ORIGINAL ARTICLE

Absence of bilateral differences in child baseball players with throwing-related pain

MANTAS MICKEVIČIUS[1], SAULIUS RUTKAUSKAS[2], SAULĖ SIPAVIČIENĖ[1], ALBERTAS SKURVYDAS[1], JAAK JÜRIMÄE[3], HANS DEGENS[1,4], SIGITAS KAMANDULIS[1]

[1]*Institute of Sports Science and Innovation, Lithuanian Sports University, Kaunas, Lithuania*

[2]*Department of Laboratory Medicine, Medical Academy, Lithuanian University of Health Sciences, Kaunas, Lithuania*

[3]*Institute of Sport Pedagogy and Coaching Sciences, University of Tartu, Tartu, Estonia*

[4]*Division of Health Science, Manchester Metropolitan University, Manchester, United Kingdom*

Correspondence: Mantas Mickevičius, Institute of Sport Science and Innovations, Lithuanian Sports University, Sporto 6, LT-44221 Kaunas, Lithuania. Phone: +370 37 302 621. E-mail: mantas.mickevicius@lsu.lt

ORIGINAL ARTICLE

Absence of bilateral differences in child baseball players with throwing-related pain

Abstract

The aim of this study was to assess whether side-to-side differences in morphology and function of the upper limbs in 11–12-year-old male baseball players with throwing-related pain (n =14) were more pronounced than that of age-matched healthy untrained subjects (n =16). Baseball players 1) had played baseball ≥ 4.5 h·wk^{-1} for ≥ 4 years and (2) suffered from moderate-intensity (3 to 6 points on 10-point questionnaire scale) throwing-related pain in the shoulder or elbow in at least two training sessions within the past month. The range of motion (ROM), function and structure of the elbows and shoulders were assessed using goniometry, isokinetic dynamometry and ultrasonography. While the ROM and eccentric external peak torque of internal shoulder rotation were lower, the thickness of the supraspinatus tendon, the ulnar collateral ligament and articular cartilage of the humeral head were larger in baseball players than controls. There were, however, no significant side-to-side differences in any parameter in either group. In conclusion, it is unlikely that side-to-side differences in shoulder and upper limb structure and function contributed to the throwing-related pain in young baseball players, but low shoulder eccentric external peak torque and range of internal rotation may predispose to throwing-related pain.

Introduction

During pitching in baseball, the upper body muscles of the dominant side generate much higher forces and angular velocities than the non-dominant side [11]. Such asymmetrical exercise can cause functional imbalance, resulting over time in side-to-side differences of individual muscle groups, tendons and ligaments [4]. For instance, it is has been shown that external rotators of the pitching arm were weaker while internal rotators and middle and lower trapezius muscles were stronger than these of the non-pitching arm [8]. In addition to this, numerous studies have demonstrated an increase in glenohumeral external rotation and a decrease in the internal rotation range of motion (ROM) for the throwing shoulder compared with the opposite side [2,4,8,34]. Such functional imbalance may not only cause microtraumatic stress in the shoulder, but also in the elbow during a high-velocity baseball throw [29,34].

Child baseball players are especially vulnerable to injury and diagnoses as little leaguer's shoulder, little leaguer's elbow, osteochondritis dissecans of the elbow, tennis elbow and distal radial epiphysitis [5] in youth players can be as high as 50% during the course of the baseball season [20,21]. Approximately 13% of all ulnar collateral ligament reconstructions are performed in high-school-age players [27]. Such injury rates may be the consequence of skeletal immaturity combined with relatively poor technique, and a lack of strength that potentially increases the stress on the upper limbs [10,20,32]. In addition to these factors, problems could arise from side-to-side differences in muscle and bone structure and function, though most of such evidence comes from studies on adults [4,6,24]. Bilateral differences in strength and flexibility are linked to failure to stabilize during throwing and may increase the risk for upper body injuries in college and professional level men [24,33]. In addition, a reduction in range of motion was potentially associated with shoulder ossceus and capsular adaptation in professional baseball players [29]. However, alterations in motion and strength of the upper extremities may be observed as early as adolescence and progress further with growth and maturation [16,18,32]. In fact, Harada et al. [13] reported a smaller ROM of external rotation of the shoulder and a larger strength of external and internal rotation of the pitching than the non-pitching shoulder in 9-12-year-old baseball players. Side-to-side differences are, however, not always found in even adult baseball players [23] casting some doubt on the impact of side-to-side differences in ROM, strength, tendon and ligament morphology of the upper body with the risk of injury in one-sided sports in children.

The aim of our research was to assess side-to-side differences in morphology and function of the upper limbs in 11–12-year-old baseball players. As the connective tissue in boys at the onset of puberty can be particularly sensitive to intense eccentric exercise [13], we hypothesized that regular baseball playing (which often aggravates joints and muscles on one side) can create asymmetry of individual muscle groups, and tendon and ligament morphology in young athletes, which make these children more prone to injury than non-trained. Baseball players with throwing-related pain were examined in this study as they maybe more prone to subsequent injury than those players free of pain.

Materials and Methods

Participants

The participants of this study were 14 male baseball players who 1) participated 4 or more years in baseball activities and 2) experienced moderate intensity (rated from 3 to 6 points on 10 points scale, where 0 – no pain and 10 – the worst imaginable pain) pain during at least two training sessions in the last month (mean ± standard deviation; age, 11.6 ± 0.6 years; height, 158.5 ± 6.3 cm; mass, 54.1 ± 11.9 kg; playing experience, 4.5 ± 0.8 years). We also recruited 16 untrained healthy control subjects (mean age, 11.8 ± 0.7 years; height, 158.0 ± 7.1 cm; mass, 55.1 ± 10.6 kg).

Baseball players were recruited from the local baseball league during the off-season preparation phase (November-December). We used a modified questionnaire by Trakis et al. [32] to determine whether a participant could be included in the study or should be excluded.

The following questions were asked: (1) whether the player had pain related with baseball throwing; (2) the number of training sessions in which the player experienced pain during baseball throwing in last month; (3) the magnitude of worst pain related with baseball throwing in last month (0 – no pain, 1 to 2 points – mild pain, 3 to 6 points – moderate pain, 7 to 9 points – intense pain, 10 – worst imaginable pain); (4) whether the player had pain lasting over the next few days after a training session; (5) whether the player had pain with non-baseball activities and (6) whether the player had pain that required medical treatment. As we were interested in early detection of injury risk, participants who suffered from 1) pain outside baseball activities, 2) pain lasted several days after a training session and/or had pain requiring medical attention were excluded from the study. Questionnaire was completed by the same researcher.

Training experience and training details were obtained from their coach. Training sessions were performed three times per week for 1.5 h all year round and competitions took place 5 months per year 7-10 times per month. All players played in national championship and little league tournaments and seven of them had been invited to represent the national team at the European championships. None of baseball players were involved in other sports. For the control group physically active boys were recruited from local high schools from the same grades and of similar mass and height as the baseball players. They were not competitively involved in any sport. The throwing arm was considered the dominant arm. Except one person, all participants were right-handed. The present study meets the ethical standards of the journal [15]. The regional ethics committee of the Lithuanian Health Science University approved the study. Written informed consent was obtained from the parent or guardian of the participant.

Testing procedures

First, the ROM at the left and right elbow and shoulder joints was determined with a goniometer. This was followed by a 5-min warm-up on arm cycle ergometer. The upper limb muscle force was measured with an isokinetic dynamometer. On the next day, the morphological integrity of the left and right elbow and shoulder joints (tendons, ligaments) was determined by ultrasound. The goniometry, isokinetic and ultrasound measurements were done by three different investigators, who performed the respective measurements in each participant to minimise inter-individual bias. The throwing and non-throwing arms were tested randomly.

Goniometry. Internal and external rotation of the right and left upper arms, as well as elbow flexion and extension, were measured using a standard goniometer [29]. The ROM was measured in a supine position. When measuring the external and internal shoulder rotation, the upper arm was abducted to 90° and the forearm was flexed to 90°. The movable part of the goniometer coincided with the anatomical axis of the upper arm and moved with it. When measuring elbow flexion and extension, the arm was stretched. The movable part of the goniometer coincided with the forearm anatomical axis and moved with it. Each motion was performed twice and the best result was used for further analysis.

Isokinetic dynamometry. An isokinetic dynamometer was used for strength testing (System 3, Biodex Medical Systems, Shirley, NY) [9]. Subjects sat on the chair and were strapped in the dynamometer by shoulder and waist belts to minimise whole body movement during muscle function testing. All tests consisted of three maximal-effort repetitions with both arms, and standardized instructions of "push as hard as possible" were given. The best result of three repetitions was used in subsequent analyses. Shoulder flexions and extensions were performed first. The upper extremity was positioned with a straight arm and 0° of shoulder abduction. Strength was tested through 90° of the ROM between 90° of extension and 180° of flexion. Elbow flexions and extensions were then performed. The shoulder joint was positioned at 90° of flexion and 0° of abduction and the forearm was supinated, holding the lever arm of the dynamometer. Finally, concentric and eccentric shoulder internal and external rotator strengths were tested. The upper extremity was positioned with the shoulder abducted to 90° and the elbow flexed to 90° [35]. Strength was tested through 90° of the ROM, between 0° of internal rotation and 90° of external rotation, for both the internal and external rotation tests. Concentric strength was tested first, followed by eccentric strength. High intraclass correlation coefficients were shown previously for shoulder concentric/eccentric and internal/external (0.87-0.97) [9], shoulder concentric flexion/extension (0.93-0.95) [1] and elbow concentric flexion/extension (0.91-0.97) [6] peak torque.

Shoulder and elbow flexion and extension muscle strengths and shoulder internal and external rotation muscle strengths were evaluated at an angular velocity of 2.09 rad·s^{-1}. We chose this speed in the middle range because we considered it to be more functional than low speeds (0.52–1.05 rad·s^{-1}) and more reliable than high speeds (4.72–5.24 rad·s^{-1}) for the assessment of strength in children. There were 5-min breaks for rest between measurements in the different arms, as well as between different arm movements. Before each new movement, subjects performed three submaximal trials to familiarize themselves with the ROM and the accommodating resistance of the dynamometer.

Ultrasonography. Ultrasonography of the shoulder and elbow regions was performed [14] using a ultrasound (GE Logiq 7, Wuppertal, Germany) device with a 7–12 MHz linear probe. The scans were performed by one of the researchers with 7 years scanning experience and who was blinded to the details of the participants. The ultrasound measurements were performed as described by others [7,17], who reported an intra- and inter-correlation coefficient of 0.92 -0.98 and 0.81-0.87, respectively.

At the shoulder, three measurements were performed. With the elbow abducted, flexed at 90° and wrist twisted to the lateral side, the thickness of the subscapular tendon 2 cm medial to the insertion was measured. After placing the patient’s arm posteriorly with a flexed elbow, the thickness of the supraspinatus tendon was measured 1 cm lateral to the tendon of the long head of the biceps brachii. The articular cartilage thickness of the humeral head was then assessed.

The thickness of the ulnar collateral ligament (ULC) was measured with the patient lying supine and the elbow flexed at 90°. The number of ossification centres was assessed in the medial epicondyle. With the elbow extended, a valgus force was applied. The medial ulnohumeral distance was measured with no force and then with a valgus force applied to the elbow. The articular thickness of the humeral capitulum was also measured.

Statistical analysis

Descriptive data are presented as means and standard deviations (SD). The Kolmogorov–Smirnov test confirmed that all data were normally distributed. Side (throwing vs non-throwing) and group (baseball players vs control) effects were compared using a two-way analysis of variance (ANOVA). For all statistical tests, difference were regarded as significant when $p<0.05$. All of the analyses were performed using SPSS (IBM SPSS Statistics for Windows, Version 20, Armonk, NY).

Results

Range of motion

There were no differences in the ROM between the dominant and non-dominant arms in both groups ($p>0.05$; Table 1). The range of internal shoulder rotation was larger in the control than the baseball players group ($p<0.05$), but external rotation was similar between the groups ($p>0.05$). There were no group differences in elbow flexion and extension ($p>0.05$).

Isokinetic strength

There were no significant differences ($p>0.05$) between the dominant and non-dominant arms in terms of the internal rotator or external rotator muscle strengths for both concentric and eccentric testing in both groups (Table 2). There were also no significant side and group interactions. The only significant difference found between the groups was for eccentric external peak torque, which was higher in the control group compared with the baseball players ($p<0.05$). Accordingly, the external-to-internal peak torque ratio was also higher in the control group ($p<0.05$). Similar results were obtained when peak torque was normalized to body weight in both groups (Figure 1).

Ultrasonography

There were no side-to-side differences within groups for any of the measured ultrasound parameters ($p>0.05$, Table 3). However, the supraspinatus tendon of baseball players was 0.08 cm thicker than that of the controls ($p<0.05$). The articular cartilage of the humeral head and ULC thickness were larger in baseball players compared with the controls ($p<0.05$). The medial ulnohumeral distance without valgus stress was greater for baseball players ($p<0.05$), but there was no significant difference between groups when the valgus stress test was used. A partial tear of the ULC was observed in the dominant arm of one baseball player. Additionally, avascular necrosis of the capitellum was identified by ultrasound for another participant in the playing group. Both diagnoses had been confirmed clinically, and their data were not analysed further. Two cases with two ossification centres in the medial epicondyle were observed in the dominant arms of baseball players and one case was found in the dominant arm of one of the controls. Both groups of participants had only one ossification centre in their non-dominant arms, except three participants from the control group who already had fusion of the medial epicondyle of both arms.

Discussion

The main finding of the present study was that there were no side-to-side differences in strength, ROM and amount of connective tissue (measured with ultrasound) in 11–12-year-old baseball players with throwing-related pain. These data suggest that it is unlikely that the relatively large number of injuries previously reported in young baseball players is due to side differences [20]. However, the lower shoulder eccentric external peak torque and range of internal rotation in both sides than that of age-matched untrained controls may predispose to throwing-related pain in young baseball players.

Previous studies have suggested that the throwing-related pain is associated with an imbalance in strength between the propulsive internal rotators and the muscles responsible for deceleration and stabilization of the shoulder during pitching in youth players [13,32]. Yet, we found that children baseball players complaining of throwing-related pain did not exhibit larger internal and lower external rotators strength in the throwing than the non-throwing arm, or side-to-side differences in flexor and extensor strength. This applied to both concentric and eccentric strength, with eccentric-to-concentric ratios for internal rotation larger than 1.1 for both the dominant and non-dominant arms of both the players and non-players. Such ratios indicate that the antagonist muscles are sufficiently strong to decelerate movement and overcome the inertia of movement produced by the agonists [31]. These data thus suggest that the shoulder pain in many child baseball players [20] is not associated with side-to-side differences in eccentric and concentric muscle strength.

We did find, however, that baseball players were relatively weaker in external compared to internal concentric rotation than untrained controls as reflected by their lower eccentric to concentric internal shoulder-rotation torque ratio. A lower eccentric strength may impair the ability to decelerate the throwing movement produced by the muscles than generate concentric force [31] and cause stress on the shoulder joint posterior capsule during throwing that may over time contribute to throwing-related pain in young players.

Throwing volume and intensity were identified as the main risk factors for elbow and shoulder pain [20], where the risk of injury risk increases 5-fold for pitching more than 8 months per year and nearly 36-fold for pitching despite arm fatigue [25]. However, it is well known that an injury can occur after a single baseball throw [25]. Such an injury after a single throw maybe related to improper throwing techniques [26]. Whatever the cause, our results suggest that throwing-related pain in child baseball players is not related to bilateral strength differences. Future studies may seek to evaluate the contribution of training volumes and inappropriate throwing techniques to the development of throwing-related pain and injuries in child baseball players.

It was no real surprise that muscle strength was similar in both arms in this young baseball player population. Baseball throwing is performed with quite low strength requirements, which do not exceed the threshold for strength development, and heavy weights programs are seldom applied to child baseball players. In line with this, it has been noted that differences in muscle strength develop rapidly when the thrower becomes involved in a strength training program [24].

It should be noted that we evaluated functional weakness was performed on isolated joints at muscle contraction speeds (2.09 rad·s^{-1}) far slower than seen during a pitch, where angular velocities can be as high as 5000–7000°·s^{-1} (78-110 rad·s^{-1}), and accelerations are generated by a co-ordinated multi-joint effort [11,12]. Part of the high angular velocity during a pitch is related to amplification of movement by the rotation along several joints, but it does suggest that for such movements particularly fast muscle fibres are required. In our work we were unable to assess the force that can be generated at high velocities and in theory we might have missed weakness at such high velocities. This is typical limitation in isokinetic testing of baseball players and also may serve as limitation in the present study. It is, however, unlikely that there would be a preferential weakness of fast muscle fibres, as at low velocities the fast fibres produce almost maximal force. It is also unlikely that there would be a large slow-to-fast fibre type transition in child baseball players, and even if weaknesses were found in any of the individual muscles, other joints and muscle activities would probably compensate this. Our data can off course not exclude the potential contribution of existing side-to-side differences in muscle strength to injuries in baseball players.

The ROM is sensitive to adaptation to training [22], while ligaments and tendons probably does not adapt to the same extent. Excessive shoulder external rotation has been linked to a variety of shoulder injuries and creates large stresses on the medial and lateral elbow joint structures [28,30], while a loss of shoulder internal rotation was related to subacromial impingement and rotator cuff disease [3,19]. Like Meister et al. [22] and Harada et al. [13] we reported a lower ROM in internal and external shoulder rotation in our 11-12-year-old baseball players, but in contrast to their observation we did not see side-to-side differences in ROM in baseball players or controls. The absence of side-to-side differences in ROM in controls and baseball players in our study suggests that the lower internal and external shoulder rotation in baseball players may be due to participant selection bias rather than a consequence of playing baseball. It has been reported that differences in ROM between the dominant and non-dominant shoulders increase with age [18,22], but we did not assess the pubertal status of the boys in our study. Nevertheless, our boys were older (11-12 years) than those in the previous study (<12 years) [13] and would thus have a more pronounced, rather than an absence of side-to-side differences. It is thus not clear what causes the discrepancy between our and previous studies, but it is possibly related to differences in the training programmes between studies.

In the present study, ultrasound examination of the elbow revealed no morphological side-to-side differences in baseball players, although some indices were different between players and untrained controls. Most pronounced was the thicker ulnar collateral ligament in baseball players than controls. Furthermore, the medial ulnohumeral distance was larger without applied valgus stress in baseball players than untrained controls. All of these differences seem to have arisen by coincidence and are related more to the random selection of subjects than to adaptation to training, bearing in mind that no side-to-side morphological differences were found.

It is worth noting that signs of pathology (partial tear of the ULC and avascular necrosis) were found in two of the 14 baseball players. It may be that these pathologies were the main cause of the manifestation of throwing-related pain for these players; however, we should emphasize that the entire cohort (not only these two subjects) complained of pain in the shoulder or elbow when throwing. The detection of pathological signs was the fairly noticeable finding in the present study, confirming the need of systematic ultrasound examination for young athletes. Such monitoring during annual medical examinations could reduce injuries development and prevent from early drop-out from the sports.

In present study we observed that the ROM and eccentric external peak torque of internal shoulder rotation were lower, while the thickness of the supraspinatus tendon, the ulnar collateral ligament and articular cartilage of the humeral head were larger in baseball players than controls. There were, however, no significant side-to-side differences in any parameter in either group. It is very unlikely that the throwing and non-throwing side would stimulate similar modifications in arms and shoulders of both sides. However, it is possible that these differences between baseball players and untrained controls predispose the baseball players to injury and throwing-related pain. Morphology and in this context it would be interesting to see in future work whether baseball players without throwing-related pain would not exhibit such differences in ROM, torque from non-players.

From the perspective of practical application one can conclude that throwing-related pain is not associated with side-to-side differences in strength and that side-specific training is not conducive to treat or prevent throwing-related pain or injury in young male baseball players. Rather, overall, bilateral eccentric strength training that also increases the ROM may help to prevent throwing-related pain. In addition, it is important to pay attention to practice appropriate throwing techniques of adequate volume and intensity to prevent arm pains in young baseball players.

A potential limitation of our study was that throwing-related pain was recalled subjectively from last month activities. Participants at such a young age may underestimate or overestimate the pain magnitude and frequency. To minimize this limitation, we also asked coaches to confirm the information provided by the participants. While in theory repeated strength measurements might induce fatigue this potential impact was limited by adequate rest periods between and randomization of different measures. Finally, we should also acknowledge that group of healthy baseball players would be relevant to include for better interpretation of the present results while we were expecting to see more obvious alterations comparing more different participants.

Conclusions

It is unlikely that side-to-side differences in shoulder and upper limb structure and function contributed to the throwing-related pain in young baseball players, but a low shoulder eccentric external peak torque and range of internal rotation may predispose to throwing-related pain.

References

1. *Bjerkefors A, Jansson A, Thorstensson A*. Shoulder muscle strength in paraplegics before and after kayak ergometer training. Eur J Appl Physiol 2006; 97: 613–618
2. *Borsa PA, Dover GC, Wilk KE, Reinold MM*. Glenohumeral range of motion and stiffness in professional baseball pitchers. Med Sci Sports Exerc 2006; 38: 21–26
3. *Burkhart SS, Morgan CD, Kibler WB*. The disabled throwing shoulder: spectrum of pathology Part III: The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation. Arthroscopy 2003; 19: 641–661
4. *Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE, Jr., Noonan TJ*. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. Am J Sports Med 2010; 38: 1375–1382

5. *Cassas KJ, Cassettari-Wayhs A*. Childhood and adolescent sports-related overuse injuries. Am Fam Physician 2006; 73: 1014–1022
6. *Chen TC, Lin KY, Chen HL, Lin MJ, Nosaka K*. Comparison in eccentric exercise-induced muscle damage among four limb muscles. Eur J Appl Physiol 2011; 111: 211–223
7. *Collinger JL, Gagnon D, Jacobson J, Impink BG, Boninger ML.* Reliability of Quantitative Ultrasound Measures of the Biceps and Supraspinatus Tendons. Acad Radiol 2009; 16: 1424–1432
8. *Donatelli R, Ellenbecker TS, Ekedahl SR, Wilkes JS, Kocher K, Adam J*. Assessment of shoulder strength in professional baseball pitchers. J Orthop Sports Phys Ther 2000; 30: 544–551
9. *Edouard P, Codine P, Samozino P, Bernard PL, Hérisson C, Gremeaux V*. Reliability of shoulder rotators isokinetic strength imbalance measured using the Biodex dynamometer. J Sci Med Sport 2013; 16: 162–165
10. *Emery CA.* Risk factors for injury in child and adolescent sport: a systematic review of the literature. Clin J Sport Med 2003;13: 256–268
11. *Escamilla RF, Fleisig GS, Zheng N, Barrentine SW, Andrews JR*. Kinematic comparisons of 1996 Olympic baseball pitchers. J Sports Sci 2001; 19: 665–676
12. *Fleisig GS, Barrentine SW, Escamilla RF, Andrews JR*. Biomechanics of overhand throwing with implications for injuries. Sports Med 1996; 21: 421–437
13. *Harada M, Takahara M, Mura N, Sasaki J, Ito T, Ogino T*. Risk factors for elbow injuries among young baseball players. J Shoulder Elbow Surg 2010; 19: 502–507
14. *Harada M, Takahara M, Sasaki J, Mura N, Ito T, Ogino T*. Using sonography for the early detection of elbow injuries among young baseball players. AJR Am J Roentgenol 2006; 187: 1436–1441
15. *Harriss DJ, Atkinson G.* Ethical standards in sports and exercise science research: 2014 update. Int J Sports Med 2013; 34: 1025–1028
16. *Hurd WJ, Kaplan KM, Elattrache NS, Jobe FW, Morrey BF, Kaufman KR*. A profile of glenohumeral internal and external rotation motion in the uninjured high school baseball pitcher, part II: strength. J Athl Train 2011; 46: 289–295
17. *Kissenberth MJ, Thigpen CA, Bailey LB, Schweppe ML, Geist DJ, Wyland DJ, Hawkins RJ, Noonan TJ, Shanley E.* Professional Pitchers Display Differences in Ulnar Collateral Ligament Morphology and Elbow Gapping Following UCLR Compared to Uninjured Pitchers. OJSM 2015; 3 (suppl) 3

18. *Levine WN, Brandon ML, Stein BS, Gardner TR, Bigliani LU, Ahmad CS*. Shoulder adaptive changes in youth baseball players. J Shoulder Elbow Surg 2006; 15: 562–566.
19. *Ludewig PM, Cook TM*. Translations of the humerus in persons with shoulder impingement symptoms. J Orthop Sports Phys Ther 2002; 32: 248–259
20. *Lyman S, Fleisig GS, Waterbor JW, Funkhouser EM, Pulley L, Andrews JR, Osinski ED, Roseman JM*. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. Med Sci Sports Exerc 2001; 33: 1803–1810
21. *Makhni EC, Morrow ZS, Luchetti TJ, Mishra-Kalyani PS, Gualtieri AP, Lee RW, Ahmad CS.* Arm pain in youth baseball players: a survey of healthy players. Am J Sports Med 2015; 43: 41–46
22. *Meister K, Day T, Horodyski M, Kaminski TW, Wasik MP, Tillman S*. Rotational motion changes in the glenohumeral joint of the adolescent/Little League baseball player. Am J Sports Med 2005; 33: 693–698
23. *Newsham KR, Keith CS, Saunders JE, Goffinett AS*. Isokinetic profile of baseball pitchers' internal/external rotation 180, 300, 450° /s^{-1}. Med Sci Sports Exerc 1998; 30: 1489–1495
24. *Noffal GJ*. Isokinetic eccentric-to-concentric strength ratios of the shoulder rotator muscles in throwers and nonthrowers. Am J Sports Med 2003; 31: 537–541
25. *Olsen SJ, 2nd, Fleisig GS, Dun S, Loftice J, Andrews JR*. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. Am J Sports Med 2006; 34: 905–912
26. *Oyama S*. Baseball pitching kinematics, joint loads, and injury prevention. J Sport Health Sci 2012; 1: 80–91
27. *Petty DH, Andrews JR, Fleisig GS, Cain EL.* Ulnar collateral ligament reconstruction in high school baseball players: clinical results and injury risk factors. Am J Sports Med 2004; 32: 1158–1164
28. *Pradhan RL, Itoi E, Hatakeyama Y, Urayama M, Sato K*. Superior labral strain during the throwing motion. A cadaveric study. Am J Sports Med 2001; 29: 488–492
29. *Reinold MM, Wilk KE, Macrina LC, Sheheane C, Dun S, Fleisig GS*. Changes in shoulder and elbow passive range of motion after pitching in professional baseball players. Am J Sports Med 2008; 36: 523–527
30. *Sabick MB, Torry MR, Lawton RL, Hawkins RJ.* Valgus torque in youth baseball pitchers: A biomechanical study. J Shoulder Elbow Surg 2004; 13: 349–355

31. *Scoville CR, Arciero RA, Taylor DC, Stoneman PD.* End range eccentric antagonist/concentric agonist strength ratios: a new perspective in shoulder strength assessment. J Orthop Sports Phys Ther 1997; 25: 203–207
32. *Trakis JE, McHugh MP, Caracciolo PA, Busciacco L, Mullaney M, Nicholas SJ.* Muscle strength and range of motion in adolescent pitchers with throwing-related pain: implications for injury prevention. Am J Sports Med 2008; 36: 2173–2178
33. *Wilk KE, Macrina LC, Fleisig GS, Aune KT, Porterfield RA, Harker 4, Evans TJ, Andrews JR*. Deficits in Glenohumeral Passive Range of Motion Increase Risk of Shoulder Injury in Professional Baseball Pitchers: A Prospective Study. Am J Sports Med 2015; 43: 2379–2385
34. *Wilk KE, Obma P, Simpson CD, Cain EL, Dugas JR, Andrews JR*. Shoulder injuries in the overhead athlete. J Orthop Sports Phys Ther 2009; 39: 38–54
35. *Zanca GG, Oliveira AB, Saccol MF, Mattiello-Rosa SM.* Isokinetic dynamometry applied to shoulder rotators - velocity limitations in eccentric evaluations. J Sci Med Sport 2011; 14: 541–546

Table 1. Comparison of peak torques between the baseball players and the control group for the dominant and non-dominant arms.

Test	Baseball players		Control group	
	Dominant	Nondominant	Dominant	Nondominant
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Shoulder				
Concentric				
Internal (N·m)	31.7 ± 8.0	28.4 ± 7.6	32.5 ± 6.81	29.5 ± 6.8
External (N·m)	18.7 ± 3.8	18.0 ± 3.5	22.4 ± 4.1	21.8 ± 4.9
Eccentric				
Internal (N·m)	37.8 ± 9.4	34.1 ± 5.0	39.9 ± 5.3	39.4 ± 7.5
External (N·m)*	16.8 ± 5.6	15.3 ± 3.8	19.9 ± 3.8	20.3 ± 6.6
Ratio				
IRecc/IRcon	1.23 ± 0.26	1.20 ± 0.24	1.31 ± 0.15	1.37 ± 0.19
ERecc/IRcon*	0.55 ± 0.05	0.55 ± 0.04	0.64 ± 0.01	0.70 ± 0.03
ERcon/IRcon	0.65 ± 0.04	0.71 ± 0.04	0.70 ± 0.01	0.74 ± 0.03
Shoulder				
Concentric				
Flexion (N·m)	35.4 ± 12.4	32.9 ± 12.2	35.2 ± 9.4	33.0 ± 7.9
Extension (N·m)	44.4 ± 7.8	42.6 ± 10.8	46.9 ± 9.1	44.8 ± 10.2
Ratio				
Flexion/Extension	0.79 ± 0.04	0.77 ± 0.06	0.78 ± 0.04	0.77 ± 0.03
Elbow				
Concentric				
Flexion (N·m)	19.5 ± 5.5	17.7 ± 4.4	19.8 ± 4.0	18.8 ± 3.6
Extension (N·m)	27.3 ± 5.6	26.7 ± 7.7	27.9 ± 8.2	26.3 ± 7.9
Ratio				
Flexion/Extension	0.71 ± 0.02	0.67 ± 0.03	0.73 ± 0.03	0.75 ± 0.04

ER, external rotation; IR, internal rotation; Ecc, eccentric; Con, concentric. * $P < 0.05$, for group effect.

Table 2. Comparison of the range of motion (deg) between the baseball players and the control group for the dominant and non-dominant arms.

Motion	Baseball players		Control group	
	Dominant	Nondominant	Dominant	Nondominant
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Shoulder				
Internal rotation*	71.9 ± 10	76.3 ± 10.6	79.9 ± 7.8	77.1 ± 7.7
External rotation	87.9 ± 9.7	88.4 ± 10.8	89.6 ± 10.2	88.8 ± 7.4
Total motion	159.7 ± 15.9	164.7 ± 18.0	169.5 ± 16.0	166.0 ± 12.8
Elbow				
Extention	5.4 ± 2.4	4.6 ± 1.3	5.7 ± 2.9	5.8 ± 4.4
Flexion	149.4 ± 5.4	151.9 ± 8.0	152.8 ± 5.7	152.5 ± 5.2
Total motion	154.7 ± 6.5	156.5 ± 8.4	158.5 ± 7.4	158.4 ± 7.7

* $P < 0.05$, for group effect.

Table 3. Comparison of ultrasonography measures (cm) between baseball players and the control group for the dominant and non-dominant arms.

Parameter	Baseball players		Control group	
	Dominant	Nondominant	Dominant	Nondominant
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Subscapular tendon thickness	0.52 ± 0.06	0.52 ± 0.06	0.48 ± 0.09	0.49 ± 0.09
Supraspinatus tendon thickness*	0.58 ± 0.09	0.56 ± 0.07	0.50 ± 0.07	0.50 ± 0.07
Articular cartilage thickness of the humeral head*	0.18 ± 0.05	0.18 ± 0.05	0.14 ± 0.03	0.14 ± 0.03
Ulnar collateral ligament thickness *	0.34 ± 0.05	0.31 ± 0.03	0.28 ± 0.03	0.27 ± 0.03
Articular thickness of the humeral capitulum	0.22 ± 0.05	0.22 ± 0.04	0.19 ± 0.04	0.20 ± 0.04
Valgus stress test:				
Medial ulnohumeral distance with no stress*	0.14 ± 0.03	0.14 ± 0.02	0.11 ± 0.03	0.12 ± 0.03
Medial ulnohumeral distance with applied valgus stress	0.20 ± 0.06	0.18 ± 0.04	0.17 ± 0.05	0.18 0.03

* P < 0.05, for group effect.

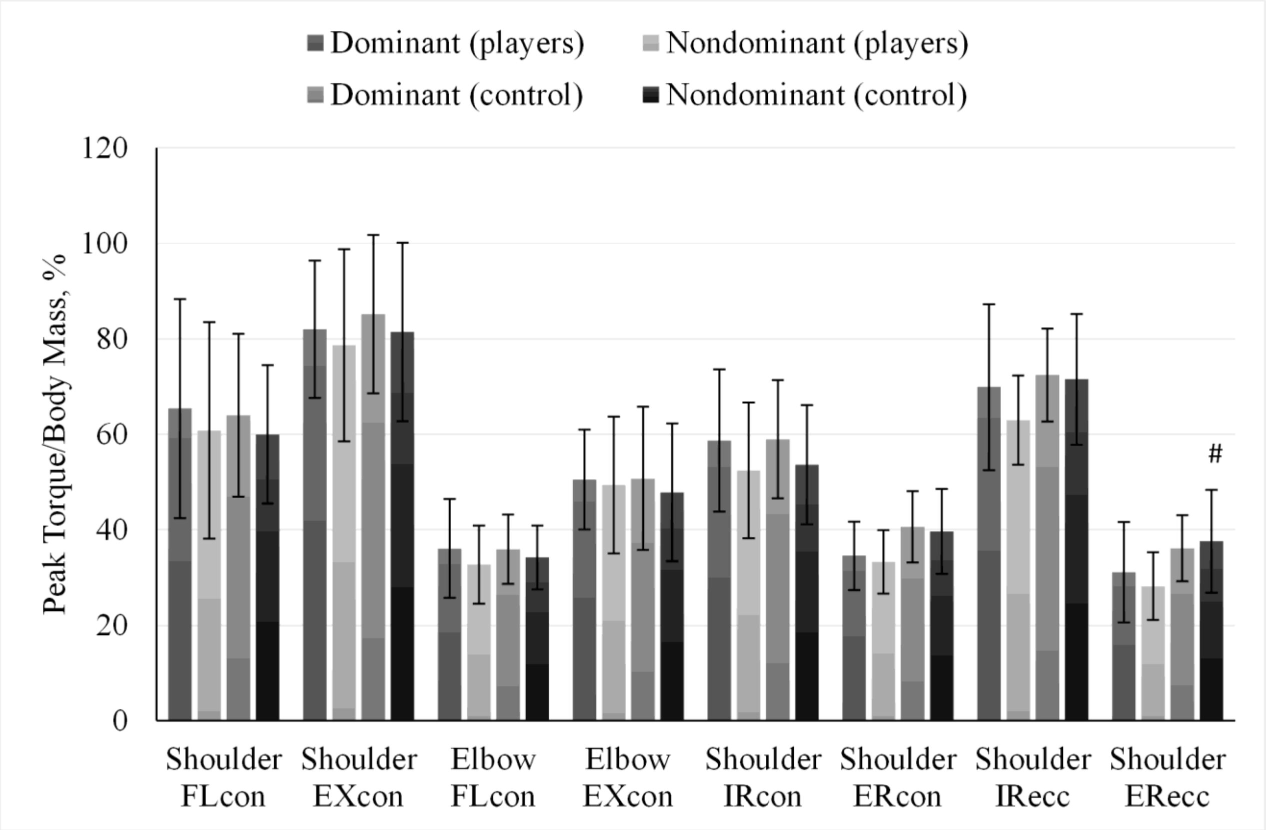

Fig. 1 Comparison of peak torques (SD) between dominant and non-dominant arms for the baseball players and the control group. FL, flexion; EX, extension; ER, external rotation; IR, internal rotation; ecc, eccentric; con, concentric. $^{\#}$ $P < 0.05$, for group effect.