 4 strokes of backstroke, 4 strokes of freestyle. Exaggerate roll of body when switching between the strokes	Promotes high elbow pull through	Early pull through, late pull through
Distance Per Stroke	Attempt to maximize arm extension and stroke length, reducing number of strokes with each length completed.	Helps to “feel the water” with hand and forearm as one unit	Early pull through, late pull through
Sculling	Prone or supine, slight motion of hands and forearms back and forth under the surface of the water to propel forward.	Appreciate the sensation of the forearm pulling the water	Hand entry, early pull through

Adapted from Spigelmen et al.[8]

Table 4: TRX Suspension Exercises for Swimmers

Exercise	Demonstration	Instruction	Muscles Targeted
Pushup	 	With feet suspended in the TRX ropes, place your hands shoulder width apart on the ground. Lower yourself into a pushup until your elbows reach ~90 degrees of flexion. Return to starting position	Pectoralis major, abdominals, biceps, triceps, deltoids, serratus anterior
M Row	 	Hold ropes in both hands and lower your body to desired level of resistance (closer to the floor = greater resistance). Keep your elbows straight and pull your arms straight down to bring your trunk to a standing position. Slowly lower back to starting position	Abdominals, triceps, latissimus dorsi, trapezius, subscapularis, rhomboids
T Row		Hold ropes in both hands and lower your body to desired level of resistance (closer to the floor = greater resistance). Keep your elbows straight and pull your arms straight out to the sides ("T" position) to bring your trunk to a standing position. Slowly lower back to starting position.	Abdominals, triceps, trapezius, rhomboids, deltoid, supraspinatus, infraspinatus

Y Row		Hold ropes in both hands and lower your body to desired level of resistance (closer to the floor = greater resistance). Keep your elbows straight and pull your arms diagonally upwards ("Y" position) to bring your trunk to a standing position. Slowly lower back to starting position.	Abdominals, trapezius, supraspinatus, deltoid, latissimus dorsi
Back Row	 	Hold ropes in both hands and lower your body to desired level of resistance (closer to the floor = greater resistance). Keep elbows close to your trunk as you pull your arms back and trunk towards a standing position.	Biceps, trapezius, rhomboids, latissimus dorsi, abdominals
Squat	 	Hold ropes in both hands with slight slack in the ropes. With your feet hip width apart, squat down until your knees reach ~90 degrees flexion. Keep your chest upright and perform a partial row as you return to standing.	Gluteus maximus, quadriceps, abdominals, rhomboids, trapezius, deltoid, supraspinatus, infraspinatus

Adapted from Mohamed et al and MySwimPro. [10, 20]

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