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Humeral elevation reduces the dynamic control ratio of the shoulder muscles during internal rotation

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Abstract

Objective: This study investigated the effect of humeral elevation in the scapular plane on the peak-torque produced by the gleno-humeral joints (GHJ) rotators in order to ascertain an appropriate progression of commonly used eccentric resistance band exercises for shoulder impingement syndrome (SIS). In order to achieve the aim, the peak-torques produced during the eccentric action of the lateral rotators (LR) and the concentric action of the medial rotators (MR) were measured in 30 asymptomatic subjects at 20° and 60° of humeral elevation. The aforementioned peak-torques form the dynamic control ratio (DCR), which plays an important role in the dynamic stability of the GHJ.

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Design: A randomised cross-over experimental design.

Setting: Biomechanics laboratory, Peninsula Allied Health Centre.

Methods: Peak-torques were measured with a Biodex (system 3) isokinetic dynamometer at speeds of 20°/s in 30 asymptomatic subjects at angles of 20° and 60° of humeral elevation in the scapular plane.

Results: The differences between the eccentric peak torques at 20º and 60º of humeral elevation (25.04%) were found to be statistically significant ($p=0.002$). However no statistically significant differences were found between concentric peak-torques at 20° and 60° ($p=0.716$). Significant differences between the DCRs at 20° and 60° of humeral elevation ($p= 0.000$) indicate that humeral elevation has a significant effect on the DCR.

Conclusion: A significant link between increased humeral elevation and decreased peak-torque during eccentric contraction of the LR in healthy subjects was demonstrated in this study. This implies that the angle of humeral elevation has clinical relevance for the application of resistance band exercises as the already impaired eccentric control of the LR will be further challenged by introducing humeral elevation. Specifically, when strengthening of the LR is indicated during the acute phase of SIS to reduce imbalance and increase control, eccentric training at lower angles of elevation will most likely be more effective due

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to greater muscle balance and increased sub-acromial space. The additional decrease of peak-torque during the eccentric action (EA) of the LR occurring at 60° of elevation implies that introducing humeral elevation can be used as a progression of resistance band exercises.

Key words: concentric medial rotators, dynamic control ratio, eccentric lateral rotators, humeral elevation, isokinetic dynamometer, lateral rotation, medial rotation, peak-torque, rotator cuff, scapular plane, shoulder impingement syndrome.

Introduction

Shoulder impingement syndrome (SIS) accounts for up to 60% of painful shoulder diagnoses and is the most frequent cause of shoulder pain (Roy *et al*. 2009; Michener *et al*. 2004). SIS pain typically occurs when the arm is actively abducted in an arc between 40° and 120° consequently limiting functionality (Hall *et al*. 2011; Hardy *et al*. 1986). SIS is caused by compression of the sub-acromial soft tissues due to reduced sub-acromial space. This can result from extrinsic factors such as structural variations of the acromion, changes in scapular-thoracic rhythm, rotator cuff (RC) imbalance and tight gleno-humeral joint (GHJ) medial rotators (MR) (Seitz *et al*. 2011; Ellenbecker and Cools, 2010). Additionally, intrinsic factors such as tendinitis, tendinopathies and tears of the tendons due to excessive repetitive stresses or trauma are responsible for reducing the sub-acromial space (Fusco *et al.* 2008).

The predominant mechanism of shoulder impingement within the symptomatic population has been repeatedly attributed to the inability of the posterior RC muscles to stabilise the humeral head by opposing the deltoid muscles during elevation as a result of RC imbalances and deficits (Manske *et al* 1999; Davies *et al.* 1997; Liu *et al*. 1997; Leroux *et al.* 1994; Warner *et al.* 1990). This imbalance not only decreases sub-acromial space due to anterior translation and excessive medial rotation but also affects functional movement as the LR prevent the overload of the joint and control the deceleration of the humerus during medial rotation when working eccentrically (Ludewig and Braman, 2011; Yildiz *et al*. 2006; Malliou *et al*. 2004; Scoville *et al*. 1997). The ratio between the peak-torques generated during the concentric action (CA) of the MR and the eccentric action (EA) of the LR during medial rotation is known as the dynamic control ratio (DCR) which plays an important role in the dynamic stability of the GHJ.

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Given the numerous aetiologies, their complex nature and a lack of diagnostic reliability, no single superior treatment has been identified (Awerbuch, 2008; Michener *et al.* 2004). Nevertheless, strengthening exercises using resistance bands are commonly employed in the clinical setting due to their simplicity, costeffectiveness and potential to address muscle imbalance of the GHJ (Hintermeister *et al*. 1998).

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Contemporary research suggests that the most effective method of reducing muscle imbalance of the GHJ is resistance training of the LR (Niederbracht *et al*. 2008). Specifically, eccentric training is considered more effective at producing force due to the superior metabolic efficiency and motor unit recruitment during muscle lengthening (Hamill and Knutzen, 2009; Hintermeister *et al*. 1998). Furthermore, the shoulder's extensive range of movement (ROM) means that exercises can be performed at various angles and in various anatomical planes (Forthomme *et al*. 2011; Radaelli *et al*. 2010). Consequently, current research has not yet ascertained the most effective angle of humeral elevation for strengthening of the LR (Radaelli *et al.* 2010).

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Positioning the humerus in the scapular plane, which is at an angle of 30-45º anterior to the frontal plane, has been suggested to increase comfort and GHJ stability due to the optimal length tension relationship of the deltoid and RC muscles (Culham and Peat, 1993). In addition, enhanced congruency of the humeral head within the glenoid fossa and reduced stress on the joint capsule occur in the scapular plane (Culham and Peat, 1993; Hellwig and Perrin, 1991). Furthermore, positioning humerus in the scapular plane does not place the supra-humeral structures in a position of impingement and has shown to be tolerated by patients with SIS (Ellenbecker and Davies, 2000). Moreover, when compared to either the frontal or sagital planes no significant differences in the strength produced by the RC muscles have been found when tested in the scapular plane (Riemann *et al.* 2010; Hellwig and Perrin, 1991). In consideration of the above factors the scapular plane was chosen for testing.

Muscle torque is defined as the product of its force and its moment arm (Liu *et al*., 1997). It has been suggested that supraspinatus, subscapularis and infraspinatus not only medially or laterally rotate and stabilise the humeral head in the glenoid fossa but also assist in gleno-humeral abduction in the scapular plane Liu *et al*. (1997). Additionally, the moment arms of the middle and anterior deltoid have been found to increase throughout humeral elevation (Liu *et al*.1997). Collectively the above factors place an increased demand on the RC, therefore the authors of this study hypothesised that the eccentric and concentric peak torques generated during gleno-humeral medial and lateral rotation will decrease if gleno-humeral elevation is introduced.

In consideration of the above factors, this study assessed the muscle balance of the RC by measuring the peak-torques generated during the concentric action (CA) of the MR and the eccentric action (EA) of the LR during medial rotation i.e. the DCR. The DCRs were assessed using isokinetic dynamometry as it is considered the gold standard for strength and muscle imbalance testing (Radaelli *et al.* 2010; Riemann *et al*. 2010; Ellenbecker and Davies, 2000) and resembles the muscle actions involved in resistance band exercises used in the treatment of SIS.

Aims of the study

The aim of the study was to investigate the effect of humeral elevation in the scapular plane on the DCR of the GHJ rotators in order to ascertain an appropriate progression of commonly used eccentric resistance band exercises for SIS. In order to achieve the aim, the peak-torques produced during the eccentric action of the LR and the concentric action of the MR were measured in 30 asymptomatic subjects at 20° and 60° of humeral elevation.

Research Approaches and Methodology

Experimental Approach to the Problem

A randomised cross-over experimental design was used in this study. Peak-torque generated by the concentric action of the MR and the eccentric action of the LR of the GHJ was measured in 30 asymptomatic subjects during medial rotation. All the isokinetic tests were performed on a Biodex (system 3) isokinetic dynamometer (Biodex Medical Systems, Shirley, New York) which was calibrated according to the manufacturer's instructions. Speeds under 60°/s were considered for isokinetic testing as evidence suggest that differences in the eccentric strength of participants are not able to be detected at greater eccentric testing speeds (Page *et al*. 1993). In order to ensure that the testing speed was representative of the speed at which resistance band exercises are typically performed a pilot study was undertaken. Therefore repeated observations of four subjects eccentrically resisting the medial pull supplied by an elastic resistance band were performed. As a result of the observations an average speed of 20°/s was chosen. Furthermore, the pilot study revealed that the ergonomics of the Biodex machine did not allow testing at 0° of humeral elevation as planned in the protocol, therefore the closest testable angle of 20° was chosen. Additionally, an angle of 60° of humeral elevation was chosen as it is within the functional range at which SIS occurs. Finally the scapular plane was defined approximately 30° anterior to the frontal plane as described by Radaelli *et al*. (2010) and ascertained by goniometry.

Data collection took place in a controlled environment. However, due to ethical reasons and practicalities neither the participants nor the data collector were blinded respectively. Nonetheless, in order to optimise the study's internal validity, testing procedures, encouragement, and exclusion criteria were standardised to reduce the potential of confounding variables affecting the results. One researcher was responsible for standardised warm-up and cool-down; a different researcher measured the angle of GHJ elevation in the scapular plane of each participant and another researcher was responsible for reading and recording the results from the isokinetic dynamometer. Furthermore, the testing angles and the rotational movements were randomised to eliminate testing bias.

The study was approved by the Human Ethics Sub-Committee of Plymouth University, United Kingdom. All participants were informed of the procedures, experimental risks, rationale and were over the age of 18. A consent form was signed prior to the investigation and all participants were informed of their right to withdraw at any time.

Methods of data collection

Participants were guided through a standardised warm-up consisting of upper limb ROM exercises for a period of three minutes with the aim of minimising the risk of injuries and undue fatigue. The seated testing position was used in order to reduce the recruitment of additional musculature, isolate the muscles of the GHJ and is more functional than the supine testing position (Hill, *et al.* 2005). Each subject was secured to the seat by chest straps, without their feet touching the ground in order to eliminate the recruitment of lower limb musculature and isolate the GHJ rotators. Each participant's dominant arm was securely placed in the arm attachment of the machine with the elbow flexed at 90° in accordance with the manufacturer's instructions. The GHJ elevation angle was randomly set at 20° or 60° in the scapular plane (30°) (see Figures 1 and 2). Randomisation of the angle of elevation and type of contraction was achieved by the participants' blinded selection of either red (20°) or green (60°) identical balls out of an opaque bag containing an equal number of each colour. The selected angles for each participant were then ascertained by goniometry which was performed by the same researcher each time. Participants subsequently performed a GHJ medial and lateral rotational movement as far as they were able without feeling any discomfort. Ten percent of full range was deducted from their inner and outer ROMs to ensure safety. Next, participants randomly selected the elevation angle and type of contraction to be performed first, followed by completing one sub-maximal contraction through both ROMs to familiarise themselves with the process. Three concentric medial rotational movements followed by three lateral eccentric rotational movements were then performed (or vice versa depending on randomisation) with 30 seconds rest periods between tests to prevent fatigue as per Radaelli *et al*. (2010). Results of each test were then recorded immediately into software. Finally a three minute standardised warm down and debrief were completed.

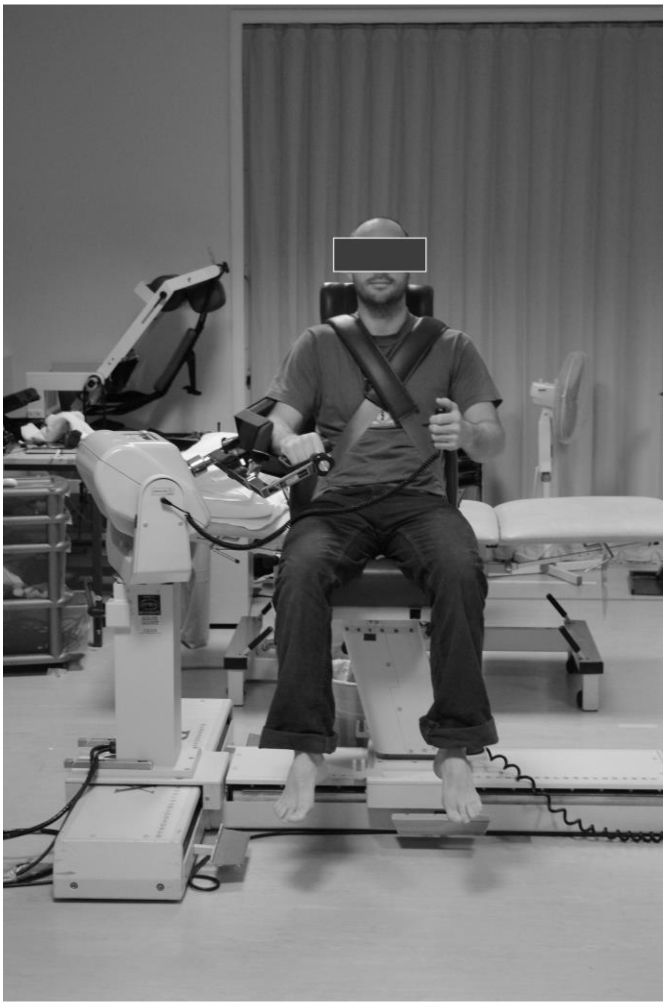

Figure 1: 30° of humeral elevation in the scapular plane

Figure 2: 60° of humeral elevation in the scapular plane

Subjects

Based on the previous research (Radaelli *et al.* 2010; Hellwig and Perrin, 1991) and logistical constraints, 32 healthy asymptomatic subjects were incidentally sampled from the university student and staff populations within Plymouth to participate in this study. All participants were free from any shoulder injuries apart from two who fulfilled aspects of the exclusion criteria (unresolved injuries to the upper limb) and were omitted (see table 1 for the exclusion criteria). The exclusion criteria were formulated in order to minimize the risk of injuries. Therefore data was collected from 30 subjects (men n = 14, women n = 16, mean age = 29.4 ± 8.9 years, BMI = 24.08 ± 5.43).

Table 1 Exclusion Criteria

	Yes	No
1. Any underlying medical condition that you think may affect your participation in this study	◻	◻
2. Any cardiac condition or illness	◻	◻
3. Hyper- or hypo-tension	◻	◻
4. Any respiratory condition or illness	◻	◻
5. Shortness of breath at rest	◻	◻
6. Osteoporosis	◻	◻
7. Haemophilia	◻	◻
8. Hyper mobility syndrome	◻	◻
9. Any other skeletal or connective tissue disorder	◻	◻
10. Any unresolved injury to your upper limb or body	◻	◻
11. Unresolved thoracic outlet syndrome	◻	◻
12. Cervical plexus compression or nerve palsy	◻	◻
13. Brachial plexus compression or nerve palsy	◻	◻
14. Any tingling, pins and needles, numbness in your arm and/or hand	◻	◻

Statistical Analysis

Data was processed using the Statistical Package for Social Sciences version 18 software (SPSS inc., Chicago, IL). Alpha level (*p*) was set to 0.05. The Kolmogorov-Smirnov test was used to determine whether the variables (gender, age, BMI) met the parametric assumption of normal distribution. As all the variables were normally distributed a paired t-test was used to compare the DCR variables at 20° and 60°. Further t-tests were performed on peak-torques generated during the eccentric and concentric contractions of the GHJ rotators during medial rotation at 20° and 60°in order to see if the changes during elevation were significant.

<u>Presentation of the results</u>

Table 2 – Results of paired t-test of the DCR at 20° and 60° of humeral elevation

Angle	20°	60°	p
Mean DCR	0.64	0.51	0.000*
[±SD]	[0.17]	[0.08]	

*significant difference between 20° and 60°

Table 2 demonstrates a 20% difference between the DCRs at 20° and 60°. The DCR at 20° is more balanced (closer to one), indicating increased imbalance at 60°, meaning that the concentric muscle action is less likely to be eccentrically opposed with an increase in GHJ elevation.

The DCRs were calculated by dividing the peak-torque generated by the concentric action of the MR by the peak-torque generated by the eccentric action of the LR. Results from the paired t-test of the DCR variables highlighted significant differences between the DCRs at 20° and 60° of humeral elevation (p= 0.000), indicating that humeral elevation has a significant effect on the DCR.

Table 3 – Results of the paired t-test of the concentric and eccentric peak torque in relation to GHJ elevation

Angle of muscle action	20° Concentric	60° Concentric	20° Eccentric	60° Eccentric
Mean Peak-Torque (Nm^{-1})	56.50	57.03	37.87	28.39
[±SD]	[20.53]	[24.35]	[21.49]	[11.01]
p	0.716		0.002	

Results in table 3 indicate that there is no statistically significant difference between concentric peak-torques at 20° and 60° (p=0.716). However, there is a statistically significant difference between the eccentric peak torques (p=0.002) as demonstrated by the t-test. These differences are also clinically relevant given the 25.03% difference between them. Therefore progression of RC resistance band strengthening exercises through elevation is indicated.

Discussion

This study has achieved its aim by identifying that the lower angle of humeral elevation enables better dynamic control as demonstrated by the DCR at 20º compared to that at 60º. The results also indicate that the angle of humeral elevation has clinical implications for the application of resistance bands exercises in the rehabilitation of SIS and other pathologies involving RC dysfunction. This supports previous studies which report that the SIS pain increases with humeral elevation (Hardy *et al*. 1986; Rathbun and McNab, 1970; Roy *et al*. 2009).

Previous research has identified that varying amounts of accessory muscles influence medial and lateral rotational forces as humeral elevation occurs (Ellenbecker and Cools, 2010; Jaggi *et al.* 2009; Pouliart and Gagey, 2005). Labriola *et al*. (2005) identified that not only the rotator cuff but also the biceps brachii, latissimus dorsi, pectoralis major, teres minor, and scapulothoracic muscles are active during shoulder motion. Specifically, the key muscles that are involved during medial rotation include the subscapularis, pectoralis major and the latissimus dorsi (Decker *et al*. 2003; Favre *et al*. 2005). The altered length-tension relationship of these accessory muscles during testing could possibly account for the maintenance of concentric peak-torque during humeral elevation in the scapular plane compared to eccentric peak-torque. Another possible explanation for the maintenance of peak-torque may lie in the contribution of latissimus dorsi to the production of medial rotation, particularly when it is more elongated due to elevation in the scapular plane (Radaelli *et al*. 2010). A further explanation for the maintenance of concentric peak torque during testing could lie in the suggestion by Decker *et al.* (2003) that the upper and lower subscapularis function independently and that the upper subscapularis muscle activity increases and lower subscapularis muscle activity decreases during humeral elevation and medial rotation.

The production of higher peak–torque in the MR over the LR could be a result of the testing procedures of contemporary studies. For example, a comprehensive study by Andrade *et al*. (2010) profiled the DCRs of 27 elite female handball players and compared them bilaterally. Specifically, a significant increase in MR strength was noted on the dominant-side. However, this increase was not proportionally matched by the eccentric action of the lateral rotators, creating a larger imbalance. Additionally, the study demonstrated slower testing speeds (such as 20°/sec) were optimal for developing concentric peak-torque. However greater eccentric peak-torque was more likely to be gained at a higher testing speed. These findings have been supported by Noffal (2003) and Ostering (2000) respectively and could be a possible factor in the maintenance of the MR peak-torque generated by the concentric action of the MR in elevation within the current study.

Furthermore, it has also been documented that the seated isokinetic testing position facilitates the medial rotators through the segmental limb weight, which in turn increases demand on the lateral rotators (Yildiz *et al*. 2005). Consequently, when compared to supine testing position, the seated position has been shown to demonstrate reduced stability of the GHJ (Forthhomme *et al*. 2011; Hill 2005; Hageman *et al*. 1989). However, the supine position is rarely used in activities of daily living making it less functional for rehabilitation exercises and testing.

Moraes and Faria (2008) demonstrated that during restricted sitting and standing positions often used in isokinetic dynamometry, optimization of the rotator cuff is hindered due to the altered dynamic stabilization of the scapula. Therefore, the seated position used in the current study may not enable optimal scapular thoracic dynamics, suggesting that values obtained are not as representative. In consideration of aforementioned research, the testing of the dominant arm, testing speed, seating position and increased segmental weight have all been demonstrated to further increase bias towards the MR and give a less representative DCR.

Further analysis of the methodology used in previous research observed generalised methodological rigour i.e. randomisation, blinding and control of the confounding variables, although some weaknesses were highlighted. For example, a proportion of the literature has tested the concentric medial and lateral ratio despite it being established that this ratio falls short in reflecting muscle function during activity (Andrade *et al*. 2010; Ellenbecker and Davies, 2000). In addition, the majority of the studies reviewed used participants with a mean age of under 23 years e.g. Radaelli *et al.* (2010), Riemann *et al*. (2010), Niederbracht *et al*. (2008), Hellwig and Perrin, (1991) despite the fact that SIS typically occurs between 40-50 years (Roy *et al*. 2009). Further common weaknesses include: inconsistent blinding e.g. Radaelli *et al*. (2010), Niederbracht *et al*. (2008) Hellwig and Perrin, (1991); and a lack of standardisation regarding visual and verbal encouragement e.g. Radaelli *et al.* (2010), Riemann *et al*. (2010), Niederbracht *et al*. (2008), Hellwig and Perrin, (1991). Moreover, none of the aforementioned research used subjects with SIS; therefore limiting the external validity of their findings to those without SIS. Thus, the present study tested the DCR using a methodology designed in order to reduce as many of the limitations highlighted as possible and increase its validity.

Nonetheless, there were limitations within the methodology of the present study. The primary limitation was that the subjects and data collector were not blinded to the study's purpose nor testing procedures due to ethical and logistical restrictions. An additional limitation was the inability to measure if the subjects had worked maximally during testing as they had been instructed. Similarly, the effect of fatigue was not measured. However, the implementation of a 30 second rest period between each test reduced the possibility of this occurring. Additionally, due to the design limitations of the Biodex (system 3) isokinetic dynamometer it was not possible to assess peak-torque at 0° of humeral elevation, which is a position known to be used for resistance band strengthening of the RC in a clinical setting (Holmgren *et al*. 2011). A further limitation of the study is that volunteers were from a convenience sample of staff and students at Plymouth University. Although the data was parametric and normally distributed for mean age, gender and BMI, the generalisability of the findings is potentially limited to individuals of 19-56 years of age without shoulder pathologies.

The strengths of the present study lie within the standardised methodology used. Importantly, testing procedures were comprehensively standardised with particular attention to verbal encouragement, visual feedback and randomisation. This ensured consistency through the testing period and helped maximise internal validity. The mean age (years) of the sample used in this study was more representative of the SIS population, which has not been evident in research to date (Radaelli *et al.* 2010; Riemann *et al*. 2010; Niederbracht *et al*. 2008; Hellwig and Perrin, 1991). In summary, the strengths of the present study increase the validity and reliability of its findings, which can be used as part of an evidence base for the application and progression of rehabilitation exercises through elevation.

Commencing rehabilitation exercises at lower angles benefits from greater dynamic control (Reinold *et al*. 2004) and increased sub-acromial space; thus reducing the chance of pathological exacerbation. Exacerbation by exercising with increased humeral elevation is a result of the change in the moment arms of the primary shoulder abductors: middle and anterior deltoid (Liu *et al.* 1997). Liu *et al.* (1997) compared the aforementioned moment arms at 0°, 60° and 90° of humeral elevation in the scapular plane and discovered that the moment arms of the middle and the anterior deltoid become progressively larger with increasing arm elevation placing a higher demand on the RC to stabilise the humeral head when opposing the deltoid muscles. Progression of rehabilitation exercises through elevation of the GHJ in the scapular plane is indicated once stability of the humeral head is obtained; this is supported by Ellenbecker and Cools (2010) who performed an evidence based review on rehabilitation of SIS and rotator cuff injuries. Additionally, they recommend that the muscle balance between the lateral and medial rotators is regularly monitored in order to guide the selection of exercises for the patient undergoing rehabilitation for rotator cuff pathology. Further support for the use of elevation as a progression is provided by a recent RCT by Holmgren *et al*. (2012) who used eccentric strengthening exercise for the rotator cuff and concentric/eccentric strengthening exercises for the scapula stabilisers in the successful treatment of 51 subjects (intervention group) with a diagnosis of SIS. Thus, the progression of rehabilitation exercises through elevation in the scapular plane is not unfounded.

Eccentric training is frequently used as treatment for tendon pathology (Berhardsson *et al*. 2010). However, due to lack of high-quality studies with clinically significant results, Woodley *et al*. (2007) were unable to make strong conclusions regarding the effectiveness of eccentric exercise in relieving pain, improving function or achieving patient satisfaction from their systematic review. Moreover, Woodley and colleagues suggest the lack of understanding about the basic pathophysiology of tendinopathy makes determining the optimal dosage of intervention difficult. Nonetheless, the training volume used successfully by Berhardsson *et al*. (2010) and Holmgren *et al*. (2012) could be used as a guide from which to prescribe and adapt eccentric training programmes for the rehabilitation of patients with SIS. Both studies used three sets of 15 repetitions performed twice daily. Berhardsson *et al*. (2010) reported a significant and clinically meaningful reduction in patient reported pain as a result of their 12 week strengthening programme. Additionally, Holmgren *et al*. (2012) progressed the exercises in weeks 9-12 by increasing the resistance, introducing humeral elevation (and halving the training volume to produce significantly greater improvement than the control exercise group in shoulder function and pain. Furthermore, subjects in the exercise group reported greater health related quality of life and a more successful outcome. Moreover, Holmgren *et al*. (2012) reported that a significantly lower proportion of subjects in the exercise group subsequently chose surgery compared to controls. These findings highlight the efficacy of eccentric training of the LR and its progression through humeral elevation.

Commented [Gary Shum6]: excellent

Once symptoms have been reduced and the patient has returned to their previous level of functional activities, research by McCarrick and Kemp (2000) suggests that performing a rehabilitation exercise routine once a week is sufficient to maintain rotator cuff strength gains in previously untrained subjects. This minimal demand on a SIS patient's time resources should be beneficial in improving adherence consequently maintaining the treatment effect.

Commented [Gary Shum7]: How can we draw conclusion from the results

In order to reliably establish the optimal progression of RC resistance band strengthening exercises through humeral elevation, further studies should be undertaken using resistance bands as a concentric and eccentric source of resistance in combination with electromyography in order to measure the activity of the MR and LR of the GHJ. Such studies would increase the relevant body of knowledge and address the limitations of the present study. Further research could also be performed on pathological patients, suffering from RC dysfunction in order to further increase generalisability of research findings to the clinical setting.

CONCLUSION

A significant link between increased humeral elevation and decreased peak-torque during eccentric contraction of the lateral rotators in healthy subjects was demonstrated in this study. This implies that the angle of humeral elevation has clinical relevance for the application of resistance band exercises as the already impaired eccentric control of the LR will be further challenged by introducing humeral elevation. Specifically, when strengthening of the LR is indicated during the acute phase of SIS to reduce imbalance and increase control, eccentric training at lower angles of elevation will most likely be more effective due to greater muscle balance and increased sub-acromial space. The additional decrease of peak torque during the EA of the LR occurring at 60° of elevation implies that introducing humeral elevation can be used as a progression of resistance band exercises.

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