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The infraspinatus muscle activity during pitching motion in baseball players with shoulder instability

Somu Kotoshiba, PT, MS[a], Yukio Urabe, PT, PhD[a], Masafumi Hara, MD, PhD[b,c], Motoyuki Fujisawa, MD, PhD[b,c], Ryohei Sumida, PT[d], Kei Aramaki, PT[d], Junpei Sasadai, PT, PhD[a], Noriaki Maeda, PT, PhD.[a,*]

[a] Department of Sports Rehabilitation, Graduate School of Biomedical and Health Sciences, Hiroshima University, Hiroshima, Japan
[b] Hara Baseball Medical Institute, Hisatsune Hospital, Fukuoka, Japan
[c] Department of Orthopedic Surgery, Hisatsune Hospital, Fukuoka, Japan
[d] Department of Rehabilitation, Hisatsune Hospital, Fukuoka, Japan

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Background: Shoulder microinstability is often overlooked, which can be problematic, especially in overhead athletes. The slipping phenomenon is defined as posterior or lateral sliding of the humeral head in an elevated arm. When the shoulder is close to the end range of stability, the infraspinatus is highly activated and keeps the shoulder in the glenoid cavity. This study aimed to examine the characteristic physical function and infraspinatus activity during the pitching motion in baseball pitchers with shoulder instability.
Methods: Twenty-one male baseball pitchers participated and were divided into 2 groups based on radiograph findings at zero position: slipped (group S) and nonslipped (group N) groups. Physical function using Hara test and infraspinatus muscle activity during pitching were evaluated.
Results: The infraspinatus muscle activity during the acceleration phase was significantly greater in group S (59.5 ± 33.0%MVC) than in group N (33.0 ± 16.9%MVC) ($P < .05$). Positive rate of the Hara test in group S was significantly high in the loose test and elbow push test.
Conclusions: This study shows that baseball pitchers with slipping phenomenon have capsular laxity and scapular instability that indicate high infraspinatus muscle activity during the acceleration phase. Therefore, repetitive pitching with hyperactivity of the infraspinatus on the slipping shoulder may cause fatigue and dysfunction.

The shoulder is predisposed to athletic injury because of the greater mobility of the glenohumeral joint, which allows for powerful throwing and smashing, but puts the shoulder at risk for injury owing to the inherently poor glenohumeral stability.[27] Shoulder instability, which was used to be a problem in overhead athletes, presents a unique challenge in that the glenohumeral joint exceeds its physiological limits during competition. Most of the shoulder disorders are because of inflammation caused by overuse or pathologic changes caused by accumulated overuse. Recently, the idea that many athletes have basic instability and impingement, which is secondary to basic instability, has been gradually accepted. Therefore, injury to this population can be catastrophic. We have experienced that in shoulder disorders in sports, not only do many cases have pathologic changes but the pathologic conditions are also functional disorders such as slipping phenomenon. The slipping phenomenon which is the rentogenographic features and means the noncentripetal relationship in the glenohumeral joint, especially seen in patients with loose shoulders.[21] In shoulder with slipping phenomenon, the position of the humeral head was located posteriorly and inferiorly in the 135 degrees elevated position rather than that of the normal shoulder. In addition, the lateral rotation of the scapula tended to be small in the slipping phenomenon.[21] This phenomenon is accompanied with discomfort and pain, loose shoulder, or posterior dislocation of the shoulder. Despite the fact that loosening or the slipping phenomenon caused by deviation of the humeral head laterally or posteriorly in the arm elevated position is a specific symptom of loose shoulder state (98%),[21] this may not be commonly known yet. This instability in elevated position is thought to affect overhead sports in particular, but its relationship to pitching is unclear.

The Hisatsune ethics committee approved the study protocol (no. 00004).

* Corresponding author: Noriaki Maeda, PT, PhD, Department of Sports Rehabilitation, Graduate School of Biomedical and Health Sciences, Hiroshima University, 1-2-3 Kasumi, Minami-ku, Hiroshima 734-8553, Japan.
E-mail address: norimmi@hiroshima-u.ac.jp (N. Maeda).

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In overhead athletes, their shoulders are involved in repetitive high-stress actions, performed at high speed, excessive range of motion, and at a high level of muscle activity,[10] which predisposes this joint to acute and overuse injuries.[2] However, many injuries have been attributed to repetitive overuse mechanisms owing to overload, abnormal overhead throwing biomechanics, and dysfunctional adaptations to the sport. This repetitive nature of pitching in baseball places players at risk for shoulder instability owing to microtrauma and microinstability.[4]

The infraspinatus muscle contributes significantly to compressive forces at the glenohumeral joint,[6] which serves a fundamental role of being a static and dynamic stabilizer of the glenohumeral joint along with the other rotator cuff muscles. Measurements of muscle activity indicate that the infraspinatus begins to become highly active at ball release, and the activity level remains elevated throughout the follow-through phase. On the contrary, baseball players with shoulder pain during throwing are reported to be the most active during the acceleration phase.[15] During the acceleration phase, it is vital to maintain scapular stabilization owing to the forward acceleration of the arm which is equivalent to a peak internal rotation angular velocity of approximately 6500°/second near ball release.[14] In overhead sports with shoulder instability of the glenohumeral joint, the infraspinatus may cause excessive muscle activity for stabilization. The overhead throwing motion leads to overstress in the posterior-inferior structures of the shoulder that cause repetitive microtraumas and, consequently, tightness of the posterior-inferior portion of the capsule and rotator cuff muscles, generating glenohumeral internal rotation deficit (GIRD).[8] Identifying the primary mechanisms of posterior shoulder tightness can provide the best approach to resolving range of motion deficit associated with pitching. However, the influence of the slipping phenomenon on the infraspinatus muscle activity during pitching motion has not been investigated. Thus, this study aimed to investigate infraspinatus activity during pitching of baseball pitchers with slipping phenomenon. The hypothesis was that the infraspinatus in baseball pitchers with slipping phenomenon would indicate a higher activity during the acceleration phase than that in patients without slipping phenomenon.

Materials and methods

Subjects

Twenty-one male baseball pitchers (mean age ± standard deviation, 17.5 ± 1.2 years; mean height ± standard deviation, 1.73 ± 0.06 m; mean body weight ± standard deviation, 69.9 ± 7.5 kg) participated in this study. Six were left-handed, and 15 were right-handed. All participants were pitchers in high school and college. The exclusion criteria were (1) a history of shoulder dislocation, (2) a history of shoulder or elbow surgery, or (3) no major trauma (including fracture, myositis ossificans, and burns). In addition, participants who could not throw at their maximum intensity were excluded.

The power of each analysis of variance was not <0.65 for an effect size >0.8. Priori power analysis by G*power revealed that the statistical power of 0.75 for an effect size of 0.8 with an alpha level of 0.05 required a sample size of at least 20 subjects. This cross-sectional, observational study has been approved by the institutional review board of the authors' affiliated institution, and all participants provided informed consent to participate in the study.

Radiography at zero position

Plain radiographs were taken at first examination: in the anteroposterior view with the shoulder elevated at 135° on scapula plane while standing, the relative positions of the humerus and the scapula were assessed (Fig. 1). Subsequently, we divided all participants into 2 groups (slipped; group S and nonslipped; group N) based on the radiographs at zero position. As per a previous report, the slipping phenomenon is defined as the center of the humeral head positioned on the outside of the lateral edge of the glenoid at the zero position.[21] In other words, when point B is located medial to the vertical white line, it is expressed as the slipping phenomenon (Fig. 1b).

Electromyography measurements

Electromyography (EMG) data from the infraspinatus were collected at a sampling rate of 1500 Hz using a TeleMyo 2400 G2 Telemetry System (Noraxon Inc., Scottsdale, AZ, USA) as per the recommended procedure.[5] The electrode sites were cleaned with alcohol, and 2 electrodes were placed 70 mm apart within the confines of the muscle as described by Criswell,[9] and a reference electrode was placed over the C7 spinous process. This array has been used by various authors who have explored the surface EMG of the infraspinatus.[1] Disposable Ag/AgCl bipolar surface electrodes with 10-mm conducting area and 20-mm interelectrode distance (Noraxon Inc., Scottsdale, AZ, USA) were used to record the EMG. Once the pitching trials were completed, the established protocol [26] was followed while participants completed 3 times, 3-second maximum voluntary isometric contraction of each muscle by contracting to the maximum against a fixed resistance with the recovery of 3 minutes between trials. The maximum voluntary isometric contraction trial involved a shoulder external rotation with shoulder neutral.

Measurement of the muscle activation during pitching motion

Two high-speed cameras (Sports Coaching Cam; Sports Sensing, Japan) were used to capture pitching motion and analyze video footages to determine the throwing phase. The pitching motion was divided into 4 event segments: early cocking phase, late cocking phase, acceleration phase, and follow-through phase.[13] Before pitching data collection, all participants were instructed to proceed through their preferred warm-up routine. Each participant was individually prepared for electrode placement by cleaning the slightest abrasion of the skin surface of the electrode site. The electrode was attached with their self-adhesive backing and then secured to the athlete's arm by overwrapping with flexible athletic tape. The wires from the electrodes were then connected to a wireless transmitter attached to the participant's waist. Before the start of the pitching test, each participant was made to throw several trial pitches at full speed to familiarize themselves with the electrodes and wires.

All participants threw from the simulated mound to a target area on a net located approximately 16 feet. Participants were given unlimited time to throw a total of 5 pitches. After the pitching trials were completed, data for the fastest 3 of the 5 strike pitches thrown by each pitcher were used for the data analysis.

Physical function examination

The Hara test was used to evaluate the physical function examination. This test[15,19] is particularly useful in assessing the upper limb kinetics for abnormalities that contribute to shoulder pain in patients with throwing disorder. It consists of 11 physical examination items related to the scapular and humeral kinetic chain: (1) scapula-spine distance (SSD) (Fig. 2), (2) elbow extension test (EET) (Fig. 3a), (3) elbow push test (EPT) (Fig. 3b), (4) muscle strength of abduction, (5) muscle strength of external rotation, (6) muscle

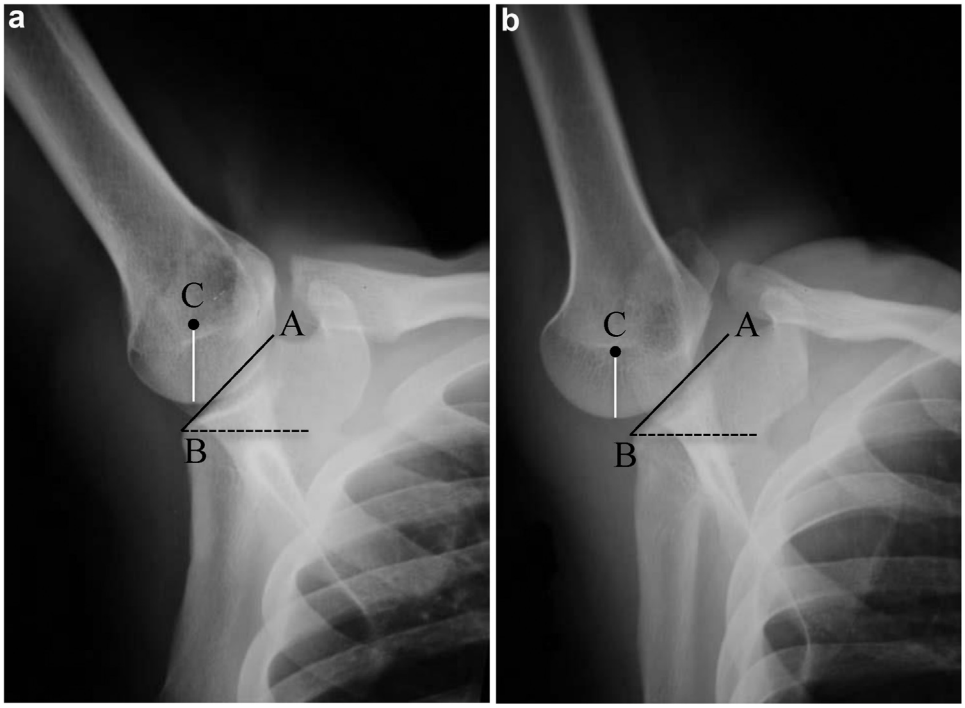

Figure 1 The centre of the humerus, marked as C, is determined by circle-fitting. The superior and inferior margins of the glenoid are represented by A and B. **a**, subject with slipping phenomenon; **b**, subject without slipping phenomenon.

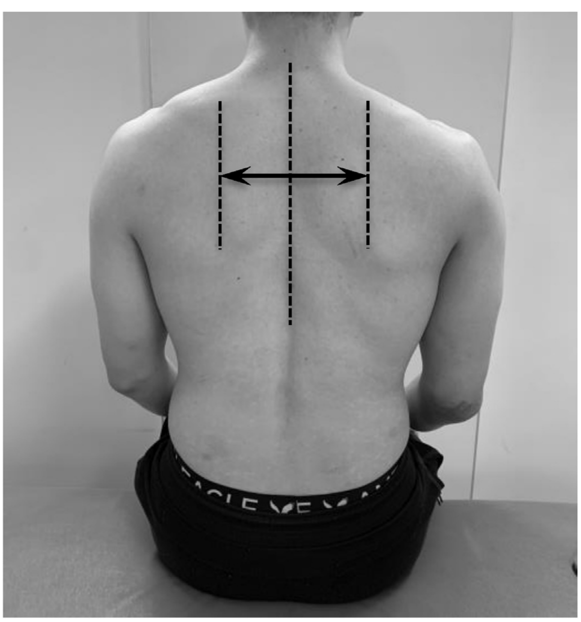

Figure 2 In the scapula-spine distance test, the distance from the medial edge of the scapular spine to the spinous process of the thoracic spine is measured with the arms at the sides.

strength of internal rotation, (7) combined abduction test (CAT) (Fig. 4), (8) horizontal flexion test (HFT) (Fig. 5), (9) capsular laxity tests (loose), (10) subacromial impingement sign, and (11) hyper-external rotation test (Fig. 6). Abnormalities in eight physical examination items, excluding the muscle strength test for all participants, were evaluated by a physical therapist with 7 years of experience who met the eligibility criteria. The abnormal rate of each examination item was used to compare each group.

In the sitting position, participants were assessed for the SSD, EET, EPT, and subacromial impingement sign. Participants underwent the CAT, HFT, loose, and hyperexternal rotation test while in the supine position.

The SSD test assesses scapular alignment. We measured the distance from the medial edge of the scapular spine to the spinous process of the thoracic spine with participants' arms at their sides (Fig. 2). When the side-to-side differences are >1 cm, the result of the SSD test was considered abnormal.

The EET and EPT were performed to assess scapular stability. In the EET, the participant with the shoulder in 90° forward flexion extended the elbow joint from 90° forward flexion with maximum force, and the examiner held the participant's forearm to counteract the extension force (Fig. 3a). In the EPT, the participant grabs the opposite elbow from both sides and alternately pushes each elbow forward with maximum force, and the examiner grips the participant's elbow to counteract it (Fig. 3b). In the present study, the results of EET and EPT were considered abnormal when the muscle strength of the dominant side was lower than that of the nondominant side.

CAT and HFT were performed to assess the shoulder posterior tightness, and the examiner immobilized and held the scapula.[23] In CAT, the humerus was abducted in the coronal plane (Fig. 4), and in HFT, the humerus was horizontally flexed (Fig. 5). The humerus was passively abducted in the coronal plane for the CAT (Fig. 4) and horizontally flexed for the HFT (Fig. 5). The CAT was graded as abnormal if the participant's upper arm failed to touch the head while the scapula was fixed. The HFT was considered abnormal when participants could not reach around the contralateral shoulder to touch the bed during horizontal flexion with the scapula being fixed.

Looseness was assessed by sulcus testing in the inferior directions. With the arm by the side in neutral position and the elbow flexed 90°, a longitudinal downwards pull is applied by the examiner on the arm. The shoulder is observed for the

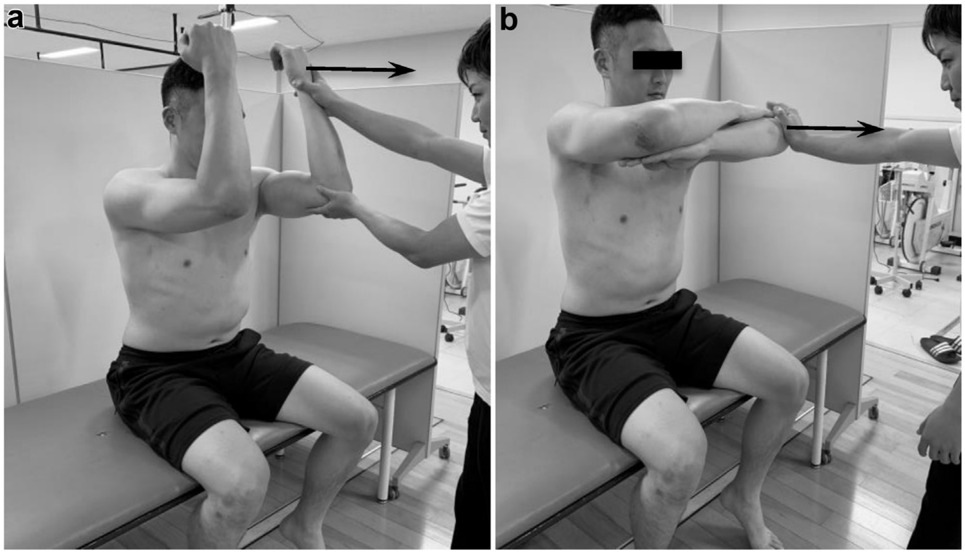

Figure 3 (**a**), Elbow extension test and (**b**), elbow push test for assessment of scapular stability. These tests are performed with the shoulders in 90° of forward flexion.

Figure 4 Combined abduction test for assessment of posterior shoulder tightness. The examiner completely prevents any movement of the scapula by holding it.

development of a sulcus on its lateral aspect between the acromion and humeral head. Looseness was graded as abnormal if it showed an inferior humeral head displacement greater than 1 cm from the acromion is suggestive of inferior laxity.

Neer, Hawkins, and Yocum tests were performed to assess subacromial impingement.[18] The subacromial impingement testing was graded as abnormal if the participant felt shoulder pain during any of these tests.

The hyperexternal rotation test (Fig. 6) evaluates pathologic internal impingement[20] and peel back of the superior labrum[28] and was performed in the supine position in 90° angle of shoulder abduction with the elbow flexed at 90°. The test result was considered abnormal when the participant felt pain to posterior-superior portion of the shoulder in response to the external rotation torque applied by the examiner beyond the maximum external rotation position.

Statistical analysis

The Shapiro-Wilk test was used to assess data normality. The infraspinatus muscle activity of each phase during pitching was compared between groups S and N using the Mann-Whitney U test. McNemar's test was used to compare the change in the positive rate of the Hara test between groups S and N. The significance level for all statistical tests was $P < .05$. Data analysis was performed using SPSS, version 21.0, for Windows (IBM, Armonk, NY, USA). If unless otherwise noted, values are given as mean ± S.D.

The effect size was calculated using the equation $r = Z/\sqrt{N}$ in which effect size (r), and Z (z-scores) was obtained from the SPSS Output for Wilcoxon signed-rank test with N as the number of total observations. Cohen's benchmarks ($r = .10$ small effect; $r = .30$ medium effect; $r = .50$ large effect) were used to interpret the effect size.[12]

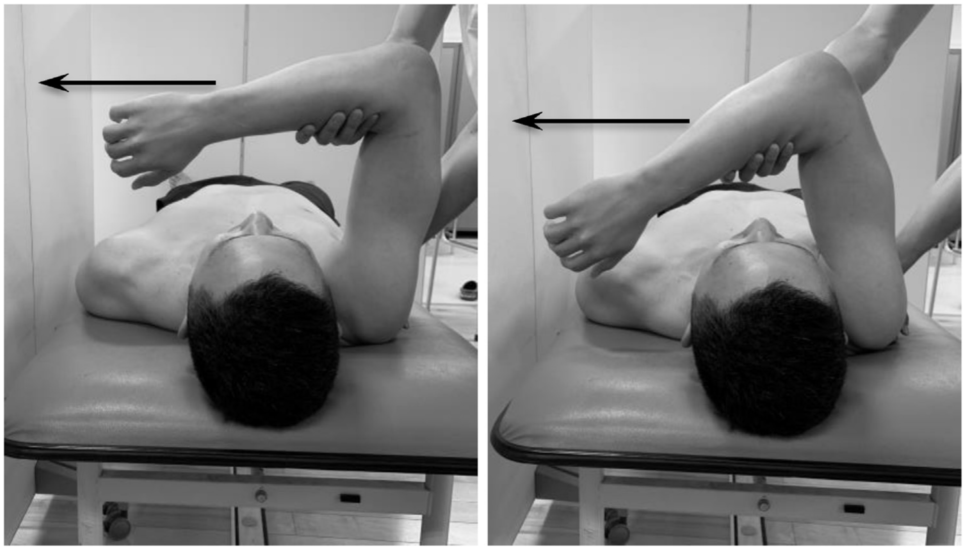

Figure 5 Horizontal flexion test for assessment of posterior shoulder tightness. The examiner completely prevents any movement of the scapula by holding it and horizontally flexes the humerus.

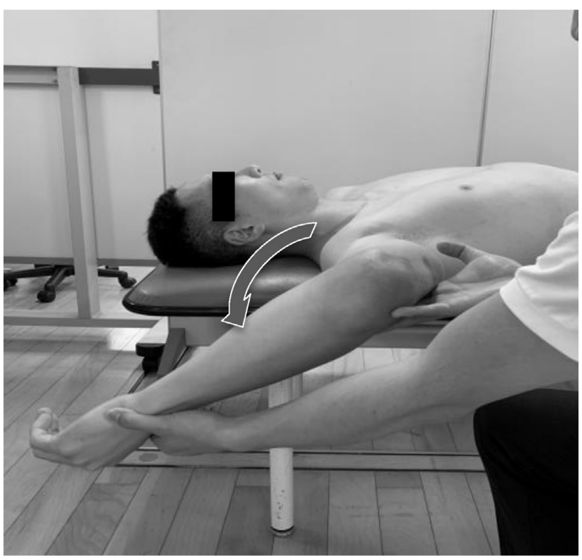

Figure 6 The hyper-external rotation test, which evaluates peel back of the superior labrum and pathological internal impingement, is performed in 90° of shoulder abduction with the elbow flexed at 90° in the supine position.

Results

A total of 21 patients (10 group S, 11 group N) agreed to participate and were enrolled in the investigation. Average age was 17 ± 1 (range, 16-19) years (Table I).

Table II shows significant differences in infraspinatus muscle activities in groups S and N. The infraspinatus activity during the acceleration phases in group S (59.5 ± 33.0) was significantly greater than that in group N (33.0 ± 16.9) ($P < .05$). The effect size was large ($r = 0.93$).

Table III depicts the abnormal rate of the Hara test. The abnormal rate of elbow push test in group S (90%) was significantly higher than that in group N (36.4%) ($P < .05$). Similarly, the abnormal rate of capsular laxity test in group S (90%) was significantly higher than that in group N (18.2%) ($P < .01$).

Table I
Baseline characteristics of both groups of participants.

Variable	Group S (n = 10)	Group N (n = 11)
Age (yr)	17.7 ± 1.1	17.3 ± 1.3
Height (cm)	173.6 ± 7.4	173.3 ± 5.0
Weight (kg)	71.1 ± 7.0	68.8 ± 8.1
Body mass index (kg/m^2)	23.6 ± 1.6	22.8 ± 1.6

Table II
Infraspinatus activity during pitching (%MVC).

Variable	Group S (n = 10)	Group N (n = 11)	*P* value	Effect size*
Infraspinatus muscle activity				
Early cocking	11.1 ± 4.6	8.4 ± 3.7	.218	0.63
Late cocking	23.0 ± 12.4	20.2 ± 11.5	.863	0.24
Acceleration	59.5 ± 33.0	33.0 ± 16.9	.0317	0.93
Follow through	35.5 ± 28.2	26.2 ± 23.1	.42	0.37

* $r = Z/\sqrt{N}$; small effect = .10; medium effect = .30; large effect = .50.

Discussion

One of the main goals of this experiment was to clarify the characteristics of baseball pitchers with posteriorly and inferiorly microinstability in glenohumeral joint at the elevated position. Our results support some of the hypotheses. Baseball pitchers with slipping phenomenon had greater infraspinatus muscle activity during the acceleration phase. A previous study confirmed that electromyographic activity of the infraspinatus peaks during the acceleration phase, which is the characteristic of baseball players with shoulder pain. In a previous study in healthy baseball players, infraspinatus and teres minor muscle activity showed a similar pattern of peak activity during the late cocking and follow-through phases.[13] In addition, infraspinatus muscle activity during the throwing motion is important to stabilize the glenohumeral joint during the follow-through phase. In the acceleration phase, rapid shoulder internal rotation occurs and the shoulder moves from the point of 140-180° of humeral external rotation to 100° of humeral internal rotation in 42-58 milliseconds.[14] Therefore, it is speculated that instability in the elevated position increased the extreme functional demands on the overhead-throwing shoulder during the

Table III
Abnormal rate of Hara test in group S and group N.

Variable	Group S (n = 10)		Group N (n = 11)		P value
	No. of patients	% Patients abnormal	No. of patients	% Patients abnormal	
Scapula-spine distance	10	70.0	11	45.5	.387
Elbow extension test	10	70.0	11	81.8	.635
Elbow push test	10	90.0*	11	36.4	.0237
Combined abduction test	10	70.0	11	54.5	.659
Horizontal flexion test	10	70.0	11	63.6	1
Capsular laxity test	10	90.0†	11	18.2	.0019
Subacromial impingement test	10	10.0	11	9.1	1
Hyperexternal rotation test	10	30.0	11	27.3	1

* Indicates a significant difference in group S compared with in group N ($P < .05$).
† Indicates a significant difference in group S compared with in group N ($P < .01$).

acceleration phase, forcing eccentric contraction of the infraspinatus muscle during the acceleration phase and adding a large eccentric load to the posterior shoulder structure. A study hypothesized that cumulative loading of the posterior shoulder during pitching might cause microtrauma and scarring of this soft tissue.[4] This situation predisposes these athletes to injuries in the rotator cuff muscles and in the joint capsule, which generates pain and posterior shoulder tightness. Therefore, pitching with slipping phenomenon leads to overstress in the posterior-inferior structures of the shoulder that cause repetitive microtraumas and, consequently, tightness of the posterior-inferior portion of the capsule and rotator cuff muscles, generating GIRD.[7]

In physical function examination, baseball pitchers with slipping phenomenon showed a higher positive rate in the capsular laxity test and EPT than players without slipping phenomenon. Sugaya[25] reported that radiographs in the elevated position sometimes demonstrate slipping of the humeral head in patients with loose shoulder. Atraumatic shoulder instability is associated with underlying dysfunction of the joint capsule, where laxity can lead to symptomatic instability.[3] In such cases, conservative management, such as physiotherapy rehabilitation, is recommended with surgery as the limited resort.[22] Physical therapy of patients with the loose shoulder is aimed at strengthening the rotator cuff to maximize the concavity-compression mechanism and stabilizing the scapula to stabilize the glenoid platform. The rotator cuff contributes significantly to compressive forces at the glenohumeral joint.[11] During overhead activity, scapular stabilization and rotator cuff muscle function are in a balanced manner, maintaining a central relationship between the humeral head and glenoid fossa. This dynamic stability mechanism is crucial to glenohumeral joint stability during the midranges of arm movement.[16] The elbow push test evaluates scapular stabilization. The stability of the scapula on the throwing side was lesser in baseball pitchers with slipping phenomenon than in those without slipping phenomenon. It is conceivable that muscle function of the scapula is stabilized during overhead motion because every glenohumeral ligament did not get taut and the anteroposterior translation became greater with increasing abduction angle, above 90°.[24] In particular, excessive activation of the upper trapezius, combined with decreased control of the lower trapezius and serratus anterior, has been proposed as contributing to abnormal scapular motion.[17] This study indicated that baseball pitchers with slipping phenomenon had shoulder laxity and scapular instability and had higher infraspinatus muscle activity in the acceleration phase during the pitching motion. This result suggested that repetitive pitching motion with hyperactivity of the infraspinatus on the slipping shoulder causes overuse and could be a factor causing posterior shoulder tightness. Scapular dysfunction, shoulder instability, or pathologic shoulder laxity, posterior shoulder tightness, and muscle imbalance are associated with pathologic internal impingement.[29] Therefore, baseball pitchers with slipping phenomenon need proper and effective physical therapy to meet the ideal upper-extremity kinetic chain. Further studies are needed to evaluate the relationship between slipping phenomenon and pitching motion in baseball players with shoulder pain.

This study had some limitations. A major limitation was that data on healthy baseball players were not included. However, this preliminary study is valuable in that muscle activity was measured during the pitching motion of baseball players with throwing disorder, which may help clarify the mechanism of throwing disorder in baseball players with slipping phenomenon. In future, we plan to investigate differences in infraspinatus muscle activity during pitching motion among baseball players with slipping phenomenon and healthy baseball players. Furthermore, changes in muscle activity occurred in the infraspinatus; however, changes in the muscle strength of the rotator cuff and other muscle activity were not examined. Therefore, the effects of the slipping phenomenon on the strength of rotator cuff muscle and other muscle activity during pitching motion should be investigated. Finally, only EMG was used to assess throwing performance.

Conclusions

The slipping phenomenon increases extreme functional demands on the overhead-throwing shoulder in the acceleration phase, and it is speculated that the eccentric force of the infraspinatus muscle makes excessive eccentric loads to the posterior shoulder. Collectively, the study findings will contribute to better understanding of the pathogenesis and optimizing physical therapy for throwing disorder with slipping phenomenon.

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