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Original Article

Prevalence and functional impact of shoulder soft tissue injuries in overhead athletes during in-season management

Vasil Potskhveria, Lela Maskhulia, Marina Matiashvili, Valeri Akhalkatsi, Irma Kvinikadze, Natalia Pavliashvili

Department of Physical Medicine, Tbilisi State Medical University, Tbilisi, Georgia

ABSTRACT

Objectives: This study aimed to assess the prevalence of shoulder soft tissue injuries and evaluate character of impact of functional limitations on sports practice in overhead competitive athletes.

Patients and methods: The prospective, observational cohort study using a mixed-method approach was conducted between the 2019 and 2022 sports seasons. The study evaluated the medical history, including clinical data such as pain, and medical records of 237 competitive overhead athletes (152 males, 85 females; mean age: 26.6±5.8 years; range, 18 to 30 years). Physical examination included assessment of shoulder range of motion, shoulder muscle strength and functional testing. The diagnosis was confirmed by magnetic resonance imaging. Functional limitation to athletes' sports practice were evaluated using patient-reported outcome measures [Kerlan-Jobe Orthopedic Clinic (KJOC) Shoulder and Elbow Score].

Results: Shoulder injuries were documented in 65, representing nearly one-third of observed athletes. Subacromial impingement syndrome was the most common shoulder injury in each individual sport, followed by partial rotator cuff (RTC) tears. The KJOC data showed the highest functional limitation in the athletes with RTC partial tears. There was a significant relationship between shoulder dysfunction and RTC muscle imbalance, which could be a cause of the RTC partial tears.

Conclusion: Subacromial impingement syndrome is the most common shoulder injury in studied overhead competitive athletes. Functional limitations are most pronounced in athletes with RTC partial tears, and they are associated with RTC muscles' imbalance. Consideration of the study results can substantially help medical staff during in-season management of functional limitations associated with shoulder pain, as well as in the prevention of disorders caused by imbalance of the RTC muscles in overhead athletes.

Keywords: Functional limitations, overhead sports, shoulder injuries, shoulder pain.

In the general population, shoulder pain is a fairly prevalent musculoskeletal condition, ranking third behind low back and neck pain.[1] At the same time, shoulder issues are common in athletes; studies show that the injuries to the rotator cuff (RTC) are among the most common source of pain and dysfunction in athletes of both overhead and contact sports across all levels of competition, having a significant impact on sports career and limiting the athlete's ability to compete.[2-4] The mechanism of shoulder injuries, which are commonly observed in overhead athletes, are mostly related to the repetitive movement of high velocity. At the same instant, severe tendonitis from prolonged impingement, degeneration, or sudden injuries can lead to partial or complete rupture of the RTC tendons. Meanwhile, the presence of partial RTC tears can be considered in any patient who has been diagnosed during examination with RTC tendinopathy.[5-7] Severity of clinical symptoms and limitation to sports practice may broadly vary. Athletes often do not have restrictions in daily activities, although symptoms frequently appear during training or competition, when the level of sports activity is high. It is important to diagnose shoulder injuries in a timely and accurate manner to ensure a rapid return to the best possible function and to minimize the risk of further progression of the damage. It is worth noting that the lack

Corresponding author: Vasil Potskhveria, MD. Department of Physical Medicine, Tbilisi State Medical University, 0186 Tbilisi, Georgia.
E-mail: vasikopotskhveria@gmail.com

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of precise diagnostic criteria for various painful shoulder conditions, adequate selection of valid scales for outcome measurement, and heterogeneity of population of examinees may be among the reasons why firm conclusions about diagnosis are difficult to draw.[8,9] Radiological diagnosis can be helpful, however in clinical practice a complex approach to diagnosis is beneficial.[10] Hence, to accurately evaluate sport performance as well as functional condition of overhead athletes, to monitor treatment and rehabilitation effectiveness, relevant sports-specific functional outcome instruments should be utilized, which will facilitate in detection of the subtle change of sports-related functions. Patient-reported outcomes are crucial because they measure physical, emotional, and social functioning as a whole, as self-doubt, hesitation, and fear can affect an athlete's return to play, hinder athletic performance, as well as increase possibility of reinjury.[11-13]

In-season management of shoulder injuries is crucial, as a quick return to play is the primary concern. Many shoulder injuries can be managed conservatively in-season, but injuries not responding to conservative treatment should be managed operatively in the off-season or immediately based on the athlete's ongoing condition, level of dysfunction, and ability to meet sport-specific demands.[14,16,17] This study aimed to assess prevalence of shoulder soft tissue injuries and evaluate character of impact of functional limitations on sports practice of overhead competitive athletes.

PATIENTS AND METHODS

This prospective, observational cohort study using a mixed-method approach was conducted in the Tbilisi State Medical University, Department of Physical Medicine, Sports Medicine and Rehabilitation Clinical Center. The data were collected from the in-season medical examinations and from the medical records of 237 competitive athletes (152 males, 85 females; mean age: 26.6±5.8 years; range, 18 to 30 years) maintained throughout three consequent seasons between 2019 and 2022. The athletes participated in competitive overhead sports, including basketball, handball, volleyball, swimming, water polo, and tennis. During the observation period of the 2019 and 2022 sports seasons, 61 basketball players (39 males, 22 females), 25 handball athletes (12 males, 13 females), 30 swimmers (16 males, 14 females), 28 tennis players (10 males, 18 females), 56 volleyball players (31 males, 25 females), and 37 water polo athletes (all males) were included in the study. Exclusion criteria were as follows: various forms of inflammatory arthritis of the shoulder, glenohumeral or acromioclavicular osteoarthritis, frozen shoulder, clinical signs of cervical radiculopathy, history of previous surgical interventions of the affected shoulder, and associated fracture of the proximal humerus. Written informed consent was obtained from each athlete prior to participation in this study. The study protocol was approved by the Tbilisi State Medical University Ethics Committee for Research (Date: 24.02.2020, No: 2-2020/79). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Medical history, including clinical data on pain and previous treatment, was collected, and all athletes underwent physical examination. Physical examination included shoulder range of motion [flexion, extension, external/internal rotation (IR) in 90°, and abduction], shoulder muscle strength (flexors, abductors and external/internal rotators by testing flexion and extension in the sagittal plane, abduction and adduction in the plane of the scapula, and rotation tested in the transverse plane with the arm abducted 15°), and functional testing. Range of motion was measured with a goniometer (Digital Protractor; iGaging Inc., San Clemente, CA, USA). Active range of motion was assessed in a seated or standing position, and passive range of motion was evaluated with patient in supine position and stabilized scapula.[18,19] Isometric shoulder rotation strength was assessed by Commander Echo Wireless Muscle Testing Starter Kit (JTECH Medical, Midvale, UT, USA). The isometric IR and external rotation (ER) nondominant shoulder strength testing was performed in the supine position, starting at 90° of abduction in the coronal plane and 45° of ER, with the arm supported by the examiner, the hand-held dynamometer positioned 2 cm proximal to the ulnar styloid and placed on the dorsal and ventral side of the forearm. The participant performed a resisted maneuver for 3 sec. An isometric rotation strength ratio of IR to ER (ER/IR×100%) ≥85% was considered good, 60 to 85% as fair, and <60% as poor.[20,21] Specific RTC functional testing was performed using the Neer, Hawkins-Kennedy, painful arc sign, and drop arm, apprehension/relocation tests, and Jobe (empty can and full can) tests. The diagnosis was confirmed by magnetic resonance imaging (MRI). According to local guidelines for the diagnosis of shoulder injuries, MRI is considered the imaging test of choice for most ligament/tendon abnormalities,

partial/full thickness RTC tears, size of tears, detailed assessment of bones, articular cartilage, and labrum, as well as the deep soft tissues of the shoulder, providing standardized and reproducible images, and resulting in accurate image interpretation.

To evaluate character of impact of functional limitations on sports practice, athletes who met the inclusion criteria were assessed using patient-reported outcome measures [Kerlan-Jobe Orthopedic Clinic (KJOC) Shoulder and Elbow score]. The KJOC questionnaire is a self-reported outcome measure with 10 items for overhead athletes to state functional condition of the shoulder and performance during the overhead sports. It includes four items related to pain, one item related to interpersonal relationships with other stakeholders within the team attributed to athletic performance, and five items related to function and sport performance on the level of competition taken. Each item of the KJOC scale ranges from 0 to 10 and is scored on a 10-cm Visual Analog Scale. The items are summed up to get the total score that ranges from 0 to 100, with higher scores representing better athletic functional status and fewer symptoms.[11]

To evaluate changes in the functional parameters of the shoulder in studied athletes, the end of active flexion (EOAF) of the affected shoulder was assessed, and the isometric rotation strength ratio (ER/IR) of the unaffected shoulder was evaluated. Notably, the decision to evaluate ER/IR of the unaffected shoulder was associated with pain in the injured shoulder, which may have prevented full and accurate assessment of rotator strength and increased the risk of over-injury of the soft tissue, given that our assessments were made in-season, within the first week of injury.

Statistical analysis

The statistical analysis assessed the prevalence of shoulder soft tissue injuries and their impact on functional limitations and muscle balance in competitive overhead athletes. To analyze the association between injury type and sport type, we used the Monte Carlo simulation as an approximation method. The Monte Carlo estimation was conducted with 10,000 iterations to provide a more stable p-value, particularly when expected frequencies in certain injury categories were too low for standard asymptotic tests. This method was chosen because the assumption of the chi-square test was violated, as most cells had expected counts below this threshold, making the chi-square test potentially unreliable. The Monte Carlo simulation addresses this issue by performing repeated random sampling (10,000 simulations) to generate more accurate p-values (Table 1).

Statistical analyses were conducted using IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated to provide baseline insights into each injury group, including means, standard deviations, and confidence intervals for KJOC scores, EOAF, and ER/IR ratios. The descriptive statistics offered an overview of the distribution of shoulder functionality and muscle balance across the different injury types.

To determine whether the type of shoulder injury significantly impacted KJOC scores, EOAF, and ER/IR ratios, a one-way analysis of variance (ANOVA) was conducted. Given the categorical nature of injury types and the continuous response variables (KJOC, EOAF, and ER/IR), ANOVA was deemed appropriate to compare means across groups. Post hoc pairwise comparisons were performed using Tukey's honest significant difference test to explore specific differences between injury types for each response variable (Table 4).

Orthogonal contrasts were used to conduct focused comparisons between groups while controlling for type 1 error. This approach partitioned overall variability into independent components, ensuring statistical validity without inflating error rates (Table 5). Additionally, Pearson correlation analyses examined the relationship between KJOC scores and ER/IR ratios within each injury group, allowing for an assessment of how muscle balance (ER/IR) relates to shoulder functionality (KJOC) depending on injury type (Table 6). A p-value <0.05 was considered statistically significant.

RESULTS

During the observation period, 91 athletes complained of shoulder pain and functional limitations, of which 65 (27%) had documented discrete shoulder injuries. Water polo athletes had the highest prevalence of shoulder injuries (38%), followed by handball players (32%), swimmers (30%), volleyball players (29%), basketball players (21%), and tennis players (18%). Shoulder injuries documented in the mentioned 65 athletes were classified into the following nosology groups: partial RTC tears,

TABLE 1
Prevalence of shoulder injuries across sports

	Basketball		Handball		Swimming		Tennis		Volleyball		Water-polo		Total	
Injury/Sport	n	%	n	%	n	%	n	%	n	%	n	%	n	%
All athletes	61		25		30		28		56		37		237	
Male	39	64	12	48	16	53	10	36	31	55	37	100	152	64
Female	22	36	13	52	14	47	18	64	25	45	-	-	85	36
Athletes with shoulder injuries														
Male	8	62	6	75	7	78	2	40	6	38	14	100	43	66
Female	5	38	2	25	2	22	3	60	10	62	-	-	22	34
Shoulder injuries														
SIS	3	23.1	3	38.0	4	44.4	2	40.0	5	31.0	6	43.0	23	
Male	2		2		2		1		2		6		15	
Female	1		1		2		1		3		-		8	
RTC partial tear	2	15.4	2	25.0	3	33.3	-	-	5	31.0	5	36.0	17	
Male	1		1		3		-	-	2		5		12	
Female	1		1		0		-	-	3		-		5	
RTC tendonitis	3	23.1	-	-	1	11.1	-	-	2	13.0	2	14.0	8	
Male	0		-	-	-		-	-	1		1		2	
Female	3		-	-	1		-	-	1		1		6	
Calcified tendinitis of shoulder	1	7.7	-	-	1	11.1	2	40.0	1	6.0	-	-	5	
Male	1		-	-	1		1		1		-	-	4	
Female	-		-	-	-		1		-		-	-	1	
Bankart lesion	2	15.4	2	5.0	-	-	1	20.0	3	19.0	-	-	8	
Male	2		2		-	-	1		3		-	-	8	
Female	-		-		-	-	-		-		-	-	-	
SLAP lesion	2	15.4	1	12.0	-	-	-	-	-	-	1	7.0	4	
Male	2		1		-	-	-	-	-	-	1		4	
Female	-		-		-	-	-	-	-	-	-		-	
Total	13		8		9		5		16		14		65	

SIS: Subacromial impingement syndrome; RTC: Rotator cuff; SLAP: Superior labrum anterior to posterior. Statistically significant prevalence at $p<0.05$

TABLE 2
Relationship between injury type and sport type by the Monte Carlo simulation

	Monte Carlo significance (2-sided)	95% CI (2-sided)
Likelihood ratio	p=0.480	0.471-0.490
Fisher exact test	p=0.592	0.583-0.602

CI: Confidence interval.

RTC tendinitis, calcified tendinitis, subacromial impingement syndrome (SIS), superior labrum anterior to posterior (SLAP) lesions, and Bankart lesions. Subacromial impingement syndrome was the most common injury (35.4%), followed by RTC partial tears (26.2%), RTC tendinitis (12.3%), Bankart lesions (12.3%), calcified tendinitis (7.7%), and SLAP lesions (6.1%).

Injuries were more common in male than in female athletes, except for RTC tendinitis, which was three times more frequent in females, while Bankart and SLAP lesions were absent in female athletes (Table 1). Monte Carlo simulation was used to analyze whether there was a significant association between the types of shoulder injuries and the sports played by athletes. The p-values were greater than 0.05, indicating no statistical evidence to reject the null hypothesis of independence between the two variables. Thus, the type of injury did not appear to be dependent on the sport played (Table 2).

In this study, there was a greater prevalence of SIS in each individual sport. While the results showed no statistically significant differences between the types of injuries and the sports (p>0.05), trends indicated that certain sports were more frequently associated with specific injures. For instance, SIS was more prevalent in swimming (44%), water polo (43%), tennis (40%), and handball (38%). Besides SIS, equal amount of tennis players suffered from calcified tendonitis of the shoulder (40%). Rotator cuff partial tears were most frequent in water polo (36%), swimming (33%), and volleyball (31%), while Bankart lesions were predominantly observed in throwing sports (basketball, handball, tennis, and volleyball). The least common injury among studied athletes was SLAP lesions (Table 1).

TABLE 3
Functional metrics (KJOC, ER/IR ratio, and EOAF) across shoulder injury types

				95% CI		
	n	Mean±SD	SE	Lower bound	Upper bound	Min-Max
KJOC						
RTC partial tear	17	69.0588±4.70997	1.14234	66.6372	71.4805	60.00-77.00
RTC tendonitis	13	78.3077±6.43408	1.78449	74.4196	82.1958	70.00-88.00
Shoulder labrum lesions	12	76.3333±3.25669	0.94013	74.2641	78.4025	71.00-82.00
Subacromial impingement syndrome	23	79.6087±3.01118	0.62787	78.3066	80.9108	75.00-85.00
Total	65	75.9846±6.06860	0.75272	74.4809	77.4883	60.00-88.00
End of flection						
RTC partial tear	17	173.1765±2.92052	0.70833	171.6749	174.6781	170.00-180.00
RTC tendonitis	13	172.5385±3.09880	0.85945	170.6659	174.4110	168.00-178.00
Shoulder labrum lesions	12	173.9167±2.19331	0.63315	172.5231	175.3102	170.00-178.00
Subacromial impingement syndrome	23	174.5217±2.39069	0.49849	173.4879	175.5556	170.00-179.00
Total	65	173.6615±2.70576	0.33561	172.9911	174.3320	168.00-180.00
ER/IR ratio						
RTC partial tear	17	76.7059±5.95572	1.44447	73.6437	79.7680	62.00-84.00
RTC tendonitis	13	88.8462±4.25923	1.18130	86.2723	91.4200	84.00-96.00
Shoulder labrum lesions	12	87.5000±4.01135	1.15798	84.9513	90.0487	80.00-92.00
Subacromial impingement syndrome	23	88.9565±4.30093	0.89681	87.0967	90.8164	82.00-98.00
Total	65	85.4615±7.01801	0.87048	83.7226	87.2005	62.00-98.00

KJOC: Kerlan-Jobe Orthopedic Clinic Score; ER/IR ratio: External to internal rotation; EOAF: End of active flexion; CI: Confidence interval; RTC: Rotator cuff; SD: Standard deviation; SE: Standard error.

Although the results did not indicate statistically significant differences, these trends suggest interesting patterns. For example, the higher prevalence of SIS in water polo and swimming could warrant further investigation using a larger dataset. Overall, injury rates did not significantly differ across observed overhead sports (p>0.05), demonstrating similar increased risk of injury in these sports disciplines.

To evaluate the impact of functional limitations, injured athletes (n=65) were divided into four larger groups based on the injury pathomechanism: RTC partial tears (n=17; Group 1), RTC tendinitis (n=13; Group 2), shoulder labrum lesions (SLL; n=12; Group 3), and SIS (n=23; Group 4). Functional status was assessed using the KJOC score. Descriptive statistics revealed notable differences in KJOC scores and ER/IR ratios across injury types. Group 1 exhibited the lowest mean KJOC score (69.06±4.71), indicating the greatest functional limitation among all injury types. Similarly, Group 1 had the lowest ER/IR ratio (76.71±5.96), suggesting a more pronounced muscle imbalance. Conversely, Group 4 displayed the highest KJOC scores (79.61±3.01) and ER/IR ratios (88.96±4.30), reflecting relatively better shoulder function and muscle balance. Descriptive analysis of EOAF showed minimal variation across groups, with Group 4 having the highest mean EOAF (174.52±2.39), indicating that shoulder flexion was relatively consistent regardless of injury type (Table 3).

Prior to conducting the one-way ANOVA, Levene's test and the Shapiro-Wilk test confirmed the assumptions of homogeneity of variances and normality of distributions. Results of the ANOVA showed significant differences in KJOC scores ($F[3, 61]=20.704$, $p<0.001$) and ER/IR ratios ($F[3, 61]=26.479$, $p<0.001$) across injury groups. However, no significant differences in EOAF were observed ($F[3, 61]=1.805$, $p=0.156$), indicating that shoulder flexion was not significantly affected by the types of shoulder injuries (Supplementary Table 1).

Tukey's honest significant difference post hoc tests further explored significant ANOVA results for KJOC scores and ER/IR ratios. Athletes with RTC partial tears (Group 1) exhibited significantly lower functionality compared to all other groups ($p<0.05$), confirming that this injury type was associated with the most severe functional limitations. No significant differences in KJOC scores were found among Groups 2, 3, and 4, suggesting that RTC

TABLE 4
Pairwise comparisons of functional metrics by injury type

Injury pair	Mean difference (KJOC)	*p*	Mean difference (EOAF)	*p*	Mean difference (ER/IR)	*p*
RTC partial tear *vs.* RTC tendonitis	–9.25	<0.001	0.64	0.914	–12.14	<0.001
RTC partial tear *vs.* labrum lesions	–7.27	<0.001	–0.74	0.881	–10.79	<0.001
RTC partial tear *vs.* SIS	–10.55	<0.001	–1.35	0.396	–12.25	<0.001
RTC tendonitis *vs.* labrum lesions	1.97	0.674	–1.38	0.569	1.35	0.893
RTC tendonitis *vs.* SIS	–1.3	0.827	–1.98	0.149	–0.11	1
Labrum lesions *vs.* SIS	–3.28	0.164	–0.61	0.919	–1.46	0.82

KJOC: Kerlan-Jobe Orthopedic Clinic Score; EOAF: End of active flexion; ER/IR ratio: External to internal rotation; RTC: Rotator cuff; SIS: Subacromial impingement syndrome.

TABLE 5
Comparing injury groups to evaluate functional differences in KJOC scores, EOAF, and ER/IR ratios*

Contrast	Group comparisons	Mean difference (KJOC)	p-value (KJOC)	Mean difference (EOAF)	p-value (EOAF)	Mean difference (ER/IR)	p-value (ER/IR)
C1 (I *vs.* others)	I *vs.* (II, III, IV)	–9.02	0.061	–0.48	0.919	–11.73	0.016
C2 (II *vs.* others)	II *vs.* (I, III, IV)	3.31	0.448	–1.33	0.759	4.46	0.308
C3 (III *vs.* IV)	III *vs.* IV	–3.28	0.582	–0.6	0.919	–1.46	0.806
C4 (III *vs.* I+II)	III *vs.* (I + II)	2.65	0.551	1.06	0.811	4.72	0.289

KJOC: Kerlan-Jobe Orthopedic Clinic Score; EOAF: End of active flexion; ER/IR ratio: External to Internal Rotation; * Orthogonal contrast analysis. Statistical significance at p<0.05.

TABLE 6
Relationship between shoulder functionality (KJOC) and muscle balance (ER/IR ratio) by injury group*

Groups	Pearson correlation (KJOC score and ER/IR ratio)	*p*
RTC partial tear	0.631	0.007
RTC tendonitis	0.473	0.102
Shoulder labrum lesions	−0.585	0.046
Subacromial impingement syndrome	−0.152	0.488

KJOC: Kerlan-Jobe Orthopedic Clinic Score; ER/IR ratio: External to Internal Rotation; RTC: Rotator cuff; * Pearson correlation analysis.

tendinitis, SLL, and SIS had less severe impacts on shoulder functionality (Table 4).

For ER/IR ratios, significant differences were observed between Group 1 and all other groups, indicating that RTC partial tears were associated with greater muscle imbalance. This finding aligned with the lower KJOC scores observed in this group, suggesting a direct relationship between muscle balance and shoulder functionality. No significant pairwise differences in EOAF were found, reinforcing that shoulder flexion remained unaffected by injury type. Complementary data regarding comparisons of functional metrics are presented in Supplementary Table 2.

Orthogonal contrasts provided additional insights into injury impacts without inflating statistical error. The analysis emphasized three key metrics: KJOC scores (pain and functionality), EOAF (shoulder flexion), and ER/IR ratios (muscle strength balance). Athletes in Group 1 faced the most significant challenges, with reduced KJOC scores and imbalanced ER/IR ratios, highlighting limited function and critical weakness in shoulder stability. Injuries such as RTC tendinitis, SLL, and SIS had less pronounced impacts, and shoulder flexion was consistent across groups (Table 5).

Pearson correlation analyses within each injury group further examined the relationship between KJOC scores and ER/IR ratios. In Group 1, a significant positive correlation (r=0.631, p=0.007) was observed, indicating that lower muscle balance (ER/IR ratio) correlated with reduced shoulder functionality (KJOC scores). For Group 3, an unexpected significant negative correlation (r=−0.585, p=0.046) was found, suggesting that greater muscle balance may not directly improve functionality in this group. This could reflect the varied mechanisms underlying labrum injuries and the associated pain during movement. In Group 4, no significant correlation was found between KJOC scores and ER/IR ratios (r=−0.152, p=0.488), indicating that muscle balance may play a lesser role in functional outcomes for this injury type. Rotator cuff tendinitis showed a moderate, nonsignificant positive correlation (r=0.473, p=0.102), suggesting a weaker association between muscle balance and functionality in Group 2 (Table 6).

DISCUSSION

In the present study, prevalence of shoulder soft tissue injuries was assessed and character of functional limitations of shoulder joint was evaluated in overhead competitive athletes. The results showed that shoulder injuries were documented in nearly one-third of observed athletes.

Shoulder lesions are multifactorial by nature, including range of motion deficits, muscle imbalances, and scapular dyskinesia, and can range from sudden injuries to repetitive, gradual onset of a lesion. In our study, the observed injuries were of traumatic origin or associated with repetitive movement due to sports training. Subacromial impingement syndrome was the most common shoulder injury in each individual sport, followed by the incidence of partial RTC tears. The high prevalence of SIS in swimming, water polo, tennis, and handball, of which the last three disciplines belong to throwing sports, may be associated with the development of high rotational forces by the shoulder during the acceleration and deceleration phases of the motion, which can increase the risk of microtraumas to soft tissue structures and cause an injury. The partial tears of RTCs were most frequently observed in water polo, swimming, and

volleyball, which can be attributed to the repetitive overhead motions, subsequent periscapular and RTC fatigue, and chronic inflammation, causing poor distensibility of tendons, ligaments, and capsules, increasing susceptibility to tearing. Furthermore, RTC partial tears may be very painful and cause significant functional limitation to athletes' sports practice.[9,10]

Based on the study results, we suggest necessary prevention measures to decrease the risk of shoulder injury, particularly of SIS and RTC partial tears, in the overhead athletes. Rotator cuff injuries include tendinopathies and partial or complete tendon ruptures, most related to the supraspinatus tendon.[9,10] Therefore, exercises to improve strength and power of the supraspinatus muscle, stretching of the posterior shoulder soft tissues, as well as periscapular strengthening and exercises to maintain strength and balance of the RTC muscles could be considered to reduce prevalence rates. These measures may also increase conformity between the humeral and scapular movements, consequently reducing the load on static restraints, and increasing the effectiveness of dynamic stabilizers, which will lead to an improvement in the effectiveness of the shoulder joint, subsequently improving sports performance and its safety.[10,22,23,29]

The study demonstrates that the injury type significantly impacts shoulder functionality and muscle balance in overhead athletes, with notable variations in functional limitations and muscle imbalances across specific injuries. Partial tears of the RTC emerged as the injury type most associated with functional impairment, evidenced by significantly lower KJOC scores and ER/IR ratios, indicating reduced shoulder functionality and pronounced muscle imbalance. The correlation analysis reinforced these insights by showing a significant positive relationship between KJOC scores and ER/IR ratios, specifically in RTC partial tears. While taking into account that, in a healthy state, RTC strength of the dominant throwing side is increased by around 10% compared to the nondominant side,[30] assessment of isometric rotation strength ratio (ER/IR) of the unaffected shoulder revealed significant relationship between shoulder dysfunction and RTC muscle imbalance, which could be considered among the leading causes of the partial tears of the RTC. The difference in muscle strength due to long-term intense sports activity can cause damage to mentioned structures. This correlation implies that improved muscle balance may be directly related to better shoulder function and decreased risk for RTC tears, highlighting the potential impact of rehabilitation strategies focused on balancing the RTC muscles in this group. Numerous studies have shown that the strength of the internal and external rotator muscles differs slightly on the dominant side, but even a small imbalance during intense training can provoke injuries.[20,21,24,25] It is worth to note, that there was a common trend in observed sport teams related to the lack of knowledge regarding the preventive measures of shoulder injuries in terms of individual approach and adjustment of the training program to the needs of athletes with muscle fatigue due to deconditioning or overuse, particularly disproportionate lack of ER exercises. External rotation of the 90° abducted shoulder is provided by the teres minor and infraspinatus muscles, while IR is provided by the subscapularis. Based on the results of our study and taking into account shoulder biomechanics, it can be recommended to emphasize resisted abduction and ER at 90° in training programs, which, in our opinion, can reduce injuries to the RTC.[26-29]

For other injury types, including RTC tendinitis and SLL, the findings revealed distinct dynamics. Shoulder labrum lesions displayed a unique negative correlation between KJOC scores and ER/IR ratios, which could be explained by the presence of significant pain due to the abovementioned lesions, which has a negative effect on overall functioning without necessarily causing rotator muscle imbalance. Shoulder labrum lesions, the most prevalent injury in the study, was associated with relatively high KJOC scores and ER/IR ratios, indicating better shoulder function and muscle balance compared to RTC partial tears. This result suggests that muscle balance may play a less critical role in functional outcomes for athletes with SIS.

Considering the study results from a clinical point of view can substantially help medical staff in management of functional limitations associated with shoulder pain, as well as in the prevention of disorders caused by imbalance of the RTC muscles in overhead athletes. Furthermore, it can be helpful for coaches working with overhead athletes in raising their awareness regarding the most common injuries in overhead athletes, as well as help them to adjust accordingly training programs in an attempt of prevention of shoulder injuries. Injury-specific rehabilitation approaches aimed at restoring muscle balance in athletes with RTC partial tears could mitigate functional limitations and enhance overall shoulder performance. For clinicians and coaches,

these insights provide guidance on tailoring training and rehabilitation programs to address the unique demands and functional challenges associated with each type of shoulder injury.

This study had some limitations that should be considered when interpreting the results. Overhead athletes may sustain repetitive microtraumatic stress to several anatomical structures of the shoulder during their sport career. Therefore, an athlete may have more than one diagnosis, as some diagnosis may overlap (e.g., SIS, RTC partial tears, or RTC tendonitis). Therefore, the assessment of the shoulder of an athlete should be carried out scrupulously and should not be limited only to findings of clinical or imaging studies. In our study, this factor was limited due to a comprehensive diagnostic approach using physical examination, appropriately selected special tests, and MRI to determine the specifics of the injury. Furthermore, since the athlete had to perform a resistance maneuver for 3 sec to assess shoulder strength, isometric IRs and ERs on the unaffected side were analyzed (pain could be limiting for accurate measurement for the affected, dominant shoulder). However, studies revealed that the most common MRI findings of the dominant shoulders in throwing sports were RTC tendon abnormalities, posterior superior shoulder impingement, as well as osteochondral lesions of the humeral head, and only 37% of them were symptomatic, while the frequency of abnormalities in symptomatic shoulders were not higher than in asymptomatic shoulders.[31] Additionally, some imperfections of the training programs may not have been fully considered in this study. In terms of external validity of the study results, it is worth noting that the study was conducted in the largest sports clinic in the country, providing medical services to athletes of different age and levels of participation, including athletes of the national Olympic team and national teams in various sports disciplines, the vast majority of which were participated in this study. The circumstances mentioned cannot prevent generalization of data for other competitive athletes. However, further studies are necessary to address findings in terms of secondary prevention and rehabilitation contexts, followed by return to sport aspects after rehabilitation management.

In conclusion, our results showed that SIS was the most common shoulder injury in the studied overhead competitive athletes and that it was more prevalent in swimming, water polo, tennis, and handball players. There was no significant relationship between injury type and sport, and injury rates did not differ between the sport disciplines, showing a similar increased risk of injury in observed overhead sports. The KJOC outcome score was an effective tool for assessment of impact of functional limitations on sports practice in overhead athletes. Athletes with RTC partial tears exhibited significantly lower KJOC scores compared to all other groups, confirming that this injury type was associated with the most severe functional limitation. In athletes with RTC partial tears, the ER/IR ratio was significantly reduced, which was manifested by the imbalance between shoulder internal and external rotator muscles strength. Despite assessment of the ER/IR ratio of the unaffected shoulder, in our study we obtained significant data that allowed us to consider imbalance in strength between the IR and ER muscles of the shoulder as a risk factor for the development of the RTC injury and to emphasize its contribution to shoulder pain and subsequent functional limitation of the shoulder. The study revealed the need for preventive measures to reduce the prevalence of shoulder injuries in competitive overhead athletes, including overuse injuries that most commonly cause SIS and RTC partial tears, and the need for proper adjustments to the training programs to avoid RTC muscles' imbalance, as preventive measures can reduce time lost in training and competition.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPLEMENTARY TABLE 1
Comparing functional metrics (KJOC, ER/IR ratio, and EOAF) by shoulder injury type*

	Sum of squares	df	Mean square	F	Sig.
KJOC					
Between groups	1189.129	3	396.376	20.704	0.000
Within groups	1167.855	61	19.145		
Total	2356.985	64			
End of flection					
Between groups	38.197	3	12.732	1.805	0.156
Within groups	430.357	61	7.055		
Total	468.554	64			
ER/IR ratio					
Between groups	1782.976	3	594.325	26.479	0.000
Within groups	1369.178	61	22.446		
Total	3152.154	64			

KJOC: Kerlan-Jobe Orthopedic Clinic Score; ER/IR ratio: External to Internal Rotation; EOAF: End of active flexion; * One-Way ANOVA results.

SUPPLEMENTARY TABLE 2
Complementary data on pairwise comparisons of functional metrics by injury type.

Dependent variable	Type of injury (I)	Type of injury (J)	Mean difference (I-J)	*p*
KJOC	RTC partial tear	RTC tendonitis	–9.25*	0.000
		Shoulder labrum lesions	–7.27*	0.000
		Subacromial impingement syndrome	–10.55*	0.000
	RTC tendonitis	RTC partial tear	9.25*	0.000
		Shoulder labrum lesions	1.97	0.674
		Subacromial impingement syndrome	–1.3	0.827
	Shoulder labrum lesions	RTC partial tear	7.27*	0.000
		RTC tendonitis	–1.97	0.674
		Subacromial impingement syndrome	–3.28	0.164
	Subacromial impingement syndrome	RTC partial tear	10.55*	0.000
		RTC tendonitis	1.3	0.827
		Shoulder labrum lesions	3.28	0.164
End of flexion	RTC partial tear	RTC tendonitis	0.64	0.914
		Shoulder labrum lesions	–0.74	0.881
		Subacromial impingement syndrome	–1.35	0.396
	RTC tendonitis	RTC partial tear	–0.64	0.914
		Shoulder labrum lesions	–1.38	0.569
		Subacromial impingement syndrome	–1.98	0.149
	Shoulder labrum lesions	RTC partial tear	0.74	0.881
		RTC tendonitis	1.38	0.569
		Subacromial impingement syndrome	–0.61	0.919
	Subacromial impingement syndrome	RTC partial tear	1.35	0.396
		RTC tendonitis	1.98	0.149
		Shoulder labrum lesions	0.61	0.919
ER/IR ratio	RTC partial tear	RTC tendonitis	–12.14*	0.000
		Shoulder labrum lesions	–10.79*	0.000
		Subacromial impingement syndrome	–12.25*	0.000
	RTC tendonitis	RTC partial tear	12.14*	0.000
		Shoulder labrum lesions	1.35	0.893
		Subacromial impingement syndrome	–0.11	1.000
	Shoulder labrum lesions	RTC partial tear	10.79*	0.000
		RTC tendonitis	–1.35	0.893
		Subacromial impingement syndrome	–1.46	0.824
	Subacromial impingement syndrome	RTC partial tear	12.25*	0.000
		RTC tendonitis	0.11	1.000
		Shoulder labrum lesions	1.46	0.824

KJOC: Kerlan-Jobe Orthopedic Clinic Score; ER/IR ratio: External to Internal Rotation; RTC: Rotator cuff. Significance is indicated by an asterisk (*), with all significant p-values (<0.05) included.