Effects of a Shoulder Injury Prevention Strength Training Program on Eccentric External Rotator Muscle Strength and Glenohumeral Joint Imbalance in Female Overhead Activity Athletes

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Abstract

Imbalance of the eccentrically-activated external rotator cuff muscles versus the concentrically-activated internal rotator cuff muscles is a primary risk factor for glenohumeral joint injuries in overhead activity athletes. Nonisokinetic dynamometer based strength training studies, however, have focused exclusively on resulting concentric instead of applicable eccentric strength gains of the external rotator cuff muscles. Furthermore, previous strength training studies did not result in a reduction in glenoumeral joint muscle imbalance, thereby suggesting that currently used shoulder strength training programs do not effectively reduce the risk of shoulder injury to the overhead activity athlete. Two collegiate women tennis teams, consisting of 12 women, participated in this study throughout their preseason training. One team (n = 6) participated in a 5-week, 4 times a week, external shoulder rotator muscle strength training program next to their preseason tennis training. The other team (n = 6) participated in a comparable preseason tennis training program, but did not conduct any upper body strength training. Effects of this strength training program were evaluated by comparing pre- and posttraining data of 5 maximal eccentric external immediately followed by concentric internal contractions on a Kin-Com isokinetic dynamometer (Chattecx Corp., Hixson, Tennessee). Overall, the shoulder strength training program significantly increased eccentric external total work without significant effects on concentric internal total work, concentric internal mean peak force, or eccentric external mean peak force. In conclusion, by increasing the eccentric external total exercise capacity without a subsequent increase in the concentric internal total exercise capacity, this strength training program potentially decreases shoulder rotator muscle imbalances and the risk for shoulder injuries to overhead activity athletes.

Key Words shoulder injury risk, isokinetic dynamometry, overhead activity, athletes

Introduction

Tennis places high biomechanical demands upon the glenohumeral joint that have been estimated to be as great as 2 times a person's body weight during the overhead motion (1,8). As a result of such extreme, repetitively-applied forces, the concentrically activated internal rotator muscles have been found to significantly increase in strength. Strength of the eccentrically-activated external rotator muscles, however, does not increase proportionally to the increase in strength of the internal rotator muscles (2,12). These differential adaptations cause a shoulder rotator muscle imbalance, which has been found to increase the athlete's risk for shoulder injuries. Evidence for this causation was gathered via a correlational study of elite volleyball players in which Wang et al. (16) identified shoulder rotator muscle imbalance to be an independent predictor of subsequently occurring shoulder injuries ($P = 0.041$).

Because of the increased risk for shoulder injury due to a prevalent shoulder muscle imbalance, early intervention strength training programs that aim at reducing such imbalances are warranted. Among many suggested programs, The United States Tennis Association (USTA) endorses a set of strength training exercises that aim to prevent or reduce the severity of shoulder injuries (13). Currently, however, no nonisokinetic dynamometer based-strength training programs that can be readily implemented with minimal

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equipment and effort, have resulted in a significant decrease in injury rates or a decrease in a shoulder injury risk as illustrated by a decrease in shoulder rotator muscle imbalance (10,15). Furthermore, all available nonisokinetic dynamometer-based studies assessed concentric strength of the external rotator muscles only, but failed to evaluate the effects on eccentric strength of the external rotator muscles, the type of muscle activation observed in the deceleration phase of an overhead motion. Hence, this study aimed to assess the effects of a shoulder strength training program on the eccentric strength capacity of the external rotator muscles and subsequent glenohumeral joint imbalance in order to fill a gap in the knowledge of the effects of currently employed strength training and injury prevention programs (2,16).

Methods

Experimental Approach to the Problem

This study provides knowledge of the effects of an external shoulder rotator muscle strength training program on the concentric internal acceleration and eccentric external deceleration capacities of the serving arm throughout overhead motions.

A pretest-posttest, 2 group design involving 2 collegiate women tennis teams was employed. Both teams were pre- and posttested on an isokinetic dynamometer using 5 maximal eccentric external immediately followed by concentric internal contractions. Throughout this 5-week preseason study, one team (experimental group) participated in a specific shoulder strength training program next to their regular, 4 times a week preseason tennis training, while the other team (control group) conducted their regular preseason tennis training only and did not engage in an upper body strength training program. Tennis training programs of both teams were comparable in intensity and duration spent on overhead training, ground strokes, volleys, and match play. The effect of the strength training program was consequently assessed by analyzing for statistical differences in concentric internal and eccentric external total work capacity and mean peak force between the pre- and posttest by the experimental group versus the control group.

Subjects

One collegiate women varsity tennis team (n = 6) was recruited as an experimental group (Dominant Hand: 5 Right, 1 Left; Age: 20.0 ± 1.8 years, Height: 165.8 ± 7.1 cm; Weight: 71.5 ± 9.9 kg Playing Experience: 7.7 ± 4.4 years; USTA ranking = 3.3 ± 0.76). Another collegiate women varsity team (n = 6) was recruited as a control group (Dominant Hand: 6 Right; Age: 18.8 ± 0.8 years; Height: 162.3 ± 5.8 cm; Weight: 63.7 ± 18.0 kg; Playing Experience: 5.7 ± 1.0 years; USTA ranking = 3.25 ± 0.175). The two groups did not significantly differ in age, height, weight, playing experience, or USTA ranking as assessed by the team's coaches according to USTA self-ranking standards (11). None of the subjects had conducted any specific shoulder strength training 6 months prior to the study, had undergone shoulder surgery, or experienced shoulder pain within the last year. All subjects and coaches were briefed on the risks of the research project before signing informed consent forms and the study was approved by the Indiana University of Pennsylvania Institutional Review Board.

Procedures

All subjects completed a brief personal history form regarding date of birth, number of years played, arm used to serve as well as shoulder injury, and strength training history. Additionally, coaches were asked to rank their players according to the USTA self-ranking scale. A pretest of isokinetic shoulder strength of the dominant arm was performed using an isokinetic dynamometer–Kin-Com AP Muscle Testing System. Weight and height measurements were also taken.

A 5-week, 4 times per week, strength training program according to exercises outlined by Roetert et al. (13) was implemented with the experimental group as part of the teams' preseason training program. The strength training program was started within 3 days after the pretraining assessment. The control group on the other hand only conducted their normal preseason tennis training and did not participate in any regular strength training program. At the completion of the 5-week period, all subjects were posttested for isokinetic shoulder strength as well as body weight. Posttesting for the experimental group was conducted within 3 days after the last strength training session.

Assessing Isokinetic Shoulder Strength

An isokinetic was available at the Center for Health Promotion and Cardiac Disease Prevention at Indiana University of Pennsylvania (Figure 1). The pre- and postassessments of muscular strength with the Kin-Com engaged concentric internal and eccentric external total work and mean peak force assessments on the dominant shoulder. An angular velocity of 120°/second was selected based upon Wang and

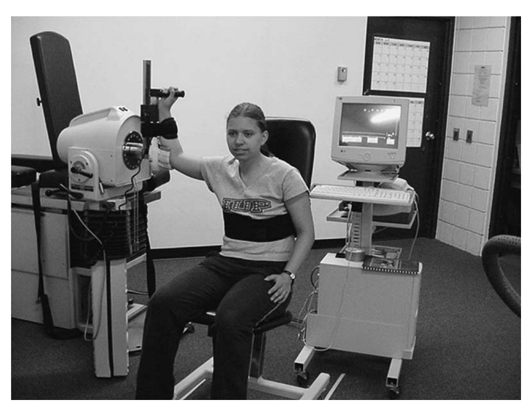

Figure 1. Kin-Com testing set-up.

Cochrane (16) and recommendations by Dvir (3) stating that medium testing velocities of up to 120°/second result in a decreased risk of injury as well as higher reproducibility of the data. Before testing, the subjects completed 10 passive contractions to familiarize themselves with the procedure and to aid in a specific neuromuscular warm-up. Throughout the assessments, the subjects were seated without the legs touching the ground. A waist strap was used to secure the trunk to the chair (Figure 1). This position was chosen since it isolates the shoulder rotator muscles by preventing recruitment of lower body muscles. Based on prior studies, the shoulder was abducted at 90° and the elbow was flexed at 90° (6,7,14,15). The elbow was then secured in a custom-made support for comfort. The range of motion was selected between 90° external rotation and 30° internal rotation to replicate an overhead serving motion. While the external range of motion was chosen based on prior studies (5,6,10), the internal range of motion was selected according to assessed passive range of motion limits that were as low as 30° for some of the subjects. Hence, greater internal range of motion during isokinetic testing would have increased the risk of injury to the subjects and was consequently avoided. Imitating the sequence of muscle involvement in a serve, concentric internal rotation was always tested first, immediately followed by eccentric external rotation. Subjects each performed 5 maximal contractions on both sides. Zero Newton mechanical preloading force and minimal force was established. Gravity compensations were not included in any parameters.

Strength Training Program

A 5-week, 4 times weekly, strength training program was implemented at the Indiana University of Pennsylvania James G. Mill Center for Health & Fitness. Exercises, according to Roetert et al. (13), included External Rotation 90°, Seated Row, Scaption, Chest Press, and External Shoulder Rotation (Rubber tubing). The 4 times weekly strength training session took place before a 1-hour tennis workout, 3 times weekly, and 1 time after a 1-hour tennis workout. Prior to each strength training session, subjects completed a 5-minute low intensity warmup on a dual-action stationary bike. For each exercise, 3 sets of 15 repetitions were conducted. Each repetition took about 2 seconds and the subjects had a rest period of 1 minute in between each set. Initial weights were chosen based on pilot data obtained 1 day prior to the first workout. Fifty percent of their 5 repetition maximum was selected as the initial training intensity. This allowed the subjects to complete three sets of 15 repetitions for each of the 5 selected resistance exercises. Once the subjects were able to perform 15 repetitions of the third set comfortably on 2 consecutive training days, the weight was increased to the next higher available resistance, which was usually in 5-pound increments. The External Rotation exercise consisted of rubber tubing called Thera-bands. Bands were 4 feet in length and attached to the side wall. Subjects grabbed the band, twisting it once around their hand, then placed the band about waist height and stood sideways, holding the band close to abdomen with little resistance on the band while in the resting position. They rotated the hand and forearm away from abdomen until they are straight out in front. Different color tubing represented different weight increments.

All subjects in the experimental group recorded their strength training data during the 5-week period.

Statistical Analyses

The data obtained from the isokinetic dynamometer were analyzed for eccentric external and concentric internal total work and mean peak force performed as well as present shoulder rotator muscle imbalances, which in this study was defined as an eccentric external total work capacity that was less than the concentric internal total work capacity. Paired t tests ($P \leq 0.05$) were used to compare mean differences between pre- and posttest data for the separate experimental and control groups, and independent samples t tests ($P \leq 0.05$) were used to compare mean differences of changes by the experimental versus the control group. All p values reported in this study were one-tailed values since only strength gains, but not strength losses, were expected to be observed as a result of the strength training program. Results are summarized as means ± standard deviations.

Results

The 5-week strength training program demonstrated statistical significant gains in eccentric external total work performed by the experimental group versus the control group ($P = 0.017$). Concentric internal total work performed, concentric internal mean peak force, and eccentric external mean peak force did not change. Relative changes in eccentric external/concentric internal total work ratios resulted in a tendency to decrease for the control group and to increase for the experimental group ($P = .077$) (Table 1).

A total of 3 subjects within the experimental group were found to have shoulder rotator muscle imbalances–an eccentric external/concentric internal total work ratio ≤1.0–at the time of pre-assessment. Of those 3 subjects, all displayed total work ratios ≥1.0 at postassessment. In contrast, 2 subjects of the control group exhibited an eccentric external/concentric internal total work ratio ≤1.0 at pretesting, and 2 subjects exhibited a ratio ≤1.0 at posttesting.

Discussion

This study is the first to assess the effects of a nonisokinetic dynamometer-based strength training program on eccentric strength of the external shoulder rotator muscles, hence providing a more accurate picture of the type of strength gains that are applicable to the overhead activity athlete. In contrast to similar studies that assessed concentric strength of the external rotator muscles and that did not result in a decrease in shoulder rotator muscle imbalance, this shoulder strength training study resulted in a decrease in shoulder rotator muscle imbalance (Table 1).

TABLE 1. Mean Pre- and Post-testing total work and mean peak force.

	Concentric internal total work (J)	Eccentric external total work (J)‡	Eccentric external/concentric internal total work ratio	Concentric internal mean peak force (N)	Eccentric external mean peak force (N)
Control Group					
Pre-test	53.54 ± 14.20§	75.43 ± 44.67	1.55 ± 1.27	40.30 ± 8.51¶	53.25 ± 30.90
Range	35.99 – 67.21	33.94 – 155.58	0.61 – 4.08	29.6 – 55.0	26.2 – 113.0
Post-test	68.75 ± 36.57¶	85.72 ± 53.07¶	1.25 ± 0.29	44.27 ± 18.28	58.74 ± 29.43
Range	30.16 – 118.69	37.1 – 170.99	0.89 – 1.66	23.8 – 66.2	28.6 – 94.4
Experimental Group					
Pre-test	89.09 ± 18.16§	96.16 ± 37.13*	1.08 ± 0.39	50.23 ± 5.86¶	59.02 ± 11.98†
Range	71.88 – 122.55	37.95 – 136.88	0.48 – 1.57	42.2 – 58.2	41.0 – 69.6
Post-test	128.22 ± 65.60¶	170.99 ± 72.98*¶	1.43 ± 0.31	63.23 ± 20.77	76.53 ± 19.28†
Range	43.97 – 201.54	89.8 – 272.85	1.15 – 2.04	40.8 – 88.4	53.2 – 101.2

*Pre and post values within group are significantly different ($P \leq 0.01$).
†Pre and post values within group are significantly different ($P \leq 0.05$).
‡Changes in Pre- and Posttraining values within the control vs. the experimental group are significant ($P \leq 0.05$).
§Control vs. experimental group are significant different ($P \leq 0.01$).
¶Control vs. experimental group are significantly different ($P \leq 0.05$).

The general decrease in eccentric external to concentric internal total work ratio observed within the control group over the 5-week period was due to an increase in concentric internal total work that was 50% higher than the increase in eccentric external total work performed. This observation reflects previous findings that internal rotator strength increases as an adaptation to frequent play, whereas external rotator strength does not increase proportionally (2,5,6). In contrast, the fact that eccentric external total work performed by the experimental group significantly increased compared to the control group, indicates that the strength training successfully targeted the external rotator muscles. Moreover, contrary to the strength training program by Treiber et al. (15), which resulted in a relative decrease in external to internal peak torque ratio, and that by Moncrief et al. (10) which did not show a change in external to internal peak torque, this study showed a relative increase in the eccentric external to concentric internal total work ratio of 14% ($P < 0.08$; Table 2).

The authors find this difference in results to be due to the contraction mode used to assess the effects of the strength training program. In contrast to Treiber et al. (15) and Moncrief et al. (10), who employed concentric internal and concentric external contraction modes, this study assessed concentric internal and eccentric external muscle strength (Table 2). Assessment modes were chosen to replicate the eccentric contraction of the external rotator muscles during the deceleration phase of the tennis serve. Therefore, this study is not only the first to show a decrease in shoulder rotator muscle imbalance due to a nonisokinetic dynamometer strength training program in women, but it can provide an experimental design that can assess a more applicable picture of the effects of a rotator cuff strength training program on tennis-specific strength.

Evidence for the assumption that differences in outcomes are due to the contraction mode used throughout the assessment comes from a study by McCarrick and Kemp (9), who found that as a result of rotator cuff muscle strength training, concentric and eccentric internal total work and eccentric external total work, but not concentric external total work, significantly increased. This suggests that the rotator cuff exercises work the external rotator muscles only in an eccentric but not in a concentric manner. Hence, it can be suggested that this study, which employed eccentric external contractions, in contrast to other studies (10,15) that employed concentric external contractions, demonstrated significant results due to its contraction testing mode in female tennis players (Table 2).

Given the frequency of shoulder muscle strength imbalances in tennis players (4), and the success this strength training program had in reducing existing shoulder rotator muscle imbalances, this study is the first to support the use of currently implemented shoulder strength training programs recommended to decrease the risk of shoulder injuries to female overhead activity athletes.

Solely based on previous studies by Moncrief et al. and Treiber et al. (10,15), that assessed concentric strength of the external rotator muscles and did not result in a decrease of shoulder rotator muscle imbalance, there was no evidence to support the effectiveness of rotator cuff exercises for shoulder injury prevention. Finally, while this ascertained the effectiveness of the employed rotator cuff strength training

Table 2. Comparison of the effects of shoulder strength training programs.

	Treiber et al. (1998)	Moncrief et al. (2002)	Niederbracht et al. (2007)
Subjects	22 collegiate tennis players (12 men, 10 women; skill 4.9)	34 college students	12 female collegiate tennis players (Div II / NAIA)
Design	Two-group	One-group	Two-group
Testing apparatus*	Cybex 6000	LIDO Multi-Joint	Kin-Com
Contraction mode	Concentric internal/ concentric external	Concentric internal/ concentric external	Concentric internal/ eccentric external
Sets/Speed	3 max at 120 deg/s; 15 max at 300 deg/s	5 max at 120 deg/s; 5 max at 180 deg/s	20 max at 120 deg/s
ROM	N/A	90° external 45° internal	90° external 30° internal
Program Duration	3 × / week; 4 weeks	5 × / week; 4 weeks	4 × / week; 5 weeks
Sets	4 × 20	2 × 15	3 × 15
Exercises	A/B) Internal and external rotation with the shoulder in 90° of abduction in the coronal plane with a Theraband elastic tube C) Scaption	A) External rotation in the prone position (Arm 90° abducted, elbow flexed at 90) B) External rotation side lying C) Scaption D) Prone horizontally abduction with the arm externally rotated E) Prone Shoulder Extension	A) External rotation 90° B) Seated Row C) Scaption D) Chest Press E) External shoulder rotation (Rubber tubing)
Results	Significant increases in internal (23.8%) and external rotation (17.0%) peak torque/body weight; Relative decline in external/internal ratio at 300 deg/s ($P < 0.08$)	Comparable increases in internal and external rotation, approximately 8–9%	NS in internal/external peak torque changes; Significant increase in external rotation total work (66%); NS increase in internal rotation total work (27); NS increase in external/internal total work ratio ($P < 0.08$) (14%)

*All studies conducted with the arm abducted at 90° and the elbow flexed at 90°.

program, further research is warranted to identify gender differences, effects of a longer duration strength training program, possible physiological mechanisms responsible for the imbalance corrections, and clarifications to the degree of maintenance of those newly-obtained strength gains in subsequent repetitions as observed throughout a regular tennis match, as well as the possibility of maintaining strength gains throughout the competitive playing season.

Practical Applications

This study is the first to show that shoulder rotator cuff exercises can result in a decrease in shoulder rotator muscle imbalances as assessed by concentric testing of the internal rotator muscles and eccentric testing of the external rotator muscles in women. In contrast to the commonly employed concentric testing of the external rotator muscles, this study assessed muscular strength gains through the type of muscle recruitment that actually does occur in an overhead activity. As a result, this study validated the use of currently employed shoulder strength and injury prevention training programs, in order to decrease shoulder rotator muscle imbalance and the risk of shoulder injury to the overhead women athletes. This study further emphasizes the importance of assessing muscle strength through a mode of muscle recruitment that is identical to the one employed in the athletes' sport. Lastly, this study showed that shoulder strength balance can be altered with a strength training program as short as 20 sessions in women, which appeals to players and coaches of overhead activities due to the limited time available to conduct an extensive strength training program throughout the year.

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