**Journal of Science and Medicine in Sport**

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

William Howard1, Jonathan Burgess1, Borut Vrhovnik1, Christian Stringer1, Sherrie T Choy2, Jonathan F Marsden1, Ingrid A Gedikoglou1, Gary L Shum3

1 School of Health Professions, Plymouth University, United Kingdom

2 Livewell Southwest, NHS, Plymouth, United Kingdom

3 Faculty of Sport & Health Sciences, University of St Mark & St John, United Kingdom

**Corresponding author:**

Dr Gary Shum PhD, MCSP

Faculty Director of Research and Associate Professor

Faculty of Sport & Health Sciences

University of St Mark & St John

Derriford Road, Plymouth PL6 8BH

United Kingdom

Email: gshum@marjon.ac.uk

Tel: 01752 636700 (Ext. 5310)

Word count: 2787

Abstract

Objectives: To determine the differences in the dynamic control ratio of the glenohumeral joint rotators, during internal rotation at 20° and 60° of humeral elevation in the scapular plan. Dynamic control ratio (DCR) is defined as the ratio between eccentric action of the lateral rotators and the concentric action of the medial rotators.

Design: A cross-sectional laboratory study

Methods: Thirty asymptomatic participants (men n = 14, women n = 16, mean age = 29.4 ± 8.9 years, BMI: 24.1 ± 5.4) were tested. Peak torque generated by the concentric action of the MR and the eccentric action of the LR of the shoulder joint and the DCR were evaluated on the dominant arm using an isokinetic dynamometer at 20° and 60° of humeral elevation at a speed of 20°/s.

Results: There was a significant decrease in the DCR at 60° humeral elevation when compared to 20° humeral elevation (p < 0.05). This decrease was due to the significant decrease in eccentric peak torques at 60° humeral elevation when compared to 20°(p < 0.05). However, there was no significant difference in the concentric peak torques between 20° and 60°(p > 0.05).

Conclusions: The significant decrease in the DCR as a consequence of a decrease in the eccentric peak torque of the LR when the humerus is in a more elevated position suggests that the introduction of humeral elevation can be used as a progression for improving the eccentric action of the shoulder LR and subsequently the dynamic control of the shoulder.

***Keywords:*** isokinetic, shoulder, rotation, elevation

**Introduction**

The shoulder joint complex consist of the scapular thoracic, sterno-clavicular, acromio-clavicular and gleno-humeral joints, is a highly mobile but intrinsically unstable joint due to poor congruency and minimal contact between the head of the humerus and the glenoid fossa1. The stability of the shoulder joint complex is largely dependent on dynamic contraction of the rotator cuff muscles1-3. It has been suggested that changes in dynamic shoulder stability can contribute to shoulder injuries and pathologies such as shoulder impingement or instability2-4. Pain in the shoulder region and accompanying impaired dynamic stability of the shoulder joint complex are typically noticeable during elevation of the upper arm and overhead activities such as tennis and volleyball serves when rotation of the humerus at the glenohumeral joint (GHJ) occurs. The shoulder medial and lateral rotators strength in patients with impingement syndrome show both weakness and muscular imbalance of the external and internal rotator muscles 5-8. Evaluation of the strength ratio between medial and lateral rotators is therefore essential to assist the planning of a resistive exercise programme.

The restraining / breaking eccentric action of the lateral rotators (LR) of the shoulder against the concentric action of the medial rotators (MR) during internal rotation of the upper arm is important to the maintenance of the dynamic stability of the GHJ. The measurement of the balance between these two opposing muscle actions and forces in known as the Dynamic Control Ratio (DCR) 3, 9. A DCR of less than one would indicate a weaker eccentric action of the LR when compared to the concentric action of the MR and considered as a shoulder rotator muscle imbalance3, 9. During humeral elevation, the rotator cuff muscles act with the deltoid muscles in a force-couple mechanism to stabilise the humeral head in the glenoid fossa10. The moment arms of the supraspinatus, subscapularis, inftraspinatus and deltoid muscles have been found to vary significantly in a non-linear fashion throughout humeral elevation in cadavers11. Since muscle torque is defined as the product of its force and its moment arm11, it is reasonable to hypothesize that the DCR and its constituent parts i.e. the concentric action of the MR and the eccentric action of the LR during internal rotation could be altered significantly when the humerus is in differing positions of elevation. This may due to the altered moment arm and the angle of movement when the humerus is in a more elevated position.

To date, no studies have investigated the effect of humeral elevation on the DCR. Despite the lack of research evidence, it is a common clinical practice to commence a programme of rotator cuff strengthening exercises with no humeral elevation and introduce humeral elevation as a progression, due to the increased demand for control by the scapular stabilizers2, 11, 12. In addition it has been proposed that eccentric strength training of the LR can in effect optimize the DCR of the shoulder rotators and thus reducing the occurrence of shoulder injuries2, 3, 13. Understanding the differences in the DCR during elevation would allow the application of an appropriate progression of prescribed exercises for improving dynamic shoulder stability.

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 rotator cuff strengthening exercises. 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.

**Methods**

Sample size was determined using a power calculation with power level of 80%, 10% mean of difference and a significance level p<0.05, resulting in a necessary sample size of 31 participants. Thirty one asymptomatic participants were incidentally sampled from the university student and staff populations to participate in this study. Exclusion criteria included any underlying medical conditions, systemic or neurological illnesses, previous shoulder dislocation, previous neck and thoracic or upper limb injury that required medical or physiotherapy treatment in the 12 months prior to the study. The study was approved by the Human Ethics Committee of the University. All participants were informed of the procedures, experimental risks, rationale and were over the age of 18 years. All participants gave written informed consent to participate in this study, which was conducted according to the Declaration of Helsinki. One participant opted to drop out of the study after completion and eventually thirty participant completed the study (men n = 14, women n = 16, mean age = 29.4 ± 8.9 years, BMI = 24.1 ± 5.4).

The scapular plane was defined approximately 30° anterior to the frontal plane, as described in a previous study14, and ascertained by goniometry. All the isokinetic tests were evaluated on the dominant arm (the arm used for throwing a ball) using a Biodex Multi Joint System 3 isokinetic dynamometer (Biodex Medical System Inc., Shirley, New York), which was calibrated according to the manufacturer’s instructions. In order to best replicate the speed at which rotator cuff strengthening exercise are commonly performed during testing, a pilot study consisting of 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 selected. 20°/s has therefore been selected to mimic the usual clinical practice in the initial stage of rotator cuff strengthening exercises.

The design of the Biodex machine did not allow testing at 0° of humeral elevation, therefore the minimal available angle of 20° humeral elevation was chosen. Additionally, an angle of 60° of humeral elevation was chosen as it is within the functional range at which shoulder strengthening exercises are commonly prescribed in clinical settings. During internal rotation at 20° and 60° of humeral elevation in the scapular plane at a speed of 20°/s, peak torque generated by the concentric action of the MR was measured. The dynamometer was then reprogrammed to measure the eccentric action of the LR at the same position, in which the dynamometer passively internally rotates the GHJ and the participant had to slowly resist the pull during the internal rotation. The DCR for the glenohumeral internal rotation is defined as the ratio of the peak torques generated during the eccentric action of the LR divided to the concentric action of the MR 3, 9.

Testing procedures and encouragement were standardised to reduce the potential of confounding variables affecting the results. Participants were guided through a standardised warm-up, consisting of upper limb range of motion exercises of shoulder flexion, extension, horizontal abduction and adduction, internal and external rotation mobilisation exercise with an end range hold for 10 seconds for 3 times in each direction 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 also because it is more functional than the supine testing position15. Each subject was secured to the seat by diagonal chest straps and pelvic straps, without their feet touching the ground, in order to eliminate the recruitment of lower limb musculature and isolate the GHJ rotators. The dominant arm of each participant was securely placed in the arm attachment of the machine, with the elbow flexed at 90° in accordance with the instructions of manufacturer, at 20° and 60° of humeral elevation at the scapular plane (Figure 1a and b). The order of testing angles and the rotational movements were randomised by sealed envelopes to eliminate testing bias. The full range of rotation of each participant was determined by performing a full GHJ internal and external rotational movement on the Biodex 3 Dynamometer. Ten per cent of full range of rotation was deducted from their inner and outer range of motions to minimise stress on the rotators. Three concentric internal rotational movements followed by three external eccentric rotational movements were then performed (or vice versa depending on randomisation) with 30 seconds rest periods between tests to avoid fatigue14.

Data was analysed using the Statistical Package for Social Sciences version 19 software (SPSS, IBM, New York). The Kolmogorov-Smirnov test was used to determine whether the variables met the parametric assumption of normal distribution. As all the variables were normally distributed. Paired t-tests were used to determine the differences in the peak torques generated during the eccentric and concentric contractions of the GHJ rotators and the DCR during internal rotation at 20° and 60°. The level of significance was set at 0.05.

**Results**

Table 1 present values of concentric peak torque of medial rotators (MR), eccentric peak torque of lateral rotators (LR) and DCR at 20° and 60° of humeral elevation respectively. None of the volunteers reported pain during the isokinetic testing.

There was also a significant difference in the DCR between 20° and 60° of humeral elevation (Table 1, p=0.000). Post-hoc t-test indicated that there was a significant difference in the eccentric peak torques between 20° and 60° humeral elevation (Table 1, p=0.002). However, there was no significant difference in the concentric peak torques between 20° and 60° humeral elevation (Table 1, p=0.716).

**Discussion**

This is the first study todemonstrate the differences in Dynamic Control Ratio (DCR) during internal rotation of the shoulder between 20° and 60° of shoulder elevation in the scapular plane, which is both statistically (p=0.000) and clinically significant (20.3%). The DCR of 0.64 at 20° of humeral elevation was more balanced when compared to the DCR of 0.51 at 60° of humeral elevation. It is important to note that while the sample size is less than that indicated by the pre-test power calculation, the 20.3% mean of difference is more than double that used in the power calculation (10%). In addition, the statistical significance of the results (p=0.000) are greater than that used in the power calculation (0.05) therefore the results of this study are not at risk of being underpowered.

The post-hoc t-test demonstrated that there was a statistically significant decrease in the eccentric peak torque of the LR when the shoulder is in a more elevated position (Table 1) while the peak torque of the MR remained unchanged. This decrease in the eccentric peak torque of the LR accounts for the decrease in the DCR when the humerus is in an elevated position. The 20% decrease in DCR as a result of the 25% decrease in the eccentric peak torque and when the humeral in a more elevated position could be considered to be clinically significant and relevant.

The results of the this study are similar to previous studies which reported significant differences in force output (strength) of the shoulder rotators when the position of the GHJ is changed14, 16, 17. It has been suggested that changes in the centre of joint rotation can directly affect isokinetic peak torque performance during isokinetic dynometry testing14, 18. This may partly explain why the DCR is significantly decreased when the humerus is a more elevated position when the centre of joint rotation is altered. The decreased DCR when the shoulder is in a more elevated position observed in the present study may also explain why the shoulder is normally considered be more unstable when the humerus is more elevated. Differences in length-tension relationships of the shoulder rotators as a result of increased elevation of the humerus at the shoulder may additionally be a contributing factor to the results of the present study. For example research has indicated that the moment arm of the anterior and middle deltoid muscles have been found be progressively greater when measured at 0°, 60° and 90° of humeral elevation11. It is reasonable to hypothesise that similar changes may have occurred at the moment arms of the external rotators.

Shoulder impingement syndrome accounts for up to 60% of painful shoulder diagnoses and is the most frequent cause of shoulder pain13. It can result from muscles imbalance between the medial and lateral rotators2, 19, 20, especially when the shoulder is in a more elevated position.21 This imbalance not only decreases sub-acromial space due to anterior translation and excessive internal rotation but also affects functional movement as the lateral rotators prevent the overload of the joint and control the deceleration of the humerus during internal rotation when working eccentrically.22, 23

It is common clinical practice to commence resistance exercise at lower humeral elevation in order to benefit from greater dynamic control and increased in sub-acromial space24, thus reducing the chance of pathological exacerbation. Research has also specifically suggested that shoulder stability exercises in patients with impingement syndrome should be progressed through humeral elevation in the scapular plane2. Further support for the use of elevation as a progression is provided by a recent randomised control trail25, in which eccentric strengthening exercise for the rotator cuff and strengthening exercises for the stabilisers of the scapula have been found be effective in treating fifty one participants with a diagnosis of shoulder impingement syndrome. The progression of rehabilitation exercises through elevation in the scapular plane when the DCR and the eccentric peak torque is reduced are supported by the results of the present study.

The results of the present study may have affected by some practical limitations. It has been reported that a seated isokinetic testing position facilitates the medial rotators through the segmental limb weight, which in turn increases demand on the lateral rotators22. Consequently, when compared to supine testing position, the seated position has been shown to demonstrate reduced stability of the GHJ15, 16, 26. However, the supine position is rarely used in activities of daily living making it less functional for rehabilitation exercises and testing. It has also been demonstrated that optimization of the rotator cuff is hindered due to the altered dynamic stabilization of the scapula in restricted sitting and standing positions during isokinetic dynamometry testing27. Therefore, the seated position used in the current study may not enable optimal scapular thoracic dynamics, suggesting that values obtained are not as representative to functional activities.

Additionally, due to the design limitations of the Biodex Multi Joint 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 strengthening exercises of the rotator cuff muscles in a clinical setting25. A further limitation of the study is that volunteers were from a convenience sample of staff and students at the university. Although the data was parametric and normally distributed for mean age, gender and BMI, the generalizability of the findings is potentially limited to individuals of 19-56 years of age without shoulder pathologies. One other limitation of the study is the testing speed of 20°/sec which has not accounted for higher speed required in shoulder movement, greater discrepancies might have been identified if a higher testing speed has been used. This study has also only tested the dominant side, a previous study demonstrated that there were significant differences between dominant and non-dominant side in the isokinetic concentric and eccentric profile of the shoulder medial and lateral rotators28.

Future studies could therefore examine the effect of humeral elevation on the DCR and isokinetic profiles of the rotators in people with shoulder pathologies. The isokinetic profile could be tested in different humeral elevations and a higher speed in the concentric and eccentric testing could also be employed.

**Conclusion**

There was a significant decrease in the DCR attributed to the significant decrease in eccentric peak torque of the lateral rotators during internal rotation of the GHJ when the humerus is in a more elevated position in healthy participants. This suggests that humeral elevation has clinical relevance for the application of rotator cuff strengthening exercises as the already impaired eccentric control of the lateral rotators will be further challenged by introducing humeral elevation. Specifically, eccentric training at lower angles of elevation will most likely be more effective due to greater muscle balance and increased sub-acromial space when strengthening of the lateral rotators is indicated to reduce rotator muscles imbalance. The significant decrease in peak torque during the eccentric action of the lateral rotators occurring at 60° of elevation suggests that introducing humeral elevation can be used as a exercise progression.

Practical implications

* Increased humeral elevation was significantly linked to decreased functional eccentric strength of the external rotators of the shoulder resulting in a functional strength imbalance between lateral and medial rotators during internal rotation.
* Adequate assessment of the eccentric strength of the lateral rotation in elevated humeral position should be considered.
* Commencing rehabilitation exercises at lower angles benefits from greater dynamic control.
* Elevation of the upper arm at the GHJ has been shown to be an effective progression of rehabilitation exercises of the rotator cuff muscles when performed in the scapular plane.

**Acknowledgement**

No benefits in any form have been or will be received form a commercial party /grant body related directly or indirectly to the participants of this study.

**Figures Legends**

Figure 1. Isokinetic testing at 30° (a) and 60° (b) humeral elevation in the scapular plane.



**References:**

1. Gray H, Standring S. Gray's anatomy : the anatomical basis of clinical practice. 40th ed. Edinburgh: Churchill Livingstone,; 2008.

2. Ellenbecker TS, Cools A. Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: an evidence-based review. *Br J Sports Med* 2010; 44(5):319-327.

3. Niederbracht Y, Shim AL, Sloniger MA et al. Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. *J Strength Cond Res* 2008; 22(1):140-145.

4. Murray IR, Goudie EB, Petrigliano FA et al. Functional anatomy and biomechanics of shoulder stability in the athlete. *Clin Sports Med* 2013; 32(4):607-624.

5. Erol O, Ozcakar L, Celiker R. Shoulder rotator strength in patients with stage I-II subacromial impingement: relationship to pain, disability, and quality of life. *J Shoulder Elbow Surg* 2008; 17(6):893-897.

6. Leroux JL, Codine P, Thomas E et al. Isokinetic evaluation of rotational strength in normal shoulders and shoulders with impingement syndrome. *Clin Orthop Relat Res* 1994(304):108-115.

7. Rupp S, Berninger K, Hopf T. Shoulder problems in high level swimmers--impingement, anterior instability, muscular imbalance? *Int J Sports Med* 1995; 16(8):557-562.

8. Tyler TF, Nahow RC, Nicholas SJ et al. Quantifying shoulder rotation weakness in patients with shoulder impingement. *J Shoulder Elbow Surg* 2005; 14(6):570-574.

9. Wang HK, Cochrane T. Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. *J Sports Med Phys Fitness* 2001; 41(3):403-410.

10. Depalma MJ, Johnson EW. Detecting and treating shoulder impingement syndrome: the role of scapulothoracic dyskinesis. *The Physician and sportsmedicine* 2003; 31(7):25-32.

11. Liu J, Hughes RE, Smutz WP et al. Roles of deltoid and rotator cuff muscles in shoulder elevation. *Clin Biomech* 1997; 12(1):32-38.

12. Phadke V, Camargo P, Ludewig P. Scapular and rotator cuff muscle activity during arm elevation: A review of normal function and alterations with shoulder impingement. *Rev Bras Fisioter* 2009; 13(1):1-9.

13. Roy JS, Moffet H, Hebert LJ et al. Effect of motor control and strengthening exercises on shoulder function in persons with impingement syndrome: a single-subject study design. *Man Ther* 2009; 14(2):180-188.

14. Radaelli R, Bottaro M, Weber F et al. Influence of body position on shoulder rotator muscle strength during isokinetic assessment. *Isokinet Exerc Sci* 2010; 18(3):119-124.

15. Hill AM, Pramsanik S, McGregor AH. Isokinetic dynamometry in assessment of external and internal axial rotation strength of the shoulder: Comparison of two positions. *Isokinetic and Exercise Science* 2005; 13(3):187-195.

16. Hageman PA, Mason DK, Rydlund KW et al. Effects of position and speed on eccentric and concentric isokinetic testing of the shoulder rotators. *J Orthop Sports Phys Ther* 1989; 11(2):64-69.

17. Greenfield BH, Donatelli R, Wooden MJ et al. Isokinetic evaluation of shoulder rotational strength between the plane of scapula and the frontal plane. *Am J Sports Med* 1990; 18(2):124-128.

18. Dvir Z. *Isokinetics : muscle testing, interpretation and clinical applications,* 2nd ed, Edinburgh, Churchill Livingstone, 2004.

19. Manske RC, Davies GJ. Postrehabilitation outcomes of muscle power (torque acceleration energy) in patients with selected shoulder conditions. *J Sport Rehab* 2003; 12181-198.

20. Seitz AL, McClure PW, Lynch SS et al. Effects of scapular dyskinesis and scapular assistance test on subacromial space during static arm elevation. *J Shoulder Elbow Surg* 2012; 21(5):631-640.

21. Hall LC, Middlebrook EE, Dickerson CR. Analysis of the influence of rotator cuff impingements on upper limb kinematics in an elderly population during activities of daily living. *Clin Biomech* 2011; 26(6):579-584.

22. Yildiz Y, Aydin T, Sekir U et al. Shoulder terminal range eccentric antagonist/concentric agonist strength ratios in overhead athletes. *Scand J Med Sci Sports* 2006; 16(3):174-180.

23. Ludewig PM, Braman JP. Shoulder impingement: biomechanical considerations in rehabilitation. *Man Ther* 2011; 16(1):33-39.

24. Reinold MM, Wilk KE, Fleisig GS et al. Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. *J Orthop Sports Phys Ther* 2004; 34(7):385-394.

25. Holmgren T, Bjornsson Hallgren H, Oberg B et al. Effect of specific exercise strategy on need for surgery in patients with subacromial impingement syndrome: randomised controlled study. *BMJ* 2012; 344e787.

26. Forthomme B, Dvir Z, Crielaard JM et al. Isokinetic assessment of the shoulder rotators: a study of optimal test position. *Clin Physiol Funct Imaging* 2011; 31(3):227-232.

27. Moraes GFS, Faria CDCM, Teixeira-Salmela LF. Scapular muscle recruitment patterns and isokinetic strength ratios of the shoulder rotator muscles in individuals with and without impingement syndrome. *J Shoulder Elbow Surg* 2008; 17(1 Suppl):48S-53S.

28. Andrade MDS, Fleury AM, de Lira CAB et al. Profile of isokinetic eccentric-to-concentric strength ratios of shoulder rotator muscles in elite female team handball players. *J Sports Sci* 2010; 28(7):743-749.

**List of table**

**Table 1** – Results of the paired t-test of the concentric peak torque, eccentric peak torque and Dynamic Control Ratio (DCR) in relation to GHJ elevation (Mean ± Standard deviation)

|  |  |  |  |
| --- | --- | --- | --- |
|  | **20° Humeral elevation** | **60° Humeral elevation** | p |
|  | **Eccentric action of external rotator** | **Eccentric action of external rotator** |  |
| **Mean Peak-Torque (Nm-1)** | 37.87 ± 21.49 | 28.39 ± 11.01 | 0.002\* |
|  | **Concentric action of Internal rotator** | **Concentric action of internal rotator** |  |
| **Mean Peak-Torque (Nm-1)** | 56.50 ± 20.53 | 57.03 ± 24.35 | 0.716 |
| **DCR** | 0.64 ± 0.17 | 0.51 ± 0.08 | 0.000\* |

\*p < 0.05, significant difference between 20° and 60° of humeral elevation (paired t test)