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Dynamometric assessment of shoulder external and internal rotators in young tennis players

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Abstract
The musculoskeletal profiles of tennis players have been the subject of a number of studies analyzing the range of motion and muscle strength, as well as the unilateral dominance of the upper limb muscles, which leads to a serious imbalance in the shoulder joint.
Objectives: To evaluate the dynamometric parameters of the external rotators (ER) and internal rotators (IR) of the shoulder joint and to generate a detailed analysis of the normalized peak torque, power, endurance and strength asymmetry characteristics, as well as time-based characteristics for the purposes of enhancing the training process.
Materials and Methods: Two elite adolescent tennis players from a professional tennis school were studied. Anthropometric characteristics were measured by impedance analysis, including segmental analysis. Isokinetic dynamometry of ER and IR was performed in isometric mode at angular positions (°): 60, 40, 20, 0, -20, -40 and in concentric mode at angular velocities of 180 °/s.
Results: The anthropometric assessments indicated that both athletes exhibited normal body composition. However, segmental analysis revealed that the dominant arm (DA) had a higher muscle mass compared to the non-dominant arm (NDA), which exhibited greater fat accumulation. These findings were supported by bilateral asymmetry data, demonstrating very high asymmetry values for ER between the DA and NDA, ranging from 25% to 52%, and high asymmetry values for IR, ranging from 15% to 27.5% in both athletes. Tennis Player 1 exhibited a unilateral asymmetry of 87.9%, significantly exceeding the normative range of 66-70% for both the DA and NDA, and reduction in acceleration time. In contrast, Tennis Player 2 did not exhibit such imbalance in the DA and the time-based parameters indicated rapid acceleration, high work capacity, and power output. These results could be associated with both prolonged training experience and potentially with hereditary factors determining the athlete's type of nervous system.
Conclusion: The findings of this study highlight the benefit of assessing ER and IR strength in tennis players. The study indicates that when assessing ER and IR of the shoulder joint, the parameters with significant informative value for optimizing the training process include the coefficients of unilateral and bilateral asymmetry, acceleration time, time to peak torque, and maximal work per kilogram of body weight. Evidence has been provided for: (1) the necessity of developing strength in the internal and external rotators of the NDA; and (2) a probable relationship between the capacity for rapid acceleration and explosive strength generation of the shoulder external and internal rotators, and the hereditary determination of the athlete's nervous system type. These findings underscore the need for individualized testing and training approaches to mitigate muscular imbalances and enhance athletic performance.

Keywords: Tennis, external and internal rotators, peak torque, shoulder joint

Introduction

The musculoskeletal profiles of tennis players have been the subject of numerous studies analyzing range of motion, muscle strength and unilateral dominance in selected upper limb muscles in adolescent and professional athletes. The repetitive muscular effort in the upper limb is characteristic for the performance of tennis players and leads to specific muscle adaptations [1]. The serve, in particular, requires high accelerations of the racket and ball through explosive upper limb movements. To achieve such high-speed motor actions, optimal muscle strength, power, flexibility, and neuromuscular coordination are essential [2]. One of the most critical determinants of tennis performance is ball speed, as it reduces the opponent's reaction time, making it a key objective in training [3]. Ball speed is the result of maximal dynamic force and power generated through a specific kinetic chain.

This chain involves the internal rotators (IR) of the shoulder—*m. subscapularis*, *m. deltoideus pars clavicularis, m. teres major, m. pectoralis major,* and *m. latissimus dorsi*—as well as the external rotators (ER), including *m. infraspinatus, m. teres minor*, and *m. deltoideus pars spinata*. Additional muscles, such as *m. supraspinatus, m. erector spinae, m. triceps brachii*, and *m. extensor carpi radialis,* also play a crucial role in this chain. The ER involved in this kinetic chain are the weakest muscles in the shoulder girdle and have significantly less muscle mass than the total mass of the IR in the glenohumeral joint, which generate about 1.75 times more torque. During gameplay, IR are frequently engaged in producing rapid and forceful movements, such as backswing motions before a shot or counteracting the moment of inertia generated by internal rotation. These biomechanical demands contribute to the development of strength asymmetry between the IR and ER in the shoulder joint, a critical factor for assessment and injury prevention. Isokinetic dynamometry is a methodology that allows for a comprehensive assessment of the strength capabilities of skeletal muscle groups and is appropriate for studying the external and internal rotators of the shoulder joint. In addition to the peak torque (PT) of the shoulder joint, which is a criterion for muscle strength of the ER and IR, isokinetic dynamometry allows for the evaluation of other critical parameters, including acceleration time, time to PT, work (as a criterion for endurance), and power, across different modes of muscle contraction [4]. Despite the benefit of analyzing these time-related parameters, the available literature provides insufficient data on their role in the IR and ER function. Some studies [5] suggest that these parameters correlate directly with the degree of motor unit recruitment, influencing both acceleration and power output. Another significant advantage of isokinetic dynamometry is its ability to quantitatively assess unilateral asymmetry (UA) and bilateral asymmetry (BA) by analyzing the PT ratios between the dominant arm (DA) and the non-dominant arm (NDA). The presence of unilateral asymmetry and prolonged time-based parameters may contribute to reduced explosive strength, lower shot power, earlier onset of muscle fatigue, decreased endurance and work capacity, scapulohumeral dysfunction, and accessory movement restrictions. Additionally, strength imbalances in the rotator cuff musculature or glenohumeral joint deficiencies in external or internal rotation may further compromise performance. These deficits, as identified through isokinetic dynamometry, not only impair athletic achievements but also increase the risk of injuries and intra-articular damage, including bursitis, tendinitis, rotator cuff tears, and labral injuries [1, 2].

The aim of the study was: 1) to evaluate the strength characteristics of the ER and IR of the shoulder joint in adolescent tennis players using isokinetic dynamometry in both concentric and isometric modes for both the DA and NDA; 2) to conduct a comparative analysis based on normative data from the literature, examining normalized PT, time-related characteristics, power, endurance, and strength asymmetry and to provide some evidence-based guidelines for addressing the identified deficits and muscular imbalances.

Materials and Methods

This study was conducted following the introduction of the research methodology to the athletes and coaching staff, and after obtaining signed informed consent from the participants' parents. The study analyzed data from two elite adolescent tennis players from a professional tennis club. Anthropometric assessments included measurements of height, body mass, fat-free mass, fat mass, muscle mass, and total body water, as well as a segmental analysis of the limbs. The strength characteristics of the ER and IR of the shoulder were measured with an isokinetic dynamometer (Biodex 4 Pro, USA) at the following angular positions (°): 60, 40, 20, 0, -20, -40 in isometric mode (2 repetitions each) with contraction duration of 3s and a 10s rest between repetitions. The rest time between angular positions was 30s. PT in concentric mode was assessed at 180°/s with 2 repetitions.

The parameters analyzed in this study included: maximum PT relative to body weight - used to compare strength capabilities across individuals with different body masses, providing a normalized ratio; acceleration time - an indicator of neuromuscular responsiveness, measuring the time required to initiate limb movement and reach a constant velocity, which serves as a criterion for explosive strength; time to PT - reflects the time needed to develop maximum force, serving as a physiological indicator of speed and recruitment efficiency of fast motor units; maximum work relative to body mass - a measure of endurance and work capacity, normalized to body weight, facilitating comparisons across different groups (e.g., age, sex, and sports disciplines); average power - represents how quickly a muscle group generates force, calculated as work per unit of time.

Due to the unilateral nature of tennis, muscular asymmetry is commonly observed between the dominant arm and the non-dominant arm, as well as between the IR and the ER within the shoulder joint. Two types of asymmetry coefficients were calculated. The bilateral asymmetry coefficient estimates the differences between the DA and NDA. Some authors [6] indicate values up to 15% as the norm for the BA coefficient in healthy, untrained individuals, or as a threshold to distinguish the norm from pathology. It is currently accepted in athletes of different disciplines to consider as threshold the BA value of 10% [7]. The unilateral asymmetry coefficient is the ratio of the peak torque of the ER to the peak torque of the IR, measured during concentric contractions. It is calculated for the DA and the NDA and is one of the most frequently applied coefficients for assessing the physiological weakness of the ER relative to the IR. It is most often based on measurements at a speed of 180°/s, at which values between 66-70% are accepted as the norm for physiological weakness. Values exceeding this range suggest weak IR, while lower values indicate weak ER.

Results and analysis

The two study participants, Tennis Player 1 (age 13, 7 years of training experience) and Tennis Player 2 (age 15, 10 years of training experience), were assessed for body composition and dynamometric parameters.

Tennis Player 1

Body mass composition. The athlete's body mass was 64.7 kg, which is 6.6 kg below the optimal range. Lean body mass (LBM) was 61.1 kg (5.6 kg below the lower threshold), indicating lower-than-expected muscle mass. Fat mass was 3.6 kg, corresponding to 5.6% of total body weight, which is below the lower limit. Muscle mass was 57.3 kg, falling 4.7 kg below the lower threshold. Total body water accounted for 44.0 kg (68%) of body mass. Given that optimal hydration levels for adolescent males typically range from 50-65%, this value aligns with expected physiological norms. Segmental analysis revealed lower-than-normal muscle mass in the upper limbs, with a tendency for greater fat accumulation and lower muscle mass in the non-dominant arm (NDA). These anthropometric findings correlate with the dynamometric characteristics and provide important morphological indicators for the coach's training strategy.

Dynamometric characteristics of IR and ER. Table 1 presents the key dynamometric parameters used for analysis. In the DA, unilateral asymmetry was 87.9%, exceeding the normative range of 66-70%, indicating a strength imbalance between the ER and the IR. Specifically, IR were insufficiently strong relative to ER, leading to muscular asymmetry between the antagonist muscle groups. A similar trend was observed in the NDA. A moderate increase in acceleration time was observed in both muscle groups of both arms, suggesting reduced explosive strength. A slight decrease in work capacity and power was observed exclusively in the IR, whereas ER indicators remained within normal ranges. To address these findings, targeted plyometric training for the upper limb is recommended to enhance explosive strength, particularly focusing on reducing acceleration time. Additionally, specific strengthening exercises should be incorporated to balance the IR/ER ratio and optimize shoulder joint function [8].

Table 1: Dynamometric characteristics of internal and external rotators of the shoulder joint in Tennis Player 1, compared to normative values indicated in the literature (mean± SD)

Concentric contractions at 180 °/s velocity	Dominant Arm R	Norms	Non-dominant Arm L	Norms
Internal Rotators (IR)				
Peak Torque to Body Mass (%)	40.9↓	53	32.6↓	50
Acceleration Time (ms)	130.0 +	84	190.0 +	96
Time to Peak Torque (ms)	450.0	450 - 740	870	500 - 800
Total Work to Body Mass(%)	73.6 ↓	93	66.3 -	74
Average Power (Watts)	51.0-	64	35.4 -	42
External Rotators (ER)				
Peak Torque to Body Mass (%)	35.9	33	28.2	30
Acceleration Time (ms)	120.0 +	73	170.0 ↑	80
Time to Peak Torque (ms)	20.0 ↓	575	10.0 ↓	622
Total Work to Body Mass(%)	49.0	58	38.0 -	58
Average Power (Watts)	34.9 +	26	22.0	22.4
ER / IR RATIO (%)				
ER/IR x 100 (%)	87.9 ↑	66-75	86.5 ↑	66-75

Designations: ↑ - increase compared to the norm; ↓ - decrease compared to the norm
+ - slight increase; — - slight decrease;

During dynamic loads in concentric mode, high BA is observed in both muscle groups: in the ER it is between 21.6 - 25.0 %, and in the IR between 20.4 - 33.0 %. The isometric strength of the internal and external rotators of the shoulder joint is normal for adolescent tennis players. BA, which is calculated between the dominant - right and non-dominant - left, upper limb in the internal and external rotators of the shoulder joint is: - very high between the ER of the dominant and non-dominant arm - from 25 to 52 %; - high between the IR- from 15 to 27.5 %. This confirms the literature data on the high bilateral asymmetry between the right and left hand in tennis players [9].

Tennis Player 2

Body mass composition. The body mass of the second player is 71.1, which is 1.0 kg above the upper limit of the acceptable range of 57.8 - 70.1. The player is overweight and his body mass is about 5.5 kg above the optimal weight. The lean body mass is 56.9 kg with a norm of 53.4 - 56.6, which is about 0.3 kg above the upper limit. This indicator reflects the body mass without fat. Fat mass reported in kilograms is 14.8 kg, which is 3.9 kg above the upper limit of the range (7.7 - 10.9 kg). Fat mass in % is 20.6 % of the total weight, which is about 3.6 % above the upper limit (12.0 - 17.0 %); Muscle mass is 52.8 kg, about 0.1 kg above the upper limit in the range of 42.6 - 52.7. The amount of water in the athlete's body is 41.0 kg or 57%, which is in the normal range for hydration levels, with the optimum level for adolescents aged 12 - 18 years being between 52-66%. Segmental analysis shows that the fat mass in kg of the upper limbs is above the norm. The fat mass of the right (dominant) arm is 0.84 kg and is lower than that of the left (non-dominant) - 0.95 kg. The muscle mass of both arms is high, with the left arm being 3.58 kg and the right (dominant) being 3.74 kg.

Table 2: Dynamometric characteristics of internal and external rotators of the shoulder joint in Tennis Player 2, compared to normative values indicated in the literature (mean± SD)

Concentric contractions in 180 °/s velocity	Dominant Arm R	Norms	Non-dominant Arm L	Norms
Internal Rotators (IR)				
Peak Torque to Body Mass (%)	70.0 ↑	53	64.3 ↑	50
Acceleration Time (ms)	70.0 -	84	90.0	96
Time to Peak Torque (ms)	240.0 –	450 - 740	310.0 –	500 - 800
Total Work to Body Mass(%)	110.0 +	93	111.0 ↑	74
Average Power (Watts)	87.0 +	64	89.0 ↑	42
External Rotators (ER)				
Peak Torque to Body Mass (%)	54.0 ↑	33	42.4 +	30
Acceleration Time (ms)	120.0 ↑	73	90.0	80
Time to Peak Torque (ms)	870.0 ↑	575	300.0 –	622
Total Work to Body Mass(%)	67.0	58	59.0	58
Average Power (Watts)	56.0 ↑	26	50.0 ↑	22.4
ER / IR Ratio (%)				
ER/IR x 100 (%)	77.5	66-75	65.9	66-75

Designations: ↑ - increase compared to the norm; ↓ - decrease compared to the norm
+ - slight increase; — - slight decrease;

Dynamometric characteristics of ER and IR.

In the dominant arm, the peak torque per kilogram of body weight of the IR is elevated, while that of the ER is within the normal physiological range (Table 2). The ER/IR ratio is 77.5%, which is within close proximity to the normative values (66.0-75.0%), suggesting the absence of significant muscular imbalance between these antagonistic muscle groups. The time-based parameters, specifically acceleration time and time to peak torque, are relatively low for both muscle groups, indicative of rapid force production. The sole exception is a minor increase in the acceleration time of the IR in the DA. These findings suggest that the athlete may possess a hereditarily determined high-lability nervous system, characterized by the capacity to generate high-frequency action potentials per unit time. This neuromuscular trait is associated with enhanced acceleration capabilities and the generation of explosive force in the shoulder joint [8, 9].

Conversely, in the NDA, both the internal and external rotators exhibit suboptimal strength, falling below normative thresholds. This deficiency represents a prevalent characteristic among tennis players, particularly those exhibiting a weaker NDA, which consequently contributes to bilateral asymmetry. Despite the fact that the ER/IR ratio remains within the normative range, absolute torque production is insufficient. Therefore, while unilateral asymmetry is not observed, the generated force remains inadequate. Notably, the time-dependent parameters for the NDA rotators are favorable, likely attributable to prolonged training exposure and genetic predisposition.

Under dynamic concentric loading conditions, the degree of bilateral asymmetry is relatively moderate, with the following values recorded: with IR only at 180°/s - 18%. The isometric strength is greater than the concentric strength. Due to the weak external and internal rotators of NDA, the BA (between the rotators of the dominant and non-dominant hand) is high in both muscle groups, which generates an imbalance. The BA in the IR is 47% at the 40° angle, 30% at the 20° angle, 22% at the 0° angle, and 23% at the -20° angle. In the ER, the bilateral asymmetry is 35% at the 40° angle, 34% at the 20° angle, 33% at the 0° angle, and 23% at the -20° angle.

The external rotators and the supraspinatus muscle, both of which play a crucial role in glenohumeral stability during overhead sports movements, particularly in eccentric deceleration during the follow-through phase, exhibit muscular imbalance [2]. This imbalance may compromise the optimal force-coupling mechanism of the rotator cuff musculature during tennis serves and strokes, potentially increasing the risk of overuse injuries. Prolonged tennis participation and accumulated mechanical loading frequently result in structural and neuromuscular asymmetries, contributing to greater functional dominance of the primary upper limb [3]. The findings further substantiate that the dominant IR, which are critically involved in forehand stroke mechanics, demonstrate superior neuromuscular efficiency compared to those of the non-dominant limb [1].

Based on these observations, the primary training objectives for shoulder musculature in tennis players should focus on enhancing the strength of both IR and ER in the non-dominant arm to mitigate bilateral asymmetry and restore muscular equilibrium. As well as perform plyometric and eccentric strength exercises for the ER and the supraspinatus muscle specifically tailored to the physiological capabilities of adolescent athletes, to optimize shoulder stability and minimize injury risk [8, 9].

Conclusion

This study highlights the utility of isokinetic dynamometry in assessing ER and IR strength asymmetries in adolescent tennis players. The analysis of the experimental data shows that isokinetic dynamometry provides parameters with great informative value for the purposes of the training process which are: - the coefficient of unilateral asymmetry between the external and internal rotators, acceleration time, time to reach peak torque, as well as the maximum work per kg of weight as a criterion for endurance. On the other hand, evidence has been presented for: (1) the necessity of developing strength in the internal and external rotators of the non-dominant arm due to the high bilateral asymmetry observed in adolescent tennis players; and (2) a probable relationship between the capacity for rapid acceleration and explosive force generation of the external and internal shoulder rotators and the hereditary determination of a highly labile nervous system type, i.e., the ability to generate action potentials at a high frequency per unit of time.

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