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original research

Asymptomatic Elite Adolescent Tennis Players' Signs of Tendinosis in Their Dominant Shoulder Compared With Their Nondominant Shoulder

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Context: Tennis is an asymmetric overhead sport with specific muscle-activation patterns, especially eccentrically in the rotator cuff. Magnetic resonance imaging (MRI) findings in asymptomatic adolescent elite tennis players have not previously been reported.

Objective: The first aim of the study was to describe MRI findings regarding adaptations or abnormalities, as well as muscle cross-sectional area (CSA), of the rotator cuff. The second aim of the study was to investigate the rotator cuff based on the interpretation of the MRI scans as normal versus abnormal, with the subdivision based on the grade of tendinosis, and its association with eccentric rotator cuff strength in the dominant arm (DA) of the asymptomatic elite adolescent tennis player.

Setting: Testing environment at the radiology department of Medicinsk Röntgen AB.

Patients or Other Participants: Thirty-five asymptomatic elite tennis players (age = 17.4 ± 2.7 years) were selected based on ranking and exposure time.

Intervention(s): We assessed MRI scans and measured the CSA of the rotator cuff muscle. The non-DA (NDA) was used as a control. In addition, eccentric testing of the external rotators of the DA was performed with a handheld dynamometer.

Results: The DA and NDA displayed different frequencies of infraspinatus tendinosis (grade 1 changes) ($P < .05$). Rotator cuff measurements revealed larger infraspinatus and teres minor CSA ($P < .05$) in the DA than in the NDA. Mean eccentric external-rotation strength in the DA stratified by normal tendon and tendinosis was not different between groups ($P = .723$).

Conclusions: Asymptomatic adolescent elite tennis players demonstrated infraspinatus tendinosis more frequently in the DA than in the NDA. Clinicians must recognize these tendon changes in order to modify conditioning and performance programs appropriately.

Key Words: magnetic resonance imaging, adolescents, overhead athletes, tennis

Key Points

- Grade 1 tendinosis of the rotator cuff in the asymptomatic adolescent elite tennis player appeared almost exclusively in the dominant arm and more frequently in the infraspinatus tendon.
- Recognition of these early changes is important so that technical instructions, conditioning and performance programs, and exposure times can be modified to prevent progression to symptomatic rotator cuff problems.

The increasing demands required to enter the highest adult elite level in any sport necessitate enormous amounts of training during adolescence. Tennis is no exception and has become, from a physical perspective, one of the most challenging sports worldwide. In view of the early specialization that has become more common, the overall exposure time in tennis today is greater for adolescent players before they reach the professional level. This could possibly explain the frequent presence of overuse injuries, especially in the upper extremity.[1] Tennis is an asymmetric sport with specific muscle-activation patterns, especially eccentrically in the supraspinatus, infraspinatus (IS), and teres minor (TM) during the complex and rapid serving motion.[2] As a result of the large demands on joint mobility, muscle strength, and complex biomechanics in the shoulder girdle during overhead sport movements, sport-specific adaptations at the glenohumeral and scapulothoracic level may occur even during adolescence.[3,4] Radiologically detectable adaptations and abnormalities in asymptomatic athletes have previously been reported.[5–7] Although findings such as these might not initially be associated with clinical symptoms, sports medicine professionals must recognize these changes to prevent progression into the continuum of symptomatic rotator cuff injury.

Shoulder injuries occur often in overhead athletes at various levels of competition.[8] Common shoulder injuries associated with repetitive throwing include tendinosis of the rotator cuff, glenohumeral instability, subluxation, and

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stress-related injury to the proximal humerus (also known as Little League shoulder).[9]

Most shoulder injuries are thought to occur during the arm-cocking and arm-deceleration phases. In particular, the external rotators are highly loaded eccentrically during the deceleration phase by resisting shoulder internal rotation and horizontal adduction.[10,11] In specific sports, such as tennis, elite players without shoulder injury have demonstrated shoulder-rotation muscle-strength imbalances that alter the ratio among the rotator cuff muscles.[12] Although these differences do not seem to immediately affect athletic performance, decreased external-rotation strength has been identified as a risk factor for shoulder pain in overhead athletes.[13] Therefore, detection and prevention with exercise programs at an early age are recommended

Internal impingement is one of the most common shoulder injuries seen in overhead athletes.[14,15] Walch et al[16] were the first to describe posterosuperior impingement, referring to a specific position in the throwing motion, with the shoulder in 90° of abduction and maximal external rotation. In this position, the posterior fibers of the supraspinatus and anterior fibers of the IS come in contact between the humerus and the posterior superior labrum.[5,17] As these areas make contact, fraying of the undersurface of the supraspinatus and IS tendons can occur and cause injury.[18] Although this adaptation might be physiologic, repeated throwing has been shown to lead to articular-side tears of the rotator cuff.[5,17] In an arthroscopic study of 41 symptomatic professional athletes, 93% had undersurface fraying of the rotator cuff tendons, thus supporting the theory of internal impingement as a factor in injury.[19] Similar findings were reported by Walch et al[16] in their study of 17 overhead athletes; 76% had evidence of undersurface rotator cuff tears. In addition, partial-thickness tears from tendon overload most often develop on the intra-articular side of the cuff and not on the bursal side.[20]

Magnetic resonance imaging (MRI) is a widely used, clinically relevant modality in the evaluation of the shoulder, especially when assessing the elite overhead athlete.[6,7,9,21,22] The aim of MRI is to identify injury; therefore, it is essential to investigate the spectrum of normal anatomic structures to accurately detect and characterize pathologic changes.[6,7,9,17,21–23] Knowledge of overhead-throwing biomechanics is crucial to understanding specific injuries encountered on diagnostic imaging in throwing athletes.[24]

Miniaci et al[7] used MRI to evaluate the supraspinatus and IS in both shoulders of asymptomatic professional baseball pitchers and showed no differences between the dominant arm (DA) and nondominant arm (NDA). However, Jost et al[6] identified abnormal MRI findings in 93% of DA throwing shoulders; of these, only 37% were symptomatic. In addition, MRI evidence of rotator cuff abnormality was present in 40% of the throwing shoulders in young asymptomatic overhead athletes compared with none (0%) of the nonthrowing shoulders.[5]

It is well established that muscle strength has a direct relationship with muscle cross-sectional area (CSA). Muscle CSA has been assessed for several reasons previously described in the literature, and MRI is considered the gold standard for in vivo estimation of muscle CSA.[25,26]

Starting a sport at an early age might lead to adaptive or abnormal changes, and the rotator cuff in asymptomatic adolescent elite tennis players should be evaluated, as has been done in baseball players.[5] Strength, measured with a handheld dynamometer (HHD), has also been described in this population.[27]

To our knowledge, no study has been published describing MRI findings in the rotator cuff of asymptomatic adolescent elite tennis players or such findings in association with eccentric rotator cuff muscle strength assessed with an HHD. Therefore, the first aim of the study was to describe adaptations or abnormalities on MRI, as well as muscle CSA of the rotator cuff. The second aim was to investigate the rotator cuff based on the interpretation of the MRI scans as *normal* versus *abnormal*, with the subdivision based on the grade of tendinosis, and its association with eccentric rotator cuff strength in the DA of the asymptomatic elite adolescent tennis player.

METHODS

The study was an independent complement to the high-performance program conducted by the Swedish Tennis Federation and was approved by the regional ethical review board. Informed consent was obtained from all players and their parent or legal guardian.

Participants

The study sample consisted of young elite tennis players from the Swedish national team. It was a convenience sample based on national ranking and national recommendations of exposure time in training and match. Exclusion criteria were a history of any shoulder injury or symptoms in the previous 3 months that resulted in rest from training or competition for more than 1 week. In our sample were 35 elite tennis players: 15 males and 20 females (age = 17.4 ± 2.7 years, height = 174.1 ± 9.9 cm, body weight = 67.9 ± 9.8 kg). Twenty-nine players were right handed, and 6 were left handed. All players except 3 played the 2-handed backhand. The players participated in training for 12–20 hours a week, depending on age, in line with the national recommendations for adolescent elite players; they played 100–120 matches per year nationally and internationally at the time of inclusion in the study. Both shoulders underwent MRI analysis, with the NDA used as the control.

Overall Procedure

All tests were performed on 2 consecutive days, with both tests for each player within a 1-day timeframe. We chose the timeframe of 1 day to guarantee measurements of strength and imaging under similar conditions for each player. For all players, the strength measurement and MRI were separated by a few hours, so the influence of the first test on the second was eliminated.[28] Between tests, the players did not perform any athletic activity.

Imaging Technique

Imaging was carried out on a 3.0-Tesla MRI system (Philips USA, Andover, MA) with a dedicated 2-channel shoulder coil. Coronal oblique images were obtained using a fat-saturated T2-weighted sequence, 3-mm-slice thick-

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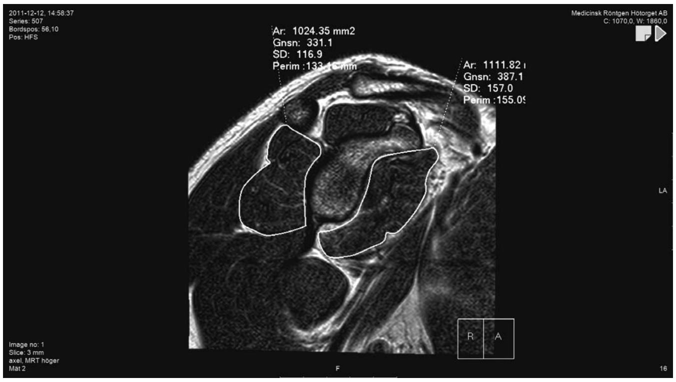

Figure 1. Measurement of the muscle cross-sectional area.

Figure 2. Infraspinatus muscle. *Grade 0* was defined as a tendon that was normal in signal intensity and morphology.

ness, and a field of view of 160 mm covering the rotator cuff muscles from anterior to posterior. Sagittal oblique images were obtained using a fat-saturated proton-density weighted sequence together with a nonfat-saturated T2-weighted sequence, both with 3-mm-slice thickness and a field of view of 130 mm. The sagittal oblique sequences were obtained from the Y view, showing the base of the coracoid process and the spine of the scapula medial to the insertion of the supraspinatus tendon laterally. Axial images were obtained using a fat-saturated proton-density weighted sequence with 3-mm-slice thickness covering the whole glenoid with a 150-mm field of view.

Imaging Assessment

All MRI scans were reviewed by 2 fellowship-trained musculoskeletal radiologists, according to a predefined protocol, who came to consensus. The radiologists were blinded to arm dominance and the data collected from the HHD eccentric testing. Images were specifically reviewed for the presence of rotator cuff tendinosis and rotator cuff lesions.

Imaging Assessment

Measurements of the muscle CSA (Figure 1) were performed on a single slice in a sagittal oblique non–fat-saturated turbo spin-echo T2-weighted sequence for the subscapularis (SSc), IS, and TM muscles where they cross the base of the coracoid process. Slice thickness was 3 mm with 0.5-mm intervals and a 0.25 $\times$ 0.25 pixel size, repetition time = 5500 milliseconds, and echo time = 80 milliseconds.

Because our aim was to compare the muscle CSA of the internal (SSc) and external (IS and TM) rotator cuff muscles, the IS and TM were evaluated as 1 muscle group (IS/TM) in accordance with previous protocols.[25,29]

Classifications of Tendons

The rotator cuff tendons were carefully scrutinized and subclassified into 1 of 4 grades. *Grade 0* was defined as a tendon that was normal in signal intensity and morphology (Figure 2). *Grade 1* was defined as a tendon with focal or diffuse high–signal-intensity tendinosis (Figure 3). *Grade 2* was defined as a tendon with abnormal signal intensity and morphology: a partial tear. *Grade 3* was defined as a tendon with increased signal of the tendon and a fluid-filled discontinuity: a full-thickness tear. These grades are similar to classifications described earlier.[30,31]

Handheld Dynamometer Testing Procedure

The testing setup consisted of an HHD (CompuFET; Hoggan Scientific, LLC, West Jordan, UT) with additional software program and a standard chair.

For the testing with the HDD, the participant was in a seated position and held the elbow and shoulder in 90° of abduction and 90° of external rotation (90°–90°) with gentle support from the examiner's hand. The HHD was positioned 2 cm proximal to the styloid process of the ulna and placed on the dorsal side of the forearm. On the counting of the investigator, which was controlled by a metronome, the participant performed a maximal external-rotation force while the investigator pushed the arm from external rotation (90°–90°) to 90° of abduction into neutral rotation (90°–0°; Figure 4). The players performed 3 sets of eccentric loading separated by 30 seconds of rest. This test of standardized eccentric rotator cuff strength in the clinical setting showed good to excellent reliability and validity between the HHD and isokinetic device in a population-based sample of healthy participants.[32] The eccentric testing with the HHD of the external rotators was performed only on the DA because the aim was to evaluate the external rotators in the sport-specific movement.

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Figure 3. **Infraspinatus muscle. *Grade 1* was defined as a tendon with focal or diffuse high–signal-intensity tendinosis.**

Statistical Analysis

Three sets of dependent variables were analyzed: (1) diagnostic interpretation of the MRI scans as *normal* versus *abnormal*, with the subdivision based on the grade of tendinosis; (2) CSA (in cm^2), measured on both sides for SSc and IS/TM; and (3) eccentric muscle strength for the external rotators (in N) on the dominant side. Data were analyzed using SPSS statistical software (version 21; IBM Corporation, Armonk, NY).

Magnetic resonance imaging findings were presented as frequencies and proportions with 95% confidence intervals. The Wilcoxon test was used for paired groups. The muscle CSA data were normally distributed according to a Kolmogorov-Smirnov test, so we used parametric statistics. Comparisons between sides and groups were analyzed with a general linear model 2-way analysis of variance, in which the within-subject factor was side (DA versus NDA) and the between-subjects factor was group (group with MRI findings of tendinosis versus normal tendons group). In the analysis of variance, 2-way interactions (side × group) were of primary interest. In the absence of interaction effects, main effects (for side or group) are presented. When interaction effects were significant, we conducted post hoc analyses using the Bonferroni procedure.

Group comparisons regarding eccentric strength testing with HHD were analyzed with an independent Student *t* test. Group comparisons were based on the presence of an IS tendinosis (IS tendinosis group: n = 10; normal tendons group: n = 25). For all statistical analysis, the α level was set at .05 (2 tailed).

Figure 4. Eccentric testing of the external rotators with the handheld dynamometer.

RESULTS

Magnetic Resonance Imaging Findings

Grade 0 and grade 1 tendon signal characteristics of the rotator cuff are presented in Table 1. In the DA, 16 tendinosis changes were found in the IS (n = 10), supraspinatus (n = 5), and SSc (n = 1) compared with 1 (n = 1) change in the supraspinatus tendon of the NDA. The IS tendinosis differed between the DA and NDA ($P = .002$). No tendons were classified as displaying grade 2 or 3 changes in our asymptomatic study sample.

Muscle CSA

Results of rotator cuff (RC) muscle CSA measurements for the SSc and IS/TM in the DA and NDA for the whole group are presented in Table 2. The descriptive data for the muscle CSA measurements of SSc and IS/TM stratified by normal tendons group and tendinosis group for both sides and both groups are displayed in Table 3.

Comparing the grade 1/IS tendinosis group (n = 10) with the normal tendons group (n = 25) revealed a main effect for group for the SSc muscle CSA ($P = .027$; Table 3). We also observed a main effect for side for the IS/TM muscle CSA ($P = .02$; Table 2). No significant interaction effect was observed for group × side for SSc CSA or IS/TM muscle CSA.

Mean eccentric external-rotation strength measurements using the HHD in the DA stratified by IS grade 0/normal (125.3 ± 29.9 N) and IS tendinosis (121.4 ± 26.2 N) showed no differences between groups ($P = .723$).

DISCUSSION

To the best of our knowledge, we are the first to investigate MRI findings in the shoulders of asymptomatic adolescent elite tennis players. The major finding of the

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Table 1. Frequencies of Signal Characteristics of the Rotator Cuff Tendons for the Dominant Arm and Nondominant Arm

	Dominant (n = 35)				Nondominant (n = 35)				
	Normal Tendons		Tendinosis		Normal Tendons		Tendinosis		
Tendon	n	Proportion, % (95% CI)	n	Proportion, % (95% CI)	n	Proportion, % (95% CI)	n	Proportion, % (95% CI)	*P* Value[a]
Infraspinatus	25	71 (56, 86)	10	29 (14, 44)	35	100 (0, 20)	0	0	.002
Supraspinatus	30	86 (74, 97)	5	14 (3, 26)	34	97 (0, 20)	1	3 (−3, 8)	.1
Subscapularis	34	97 (92, 103)	1	3 (−3, 8)	35	100 (0, 20)	0	0	.3
Teres minor	35	100 (0, 20)	0	0 (0 to 20)	35	100 (0, 20)	0	0	>.99

Abbreviation: CI, confidence interval.
[a] Wilcoxon test ($P < .05$).

study is that asymptomatic adolescent elite tennis players showed more tendinosis in the IS of the DA compared with the NDA. In addition, the IS/TM muscle CSA measurement was larger on the dominant side, as expected due to repetitive loading. However, no correlation between tendinosis and eccentric external-rotation strength was found.

Similar findings of changes in the rotator cuff tendons of asymptomatic athletes have been shown in previous MRI studies of tennis players and baseball pitchers.[7,21] Miniaci et al[7] evaluated the MRI findings in both shoulders of asymptomatic professional baseball pitchers, noting abnormal tendons (grade 1) in 86% of the throwing shoulders. Connor et al[21] investigated asymptomatic shoulders of elite overhead athletes (12 college baseball pitchers and 8 professional tennis players); 40% of the dominant shoulders had findings consistent with partial-thickness or full-thickness tears of the rotator cuff. However, the participants in those studies were older (means = 20.1 and 33.1 years, respectively) than in our study sample (mean = 17.4 years). Zbojniewicz et al[33] recently examined symptomatic adolescents and concluded that rotator cuff tears can be identified during MRI examination and often consist of tear patterns associated with repetitive microtrauma from overhead athletic activities or a single traumatic event. Rotator cuff tears are seen throughout the range of skeletal maturity and are typically found in athletes. Therefore, our results suggest that there might be premature degeneration of these tendons due to tensile or torsional forces in the overhead motion.

The literature indicates that the demands of overhead throwing sports, which require the athlete's shoulder to be in the position of abduction and maximal external rotation, increase the risk for internal impingement. Considering the underlying mechanism of internal impingement, our findings might strengthen the theory that the repetitive overhead-throwing motion creates overuse and fraying of the tendons in the DA, presenting as early grade 1 tendon changes in our participants. However, although abnormalities seem to be common in this population, none of our players were symptomatic and none had any recent history of shoulder injury. Therefore, clinicians should be cautious when interpreting tendon changes or other abnormalities that are not necessarily related to clinical symptoms.[5,7,18]

With respect to strength measurements, our data do not support an association between grade 1 tendon changes/tendinosis on MRI and decreased rotator cuff strength in the DA. Ellenbecker and Roetert[3] demonstrated a lower ratio between the external and internal rotators in the DA shoulders of tennis players. Because our players demonstrated no differences in eccentric strength of the external rotators stratified by the normal tendons group and tendinosis group, we conclude that our participants produced the same amount of eccentric force with or without tendon changes. Yet the mechanical stimuli eliciting adaptations may be different for tendon than for muscle tissue.[34] Therefore, it may be argued that our findings might be related more to mechanical tendon stress and adaptation than to abnormality. This reasoning can be supported by the fact that development of muscle strength and tendon mechanical and morphologic properties in adolescent athletes is often imbalanced.[35] Taking all variables into account regarding muscle CSA and eccentric strength, we showed no difference even though many players presented with tendinosis on MRI. Thus, it is reasonable to argue that these tendon changes might reflect a possible risk for injury, although at present, our data do not support this suggestion.

LIMITATIONS AND FUTURE STUDIES

Some limitations of this study should be addressed. The tennis players who underwent MRI were relatively young and at the start of their professional careers. Hence, our findings may not fully represent the spectrum of abnormalities and adaptations that could be present among all senior tennis players. A prospective longitudinal study is mandatory to identify which findings are precursors of future injuries and which represent normal signal changes as a result of the athlete's specific activity. The lack of eccentric data for the NDA could be a limitation, so future

Table 2. Descriptive Analysis for Muscle Cross-Sectional Area Measurements in the Dominant Arm and Nondominant Arm Presented as Whole Group (n = 35)

	Muscle Cross-Sectional Area, cm² (Mean ± SD)		
Tendon: All Participants	Dominant Arm (n = 35)	Nondominant Arm (n = 35)	95% Confidence Interval
Infraspinatus/teres minor[a]	1.04 ± 0.23	0.97 ± 0.20	0.11, 0.02
Subscapularis	1.08 ± 0.32	1.01 ± 0.23	0.16, − 0.026

[a] Significant main effect for side: $P = .02$.

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Table 3. Muscle Cross-Sectional Area Measurements of Subscapularis and Infraspinatus/Teres Minor Stratified in Grade 0/Normal Tendons Group and Grade 1/Tendinosis Group for Both Sides and Both Groups

	Muscle Cross-Sectional Area, cm^2			
	Normal Tendons (n = 25)		Tendinosis (n = 10)	
Tendon(s)	Dominant Arm	Nondominant Arm	Dominant Arm	Nondominant Arm
Infraspinatus/ teres minor	1.08	1.00	0.95	0.90
Subscapularis[a]	1.12	1.08	0.97	0.84

[a] Significant main effect for group: $P = .027$.

authors should measure both sides. The MRI scans were evaluated by 2 experienced radiologists; however, MRI arthrography (MRI after intra-articular deposition of gadolinium contrast), especially in the abduction external-rotation position, could perhaps better show labral lesions not detected in our study. To minimize this problem, we used a 3-Tesla MRI scanner.

CONCLUSIONS

In summary, tendinosis of the rotator cuff in the asymptomatic adolescent elite tennis player occurred almost exclusively in the DA and more frequently in the IS tendon. The MRI changes might reflect a risk for early development of structural changes in the rotator cuff tendons, even though they do not present as clinical signs of overuse at this stage. Recognition of these changes is important so that technical instructions, conditioning and performance programs, and exposure time can be modified to prevent progression to symptomatic rotator cuff problems.

REFERENCES

1. Pluim BM, Staal JB, Windler GE, Jayanthi N. Tennis injuries: occurrence, aetiology, and prevention. *Br J Sports Med*. 2006;40(5): 415–423.
2. Kibler WB, Chandler TJ, Shapiro R, Conuel M. Muscle activation in coupled scapulohumeral motions in the high performance tennis serve. *Br J Sports Med*. 2007;41(11):745–749.
3. Ellenbecker T, Roetert EP. Age specific isokinetic glenohumeral internal and external rotation strength in elite junior tennis players. *J Sci Med Sport*. 2003;6(1):63–70.
4. Cools AM, Johansson FR, Cambier DC, Velde AV, Palmans T, Witvrouw EE. Descriptive profile of scapulothoracic position, strength and flexibility variables in adolescent elite tennis players. *Br J Sports Med*. 2010;44(9):678–684.
5. Halbrecht JL, Tirman P, Atkin D. Internal impingement of the shoulder: comparison of findings between the throwing and non-throwing shoulders of college baseball players. *Arthroscopy*. 1999; 15(3):253–258.
6. Jost B, Zumstein M, Pfirrmann CW, Zanetti M, Gerber C. MRI findings in throwing shoulders: abnormalities in professional handball players. *Clin Orthop Relat Res*. 2005;434:130–137.
7. Miniaci A, Mascia AT, Salonen DC, Becker EJ. Magnetic resonance imaging of the shoulder in asymptomatic professional baseball pitchers. *Am J Sports Med*. 2002;30(1):66–73.
8. Wilk KE, Obma P, Simpson CD, Cain EL, Dugas J, Andrews JR. Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther*. 2009;39(2):38–54.
9. Banks KP, Ly JQ, Beall DP, Grayson DE, Bancroft LW, Tall MA. Overuse injuries of the upper extremity in the competitive athlete: magnetic resonance imaging findings associated with repetitive trauma. *Curr Probl Diagn Radiol*. 2005;34(4):127–142.
10. Laudner KG, Stanek JM, Meister K. Assessing posterior shoulder contracture: the reliability and validity of measuring glenohumeral joint horizontal adduction. *J Athl Train*. 2006;41(4):375–380.
11. Escamilla RF, Andrews JR. Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. *Sports Med*. 2009;39(7):569–590.
12. Cools AM, Palmans T, Johansson FR. Age-related, sport-specific adaptions of the shoulder girdle in elite adolescent tennis players. *J Athl Train*. 2014;49(5):647–653.
13. Clarsen B, Bahr R, Andersson SH, Munk R, Myklebust G. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *Br J Sports Med*. 2014; 48(17):1327–1333.
14. Beltran LS, Nikac V, Beltran J. Internal impingement syndromes. *Magn Reson Imaging Clin N Am*. 2012;20(2):201–211, ix–x.
15. Cowderoy GA, Lisle DA, O'Connell PT. Overuse and impingement syndromes of the shoulder in the athlete. *Magn Reson Imaging Clin N Am*. 2009;17(4):577–593, v.
16. Walch G, Boileau P, Noel E, Donell ST. Impingement of the deep surface of the supraspinatus tendon on the posterosuperior glenoid rim: an arthroscopic study. *J Shoulder Elbow Surg*. 1992;1(5):238–245.
17. Huang BK, Hughes TH. Imaging of the rotator cuff. *Sports Med Arthrosc*. 2011;19(3):279–299.
18. Tuite MJ. MR imaging of sports injuries to the rotator cuff. *Magn Reson Imaging Clin N Am*. 2003;11(2):207–219, v.
19. Paley KJ, Jobe FW, Pink MM, Kvitne RS, El Attrache NS. Arthroscopic findings in the overhand throwing athlete: evidence for posterior internal impingement of the rotator cuff. *Arthroscopy*. 2000;16(1):35–40.
20. Blevins FT. Rotator cuff pathology in athletes. *Sports Med*. 1997; 24(3):205–220.
21. Connor PM, Banks DM, Tyson AB, Coumas JS, D'Alessandro DF. Magnetic resonance imaging of the asymptomatic shoulder of overhead athletes: a 5-year follow-up study. *Am J Sports Med*. 2003;31(5):724–727.
22. Koh ES, Lee JC, Healy JC. MRI of overuse injury in elite athletes. *Clin Radiol*. 2007;62(11):1036–1043.
23. Smith TO, Daniell H, Geere JA, Toms AP, Hing CB. The diagnostic accuracy of MRI for the detection of partial- and full-thickness rotator cuff tears in adults. *Magn Reson Imaging*. 2012;30(3):336–346.
24. Ouellette H, Kassarjian A, Tetreault P, Palmer W. Imaging of the overhead throwing athlete. *Semin Musculoskelet Radiol*. 2005;9(4): 316–333.
25. Juul-Kristensen B, Bojsen-Moller F, Finsen L, et al. Muscle sizes and moment arms of rotator cuff muscles determined by magnetic resonance imaging. *Cells Tissues Organs*. 2000;167(2–3):214–222.
26. Lehtinen JT, Tingart MJ, Apreleva M, Zurakowski D, Palmer W, Warner JJ. Practical assessment of rotator cuff muscle volumes using shoulder MRI. *Acta Orthop Scand*. 2003;74(6):722–729.
27. Magnusson SP, Gleim GW, Nicholas JA. Shoulder weakness in professional baseball pitchers. *Med Sci Sports Exerc*. 1994;26(1):5–9.
28. Cahoy PM, Orwin JF, Tuite MJ. Evaluation of post-exercise magnetic resonance images of the rotator cuff. *Skeletal Radiol*. 1996;25(8):739–741.
29. Zanetti M, Gerber C, Hodler J. Quantitative assessment of the muscles of the rotator cuff with magnetic resonance imaging. *Invest Radiol*. 1998;33(3):163–170.

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30. Farley TE, Neumann CH, Steinbach LS, Jahnke AJ, Petersen SS. Full-thickness tears of the rotator cuff of the shoulder: diagnosis with MR imaging. *AJR Am J Roentgenol*. 1992;158(2):347–351.
31. Neumann CH, Holt RG, Steinbach LS, Jahnke AH, Petersen SA. MR imaging of the shoulder: appearance of the supraspinatus tendon in asymptomatic volunteers. *AJR Am J Roentgenol*. 1992;158(6):1281–1287.
32. Johansson F, Skillgate E, Lapauw M, et al. Measuring eccentric strength of the shoulder external rotators using a hand-held dynamometer: reliability and validity. *J Athl Train*. 2015;50(7):719–725.
33. Zbojniewicz AM, Maeder ME, Emery KH, Salisbury SR. Rotator cuff tears in children and adolescents: experience at a large pediatric hospital. *Pediatr Radiol*. 2014;44(6):729–737.
34. Arampatzis A, Peper A, Bierbaum S, Albracht K. Plasticity of human Achilles tendon mechanical and morphological properties in response to cyclic strain. *J Biomech*. 2010;43(16):3073–3079.
35. Mersmann F, Bohm S, Schroll A, Boeth H, Duda G, Arampatzis A. Evidence of imbalanced adaptation between muscle and tendon in adolescent athletes. *Scand J Med Sci Sports*. 2014;24(4):283–289.

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