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Musculoskeletal dysfunctions associated with swimmers' shoulder

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ABSTRACT

Shoulder pain is the most reported area of orthopaedic injury in swimmers. The so-called “swimmers’ shoulder” has been applied to a variety of complaints involving shoulder pain in swimmers without specific reference to contributing mechanisms or structures. Knowledge of dysfunctions associated with swimmers’ shoulder can assist clinicians in developing rehabilitation strategies. This literature review aims to providing clinicians insight into the musculoskeletal mechanisms and impairments associated with swimmers’ shoulder that could aid them in developing rehabilitation strategies. The following musculoskeletal dysfunctions will be discussed: muscle activity, strength, endurance, muscle control, range of motion, glenohumeral laxity, glenohumeral instability, shoulder posture, scapular dyskinesis. The findings of this review may have implications for the swimmer, their coach, and the rehabilitation specialist working with swimmers.

What is already known?

1. The voluminous quantity of shoulder revolutions in swimmers can easily overload soft tissue structures around the shoulder and lead to pain at rest as well as during daily activities and swimming.
2. The so-called “swimmers’ shoulder” is a term that has generally been used to describe a syndrome with anterior shoulder pain elicited by repetitive impingement of the rotator cuff under the coracoacromial arch.
3. The heterogeneity of ‘swimmers’ shoulder’ and lack of knowledge regarding the etiology has reduced the ability to define and devise successful interventions.

What are the new findings?

1. Reduced shoulder and core trunk endurance is present with swimmers who report shoulder pain, but it is unclear if poor endurance is a cause or effect.
2. It is unclear whether laxity predisposes swimmers to pain or if it occurs in symptomatic swimmers as a result of cumulative microtrauma.
3. Swimming may alter scapular position, but it is unclear if these changes are related to the development of shoulder pain.

INTRODUCTION

Swimming is a unique sport combining endurance, strength and control in a non-weight bearing environment. Highly repetitive upper extremity overhead movements provide the majority of the propulsive forces for all four main strokes: freestyle, butterfly, breaststroke and backstroke [1]. Elite swimmers may swim up to 14.000 meters each day, which requires more than 2500 shoulder revolutions per day [2] or up to 16.000 shoulder revolutions per week. This voluminous quantity of shoulder revolutions can easily overload soft tissue structures around the shoulder and lead to pain at rest as well as during daily activities and swimming. Shoulder pain occurs frequently and is the most reported area of orthopaedic injury in swimmers. Prevalence rates of the so-called swimmers' shoulder can be as high as 91% in competitive swimmers [3-5]. Rates vary, depending on age, level of competition, swim stroke, amount of training, time of season and the definition of shoulder pain. Symptoms may begin at an early age with 21% of swimmers aged 8-11 reporting significant pain, but high school swimmers were found to be the most symptomatic age category [6],[7]. A belief even exists that shoulder pain is normal and should be tolerated to complete practice [8]. In fact, a study of high school competitive swimmers revealed that 72% used pain medication to manage their shoulder pain during practice, with 47% reporting regular medication use [9]. Shoulder symptom prevalence rates in competitive swimmers can be some of the highest in competitive sports, and may lead to termination of sports' participation[9]. The functional performance scores for active swimmers are even reported to be quite similar to those seen in injured athletes in other sports [10].

The so-called "swimmers' shoulder" is a term that has generally been used to describe a syndrome with anterior shoulder pain elicited by repetitive impingement of the rotator cuff under the coracoacromial arch [6 11-13]. However, this term has been applied to a variety of complaints involving shoulder pain in swimmers without specific reference to contributing mechanisms or structures. Typically, this diagnosis has been labelled 'impingement syndrome'. Because the mechanism may not be impingement of the rotator cuff, other terminology has been suggested to include subacromial pain syndrome, rotator cuff related pain, and rotator cuff disease to name a few [14-16]. In addition, the swimmers' shoulder may reflect many other causes of shoulder pain located outside the subacromial space. The heterogeneity of 'swimmers' shoulder' and lack of knowledge regarding the etiology has

reduced the ability to define and devise successful interventions. Suggested pathophysiological impairments include reduced endurance, incoordination or weakness of the shoulder muscles, a lack of scapular stability, poor posture, lack of core stability and altered shoulder and spinal mobility [4 5 11 17], which may predispose swimmers to the development of swimmer's shoulder [17]. Knowledge of dysfunctions associated with swimmers' shoulder can assist clinicians in developing rehabilitation strategies. Although impairments associated with shoulder pain in swimmers have been studied, there is a lack of prospective research identifying the risk factors for the development of swimmers' shoulder. Moreover, it is not clear to what extent these associated factors are the cause or effect of the swimmers' shoulder pain, or if the impairment is a sport-specific adaptation needed for high level swimming performance.

A critical review of the dysfunctions in swimmers with shoulder pain will provide the necessary understanding to assess and develop rehabilitation programs based on impairments. It has been suggested that the primary cause of shoulder pain in swimmers is impingement of the subacromial structures [12], however the pathology alone does not define strategies for rehabilitation [18]. Consequently, this literature review aims to providing clinicians insight into the musculoskeletal mechanisms and impairments associated with swimmers' shoulder that could aid them in developing rehabilitation strategies.

MUSCLE PERFORMANCE AROUND THE SWIMMERS' SHOULDER

Several studies have investigated muscle performance in swimmers suffering from shoulder pain. Muscle performance is a broad term covering muscle activity, strength, endurance, and control. Knowledge of muscle performance is necessary for monitoring disease progression or the development of secondary disorders in clinical practice [19]. Some studies have analyzed *muscle activity* throughout the different phases of a swimming stroke using electromyography and cinematographic analysis during freestyle and breaststroke swimming in swimmers with and without shoulder pain [20 21]. During freestyle swimming, the rhomboids, upper trapezius, anterior deltoid and middle deltoid were less active in swimmers with shoulder pain during the hand entry phase than the unimpaired controls. The serratus anterior demonstrated less activity during the pulling phase, while the rhomboids become more active than in the controls. In addition, in

symptomatic swimmers, the anterior and middle deltoid demonstrated less activity during the hand-exit phase, while the infraspinatus became overactive [20]. Finally, the mid-recovery phase was characterized by reduced activity of the subscapularis muscle in painful shoulders [20]. During breaststroke swimming, decreased teres minor activity was found during the pulling phase in painful shoulders [21]. During the mid-recovery phase, there was decreased activity of the middle deltoid, upper trapezius and supraspinatus and increased activity of the infraspinatus in swimmers with painful shoulders [21]. Finally, the subscapularis demonstrated a significantly increased activity during the pulling phase in those with shoulder pain compared to the unimpaired controls [21]. In addition, Wadsworth et al.[22] found increased intra-subject variability in the recruitment of scapulothoracic muscles in swimmers with shoulder pain when contrasted to swimmers without pain. Prior to shoulder movement, the upper trapezius is activated, followed by serratus anterior immediately after motion begins. After approximately 15° of shoulder elevation, the lower trapezius is recruited [22]. Swimmers with a shoulder injury demonstrated the same sequence, but with more intra-subject variability [22]. In addition, they suggested that swimmers with shoulder pain on one side might have muscle performance deficits on their unaffected side [22].

In addition to muscle activity, several researchers have highlighted the importance of muscle imbalances between internal (IR) and external rotation (ER) shoulder strength. Competitive swimmers present with a significant lower ER:IR ratio compared to non-swimmers[23] due to stronger IR strength. However, this ratio is not seen in those with shoulder pain. It is unclear if the swimmer produces less IR strength due to inhibition from pain or if the muscle ratio imbalance is an attempt to remain pain free. Swimmers with shoulder pain tended to have lower concentric and eccentric IR strength in the painful shoulder in one study [24], but others [11 25] did not find any difference in strength between swimmers having shoulder pain and unimpaired swimmers. A systematic review on the risk factors for developing shoulder pain in swimmers confirmed these findings and stated that there is insufficient evidence that IR or ER strength is a risk factor for shoulder pain in swimmers [13].

In order to identify factors that differentiate swimmers with and without shoulder pain and disability, Tate et al. [6] studied 236 female competitive swimmers. They found that

young (12-14 year old) swimmers with shoulder pain and disability had significantly less core endurance (measured by the time held during the side bridge position) than their less symptomatic colleagues. Beach et al. [11] support these findings by reporting that shoulder muscle endurance for abduction and external rotation was negatively correlated with shoulder pain in swimmers. In summary, reduced shoulder and core trunk endurance is present with swimmers who report shoulder pain, but it is unclear if poor endurance is a cause or effect.

SHOULDER RANGE OF MOTION

Several studies investigated the relationship between glenohumeral joint (GH) flexibility and shoulder pain in swimmers. Most studies did not find any significant association between shoulder pain and shoulder joint flexibility [11 24 25]. There were 2 studies [6 26] that reported a relationship between altered GH ROM and shoulder pain. In a 12-month prospective cohort study in 74 swimmers, Walker et al. [26] found that swimmers with a high ($\geq 100^\circ$) or low ($< 93^\circ$) ER ROM had an increased risk of developing shoulder pain, but no relationship between IR ROM and shoulder pain. In contrast, Tate et al.[6] found a relationship between reduced shoulder flexion and IR ROM and shoulder pain in female swimmers aged 8-11 years. ROM was assessed using an inclinometer with the participant lying supine[6]. These findings are confirmed by the systematic review of Hill et al. [13], which demonstrated with moderate certainty that there is sufficient evidence that reduced shoulder IR ROM and either increased or decreased ER ROM (measured with either a goniometer or inclinometer) is a risk factor for shoulder pain in swimmers. However, recent studies in an overhead athlete population have highlighted that different methods exist for analyzing shoulder ROM for the classification of a shoulder at risk[27 28]. In addition, these measures should not be used interchangeably [27 28]. These methods include Glenohumeral Internal Rotation Deficit (GIRD), Total Rotational Range of Motion (TRROM) and humeral torsion[27]. However, to the best of our knowledge, no studies examined humeral torsion in a swimming population.

GLENOHUMERAL LAXITY AND INSTABILITY

Using clinical laxity tests, several authors have found that, in comparison to other athletes, greater GH laxity exists in competitive swimmers [1 23 29 30]. However, GH laxity may be defined as increased humeral head translation, but without any complaints of shoulder pain [29]. In addition, laxity can exceed this physiologic boundary and give rise to complaints (pathologic laxity) when not controlled, resulting in glenohumeral instability [29]. Moreover, there is greater laxity in elite swimmers than in recreational swimmers [30]. McMaster et al. [29] examined 40 high level competitive swimmers, of whom 35% (n=14) reported interfering shoulder pain. The presence of GH laxity was clinically examined with the sulcus sign, anterior and posterior drawer tests. All clinical tests evaluated humeral head excursion, and the presence of apprehension. There was a significant positive correlation between the presence of pain and the clinical tests for GH laxity within these competitive swimmers. Rupp et al. [23] clinically examined 22 competitive swimmers and compared them with a non-overhead sporting population. Sixty-four percent (n=14) of all swimmers reported shoulder pain. Half of all swimmers (n=11) -of which 8 had a positive Hawkins test- had a positive apprehension sign. Indications of GH instability were supported by Bak & Fauno [31] who studied 36 competitive swimmers (72 shoulders) of which 68% of shoulders were painful. Although no clear statistical significance could be noted, 21 shoulders presented with a positive apprehension signs. Nineteen painful shoulders demonstrated a positive anterior drawer test, 16 a positive sulcus sign. Finally, Sein et al. [1] studied 80 competitive swimmers; 54% reported unilateral shoulder pain, 37% reported bilateral shoulder pain and only 9% reported no shoulder pain. Many swimmers had mild anterior translation (61%), posterior translation (33%), or a positive the sulcus sign (51%). Shoulder laxity correlated positively with a greater IR ROM. However, although laxity was correlated with the swimmers' amount of pain, Sein et al. did not find a strong correlation with the swimmers' level of competition or hours of training. The latter did relate to the incidence of supraspinatus tendinopathy on magnetic resonance imaging. Current evidence suggests uncertainty regarding GH laxity or instability being a risk factor for shoulder pain in swimmers [13] Although frequently identified in swimmers, it is unclear whether laxity predisposes swimmers to pain or if it occurs in symptomatic swimmers as a result of cumulative microtrauma.

SHOULDER POSTURE

Shoulder posture can be defined by the general shoulder or specific humeral head position. A prospective study by Mckenna et al.[7] investigated whether humeral head position is predictive of the development of shoulder pain in competitive swimmers. They studied 46 adolescent swimmers. They concluded that swimmers who had a greater posterior humeral head position (larger distance between the anterior humeral head and the anterior edge of the acromion) were more likely to develop shoulder pain. As highlighted by the authors[7], it is currently unknown whether the more posteriorly positioned humeral head (in relation to the acromion) is due to a change in the acromion position (more anterior) or the humeral head position (more posterior).

Because the pectoralis minor muscle attaches anteriorly to the scapula, shortening of this muscle has been related to an altered scapular position and to the prevalence of shoulder pain[32 33]. It has been suggested that the pectoralis minor muscle length is affected by repetitive use, which is often seen on the dominant side in overhead athletes[34]. Consequently, the pectoralis minor muscle length is often studied when investigating altered shoulder posture[35]. Tate et al.[6] found a reduced resting length of the pectoralis minor in the high school swimmers with shoulder pain and disability in contrast to their pain-free controls. These findings are supported by a cross-sectional study in 37 female collegiate swimmers of Harrington et al.[25] who also reported a shorter pectoralis minor muscle length in swimmers with shoulder pain and disability in contrast to an unimpaired control group. In summary, current evidence suggests that an anteriorly tilted scapular position (and potentially shortened pectoralis minor muscle) may play a predisposing role in the development of shoulder pain in swimmers.

SCAPULAR DYSKINESIS

Abnormalities in scapular position and scapular motion – termed scapular dyskinesis – have been linked to shoulder pain [36]. In swimmers, the results are mixed. Tate et al. [6]. found that the prevalence of obvious scapular dyskinesis was not different between those with and without significant shoulder pain and disability. Interestingly, Tate et al.[6] did find greater middle trapezius muscle weakness in swimmers with painful shoulders, but not in other scapular muscles. A critical threshold of altered scapular muscle activity or control

may be necessary to result in visually altered scapular motion and shoulder pain. McKenna's et al.[7] prospective study determined that altered scapular position was predictive for the development of shoulder pain in competitive swimmers. Specifically, those with a more protracted scapular position (larger distance between the spinous process of the seventh thoracic vertebrae (T7) and the most inferior point of the scapula) were predictive for the development of shoulder pain in swimmers. Given these findings, it is unclear if scapular dyskinesis is involved in the etiology of shoulder pain or results from the repetitive swimming mechanism.

The effects of swimming on scapular motion has been studied by Su et al.[37] by measuring scapular upward rotation in swimmers with and without impingement syndrome (n=40) before and after a 1–2 hour practice session. There was a decrease in scapular upward rotation at 45°, 90° and 135° elevation in those with shoulder impingement after practice, but not for the healthy swimmers. However, based on this study[37], it is not clear whether the decrease in scapular upward rotation resulted in a meaningful decrease in subacromial space, which could mechanistically relate to the impingement symptoms. Interestingly, both groups revealed significant reduction (13-14%) in strength after the practice session, but there were no between-group differences. Likewise, Crotty & Smith[38] studied the effect of an intense swimming exercise on scapular position in male high school swimmers. However, based on their scapular assessment technique, a fatiguing exercise protocol failed to demonstrate significant changes in scapular position. Regarding its predisposing role, there is insufficient evidence that scapular dyskinesis is a risk factor for shoulder pain in swimmers [13]. Swimming may alter scapular position, but it is unclear if these changes are related to the development of shoulder pain.

PUTTING IT ALL TOGETHER: MECHANISMS AND IMPAIRMENTS THAT MAY RELATE TO SHOULDER PAIN IN SWIMMERS

The aim of this review was to investigate the musculoskeletal dysfunctions theorized to be associated with swimmers' shoulder. The findings of this review have implications for the swimmer, their coach, and the rehabilitation specialist working with the swimmers either after they develop shoulder pain or in a preventative role. However, because of the non-systematic nature of this review, together with a clear lack of well-powered longitudinal

277 prospective studies, it is difficult to generalize the results for practice in the evaluation and
 278 treatment of swimmers. Table 1 summarizes the key findings in swimmers with shoulder
 279 pain.

280

281 **Table 1: Differences in musculoskeletal function in swimmers with shoulder pain versus the unimpaired**
 282 **swimmer.**

Shoulder muscle performance

muscle activity during freestyle swimming	less activity of UT, R, AD, MD (hand entry); less activity of SA; higher activity of R (pulling phase); less activity of IS (hand exit); less activity SSc (mid-recovery)
muscle activity during breaststroke swimming	less activity of Tmi; higher activity of SSc (pulling phase); less activity of MD, UT, SSp; higher activity of IS
Muscle strength	Tendency of reduced IR strength (18)
Muscle endurance at the shoulder	less AB & ER endurance (9)
Core endurance	less core endurance (6)

Shoulder range of motion higher ($\geq 100^\circ$) or lower ($< 93^\circ$) ER ROM (20); reduced shoulder flexion and IR ROM (6)

Glenohumeral laxity & instability greater GH laxity & instability (1, 17, 21, 22)

Shoulder posture greater posterior humeral head position (7); shorter PM (6, 19)

Scapular dyskinesis tendency to greater incidence of SD (7); decreased scapular upward rotation after swim practice (29)

Abbreviation: GH= glenohumeral; ER= External Rotation; ROM= Range of motion; SD= scapular dyskinesis; AB= abduction; IR= internal rotation; R=Rhomboids; AD=anterior deltoid; MD=middle deltoid; SA=Serratus Anterior; IS=Infraspinatus; SSc=subscapularis;SSp=Supraspinatus Tmi=Ter

283

284 First, this review did not focus on other than musculoskeletal factors, which may
 285 contribute to shoulder pain and disability, such as stroke technique, breathing pattern, swim
 286 yardage or body composition. Second, most studies were retrospective or cross-sectional in
 287 design, which make it difficult to resolve the cause or effect question. However, based on
 288 the presented evidence, there appears to be collective themes of associated dysfunctions in
 289 swimmers. This evidence may benefit the development of rehabilitation strategies and
 290 prevention programs, rather than the use of a single label of swimmers' shoulder. The
 291 musculoskeletal dysfunctions highlighted in this review require further study, and in
 292 particular the use of prospective longitudinal research designs. Regarding muscle
 293 performance, a compensatory muscle activation strategy may be employed in order to try to
 294 maintain optimal motor output in painful shoulders. These strategies may vary from subtle
 295 changes in sharing of load with the synergist muscles, to a complete avoidance of a
 296 movement. Redistribution of muscle activity to synergist muscles has been demonstrated in
 297 non-swimming individuals with shoulder pain[39-42]. In swimmers after swim practice, a
 298 significant reduction of force (measured with a handheld dynamometer) has been

demonstrated for a variety of shoulder movements[24 37]. A reduction in muscle force has also concurrently been found in swimmers with altered scapular motion after swim practice. In addition, it is still a matter of debate on how to interpret muscle activity (EMG) results, and also how to transfer the findings to clinical practice.

As highlighted by Beach et al.[11], ER ROM might not be limited; but rather the IR ROM is limited. This phenomenon, in which the overhead athlete has a GH IR decrease, is described as GIRD (Glenohumeral Internal Rotation Deficit) [43]. Shanley et al. [44] found that a loss of IR $>25^{\circ}$ was predictive for an arm injury in the overhead baseball athletes. However, GIRD is labelled on a left-to-right difference often seen in unilateral overhead athletes. A side to side difference in IR ROM may not be present or as great in swimmers due to equal or nearly equal upper extremity use bilaterally. It is suggested that because swimming has no abrupt deceleration as other overhead sports, posterior tightness might occur at an older age [45]. However, caution should be used in interpreting the results of Torres and colleagues, as their subjects were recreational swimmers who likely incur reduced repetitive shoulder use compared to younger competitive swimmers. Tate et al.[6] and Walker et al. [26] hypothesized that there may be an ideal range of flexibility needed to swim without developing a shoulder injury. According to Walker et al. this could be within the range of 93° - 100° for ER ROM. As IR ROM was not predictive for pain in Walkers' study, it is difficult to recommend an ideal IR ROM. In addition, age groups present with different ROM, their guidelines for an ideal ROM should be based on age categories and gender[6]. However, as mentioned above, caution must be taken when interpreting these results. Whitely and Ocegüera [27] recently explained the impact of humeral torsion on IR and ER ROM measurements. Humeral torsion is described as the amount of bony twist about the long axis of the humerus. Greater ER torsion (retrotorsion) will increase ER ROM and visa versa [27]. To date, it is still unknown as to what extent humeral torsion is clinically important in a swimming population. It is indeed suggested that humeral torsion is likely a result of throwing [27]. Therefore, we conclude that alterations in shoulder rotational and flexion ROM are seen in swimmers with shoulder pain, but we cannot univocally conclude that these deficits are a risk factor for developing shoulder pain.

An increase in glenohumeral motion in the form of laxity and instability are present in those swimmers with shoulder pain. However, caution should be taken before interpreting

results concerning glenohumeral laxity and instability tests. The criteria used for labeling a test result as positive for laxity is excessive humeral head translation. Laxity alone is not symptomatic. Laxity may be a related mechanism leading to overload of shoulder musculature or other soft tissues. The criterion to confirm symptomatic GH instability is apprehension, which is suggested to be a strong and reliable clinical sign for glenohumeral instability [46 47].

Current evidence showed moderate certainty that forward shoulder posture due to an anteriorly tilted scapula may play a role in the development of shoulder pain in swimmers. Interestingly, Lynch et al. [48] revealed that the swimmers (78% with shoulder pain) who participated in the 8-week stretching and strengthening program had significantly decreased forward shoulder posture, with the acromion process closer to the wall in post-exercise testing. However, based on these results, an exercise regime could improve shoulder posture, but did not reduce their pain levels.

Whether or not scapular dyskinesia is predictive for shoulder pain is still a matter of debate. Several prospective longitudinal studies in overhead and rugby athletes have focused their study on the prediction of shoulder pain based on the presence of scapular dyskinesia [49-53]. Whereas 2 studies [49 51] found predictive value of the presence of scapular dyskinesia, 3 studies[50 52 53] did not. None of these studies included swimmers. The only remarkable difference between these studies is the level of overhead activity. Apparently, those studies that predicted the development of shoulder pain during the subsequent season included top-league elite athletes, whereas the studies not predicting the development of shoulder pain included recreational high school athletes. One area for future study would be to investigate if those with scapular motion deviations incurring greater loads on the shoulder due to higher training levels would be more likely to develop pain.

High training volume has been frequently reported as a risk factor for shoulder injuries in competitive swimmers[1 6 26]. Swimmers at elite level may train for 9 to 12 kilometres per day, six to seven day a week [2], which makes monitoring of training load and training increment important parameters requiring further investigation. In addition to training volume, stroke biomechanics are also of great relevance. Virag et al.[54] demonstrated a high prevalence of stroke errors in a group of collegiate swimmers. A

dropped elbow during the pull-through and recovery phase were the most commonly seen stroke errors, present in respectively 61% and 53% of the included swimmers. Interestingly, many of these stroke errors were interrelated, which resulted in the authors suggestion that one error may lead to other errors [54]. High training volume and volume increment in combination with stroke errors may be an important contributor to shoulder dysfunction. Finally, Hibberd et al. [17] recently highlighted that factors not relating to swimming, such as school and technology use, may have a significant effect on posture adaptations found in adolescents, both swimmers and non-overhead athletes [17].

In conclusion, as swimmers combine endurance, strength, flexibility and control in a repetitive manner, high levels of training might easily overload soft tissue structures around the shoulder and lead to pain, dissatisfaction, and disability. This can give rise to the so-called “swimmers’ shoulder” in which suggested pathophysiological factors include reduced endurance, incoordination or weakness of the shoulder muscles, a lack of scapular stability, poor posture, and lack of core stability. This literature review aimed at providing clinicians insight into the musculoskeletal mechanisms and impairments associated with swimmers’ shoulder.

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