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Which muscle performance can be improved after arthroscopic Bankart repair?

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Background: There are no published reports available regarding neuromuscular control recovery in nonathletic patients after arthroscopic (A/S) Bankart repair. This study aimed to compare neuromuscular control and performance of the rotator cuff muscles between patients who underwent A/S Bankart repair and normal controls.
Methods: In total, 32 nonathletic patients who underwent A/S Bankart repair were compared with 32 asymptomatic nonathletic volunteers. Neuromuscular control index (time to peak torque and acceleration time), muscle strength ratio, muscle strength, and muscle endurance of the internal rotators (IRs) and external rotators (ERs) were measured using an isokinetic device at an angular velocity of 180°/s, with 90° shoulder abduction.
Results: The neuromuscular control indices of both IRs and ERs were significantly lower in patients who underwent A/S Bankart repair than in normal controls (time to peak torque, IRs: 1059 ± 143 ms vs. 679 ± 226 ms, $P = .011$; ERs: 595 ± 286 ms vs. 379 ± 123 ms, $P = .044$; acceleration time, IRs: 75 ± 16 ms vs. 62 ± 15 ms, $P = .039$, ERs: 70 ± 19 ms vs. 54 ± 18 ms, $P = .047$). Muscle endurance was significantly lower in patients who underwent A/S Bankart repair than in normal controls (IRs: 670 ± 1 J vs. 718 ± 2 J, $P = .002$, ERs: 422 ± 6 J vs. 501 ± 2 J, $P = .044$). The neuromuscular control index showed a significant negative correlation with muscle endurance for both IRs and ERs after the operation (IRs: $r = -0.737$, $P = .003$, ERs: $r = -0.617$, $P = .019$).
Conclusion: Compared with normal controls, patients who underwent A/S Bankart repair did not show complete recovery of neuromuscular control of IRs and ERs, although their muscle strength ratio and muscle strength had fully recovered.
Level of evidence: Level III; Case-Control Design; Treatment Study

Keywords: Arthroscopic Bankart repair; neuromuscular control; muscle strength ratio; muscle strength; muscle endurance

The stability of the glenohumeral (GH) joint is maintained through interaction of the static and dynamic stabilizers and the neural subsystem.[21,22] Many previous studies have found the existence of mechanoreceptors in the static and dynamic stabilizers,[20,34] including articular and muscle mechanoreceptors,[5] which are sensory neurons that transmit sensory stimuli to the central nervous system.[34-36] After disruption of the capsuloligamentous structures in patients with traumatic shoulder instability, defects of the mechanoreceptors in the static and dynamic stabilizers can cause abnormal afferent sensory input to the central nervous system, which can result in recurrent or functional shoulder instability.[32,35,43,44,48] Therefore, shoulder stabilization surgery such as Bankart repair, performed openly or arthroscopically (A/S), has been considered the standard surgical treatment for restoration of the mechanical structures in patients with traumatic shoulder instability.[7,45]

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Although the incidence of recurrent instability is lower after surgical repair than after conservative treatment,[9] it has been frequently reported,[1,16] possibly owing to the loss of muscle performance, such as muscle strength, proprioception, and neuromuscular control, and improper recovery.[32,33,37]

The rotator cuff (RC) muscles work to center the humeral head onto the glenoid in all positions including the apprehension position.[28,31] Therefore, the functional recovery of neuromuscular control of the RC muscles cannot be ignored for the stability of the GH joint after surgical repair. A recent study reported decreased neuromuscular control of the RC muscles in nonathletic patients with traumatic anterior shoulder instability during preoperative evaluation.[27] In addition, some previous studies have shown that proprioception on the operated shoulder of patients with shoulder instability improved to the level of the nonoperated shoulder after Bankart repair.[15,30,47] However, to our knowledge, there have been no investigations regarding the restoration of neuromuscular control of the RC muscles after A/S Bankart repair. Therefore, this study aimed to evaluate neuromuscular control, muscle strength ratio, muscle strength, and muscle endurance of the RC muscles in nonathletic patients with traumatic anterior shoulder instability at 1 year after A/S Bankart repair. We hypothesized that neuromuscular control, muscle strength ratio, muscle strength, and muscle endurance of the RC muscles would be restored in patients who underwent A/S Bankart repair, compared with normal control subjects, at 1 year after the operation.

Materials and methods

Study design and patient classification

Sample size estimation

On the basis of a previous study,[27] a difference of greater than 10% of muscle strength between the shoulders of the patients and controls was considered significant. A prior power analysis was performed to determine the sample size, at a power of 0.8 and an alpha level of 0.05. According to a pilot study, for the 5 shoulders in each group, 26 shoulders would be required to detect a significant difference. A power of 0.851 was required in this study for detecting a significant difference between the muscle strengths of the 2 groups.

Patients with shoulder instability

This was a prospective case-control study, and 74 nonathletic patients participated to undergo A/S Bankart repair in our institution from July 2017 to May 2018, the requirement for which was confirmed by magnetic resonance imaging and physical examination. Only the right (dominant) arms with traumatic anterior shoulder instability were included. In total, 42 patients were excluded owing to the following reasons: posterior instability, bilateral instability, involvement of the nondominant shoulder, multidirectional shoulder instability, bony Bankart lesions, and restricted range of motion. Patients with a history of prior operation on the same or contralateral shoulder and those who experienced redislocation after surgery were also excluded. Thus, 32 patients were finally enrolled. Table I shows the baseline demographic data of these patients.

Normal controls

In total, 32 nonathletic normal volunteers who had no history of major shoulder disorders were enrolled and agreed to participate in this study. The dominant arm of all normal volunteers was matched with the right (dominant) arm of the patients with shoulder instability.

Assessment of isokinetic muscle performance

Many investigators have reported that the time to peak torque and acceleration time reflect neuromuscular control.[3,24-27] In particular, these 2 factors are noninvasive and are not affected by the subcutaneous fat layer. Time to peak torque (in milliseconds [ms]) was defined as the time from the initial contraction to the peak torque, and acceleration time (in ms) was defined as the time from the initial contraction to the preset angular velocity (180°/s) during maximal muscle contraction. Higher values for time to peak torque and acceleration time indicated delayed neuromuscular control. Peak torque to body weight (in Nm/kg $\times$ 100) was measured to determine the muscle strength.[25,27] Muscle strength ratio (%) was measured to determine the reciprocal balance for the strength of the internal rotators (IRs) and external rotators (ERs).[13] Total work (J) was defined as the sum of all torque curves during the 15 repetitions for the IRs and ERs, and it was evaluated to determine muscle endurance[23,26] to estimate muscle fatigue.[18,26]

In this study, the IRs and ERs of the participants were evaluated using a quantified isokinetic device (Biodex Multi-Joint System 4; Biodex Medical Systems Inc., Shirley, NY, USA). The test was performed with the patient in an upright sitting position, and the rotational center of the GH joint and the rotational axis of the machine were aligned with the shoulder in 90° abduction, with the elbow joint flexed at 90°. Before the test, all patients performed a warmup exercise such as stretching or upper extremity cycling. The isokinetic tests were performed 15 times at a high speed of 180°/s for internal and external rotation (concentric–concentric contraction mode). All patients underwent the isokinetic muscle performance test 1 week before surgery and at the 1-year follow-up. The same value was used for the data before and after surgery in the normal control group.

Postoperative protocol

All patients participated in the postoperative rehabilitation for 12 weeks. The same rehabilitation protocol was used for all patients, which comprised shoulder immobilization with an abduction brace for 4 weeks after the A/S Bankart repair. At 4 weeks after operation, the brace was removed, and passive, active-assisted, and active range of motion exercise was gradually started for the patients. The exercise was increased gradually to restore the active full range of

Table I Demographic data of patients who underwent A/S Bankart repair and normal controls

	Instability group	Control group	*P* value
Sample size, n	32	32	
Sex, male/female, n	29/3	27/5	.345
Age, yr	25 ± 5	25 ± 1	.178
Height, cm	175 ± 5	173 ± 6	.376
Weight, kg	78 ± 16	71 ± 15	.210
Body mass index	25 ± 3	23 ± 4	.085
Dominant or injured side, right/left, n	32/0	32/0	
Sports and activity, low/high, n	21/11	18/14	.423

A/S, arthroscopic.
Unless otherwise noted, values are expressed as mean ± standard deviation.

motion by 12 weeks after the operation. At 8 weeks, patients began shoulder-strengthening exercises, including those for periscapular musculature. Shoulder-strengthening exercises in the 90° abduction position were allowed at 12 weeks after surgery. In addition to exercising, neuromuscular retraining was started from 6 weeks after surgery. After 12 weeks, the patients were recommended a home exercise program such as muscle strengthening, neuromuscular control, and proprioception exercises. Patients were allowed to return to noncontact sports at 6 months after surgery and gradually allowed unrestricted activities in sports.

Statistical analysis

Paired *t* test was used to compare the neuromuscular control index (time to peak torque and acceleration time), muscle strength ratio, muscle strength, and muscle endurance in the IRs and ERs between both shoulders of the patients in the shoulder instability group. Student *t* test was used to compare the means of independent variables in the IRs and ERs of both shoulders between the 2 groups. The Shapiro-Wilk test was used to determine whether a continuous variable followed a normal distribution. Correlations between neuromuscular control index, muscle strength ratio, muscle strength, and muscle endurance were assessed using Pearson coefficient of correlation. Statistical analysis was conducted using the SPSS software (version 21.0; IBM Corp., Armonk, NY, USA). A P value $<.05$ was considered significant.

Results

There were no significant demographic differences between the 2 groups. Detailed data are presented in Table I.

Shoulders that underwent A/S Bankart repair showed considerably improved neuromuscular control index (time to peak torque and acceleration time) and muscle endurance. However, there were no significant differences in the muscle strength ratio and the muscle strength of the operated shoulders before and after A/S Bankart repair (Fig. 1).

Compared with normal controls, nonathletic patients who underwent A/S Bankart repair showed significantly decreased neuromuscular control index (time to peak torque and acceleration time) on the operated shoulders (time to peak torque, 1059 ± 143 ms vs. 679 ± 226 ms for IRs, $P = .011$; 595 ± 286 ms vs. 379 ± 123 ms for ERs, $P = .044$, Table II; acceleration time, 75 ± 16 ms vs. 62 ± 15 ms for IRs, $P = .039$; 70 ± 19 ms vs. 54 ± 18 ms for ERs, $P = .047$, Table II).

There were no significant differences in the muscle strength and muscle strength ratio of the operated shoulders between patients who underwent A/S Bankart repair and normal controls (muscle strength, 48 ± 8 Nm/kg × 100 vs. 50 ± 5 Nm/kg × 100 for IRs, $P = .312$, and 29 ± 9 Nm/kg × 100 vs. 34 ± 6 Nm/kg × 100 for ERs, $P = .082$; muscle strength ratio, 64% ± 10% vs. 62% ± 8%, $P = .460$; Table III). However, patients who underwent A/S Bankart repair showed significantly lower muscle endurance on the operated shoulder than the normal controls (muscle endurance, 670 ± 1 J vs. 718 ± 2 J for IRs, $P = .002$; 422 ± 6 J vs. 501 ± 2 J for ERs, $P = .044$; Table III). On the nonoperated shoulder, there was no difference in the time to peak torque (IRs: $P = .646$, ERs: $P = .603$), acceleration time (IRs: $P = .982$, ERs: $P = .194$), muscle strength (IRs: $P = .405$, ERs: $P = .989$), muscle strength ratio ($P = .160$), and muscle endurance (IRs: $P = .120$, ERs: $P = .319$) of the IRs or ERs between patients who underwent A/S Bankart repair and normal controls (Tables II and III).

The correlations between neuromuscular control index (time to peak torque and acceleration time), muscle strength ratio, muscle strength, and muscle endurance are shown in Table IV. In the operated shoulders, there was a significant negative correlation between time to peak torque and muscle endurance of both the IRs and ERs ($r = -0.737$, $P = .003$, for IRs and $r = -0.617$, $P = .019$, for ERs). The acceleration time of both the IRs and ERs showed no significant correlation with muscle endurance ($r = 0.246$, $P = .396$, for IRs and $r = 0.020$, $P = .946$, for ERs). In nonoperated shoulders, significant correlations between time to peak torque and muscle endurance of both the IRs and ERs were identified ($r = -0.650$, $P = .012$, for IRs and $r = -0.549$, $P = .043$, for ERs). Acceleration time of the ERs showed significant negative correlation with muscle endurance ($r = -0.562$, $P = .037$); however, this was not evident for the IRs. In both operated and nonoperated shoulders, there were no significant correlations between the

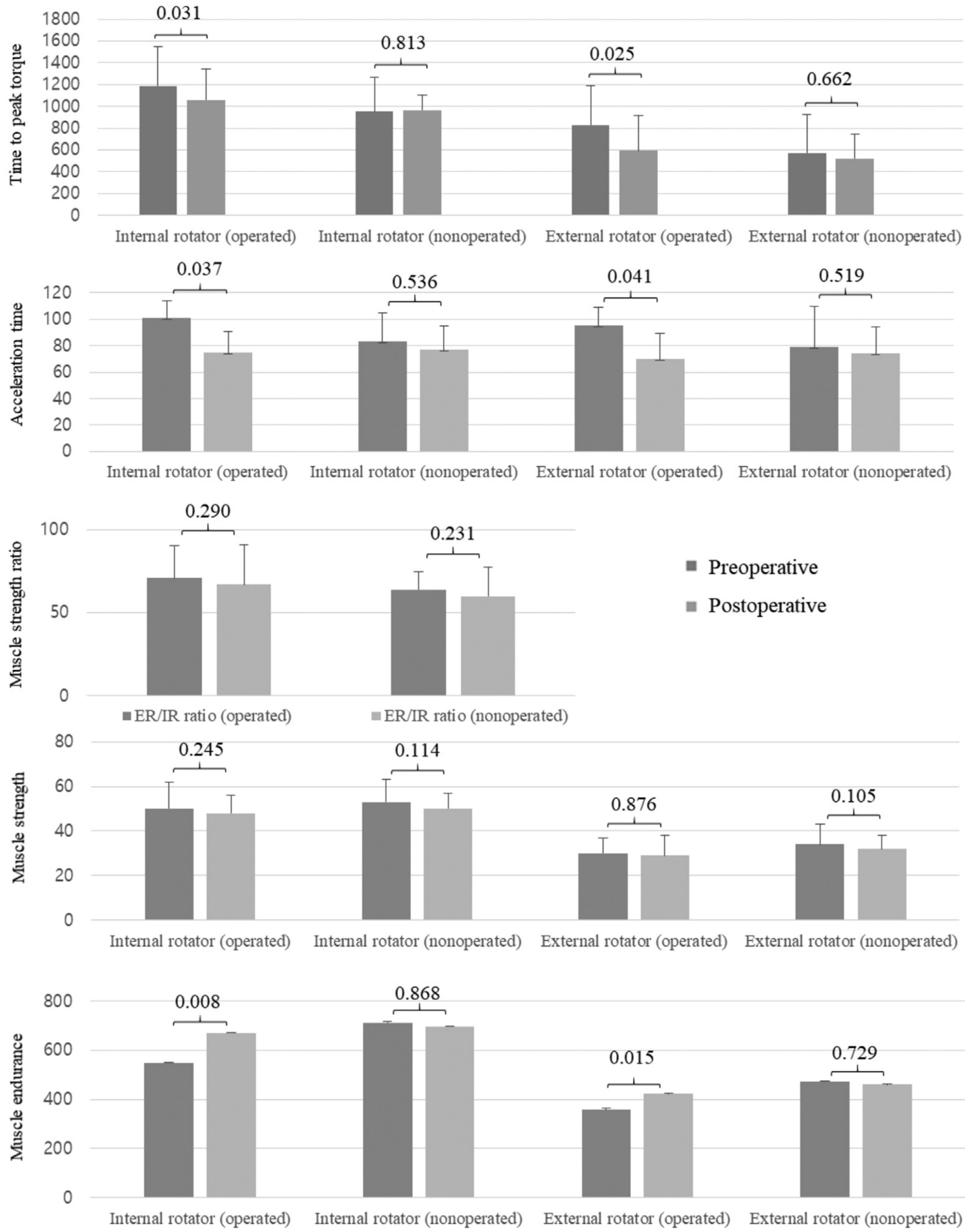

Figure 1 Time to peak torque, acceleration time, muscle strength ratio, muscle strength, and muscle endurance of the operated and nonoperated shoulders of patients in the shoulder instability group before and after surgery.

neuromuscular control index and muscle strength ratio and muscle strength of the IRs and ERs.

Discussion

The most important finding of the present study was that compared with normal controls, nonathletic patients who underwent A/S Bankart repair showed lower neuromuscular control and muscle endurance of both the IRs and ERs of the operated shoulders, even 1 year after the surgery. These findings suggest that recovery of the neuromuscular control system of the RC muscles may be a quite slow process, in contrast to the recovery of the muscle strength ratio and muscle strength.

Proprioception and neuromuscular control play an important role in the coordination and stabilization of the GH joint. A previous study[42] insisted that compared with 15 normal controls, 14 patients with shoulder instability who underwent A/S Bankart repair showed a sustained impaired proprioceptive function at 6 years after surgery.

Table II Time to peak torque and acceleration time of both shoulders between patients who underwent A/S Bankart repair and normal controls

	Preoperative						Postoperative					
	Operated shoulder			Nonoperated shoulder			Operated shoulder			Nonoperated shoulder		
	Instability group	Control group	*P* value	Instability group	Control group	*P* value	Instability group	Control group	*P* value	Instability group	Control group	*P* value
Time to peak torque												
IRs	1186 ± 259	679 ± 226	.007*	951 ± 311	833 ± 468	.621	1059 ± 143	679 ± 226	.011*	963 ± 274	833 ± 468	.646
ERs	829 ± 123	379 ± 123	.018*	571 ± 252	468 ± 211	.681	595 ± 286	379 ± 123	.044*	519 ± 225	468 ± 211	.603
Acceleration time												
IRs	101 ± 13	62 ± 15	.003*	83 ± 22	78 ± 25	.977	75 ± 16	62 ± 15	.039*	77 ± 18	78 ± 25	.982
ERs	95 ± 14	54 ± 18	.004*	79 ± 31	66 ± 15	.238	70 ± 19	54 ± 18	.047*	74 ± 20	66 ± 15	.194

A/S, arthroscopic; *IRs*, internal rotators; *ERs*, external rotators.
The values are expressed as mean ± standard deviation at 180°/s.
All measurement units are milliseconds (ms).
* Statistically significant ($P < .01$).

Table III Muscle strength ratio, muscle strength, and muscle endurance of both shoulders between patients who underwent A/S Bankart repair and normal controls

	Preoperative						Postoperative					
	Operated shoulder			Nonoperated shoulder			Operated shoulder			Nonoperated shoulder		
	Instability group	Control group	*P* value	Instability group	Control group	*P* value	Instability group	Control group	*P* value	Instability group	Control group	*P* value
Strength												
IRs	50 ± 12	50 ± 5	.988	53 ± 10	51 ± 10	.319	48 ± 8	50 ± 5	.312	50 ± 7	51 ± 10	.405
ERs	30 ± 7	34 ± 6	.124	34 ± 9	32 ± 7	.431	29 ± 9	34 ± 6	.082	32 ± 6	32 ± 7	.989
Muscle strength ratio	71 ± 19	62 ± 8	.108	67 ± 23	68 ± 11	.911	64 ± 10	62 ± 8	.460	60 ± 17	68 ± 11	.160
Endurance												
IRs	549 ± 1	718 ± 2	.001*	713 ± 4	706 ± 1	.942	670 ± 1	718 ± 2	.002*	697 ± 4	706 ± 1	.120
ERs	358 ± 3	501 ± 2	.001*	473 ± 2	466 ± 4	.178	422 ± 6	501 ± 2	.004*	460 ± 3	466 ± 4	.319

A/S, arthroscopic; *IRs*, internal rotators; *ERs*, external rotators.
The muscle strength ratio (%), muscle strength (Nm/kg × 100), and muscle endurance (J) are expressed as mean ± standard deviation at 180°/s.
* Statistically significant ($P < .01$).

Table IV Correlations between neuromuscular control index (time to peak torque and acceleration time), muscle strength ratio, muscle strength, and muscle endurance

Parameters	Operated shoulder				Nonoperated shoulder			
	Time to peak torque		Acceleration time		Time to peak torque		Acceleration time	
	PCC (*r*)	*P* value	PCC (*r*)	*P* value	PCC (*r*)	*P* value	PCC (*r*)	*P* value
Muscle strength ratio	0.089	.762	0.006	.984	0.233	.423	0.368	.195
Strength								
IRs	0.305	.289	0.013	.965	0.164	.576	0.205	.481
ERs	0.022	.941	0.291	.312	−0.029	.922	−0.197	.500
Endurance								
IRs	−0.737	.003*	0.246	.396	−0.650	.012*	0.487	.078
ERs	−0.617	.019*	0.020	.946	−0.549	.043*	−0.562	.037*

PCC, Pearson correlation coefficient; *IRs*, internal rotators; *ERs*, external rotators.
* Statistically significant.

The results of the present study agreed with this finding and showed that compared with normal controls, patients who underwent A/S Bankart repair showed significantly reduced neuromuscular control of the RC muscles, even 2 years after the surgery. This could be attributed to the insufficient recovery of the mechanoreceptors. Many previous studies have reported that the recovery of proprioception and neuromuscular control are related to the recovery of the mechanoreceptors,[34,43,44] including Ruffini endings, muscle spindles, Golgi tendon organs, and Pacinian corpuscles, and the re-formation of these mechanoreceptors was not restored at 1 year after the operation.[19] Another possible reason for the reduced neuromuscular control of the RC muscles may be insufficient dynamic retensioning of the capsuloligamentous structures in the 90° abduction shoulder position after A/S Bankart repair. Many investigators demonstrated that the capsuloligamentous structures become stiff to resist anterior humeral displacement in the 90° shoulder abduction position.[10,39,40] Pötzl et al[42] reported that retensioning of the capsuloligamentous structures may be possible for at least 5 years after A/S Bankart repair, which may affect the contraction of the RC muscles.[8,11] According to Myers et al,[35] dynamic capsular tensioning and cocontraction of the RC muscles play important roles in neuromuscular responses. Therefore, insufficient recovery of the mechanoreceptors and inadequate dynamic retensioning of the capsuloligamentous structures after A/S Bankart repair may lead to the improper neuromuscular control of the RC muscles.

A recent study[2] reported that although the muscle strength of both the IRs and ERs of the operated shoulders was not significantly different, compared with that of the nonoperated normal shoulders, the shoulders that underwent A/S Bankart repair showed significantly reduced muscle endurance at 2 years after the surgery. This finding was consistent with our results. However, the results of the present study also showed that compared with normal controls, patients who underwent A/S Bankart repair showed reduced muscle endurance but not muscle strength. Further, the results of the present study showed that there was a significant negative correlation between the neuromuscular control index and muscle endurance of both the IRs and ERs of the operated shoulders, but not with the muscle strength ratio and muscle strength. These findings indicate that impaired muscle endurance in nonathletic patients after A/S Bankart repair may affect their neuromuscular control system. Muscle endurance is defined as continued capability in response to repetitive muscle contraction activity[33,35]; thus, low endurance capability relates to muscle fatigue.[17] A previous study[35] reported that muscle fatigue may cause shoulder instability by affecting the muscle spindle system,[41] proprioceptive feedback, and the feed-forward system,[6] leading to changes in the neuromuscular response.[33,35] By contrast, impaired neuromuscular control can lead to joint instability,[37] which requires excessive muscle activity for joint stability, thereby resulting in increased muscle fatigue or reduced muscle endurance capability.[4] Thus far, the recovery of muscle strength was the first priority while assessing the extent of functional recovery after A/S Bankart repair; thus, muscle strength exercises were emphasized during rehabilitation after the operation. Based on the results of the present study, we believe that the recovery of muscle endurance may be important to improve neuromuscular control after A/S Bankart repair in nonathletic patients. Therefore, we recommend muscle endurance training such as low-intensity repetitive band exercises and neuromuscular control drills with or after the muscle-strengthening exercise to restore muscle endurance and neuromuscular control in the RC muscles over time after A/S Bankart repair.

This study has several limitations. First, we did not measure proprioception. However, the functional roles of proprioception and neuromuscular control are similar to those of the neural response by mechanoreceptors.[30,34,36] Second, our study may not adequately challenge the finding that there is no difference in the muscle strength ratio by concentric contraction in the isokinetic tests between nonathletic patients with A/S Bankart repair and normal control subjects. Edouard et al[13] reported that the conventional strength ratio (concentric ERs/concentric IRs) showed no difference between patients with anterior shoulder instability and normal control subjects. Although this finding is consistent with our results, the reliability of the conventional strength ratio is critically low.[14] Previous studies have suggested that eccentric rotation strength ratio (functional strength ratio) was an appropriate indicator for dynamic stability and prevention of injuries in the GH joint.[38,46] However, we did not measure the functional strength ratios, defined as the muscular ratios between the eccentric and concentric peak torques for the IRs and ERs during muscle contraction (eccentric ERs/concentric IRs and concentric ERs/eccentric IRs).[38,46] Therefore, further prospective studies focusing on functional strength ratios are necessary to more clearly elucidate the results of the present study. Third, we were unable to ascertain or confirm the adherence of the patients to the home exercise program such as neuromuscular retraining and proprioceptive exercise after completing the rehabilitation for 12 weeks in our institution. These exercises are particularly important to improve neuromuscular control.[29] Finally, for comparison with the shoulder instability group, the same values were used before and after surgery in the normal control group, because postoperative side-to-side comparisons may be misinterpreted in the determination of strength deficiency and recovery of RC muscles.[12] Thus, use of the same protocol by the same physiotherapist might minimize errors because of time differences.

Conclusion

Compared with normal controls, patients who underwent A/S Bankart repair failed to show complete recovery of neuromuscular control of both the IRs and ERs even 1 year after the surgery, although their muscle strength ratio and muscle strength had fully recovered. Therefore, clinicians and therapists need to focus on neuromuscular retraining and improvement of muscle endurance for the recovery of neuromuscular control in nonathletic patients with traumatic anterior shoulder instability who undergo A/S Bankart repair.

Disclaimer

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