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Authors	Fanning, Edel;Daniels, Katherine;Cools, Ann;Mullett, Hannan;Delaney, Ruth;Mcfadden, Ciaran;Falvey, Éanna
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Edel Fanning[1,2], Katherine Daniels[2], Ann Cools[3], Hannan Mullett[1], Ruth Delaney[1], Ciaran Mcfadden[1], and Eanna Falvey[4]

[1]Sports Surgery Clinic, Dublin, IRELAND; [2]Manchester Met University, Manchester, UNITED KINGDOM; [3]University of Gent, Gent, BELGIUM; [4]University College Cork, Cork, IRELAND

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Edel Fanning[1,2], Katherine Daniels[2], Ann Cools[3], Hannan Mullett[1], Ruth Delaney[1], Ciaran Mcfadden[1], and Eanna Falvey[4]

[1]Sports Surgery Clinic, Dublin, IRELAND; [2]Manchester Met University, Manchester, UNITED KINGDOM; [3]University of Gent, Gent, BELGIUM; [4]University College Cork, Cork, IRELAND

Address for Correspondence: Edel Fanning, Sports Surgery Clinic, Sports Medicine, Dublin, Ireland; E-mail: edelfanning@hotmail.com; Twitter: @edel_fanning; Phone: +35315262030/ +00353834423436

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ABSTRACT

Purpose: The primary aim was to identify and quantify differences in interlimb asymmetry magnitudes across a battery of upper extremity strength and performance tests at four and six months after glenohumeral-joint-stabilisation surgery shoulder stabilisation in contact and collision athletes compared to an un-injured group. A secondary aim was to investigate if identified asymmetry magnitudes changed from four months to six months post glenohumeral-joint-stabilisation. The third aim was to explore associations within the different performance and strength variables. **Methods:** Fifty-six male contact and collision sport athletes who had had undergone unilateral glenohumeral-joint-stabilisation were tested at 4 and 6 months post-surgery. An un-injured control group (n=39 for upper extremity performance tests, n= 47 for isokinetic dynamometry) were tested on a single occasion. Three upper extremity force platform-based performance tests and angle-specific concentric internal and external isokinetic shoulder rotational strength were assessed, and inter-limb asymmetries were compared between the two groups. **Results:** At four months post-surgery, the glenohumeral-joint-stabilisation group demonstrated significantly higher absolute interlimb asymmetry values than the un-injured group for almost all the performance test variables. In the ballistic upper-body performance tests, the glenohumeral-joint-stabilisation group achieved only half the body elevation reached by the un-injured (counter-movement push-up jump height ($\eta^2 = 0.50$) and press-jump jump height ($\eta^2 = 0.39$)). At 6 months post-surgery absolute inter-limb asymmetries reduced for the performance tests variables but some asymmetry persisted. The glenohumeral-joint-stabilisation group had significantly greater absolute inter-limb asymmetries for five out of the eight isokinetic variables. **Conclusions:** Contact and collision athletes who may be cleared to return to sport at four to six months after glenohumeral-joint-stabilisation surgery shoulder stabilisation continue to demonstrate upper limb strength and performance deficits when compared to their un-injured limb and to their un-injured counterparts.

Key Words: SHOULDER STABILISATION, CONTACT ATHLETES, ISOKINETIC STRENGTH, PERFORMANCE TEST

INTRODUCTION:

Traumatic glenohumeral joint dislocation is one of the most common shoulder injuries in athletes involved in collision and contact sports(1–3). These injuries can have a significant impact on an athlete’s ability to return to sport and can be particularly detrimental in the sporting career of an adolescent involved in collision sports(4, 5). Contact and collision sports (specifically rugby) have a higher rate of recurrent shoulder instability than other sports(6, 7). This is not surprising considering the physical demands experienced by collision and contact athletes in sports like rugby league, rugby union and American football. Players are often required to produce upper body force quickly in activities such as tackling, being tackled, handing-off and falling to the ground; in all cases withstanding large external forces(8). Despite the advances in shoulder stabilisation surgery, the relatively high recurrence rates of shoulder instability in this population (5.9% to 51%) and low success rate of athletes returning to their previous level of performance is concerning(6, 7).

Return-to-sport tests can provide important feedback regarding progress and restoration of functional capability after surgery and are often used to facilitate return to sport (RTS) decision making, particularly for lower-limb injuries(9).However, one of the challenges of ensuring safe RTS following shoulder surgery is the lack of functional testing and data regarding normal strength ratios and other measures for this cohort of athletes(9). Most work in this area to date has largely focused on overhead throwing athletes, who would be expected to present with substantially different strength and symmetry profiles(10, 11). Previous studies from our group have demonstrated good reliability for a series of upper extremity performance test parameters (the counter-movement push-up (CMPU), box drop landing (BDL) and press-jump (PJ)) assessed on a dual force plate system(12) and maximum angle-specific isokinetic shoulder rotational strength measures in a cohort of un-injured collision and contact athletes(13). However it is not known how these test metrics are affected after glenohumeral joint stabilisation (GHJS) surgery. Examining differences in limb symmetry between athletes who have had GHJS (consisting of anterior shoulder stabilisation surgery only) and a matched un-injured cohort may provide a more complete analysis of return to function after GHJS surgery and identify modifiable (trainable) variables of strength to be targeted during rehabilitation that may help clinicians better prepare athletes for RTS.

The primary aim of this study was to identify differences in magnitude of interlimb asymmetry in isokinetic variables and upper extremity performance tests at the key stages of 4 and 6 months post GHJS surgery, which span the typical range of RTS timepoints(14), in a population of collision and contact athletes compared to a un-injured group. Our secondary aim was to investigate if magnitude of asymmetry differed at 4 months and 6 months for the identified variables, in the post-operative group. The third aim was to assess if associations existed within the performance test variables and within the isokinetic strength variables. We hypothesised that contact and collision athletes, following GHJS shoulder stabilisation, would demonstrate upper limb strength and performance deficits compared to their un-injured limb or their un-injured counterparts at 4 and 6 months post-surgery.

METHODS

Design

This was a prospective cohort study with assessments at 4 and 6 months after GHJS surgery. Surgical participants were part of a longer-term longitudinal research project with physical testing at 4, 6 and 12 months postoperatively and via email at 2 and 5 year follow-up.

Participants

A power calculation (G*Power, version 3.1.9.2, Universität Düsseldorf) to answer the primary research question was carried out. This was based on a previous study examining isokinetic rotational peak torque (the current gold standard of strength analysis for the upper limb), in an injured group of rugby players against a control group(15). A total sample size of 86 individuals was calculated based on a significance level of 5%, a power of 0.8 and a meaningful clinical difference (MCD) of 8.1 Nm (left concentric internal peak torque difference).

This study looked at a cohort of athletes post GHJS surgery and an un-injured group. Male athletes, involved in contact or collision sports, who had had undergone unilateral anterior GHJS surgery were consecutively recruited prior to surgery from the caseload of two orthopaedic shoulder consultants at XXX between October 2019 and October 2022. Inclusion criteria were male, eligible to play adult sport and currently engaged in contact or collision sport. We defined collision athletes as athletes that purposely hit or collide with each other or with inanimate objects (e.g. rugby players) and contact athletes as athletes that routinely make contact with each other or with inanimate objects but with less force than in collision sports (e.g. basketball players)(16). We focused on male contact and collision athletes as they are a high-risk population for traumatic shoulder dislocations and up to four times more likely than females to sustain a further dislocation (17, 18). In addition, male athletes may present with different strength and power characteristics to female athletes (19). A convenience sample of athletes who were participating in competitive collision and/or contact sport locally, with no history of shoulder instability or upper limb surgery, meeting the same inclusion criteria as the GHJS athletes were recruited between March 2017 and December 2018. They acted as the un-injured control group (12). Participants gave informed written consent prior to testing and the study received ethical approval from Sports Surgery Clinic Hospital Ethics Committee.

Surgery

Athletes underwent an arthroscopic Bankart procedure, open Bankart procedure or a Latarjet procedure. Various factors influenced the decision around the choice of surgical procedure, including surgeon and patient preference, bone loss, humeral avulsion of the glenohumeral ligament, age, and sports participation(20, 21).

Post operative rehabilitation

Patients were given a post-operative physiotherapy protocol by their surgeon and were rehabilitated under the guidance of their physiotherapist. In the early stages (post-surgery), athletes were placed in a sling for 3-4 weeks, while allowing non-resisted exercise and activities of daily living without excessive elevation or external rotation of the shoulder. In the intermediate phase (4-12 weeks) emphasis was put on achieving full range of motion, optimising timely recruitment, endurance and strength of the deep stabilising muscles of the shoulder and building overall upper and lower body strength. The final (late /RTS phase) (12 weeks +), involved re-introducing graded return of exercises required for the athlete's game, e.g., ball skills, contact skills, and drop and landing drills and sport-specific training. The timing of RTS was a multifactorial decision made between the athlete, surgeon, physiotherapist and coaching team. (See Supplemental Digital Content, Rehabilitation guidelines post anterior shoulder stabilisation, http://links.lww.com/MSS/C905.)

Testing procedures

The testing took place at the biomechanics laboratory at the XXX. Mean time post-surgery was 17±2 weeks (4 months post-GHJS assessment) and 29±1 weeks (6 months post-GHJS). The un-injured cohort were tested on a single occasion(12, 13).

Before each testing session, all participants completed a standardised warm-up comprising two minutes of jogging, five body-weight squats and 20 shoulder internal and external rotations against light resistance at 90° abduction. Participants first executed the three upper-extremity performance tests, the counter-movement push-up (CMPU), box drop landing (BDL) and press-jump (PJ). We attached a 14mm retro-reflective marker to the skin over the 7th cervical vertebra (C7). We used a 10-camera optical motion analysis system (200 Hz; Bonita B10, Vicon, UK) to track the position of the C7 marker during testing. This was synchronised with two 400×600 mm force platforms (1000 Hz; BP400600, AMTI, USA) to collect vertical ground reaction force (vGRF) data during the performance tests in line with a previously published protocol(12).

For the CMPU, participants began in a push-up position with arms fully extended, one hand on each force plate, 90° shoulder flexion, legs, and torso straight and feet together. The participant was cued to use a counter-movement and explode away from the ground as quickly as possible, taking off with the elbows fully extended. The starting position for the PJ was identical to CMPU. Participants then lowered their body to a press-up base position and held the position stationary for 1-2 seconds and cued to explode away from the ground as quickly as possible, taking off with the elbows fully extended. The starting position for BDL was again as per CMPU except that the hands were placed on 20 cm raised boxes positioned 65 cm apart, lateral to the landing position. The participant was cued to simultaneously drop off the box with both arms and decelerate themselves as quickly as possible when they landed on the force plates, returning to a push-up position with elbows fully extended and holding for two seconds before relaxing. For data collection two familiarization trials were carried out followed by three trials of the CMPU, PJ and BDL. Bilateral ground reaction forces were recorded at 1000 Hz.

Participants then performed concentric shoulder internal rotation (IR) and external rotation (ER) isokinetic strength testing at 90°/s (Cybex Humac NORM, Computer Sports Medicine, Inc., Soughton, MA, USA). Participants required 90° of passive ER and 60° of passive IR measured with a goniometer, in the supine position with the arm at 90° abduction, for the isokinetic rotational strength testing protocol. Any participant who did not have the required range of motion was excluded from this component of the study.Participants performed a 5-repetition familiarisation set of concentric-concentric external and internal rotation at 90°/s followed by a 60 second rest period. They then preformed 2 sets of 5 maximal repetitions with a

60 second rest period between sets(13). The GHJS limb and the non-dominant limb (dominance defined by the preferred throwing arm) was assessed first for the GHJS and the un-injured group, respectively. The GHJS limb was tested first to ensure the patient was comfortable testing in the set range (90° of passive ER and 60° of passive IR) on the isokinetic machine before comparing to the non-injured limb.

Data processing

Data was processed for the upper-extremity performance tests and isokinetic dynamometry as described in previous studies of the un-injured group (12, 13).

The outcome measures for the GHJS group were absolute asymmetry index (AAI) and asymmetry index (AI) for the following variables: CMPU (jump height (C7 peak vertical displacement during ballistic phase of movement); take-off peak force; landing peak force; take-off eccentric deceleration phase impulse; take-off concentric impulse; landing impulse); PJ (jump height; take-off peak force; take-off concentric impulse) DBL (landing peak force; landing impulse); ER peak torque; ER torque at joint angle 0°(ER0°) ; ER torque at the internally rotated position of 50° (ER50°) , ER torque at the externally rotated position of 80° (ER80°), IR peak torque, IR torque at joint angle 0° (IR0°) ; IR torque at the internally rotated position of 50° (IR50°) and IR torque at the externally rotated position of 80° (IR80°) . All force, impulse and isokinetic variables were divided by body mass before analysis. Jump height, force and impulse variables were extracted from the working set with the highest CMPU jump height. Shoulder rotational torques were extracted from the working set with the highest peak ER torque.

AAI and AI were calculated as:

$$AbsAsymmetry\ Index = (1 - \frac{Minimum\ of\ Dominant\ and\ Nondominant\ limb}{Maximum\ of\ Dominant\ and\ Nondominant\ limb}) \times 100$$

$$Asymmetry\ Index = (\frac{Uninjured\ minus\ GHJS\ limb}{Maximum\ of\ Uninjured\ and\ GHJS\ limb}) \times 100$$

AAI was used in all between-group comparisons to remove direction from the calculation, as the reference value used in un-injured group is arbitrary but affects the results of group comparisons(23). AI was used for within group comparisons in order to preserve information regarding the direction of the asymmetry. A positive AI indicated that the value of the parameter was greater for the un-injured limb, and a negative AI indicated that the value of the parameter was greater for the GHJS limb.

Statistical analysis

Histograms were used to examine data distribution and all dependent variables were tested for normal distribution and homogeneity of variance using the one-sample Kolmogorov–Smirnov test and Levene's test. Parametric models were used when no evidence of deviation from normality and homogeneity of variance was identified, otherwise non-parametric models were used to compare the groups. Mann-Whitney U tests were used for between-group comparisons. Paired t-tests were used for within-group comparisons. Eta squared (η^2 = ((Z/square root (N))^2) was used to quantify effect size for non-parametric tests and interpreted as $\eta^2 > 0.01$ = small; $\eta^2 > 0.06$ = moderate; $\eta^2 > 0.14$ = large(24). Cohen's d effect size (d=(mean

1)−(mean 2)/standard deviation) was used to quantify effect size for parametric tests and interpreted as d > 0.2 = small; d >0.5= moderate; d >0.8 = large(24). Pearson's product-moment correlation coefficients (r) and associated *p* values were used to assess associations within the performance test variables and within the isokinetic variables. Statistical significance was accepted at an alpha level of 0.05. Summary statistics are reported as mean ± standard deviation (SD). All statistical analyses were performed using IBM SPSS 2020 version 26 for Mac (IBM Inc).

RESULTS

Fifty-six male contact and collision athletes were recruited into the GHJS group. In the un-injured control group 39 athletes were recruited for the upper extremity performance tests and 47 for the isokinetic dynamometry (the performance test group was a subset of the isokinetic group) (12). Baseline player anthropometric characteristics are outlined in table 1. The GHJS group were on average slightly younger, taller and heavier than the un-injured group (Table 1).

GHJS group *vs* un-injured group

The un-injured group achieved on average 10.7cm (SD=3.5) body elevation on the CMPU and 9cm (SD=3.8) on the PJ. At 4 months the GHJS group on average achieved 5.1cm (SD=2.6) body elevation on the CMPU and 4.3cm (SD=2.2) on the PJ and at 6 months they achieved 6.6cm (SD=3.2) body elevation on the CMPU and 5.2cm (SD=3.0) on the PJ. Mean absolute asymmetry values of the performance test variables for the un-injured group and the GHJS group as 4 and 6 months post-surgery are illustrated in Figure 1.

At 4 months post-surgery, absolute asymmetry of the vertical ground reaction forces and impulse variables were significantly greater in the GHJS group than in the un-injured group. . In the ballistic upper-body performance tests, the GHJS group achieved only half the body elevation reached by the un-injured (CMPU jump height (η2 = 0.50) and PJ jump height ((η2 = 0.39)), with these variables revealing the largest between group differences and effect sizes across all the variables (Table 2). By 6 months post-surgery, effect sizes had reduced from small to moderate for all performance test variables except for CMPU jump height (η2 = 0.30) and PJ take-off concentric impulse (η2 = 0.18), which both still demonstrated large effect sizes (Table 2). For the BDL there were significant inter-limb asymmetry differences between groups on landing peak force and landing impulse at 4 months. At 6 months post-surgery only the landing impulse variable remained significant between groups, with a moderate effect size (Table 2).

At 4 months post-surgery just over half of the group (n=30) achieved the range (90° ER to 60° IR at 90° abduction) to carry out the isokinetic rotational strength assessment. Therefore, no comparisons for the isokinetic variables were made to the GHJS group at this time point. At 6 months 51 participants achieved the range for the isokinetic rotational strength assessment protocol. Mean absolute asymmetry values of the isokinetic variables for the un-injured group and the GHJS group at 6 months post-surgery are presented in Figure 2. Absolute inter-limb asymmetry values for the isokinetic variables were significantly higher for the GHJS group for ER50° ($\eta^2 = 0.09$), IR peak torque ($\eta^2 = 0.07$), ER80° ($\eta^2 = 0.06$), IR80° ($\eta^2 = 0.06$) and IR0° ($\eta^2 = 0.06$) at this time point (Table 3).

4 months *vs* 6 months post-GHJS

We found significantly higher interlimb asymmetry values at 4 months post-surgery than at 6 months post-surgery for PJ take-off peak force (d = 0.53), CMPU take-off peak force (d = 0.47), CMPU take-off eccentric deceleration phase impulse (d = 0.43), PJ take-off concentric impulse (d = 0.42) and BDL landing impulse (d= 0.28) (Table 4). There was also a significant difference for CMPU jump height, with athletes on average jumping 1.5 cm higher at 6 months post-surgery. However, there was no significant difference between 4 and 6 months for PJ jump height (d = - 0.02) (Table 4).

Correlation between performance test variables and between isokinetic strength test variables

Correlations were carried out at 6 months rather than 4 months due to limited end range rotational range which excluded just under half of the GHJS cohort for isokinetic testing. Among the performance variables, at 6 months post GHJS, there were statistically significant large positive correlations between CMPU and PJ jump height (r =.85, p <.001); PJ take-off peak force and PJ take-off concentric impulse (r =.85, p <.001); CMPU take-off eccentric deceleration phase impulse and CMPU take-off peak force (r=.81, p <.001); CMPU take-off peak force and PJ take-off peak force (r =.79, p, <.001) and CMPU take-off peak force and PJ take-off concentric impulse (r =.74, p, <.001) 6 months post-GHJS. There was moderate correlations between CMPU take-off eccentric deceleration phase impulse and PJ take-off peak force (r =.58, p, <.001); CMPU take-off eccentric deceleration phase impulse and PJ take-off concentric impulse (r =.58, p, <.001); CMPU take-off concentric impulse and PJ take-off peak force (r =.51, p, <.001); CMPU landing peak force and BDL landing peak force (r =.47, p, <.001); CMPU landing peak force and BDL landing impulse (r =.42, p, <.001); CMPU take-off concentric impulse and PJ take-off peak force (r =.39, p, <.01); CMPU take-off concentric impulse and BDL landing impulse (r =.39, p, <.01); CMPU take-off eccentric deceleration phase impulse and CMPU take-off concentric impulse (r =.32, p, <.05) and BDL landing peak force and BDL landing impulse (r =.31, p, <.05). Finally there was a weak correlation between CMPU take-off peak force and CMPU take-off concentric impulse (r =.28, p, <.05).

At 6 months post-surgery, for the external rotation variables there was a statistically significant large positive correlation between ER50° and ER peak torque (r =.80, p <.001); a moderate correlation between ER0° and ER peak torque (r =.60, p <.001) and weak correlations between ER50° and ER0° (r =.33, p <..05) and ER80° and ER0° (r =.28, p <..05). There was no significant correlation between ER80° and ER peak torque (r =.27, p= .06) or ER80° and ER50° (r =.27, p= .06). For the internal rotation variables there was a strong correlation between IR0° and IR peak torque (r =.83, p <.001) and IR80° and IR peak torque (r =.70, p <.001). There was moderate correlations between IR0° and IR80° (r =.58, p <.001); IR50° and IR0° (r =.40, p ≤ 0.01) and IR50° and IR peak torque (r =.36, p ≤ 0.01) and a weak correlation between IR50° and IR80° (r =.29, p ≤ 0.05).

DISCUSSION

There are enduring deficits across rotational strength and performance variables in contact and collision athletes post GHJS at the normal time range for return to sport (4-6 months). The largest deficits identified overall were for the performance test variables and the largest effect sizes were for variables related to take-off rather than landing. This suggests the importance of including explosive upper extremity performance tests when designing RTS testing batteries for this cohort. Lack of normal end rotational range of motion remained an issue for just under half the GHJS group at 4 months post-surgery, limiting isokinetic strength comparisons to the un-injured group at this time point. At 6 months post-surgery, isokinetic end ranges revealed greater deficits than peak torque for ER. Measuring peak torque alone may overestimate rehab status and it is important to look at end ranges for a comprehensive picture of the shoulder rotational torque-producing muscles.

Contact and collision athletes need power and stability to safely execute dynamic activity such as tackling an opponent with an abducted arm. Advances in surgery and an increasing trend for the use of bony reconstruction procedures such as the Latarjet procedure, favoured due to reported lower recurrence rate and higher return to sport rates in high demand athletes, can result in athletes returning to sport earlier post GHJS(25). This study shows that the largest deficits identified overall were for the upper extremity performance test variables. Athletes did not generate force equally on both limbs during the ballistic tests and could not generate the same upper-extremity explosive power and body elevation reached by the un-injured athletes, even at 6 months post- surgery when many athletes will have returned to sport(14). 25% of the athletes in this study had returned to full competition in their previous contact and collision sport by 6 months, 67% by 9 months and 73% by 12 months. 13% had not returned by 12 months. A further 14% of athletes cited current government covid-19 restrictions as to why they had not returned to their sport 6 months after surgery. These findings suggest that male contact and collision athletes are not fully rehabilitated by the time they commonly return to sport post GHJS, with inter limb differences on upper extremity performance tests present at 4 and 6 months. This could have implications on athletic performance.

The take-off variables may be of key interest in this battery of upper extremity performance tests. The largest effect sizes for the performance test variables were related to take-off (jump height, take-off concentric impulse, take-off eccentric deceleration impulse and take-off peak force) compared to the landing variables. Rehabilitation interventions should target limb symmetry during the concentric and eccentric phases of take-off on the ballistic upper extremity performance tests to improve outcomes.

Correlations amongst the performance test variables were carried out to help identify redundant information across the performance tests variables and further aid clinical utility of the tests. On the CMPU, take-off peak force strongly correlated with take-off eccentric deceleration phase impulse but only weakly correlated with take-off concentric impulse. Therefore take-off eccentric deceleration phase impulse (or take-off peak force) along with take-off concentric impulse and jump height may give clinicians sufficient information when assessing a CMPU on a set of dual force plates. For the PJ take-off peak force strongly correlated with take-off concentric impulse implying take-off concentric impulse (or take-off peak force) alongside jump height which may be adequate to assess on a PJ. For the BDL landing impulse correlated with landing peak force. However only landing impulse remained significantly different to the un-injured group at 6 months. Impulse, a measure of how force is applied over time, may be of greater interest in investigating landing asymmetries than peak force(26).

Rotational strength remains an important competent to assess. Previous studies have shown a relationship between the loss of isokinetic rotational muscle strength and recurrent instability in the non-operative shoulder instability suggesting the importance of restoring optimal rotational strength post-surgery(27). In this study, just under half of the GHJS group lacked normal end rotational range to carry out the isokinetic rotational strength protocol at 4 months post-surgery. A recent consensus paper on return to sport for athletes post shoulder injury suggested that restoring range of motion may be a lower priority for contact and collision athletes (particularly sports played below shoulder height)(28). However many contact and collision sports will involve reaching above the head to gather possession of the ball or falling on an outstretched hand (e.g. the try scoring position in rugby). In this study the majority of athletes had achieved the range for the shoulder rotational range of 90° ER to 60° IR (at 90° abduction) by 6 months post-surgery compared to 4 months post-surgery, suggesting range improves with a longer time frame.

Rotational strength recovery has been evaluated in some studies post GHJS, but only peak torque has been examined(29). We found that absolute interlimb asymmetries were significantly higher for the GHJS group at the outer and inner ranges of ER (ER50° and ER80°) at 6 months post-surgery, with the largest effect size for ER50°. ER peak torque (or ER0°) interlimb asymmetries did not quite reach significance between groups. For internal rotation, the post-surgical group demonstrated greater absolute interlimb asymmetries compared to the un-injured group for IR peak torque, IR80° and IR0°, with IR peak torque demonstrating the greatest magnitude of difference amongst the internal rotational strength variables. These findings suggest that peak torque may be adequate for assessing IR strength, however for assessing ER strength end range deficits can be missed if only ER peak torque is examined. The results emphasise the need for targeted rotational strength development post GHJS particularly in the end ranges of ER.

Correlations between the ER variables highlighted moderate to strong correlations between ER peak torque and ER0° and ER50° however there was no significant correlation between ER peak torque and ER80°. IR peak torque strongly correlated with IR80° and IR0°, with no significant correlation with IR50°. This provides further evidence for the importance of assessing rotation at end range not just assessing the traditional mode of analysis of peak torque alone.

Multiple previous studies demonstrate high recurrence rates of re-injury following GHJS, particularly in young contact and collision athletes who have undergone arthroscopic repair(6, 7). It may therefore be increasingly important for practitioners to target these modifiable strength and performance deficits. Conventional resistance training and rehabilitation programmes may not sufficiently enhance explosive strength. Incorporating periodised resistance training programmes to address this may be required. Our findings are not dissimilar to studies identifying strength and power deficits at 6 months post anterior cruciate ligament repair, with some studies showing a relationship between decreased strength and risk of knee re-injury(30, 31).

This is the first study to examine jump height, vertical ground reaction forces and impulses the CMPU, PJ and BDL and isokinetic angle-specific rotational torque post GHJS. We focused on male contact and collision athletes, who are a high-risk population for traumatic shoulder dislocations and re-injury(7). Comparisons across different sporting groups may be limited because these groups are often profoundly different with varying sporting demands. The findings may not be generalisable to the female athlete, and specific considerations are needed for the female athlete and the female sporting environment(32). Future studies should aim to establish more normative values for each sex and activity level. We included three stabilisation procedures; arthroscopic bankart repair, open latarjet, and open bankart repair. As this study was primarily concerned with RTS criteria and outcomes, we chose the boarder definition of anterior GHJS in the inclusion criteria. However, it adds heterogeneity to the post-surgical group and may affect the clinical application of the results. Although we provided a post-surgery physiotherapy protocol for participants, we not did not fully monitor the rehabilitation pathway or compliance of athletes, which may be a confounding variable for the GHJS group results. The purpose of this paper was to characterise the progression of athletes in the early to mid-phases (first 6 months) following GHJS. As we don't present data beyond 6 months, we are unable to draw conclusions on the longer term outcomes of the athletes. There was a time difference between collecting data from the un-injured group and the GHJS group which could affect results. However the protocol was well established before we started data collection and we report interlimb asymmetries which limits the impact of a testing cohort effect on the study's findings. We performed multiple comparisons. We could have used a multiple comparisons correction such as a Bonferroni correction to reduce the type 1 error. However, as type I error decreases, the chance of type II errors increases. Instead, we used P Values in conjunction with effect sizes to support our conclusions and handled differences with weak effect sizes with care.

CONCLUSIONS

At 4 and 6 months post GHJS, male contact-and-collision athletes demonstrate significant isokinetic rotational strength and power deficits detectable on upper extremity performance tests compared to an un-injured group. Differences reduced between 4 and 6 months post-surgery, however did not completely disappear, suggesting athletes are not fully rehabilitated at these time points, despite most athletes having returned to sport by then. Clinicians should be aware that strength deficits exist at these time points post GHJS, particularly explosive strength as demonstrated on the upper extremity performance tests, which to our knowledge has not been investigated previously**.** Future studies should corelate strength and performance tests to patient reported outcomes, psychological measures, return to sport and performance and rates of re-injury.

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Conflicts-of-interest

None declared. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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FIGURE LEGENDS

Figure 1: Mean Absolute Asymmetry Values of the Performance Test Variables for the Un-Injured Group and the Glenohumeral Joint Stabilisation Group at 4 and 6 Months

AAI, Absolute Asymmetry Index; SD, standard deviation

*Indicates a statistically significant difference (p <.001) in the average absolute asymmetry values of the performance test variables at 4 and 6 months post-surgery compared to the un-injured group

Figure 2: Mean Absolute Asymmetry Values for the Isokinetic Variables of the Un-Injured Group and the Glenohumeral Joint Stabilisation Group at 6 months

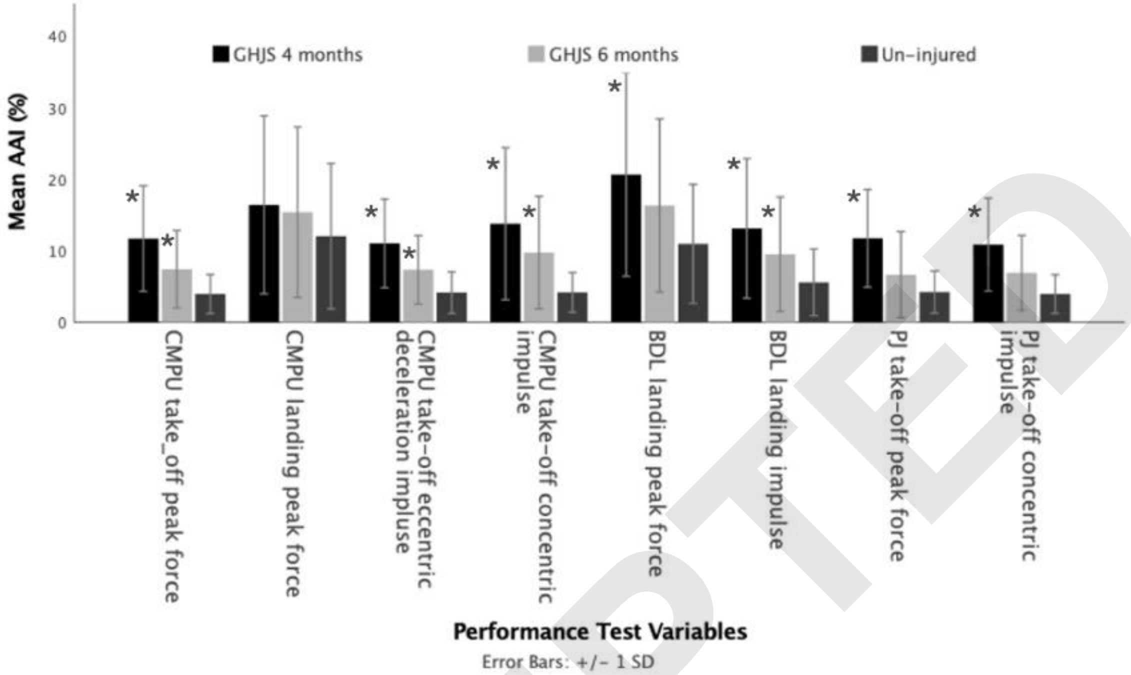
AAI, Absolute Asymmetry Index; ER, external rotation; IR, internal rotation; ER0°, ER torque at joint angle; ER50°, ER torque at the internally rotated position of 50°; ER80°, ER torque at the externally rotated position of 80°; IR0°, IR torque at joint angle 0°; IR50°, IR torque at the internally rotated position of 50° ; IR80°, IR torque at the externally rotated position of 80°; SD, standard deviation

*Indicates a statistically significant difference (p <.001) in the average absolute asymmetry values of the isokinetic variables at 6 months post-surgery compared to the un-injured group

SUPPLEMENTAL DIGITAL CONTENT

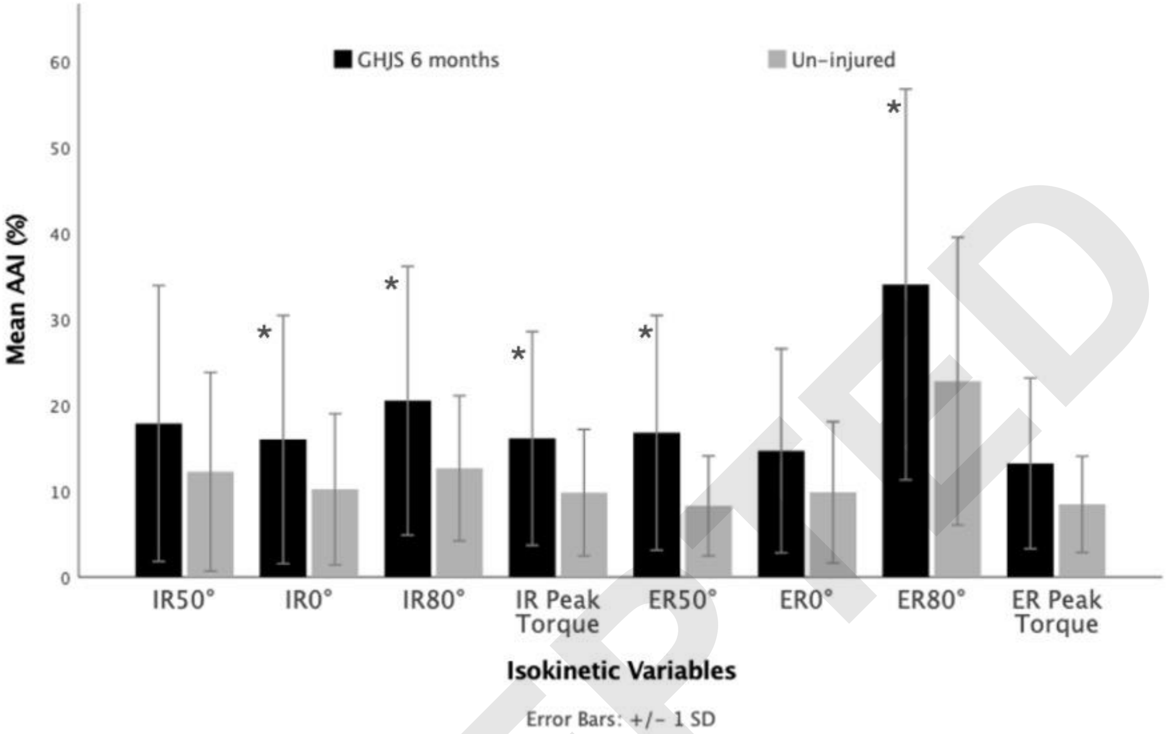
SDC 1: Rehabilitation guidelines.docx

Figure 1



40
30
20
10
0
Mean AAI (%)
GHJS 4 months
GHJS 6 months
Un–injured
*
CMPU take_off peak force
CMPU landing peak force
CMPU take–off eccentric deceleration impluse
CMPU take–off concentric impulse
BDL landing peak force
BDL landing impulse
PJ take–off peak force
PJ take–off concentric impulse
Performance Test Variables
Error Bars: +/– 1 SD

Figure 2



■ GHJS 6 months
■ Un-injured
Mean AAI (%)
0
10
20
30
40
50
60
*
*
*
*
*
IR50°
IR0°
IR80°
IR Peak Torque
ER50°
ER0°
ER80°
ER Peak Torque
Isokinetic Variables
Error Bars: +/- 1 SD

Table 1 Baseline characteristics of the study groups

	GHJS	Un-injured (performance jumps)	Un-injured (isokinetics)
n	56	39	47
Age (years)	23.5±4.3	27.6±5.8	27.3±5.4
Height (cm)	185.6±6.2	179.6±26.6	175.9±24.3
Weight (kg)	91.0±16.56	85.7±12.2	85.5±11.4
Sport			
%Gaelic Football	43%	38%	36%
%Rugby	32%	33%	34%
%Soccer	9%	13%	13%
% Mixed Martial Arts	2%	8%	7%
%Hurling	11%	3%	2%
%Basketball	0%	3%	7%
%Multiple	3%	2%	2%
Dominance			
%Right	90%	82%	85%
%Left	10%	18%	15%
Dominant limb affected			
%Yes	50%	-	-
%No	50%	-	-
Surgery			
Arthroscopic Bankart Repair	34%	-	-
Open Latarjet	59%	-	-
Open Bankart Repair	7%	-	-

* Mean & standard deviations are reported for age, height and weight

Table 2: Mann–Whitney U test comparing performance variables at 4 and 6 months post-surgical glenohumeral joint stabilisation with an un-injured group. All measures indicate absolute asymmetry index except jump height which is an absolute measure.

Measures	Testing time post-surgery	Mean rank			
		GHJS	Un-injured	P	η^2
Counter Movement Push Up **n=39 (Un-injured) n=56 (post-surgery)**					
Jump Height (cm)	4 months	31.8	71.3	***<.001	0.5
	6 months	35.5	66.0	***<.001	0.3
Take-off peak force AAI	4 months	59.9	30.9	***<.001	0.27
	6 months	55.6	37.1	***0.001	0.11
Landing Peak force AAI	4 months	51.8	42.6	0.112	0.03
	6 months	51.0	43.8	0.212	0.02
Take-off Eccentric Deceleration Phase Impulse AAI	4 months	61.0	29.4	***<.001	0.32
	6 months	56.0	36.6	***<.001	0.12
Take-off Concentric Impulse AAI	4 months	61.1	29.1	***<.001	0.33
	6 months	57.6	34.2	***<.001	0.18
Press Jump **n=34 (Un-injured) n=56 (post-surgery)**					
Jump Height (cm)	4 months	37.8	66.6	***<.001	0.39
	6 months	40.0	59.4	***<.001	0.13
Take-off peak force AAI	4 months	57.6	25.7	***<.001	0.35
	6 months	49.1	39.5	0.09	0.03
Take-off Concentric Impulse AAI	4 months	57.2	26.2	***<.001	0.33
	6 months	51.5	35.6	**0.005	0.09
Box Drop Land **n=39 (Un-injured) n=56 (post-surgery)**					
Landing Peak force AAI	4 months	57.1	34.9	***<.001	0.16
	6 months	53.4	40.2	0.021	0.06
Landing Impulse AAI	4 months	57.8	34.4	***<.001	0.17
	6 months	54.3	39.0	**0.008	0.07

AAI, Absolute Asymmetry Index; AX, assessment; SD, standard deviation; η^2 *eta squared*

*Significant difference between un-injured and GHJS at $P \leq 0.05$.
**Significant difference between un-injured and GHJS at $P \leq 0.01$.
*** Significant difference between un-injured and GHJS at $P \leq 0.001$.
† 4 months /6 months mean rank are based on the assessment of the comparison of GHJS 4 months and the un-injured and GHJS 6 months and the un-injured group

Table 3: Mann–Whitney U test comparing isokinetic variables at GHJS 6 months post-surgery with an un-injured group. All measures indicate absolute asymmetry.

Measures	Mean rank		P	*η2*
	GHJS 6 months (n=52)	Un-injured (n=47)		
ER Peak Torque AAI	55.4	44.1	0.051	0.04
ER80° AAI	56.6	42.7	*0.016	0.06
ER0° AAI	54.9	44.6	0.075	0.03
ER50° AAI	57.9	41.2	**0.004	0.09
IR Peak Torque AAI	57.2	42.0	**0.009	0.07
IR80° AAI	56.4	43.0	*0.021	0.06
IR0° AAI	56.4	43.0	*0.02	0.06
IR50° AAI	54.5	45.0	0.101	0.03

AAI, Absolute Asymmetry Index;ER, external rotation; IR, internal rotation; ER0°, ER torque at joint angle; ER50°, ER torque at the internally rotated position of 50°; ER80°, ER torque at the externally rotated position of 80°; IR0°, IR torque at joint angle 0°; IR50°, IR torque at the internally rotated position of 50° ; IR80°, IR torque at the externally rotated position of 80°

*Significant difference between un-injured and GHJS at P ≤ 0.05.

**Significant difference between un-injured and GHJS at P ≤ 0.01.

*** Significant difference between un-injured and GHJS at P ≤ 0.001.

Table 4. Paired t test comparing performance test variables at 4 and 6 months post-surgical glenohumeral joint stabilisation. All measures indicate asymmetry index except jump height which is an absolute measure.

Measures	Mean +/- SD		Mean difference (95% CI)	P	*d*
	GHJS 4 months (n=56)	GHJS 6 months (n=56)			
Counter Movement Push Up					
Jump Height (cm)	5.1 +/- 2.6	6.56 +/- 3.2	-1.6 (-2.5,0.6)	**0.003	-0.42
Take-off peak force AI	11.2 +/- 8.4	7.0 +/ - 5.9	4.2 (1.8,6.5)	***<.001	0.47
Landing Peak force AI	7.4 +/-19.2	6.56 +/- 18.4	1.0 (-5.3,7.3)	0.755	0.04
Take-off Eccentric Deceleration Phase Impulse AI	10.1 +/- 7.8	6.4 +/- 5.9	3.7 (1.4,6.0)	**0.002	0.43
Take-off Concentric Impulse AI	10.9+/- 13.7	6.56 +/- 15.0	4.4 (0.3,10.6)	0.128	4.85
Press Jump					
Jump Height (cm)	4.3 +/- 2.2	6.1 +/- 6.6	-1.8 (-3.7,0.1)	0.061	-0.02
Take-off peak force AI	10.5 +/- 8.5	5.9 +/- 6.4	4.6 (2.3,7.0)	***<.001	0.53
Take-off Concentric Impulse AI	9.6 +/- 8.3	5.9 +/- 6.4	3.7 (1.4,6.1)	**0.003	0.42
Box Drop Land					
Landing Peak force AI	9.8 +/- 22.9	6.8 +/- 19.2	3.0 (-3.7,9.8)	0.371	0.12
Landing Impulse AI	9.2 +/- 13.3	5.0 +/- 11.4	4.2 (0.1,0.8)	*.043	0.28

AI, Asymmetry Index

*Significant difference between un-injured and GHJS at P ≤ 0.05.

**Significant difference between un-injured and GHJS at P ≤ 0.01.

*** Significant difference between un-injured and GHJS at P ≤ 0.001.

Rehabilitation guidelines post anterior shoulder stabilisation

Early phase (Weeks 0-4)

- The sling is worn for 3-4 weeks to relieve pain and to protect the repair. In patients who present with high pain levels and, or lack neutral rotation at 2 weeks post-surgery, it is important to remove the sling at this stage.
- It is important to be aware to the ‘safe zone’ from the post-operative notes. The ‘safe zone’ positions are areas in space where it is safe to move the surgical arm, preventing significant stress on the surgical repair or injury. Generally, this is movement anterior to the scapula plane below 120 degrees of elevation.
- Avoid combined abduction and external rotation
- Avoid forced end range mobilization especially external rotation with arm in neutral.
- Elbow/wrist/hand range of motion and grip strengthening
- Begin shoulder active assisted / active supported range of motion (do not force any painful motion) within the safe zone.
- Rotator cuff / scapula muscle facilitation exercises. Note that the patient requires adequate rotational range of motion before introducing active, through range cuff facilitation work above 90.
- Closed kinetic chain work within the safe zone

Intermediate phase (Weeks 4-10)

- Avoid passive stretching into combined abduction / external rotation. Can encourage active movement into this position provided the patient demonstrates good control and does not report apprehension.
- Progress cuff and scapula recruitment through range
- Incorporate kinetic chain
- Dynamic rhythmical stabilisation for cuff and scapula

Late phase (Weeks 10-16)

- Regain range of motion into combined positions
- Dynamic rhythmical stabilisation drills in risk positions
- Functional specific strengthening, power and endurance exercises
- Functional specific kinetic chain strength and endurance

Overhead activity / return to sport (Months 4+)

- Maintain range
- Continue progression of upper and lower body strength and power
- Re-introduce graded return of exercises required for the athlete's game, e.g. ball skills, contact skills, and drop and landing drills