Journal of Tissue Viability 34 (2025) 100934

Contents lists available at ScienceDirect

Journal of Tissue Viability

journal homepage: www.elsevier.com/locate/jtv

The effect of core exercises on shoulder rotator strength, core endurance and suprasipinatus structure in tennis players with rotator cuff injuries

Emine Merve Ersever [a,*], Bayram Goktas [b]

[a] Haymana Vocational School Physiotherapy and Rehabilitation, Physiotherapy Department, Ankara University, Ankara, Turkiye
[b] Faculty of Health Sciences, Department of Health Management, Ankara University, Ankara, Turkiye

ARTICLE INFO

Keywords:
Isokinetic
Muscle thickness
Fibre bundle length
Core endurance
Tennis
Rotator cuff

ABSTRACT

Objective: — Tennis is a demanding sport that requires proper physical conditioning to prevent injuries in players with rotator cuff issues. This study aims to evaluate the effects of an eight-week core exercise training program on pain, core endurance, rotator strength, and muscle architecture in rotator cuff tennis players.
Materials and methods: — The study group consisted of 41 subjects (22 women, 19 men) with a mean age of 42.06 ± 8.17. The core exercise group trained with core exercises in addition to routine training 3 times a week for 8 weeks; The control group only performed routine training 3 times a week for the same duration. Assessments of pain, muscle endurance, strength, and architecture were conducted before and after the 8-week intervention.
Results: — Data analysis revealed a significant improvement in the experimental group compared to the control group. This indicates a large effect size ($p < 0.05$) in pain, muscle strength, endurance, and muscle architecture length (excluding pennation angle).
Conclusions: —The results of this study demonstrate that core exercise training is an effective method for reducing pain and improving functional outcomes in tennis players with rotator cuff lesions. Furthermore, the findings highlight the importance of targeted and comprehensive core stability training in minimizing the risk of re-injury.

1. Introduction

Tennis players are prone to upper extremity injuries due to the repetitive and supraphysiologic forces generated at the shoulder and elbow during a typical match. The shoulder is vulnerable to injury during the serve and overhead in all strokes of the sport [1]. Upper extremity injuries in tennis are often chronic and caused by repetitive microtrauma and overuse, while lower extremity injuries tend to be acute [2,3]. The spectrum of shoulder pathology includes chronic rotator cuff inflammation (tendinosis), subacromial bursitis, partial-thickness rotator cuff tears, long head of biceps injuries, and superior labrum anterior-to-posterior (SLAP) tears. Rotator cuff muscle injuries are frequently related to overloading or repeated movements in overhead sports such as tennis, squash, volleyball, and pitchers [4,5].

Playing tennis can cause injuries that include supraspinatus muscle degeneration, tendon tears, and calcification of the shoulder [6]. These injuries are commonly associated with the overhead nature of the sport. The supraspinatus, as one of the most important rotator cuff muscles, is a substantial dynamic stabilizer of the glenohumeral joint in multiple shoulder positions and activities. The quality of the supraspinatus muscle and tendon is a crucial factor in predicting the biomechanical strength of rotator cuff repairs, with a significant impact on clinical outcomes [7].

The core and rotator cuff muscles biomechanically connect the shoulder in several functional movements [8]. Core muscles are crucial for stabilizing the spine reinforcing the trunk during upper extremity movements and maximizing balance in the lower extremity movements, especially in the early stages of motor development [9]. In tennis, decreased muscle strength and control may lead to slower speed, instability, and a greater risk of injury [10]. In addition, core

* Corresponding author. Haymana Vocational School Physiotherapy and Rehabilitation, Physiotherapy department, Ankara University, Ankara University Haymana Vocational School Physiotherapy and Rehabilitation, 06860, Ankara, Turkiye.
E-mail address: emersever@gmail.com (E.M. Ersever).

https://doi.org/10.1016/j.jtv.2025.100934
Received 16 January 2025; Received in revised form 18 June 2025; Accepted 30 June 2025
Available online 4 July 2025

stabilization is crucial for enhancing athletic performance, improving leg balance and trunk strength, and preventing various sports injuries [11,12].

At this point, it is possible to affirm that tennis is a complex and intermittent sport that requires an accurate combination of the major physiological variables [12]. Most tennis players with rotator cuff injuries experience dull shoulder pain, early fatigue, and decreased performance. Many overhead tennis players experience generalized shoulder pain due to repetitive terminal external rotation, and internal rotation with abduction and elevation. Rehabilitation programs for shoulder pain commonly focus on strengthening, mobility, and sport-specific movements that target the affected joint and can often lead to successful outcomes [12,13].

Based on the current literature, this study aimed to investigate the effects of 8-week specific core stability training on pain, muscle strength, and muscle architecture in tennis players with rotator cuff injuries. We hypothesized that tailoring specific core stability training to tennis players would improve muscle architecture and strength which could prevent injury.

2. Materials and methods

2.1. Study participants

We used G*Power software (G*Power version 3.0.10, Franz Faul, Universität Kiel) to calculate a power analysis, assuming an effect size of d = 0.55, α = 0.05 type I error, and β = 0.20 type II error. This calculation yielded an estimated required sample size of 36 athletes. To account for potential dataloss, we planned to include 50 tennis players with 25 participants in each group. At the beginning of the study, 50 players with rotator cuff injuries underwent evaluation using four shoulder tests. Six players were excluded from the study due to negative test results and unwillingness to participate. The remaining 44 athletes were randomly divided into 2 groups, control and exercise, each consisting of 22 athletes, using a computer-aided randomisation program (https://www.randomizer.org/) by block randomisation method. However, 1 from the CT group and 2 from the CE group did not complete the study. These assignments were unknown to both the participants and the physiatrist working with them Forty-one tennis players playing competition level tennis, (19 males and 22 females) were recruited in this study (age: 23.5 ± 4.1 years, height: 169.6 ± 10.4 cm and weight: 64.7 ± 10.4 kg). In order to be considered eligible to participate in this study, they had to be involved in tennis for more than five years, at a rate of three times per week, with a minimum playing time of one and a half hours and they were in regular training season. The inclusion criteria of the study were: the presence of unilateral shoulder pain a diagnosis of rotator cuff tendinopathies by the physiatrist, and no physiotherapy for the shoulder in the four weeks before the study. Patients with rotator cuff tendinopathies and grade 1–2 rupture were included in the study after evaluation by ultrasonography with dynamic tendon method (GE Logiq P5, Wisconsin, USA) using a 12 MHz linear array probe. In addition, potential study subjects needed to have at least two of the following positive signs: Neer, Hawkins tests, or the drop arm or pain during the abduction of the shoulder with a painful arch [14]. Exclusion criteria were prior or current history of shoulder injury or pathology and the presence of any medical condition of the glenohumeral joint such as infection or systematic disease and trauma [15]. The study was approved by the local ethics committee of Ankara University and written informed consent was obtained from all participants. it was also prospectively registered at Clinicaltrials.gov (registration number: NCT06402162)

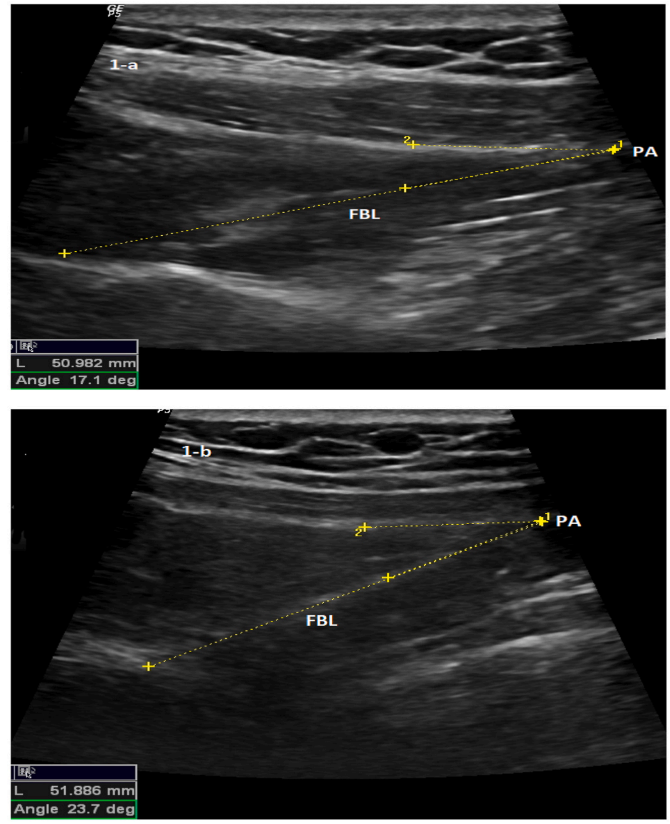
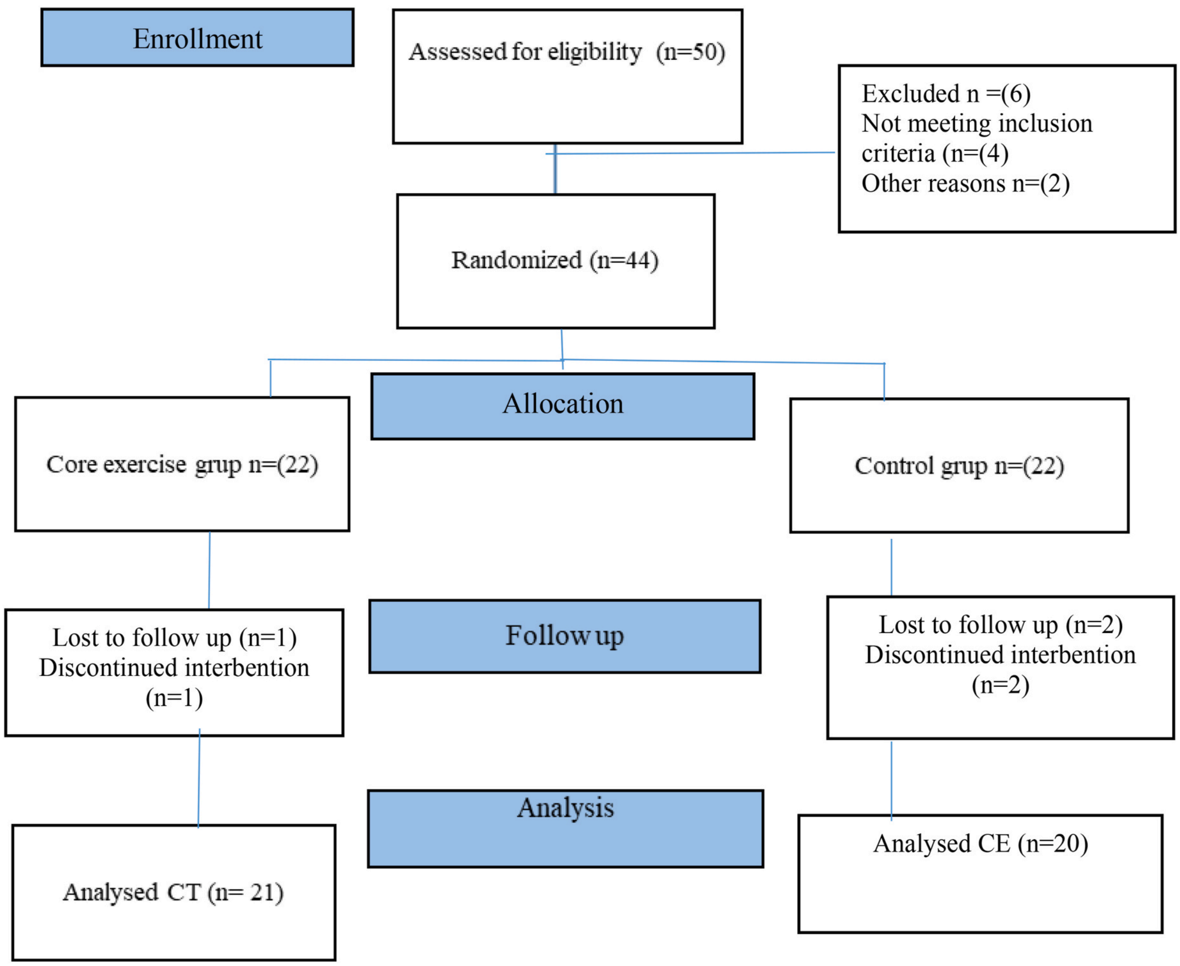


Fig. 1. Evaluation of fibre bundle length and pennation angle using ultrasonography. Panoramic US images show the right supraspinatus following before core exercise training in the relaxed state (1-a); (1-b) after core exercise training. FBL: fibre bundle length, PA: pennation angle.

2.2. Experimental design

This is a prospective, randomized, single-blind, controlled study. All tennis players were evaluated by the same physiotherapist before and immediately after core exercise training (in the 8th week) with visual analog scale (VAS) and isokinetic measurements of shoulder external rotation (ER) and internal rotation (IR) muscles, core endurance tests and muscle architectural features. During a regular in-season training week held in April and May, data collection of the control group was carried out after the players' normal technical-tactical training in groups of 4 or 5 people. Core exercises were added to the regular in-season training in April and May for the core exercise group, and they were performed in groups of 4 or 5 people after the player's normal technical-tactical training. Core stability training includes the following exercises: Isometric activation of the trunk's deep stabilizers while in the supine position, with the lower legs flexed at the hips and knees, and feet flat on the floor, utilizing an active posterior pelvic tilt; side plank with leg lift; supermans; glute bridges; planks; side planks (on both the right and left sides); static push-ups on the fingertips; lying on your back with legs together and arms positioned under the scapula; and prone cobras.



2.3. Procedures

2.3.1. Shoulder rotator cuff muscle strength measurement

We conducted isokinetic evaluations of shoulder ER and IR muscle strength using a Biodex System 3 Pro™ dynamometer at 60°/second and 180°/second, with the same physiotherapist administering the tests. Before measurements started, the dynamometer was calibrated and positioned at a 50° tilt and 20° orientation, with the seat at 85° tilt and 15° orientation. Patients were seated supine in the isokinetic dynamometer chair at 80° hip flexion and 90° knee flexion, with unrestricted ankles. Straps were used to stabilize their trunks and legs. Muscle strength was tested with the shoulder at 45° abduction and 30° flexion, and the elbow flexed at 90°. The rotation axis was adjusted longitudinally through the humerus head and the glenohumeral joint. The elbow axis aligned parallel to the dynamometer entrance, and the neutral hand position was set as per the user manual [14]. The movement range was set to a painless 90° shoulder rotation from a modified neutral position (45° IR and 45° ER). After explaining the procedure, patients practiced three submaximal and five maximal repetitions at each speed. The movement range was set to a painless 90° shoulder rotation from a modified neutral position (45° IR and 45° ER), with gravity correction applied. Patients practiced three submaximal and five maximal repetitions at each speed after the procedure was explained. The isokinetic evaluation at 60°/second involved five maximal effort repetitions, while at 180°/second, there were ten. We measured muscle strength as peak torque (PT) of ER and IR at each speed, using the highest recorded value (Newton meters) for analysis [15].

2.3.2. Muscle architecture measurements

Muscle architecture measurements of the supraspinatus were performed using a GE Logiq P5 ultrasound system with a 12-MHz linear array probe. A trained sonographer acquired the images while the patient sat with the arm adducted and internally rotated, the elbow at 90°, and the hand in a neutral midline position, exposing the affected shoulder. Muscle measurements, including thickness, fascicle length, and pennation angle, were taken before and after treatment, with three measurements taken for each and the mean value recorded. Fiber length was measured using a linear probe placed parallel to the fiber bundles. The probe was positioned along the fascicles to assess the organization between the superficial and deep aponeurosis. Pennation angles were measured between the fiber bundle and the intramuscular tendon at the attachment point. Muscle thickness was measured at its widest point, based on the midpoint of the acromion, with the probe on the supraspinatus fossa in a transverse position [16]. Ultrasonographic measurements of muscle architecture are shown in Figs. 1 and 2.

2.3.3. Core stability assessment

The text outlines core stability assessment using three tests: the side bridge test, abdominal endurance test, and trunk extensors endurance test. The side bridge test requires maintaining a position supported by the forearm and feet to evaluate hip and trunk stabilizers, focusing on the quadratus lumborum muscle [17]. The abdominal muscles endurance test (ABSET) assesses the strength of the rectus abdominis by having the subject hold a sit-up position with a 60° trunk flexion. In the

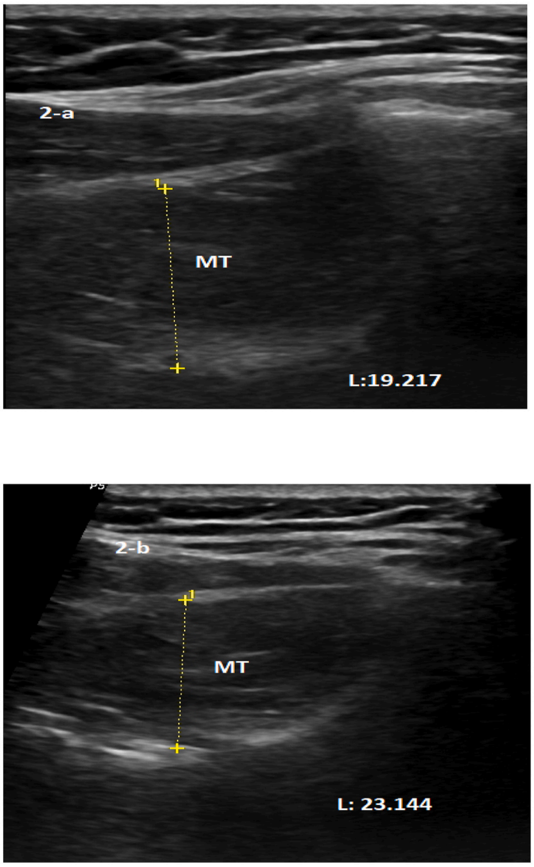


Fig. 2. Evaluation of muscle thickness using ultrasonography. Panoramic US images show the right supraspinatus following before core exercise training in the relaxed state (a); (b) after core exercise training. MT: muscle thickness, L:length.

trunk extensors muscle endurance test (TEMET), the subject lies prone on a rehabilitation table with their pelvis supported and arms crossed while extending the trunk. Following these evaluations, an eight-week core stability exercise program was implemented, focusing on strengthening and stabilizing the lumbopelvic and shoulder muscles [17,18]. The exercises were designed with a focus on proper technique, and each subject received a detailed program outlining a warm-up, sets, repetitions, and exercise descriptions. Subjects performed the core stability exercises three times a week for eight weeks while also participating in regular tennis training three times a week. The core stability tests were re-evaluated using the same procedures after the eight-week program.

2.4. Statistical analysis

Statistical analysis was performed using SPSS Statistics for Windows version 17.0 software program (SPSS Inc., Chicago, IL, USA). For each

Table 1
Demographic characteristics of the study groups.

variables		CT	CE
		N = 21 (%) mean (SD)	N = 20(%) mean (SD)
Gender	man	11 (%52,3)	13 (%35,0)
	woman	10 (%47,7)	7 (%65,0)
Age (years)		42,00 ± 6,69	43,20 ± 9,66
BMI (kg/cm^2)		21,12 ± 3,24	22,48 ± 4,28

CT: control group, CE: core exercise; BMI: Body Weight Index SD: standard deviation. *P < 0.05.

Table 2
VAS- Isokinetic measurements and ultrasonographic parameters regarding muscle architecture before and after core exercise treatment.

		Pre-test median (SD)	Pa between groups	Post-test median (SD)	Pb within group	*Pc* between groups
VAS	CT	**7.19 ± 2,13**	**0,433**	**0,81 ± 1,03**	**0,805**	**0,00**
	CE	**6,70 ± 1,80**		**0,90 ± 1,29**		**0,00**
Muscle thickness	CT	**18,3 ± 2,52**	**0,000**	**20,08 ± 3,08**	**0,000**	**0,000**
	CE	**22,3 ± 3,04**		**24,74 ± 3,19**		
Fiber bundle length	CT	**46,25 ± 4,71**	**0,777**	**49,29 ± 3,91**	**0,665**	**0,000**
	CE	**46,73 ± 5,85**		**50,14 ± 6,62**		
Pennation angle	CT	**16,00 ± 2,26**	**0,210**	**18,28 ± 2,46**	**0,089**	**0,199**
	CE	**17,97 ± 2,65**		**19,91 ± 3,45**		
External Rotation 60 °/sn	CT	13,9 ± 5,13	0,045	18,40 ± 5,58	0,162	**0,000**
	CE	12,30 ± 7,42		19,70 ± 9,96		
İnternal Rotation 60°/sn	CT	15,12 ± 5,06	0,037	19,40 ± 10,09	0,160	**0,000**
	CE	15,37 ± 7,20		24,74 ± 11,17		
External/ İntern al Rotation 60°/sn	CT	1,05 ± 0,77	0,733	0,88 ± 0,44	0,314	0,487
	CE	0,97 ± 0,49		0,84 ± 0,24		
External Rotation 180 °/sn	CT	11,93 ± 4,01	0,071	23,79 ± 6,87	0,402	**0,000**
	CE	14,73 ± 5,57		26,07 ± 9,44		
İnternal Rotation 180°/sn	CT	17,17 ± 6,78	0,919	33,95 ± 10,34	0,396	**0,003**
	CE	16,95 ± 6,85		32,09 ± 12,10		
External/ İntern al Rotation 180°/sn	CT	0,81 ± 0,20	0,021	0,80 ± 0,27	0,836	0,077
	CE	0,90 ± 0,20		0,86 ± 0,26		

SD: standard deviation. *p < 0.05 between two groups for values (independent sample *t*-test) and within the group after 8 weeks (dependent sample *t*-test), P^a, p values of comparison of baseline values between groups; P^b, p-value of the comparison of the pre-test and 8 weeks later within the group(chi-square test); P^c, p values of the comparison of change between groups; CT: control group, CE: core exercise.

continuous variable, distribution normality was checked using the Shapiro-Wilk tests. Chi-square tests were used to quantify possible differences in all outcome measures between groups in the study. For the purpose of comparing data between the first and second evaluations, the Wilcoxon signed-rank test was performed. Results were mentioned as mean value ± standard deviation (SD). P-values less than 0.05 were considered statistically significant. Effect size (η2) was calculated for the changes observed during the treatment process in each group. The effect size (η2) was interpreted as "small effect size" if it was between 0.10 and 0.29, "medium effect size" if it was between 0.30 and 0.49, and "large effect size" if it was ≥0.50.

3. Results

A total of 41 tennis players with rotator cuff pathology were enrolled in this study. The mean ages of the CT group and CE were 42,00 ± 6,49 and 44,20 ± 9,66 years, respectively. There is a statistically significant difference between the groups in terms of mean age (Table 1). Statistical

Table 3
Results of the core stability tests before and after core exercise training program.

		Pre-test median (SD	Pa between groups	Post-test median (SD)	Pb within group	*Pc* between groups
LTMET	CT	76,09 ± 7,89	0,045	82,40 ± 8,08	0,162	**0,000**
	CE	77,27 ± 8,42		86.48 ± 9,08		
ABSET	CT	15,12 ± 5,06	0,037	19,40 ± 10,09	0,160	**0,000**
	CE	15,37 ± 7,20		24,74 ± 11,17		
TEMET	CT	155,32 ± 21,67	0,033	165,97 ± 20,22	0,014	0,000
	CE	138,75 ± 13,81		155,88 ± 21,44		

LTMET-lateral trunk muscles endurance test; ABSET–abdominal muscles endurance test; TEMET–trunk extensors muscle endurance test; n–sample size; ±; SD−mean value and standard deviation of the core stability tests results (in seconds). SD: standard deviation. *p < 0.05 between two groups for values (independent sample *t*-test) and within the group after 8 weeks (dependent sample *t*-test), P^a, p values of comparison of baseline values between groups; P^b, p-value of the comparison of the pre-test and 8 weeks later within the group(chi-square test); P^c, p values of the comparison of change between groups; CT: control group, CE: core exercise.

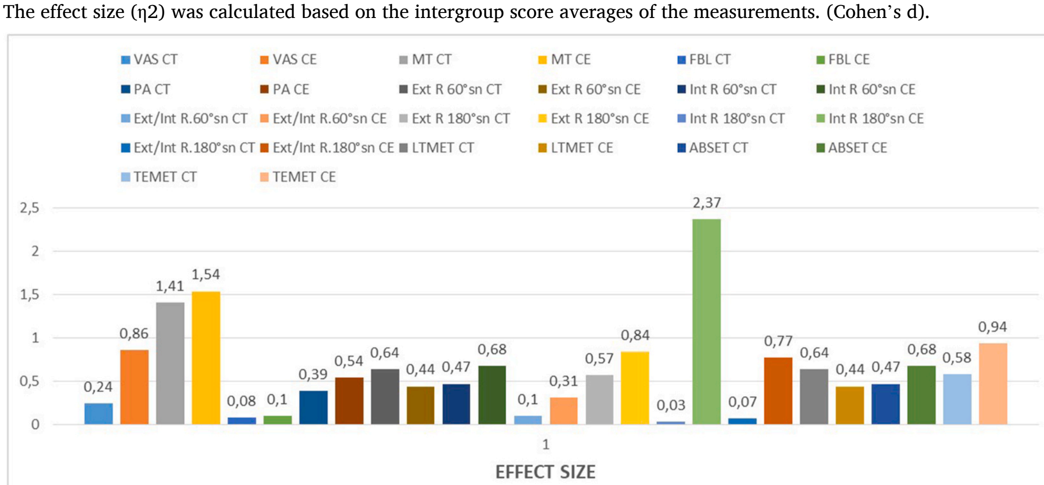
analysis of the results in the first and second studies (before and after introducing the core stability exercise program) revealed significant differences in core stability test results. In addition, the pre-intervention values of the VAS (Table 2), the core stability test results, the isokinetic measurements, and the muscle architecture were similar for both groups. There were statistically significant improved pain, muscle strength, core stability, and changes in the muscle architecture of the two groups after treatment ($p < 0.05$; Tables 2 and 3), (pennation angle, except, $p > 0.05$; (Table 2). However, there were statistically significant differences in pain, muscle strength, core stability, and changes in the muscle architecture in the CE group compared to the CT group after the treatment (pennation angle, except), ($P < 0.05$; Tables 2and3). Table 4 presents the results of core stability tests before and after the core stability training program between groups. We observed a statistically significant increase in all test scores, in both CT and CE, although the average improvement after the eight-week core stability exercise program was greater in CE tennis players. According to do effect size it was found that the decrease in pain level in the CE group, and the increase in core stability scores, muscle thickness, and ER/IR 180°/sec were greater (VAS CE; η2 = 0,86, int r 60° CE; η2 = 0,68, TEMET CE; η2 = 0.94; table 4).

4. Discussion

The repetitive demands and motions of tennis can stress the upper and lower extremities, leading to characteristic injury patterns and musculoskeletal adaptations. To address these effects, preventive approaches can include extensive core stability training [19]. This study aimed to investigate the effects of 8-week specific core stability training on pain, muscle Strength, and muscle architecture in tennis players with rotator cuff injuries. We hypothesized that this exercise approach, which includes specific core stability training, could lead to improvements in pain, strength, and postural stability, thereby reducing the risk of shoulder muscle injury. Our hypotheses have been supported by the results that show positive and foremost effects in the experimental group of tennis players after 8 weeks of intervention. In rotator cuff injuries, players experience increased pain during training due to tendon damage and repetitive overuse. There are few studies on non-pharmacological methods to reduce this pain. In this investigation, individuals in the core exercise group experienced reduced pain levels. The effect size indicating the difference in pain intensity between the groups was significant. A review of the literature revealed that core exercises alleviated pain experienced by patients due to consistent practice in the upper extremities and diminished pain during training when they resumed sports activities [20].

These results are in line with previous reports documenting the foremost and positive effects after a specific core training program. Xiao et al. [21], showed a significant increase in physical performance in the experimental group, compared with controls, after 6 weeks of core training. Fernandez et al. [22] and Majewska et al. [23] obtained the same results after 6 weeks of specific core training and prevention exercises in a group of young, elite tennis players. Š'cepanović et al. [20] evaluated the effects of a six-week core strengthening exercise in a group of 36 female, untrained students, randomly assigned to two groups. In a specific, core strengthening exercise training group, they observed higher results in the isokinetic test, compared with a group of female students participating in a traditional exercise program. Wang et al. [24] confirmed that 9 weeks of core training positively increased tennis players' core strength, muscle thickness, and muscle strength. A healthy neuromuscular system provides essential core stability during functional activities and regulates the movement and strength of the terminal segments, as well as the overall body position. Impairments in

Table 4
The effect size (η2) was calculated based on the intergroup score averages of the measurements. (Cohen's d).



neuromuscular control within the kinetic chain can lead to biomechanical changes and force imbalances during upper extremity movements, making the shoulder joint more susceptible to injury. Several studies conducted on athletes suggest that strong core stability enhances force production and reduces stress on the peripheral joints [25]. Conversely, weak core stability increases the risk of injury, contributing to shoulder and elbow pain in athletes. A program designed to prevent or treat shoulder injuries must include core stability training. Our study clearly demonstrates a significant increase in core stabilization and upper extremity muscle strength within the exercise group when compared to the control group, reinforcing this assertion (Tables 2 and 3).

In the present study, statistical analysis showed that the whole specific protocol (core exercise training) had a significantly positive effect on the performance of the experimental group. We observed significant differences in every parameter of postural stability in the LTMET, ABSET, and TEMET assessments [26]. These differences indicate that the acquired postural control has improved the weakened rotator strength and muscle values. Especially, we observed a great improvement in strength and muscle thickness scores in the external and internal directions, which are the areas of weakness in rotator cuff injuries. In parallel with our results, Bashir et al. [27] reported a statistically significant effect of core training on external and internal strength in tennis players. Furthermore, this relationship potentially may have a significant and positive impact on preventing and reducing injury risk [28–30]. In the sporting environment, therefore, core stability and core strength are essential for controlling the position and motion of the trunk, and for performance enhancement. Previous research suggests that repeated overhead activities cause a build-up of trauma, resulting in differences in shoulder rotator strength. These differences eventually result in an imbalance between the ER/IR ratios on the throwing shoulder. Ellenbecker and Davies speculated that an ER/IR ratio lower than 66 % would be a risk factor for shoulder injuries, and the proper balance between the ER and IR is important for injury prevention [31]. The authors believed this strength imbalance might put the players' shoulders at risk during repetitive tennis serve and stroke. They also reported a decrease in ER/IR ratio from the youngest (74 %) to the oldest players (66 %), reflecting relative weakness in ER strength in the oldest players. We found a greater ER strength and a similar IR strength between the shoulders at both angular speeds. These results cannot be directly compared with Cools et al.'s study as a different strength measurement method was used and the players are older (mean age 43.20 y) in the present study than in Cools et al. [32]. However, some may interpret this as non-elite tennis players not yet demonstrating an adaptive pattern in rotator strength. Nonetheless, the ER/IR ratio remains below 41 %, highlighting the importance of closely monitoring games to detect potential muscle imbalances between the shoulders in later years.

Supraspinatus muscle strength strongly depends on the morphologic properties of the muscle. Several factors can influence the morphological components of muscles [33]. These factors include muscle thickness, which refers to the diameter or cross-sectional area of the muscle fibers, fiber length, which relates to the overall length of muscle fibers, and pennation angle, which is the angle at which muscle fibers attach to the tendon [24,33,34]. Each of these factors plays a crucial role in determining the overall structure and function of skeletal muscles. In the literature, few studies have investigated that muscle thickness is highly related to the cross sectional area (CSA), which is often measured to evaluate muscle atrophy or exercise induced hypertrophy after injury and rehabilitation specific regimes [35,36]. In this study, we thoroughly examined the architectural changes in the supraspinatus muscle following the implementation of core training as a crucial component of the rehabilitation process for tendinopathies and rotator cuff tendon tears. Substantial differences in fiber bundle architecture and muscle thickness were identified after an intensive eight-week core training program for the supraspinatus. Blazevich et al. for example, reported a similar increase in FBL of the vastus lateralis between concentrically and eccentrically core-trained participants [37]. In studies where the training program incorporated a combination of both concentric-eccentric resistance and core mean FBL also significantly increased post-training. Potier et al. also found an increase in FBL following an eight week core training program for the biceps femoris; however, the changes were not significant between the controls. Studies have reported an increase in muscle thickness and fiber length following core training [38].

The supraspinatus tendon which coalesces with the other rotator cuff tendons may have tendon properties different from those of the upper extremity muscles. In addition, the anterior region of the supraspinatus muscle, which was investigated in the present study, is circumpennate in architecture with a long intramuscular portion of the tendon extending medially into the muscle belly [38,39]. Compared to other studies, the differences between our findings in fiber bundle architecture and the mechanical properties of the muscle contributed to the literature. It was concluded that further investigation should be conducted in future studies. Muscle thickness is a common measurement used to indicate muscle hypertrophy after training [39,40]. In pennated muscles, hypertrophy is associated with an increase in PA. An increase in PA can in turn affect the force producing capability of the muscle by allowing a greater amount of contractile tissue to attach to a given area of tendon which in turn can lead to a larger physiological cross sectional area. Numerous studies have shown that muscle growth is higher after combined core and strength training compared to strength training alone [41–44]. In our study, we also observed differences between the groups in muscle thickness (MT), fascicle length (FL), and pennation angle (PA). Similar to MT, FL increased significantly with shoulder core training, but we found no difference in PA values between the core exercise group and the control group. The significant increase in fL and MT observed over time in this study can be explained by adaptation and decreased tension on the muscle fibers and hypertrophy caused by rehabilitation. Despite the significant increase in muscle fiber lengthening and MT, no significant change in PA was seen after 8 weeks. One possible explanation for this is microtrauma, which occurs when the muscle becomes inflamed from tension initially applied to strengthen the muscle and the tendon reattaches to its insertion site. By 8 weeks after the rotator cuff lesion, the damage would likely have diminished, so the change could be explained by new muscle fiber growth accounting for the area previously occupied by inflammation. Although these changes cannot be easily distinguished using US, they are promising in observing the muscle condition as a result of core exercises.

4.1. Limitations of the study

The study's first limitation may be that the rotator cuff of the injured shoulder was not compared with the uninjured side. Another limitation was that the muscle architecture of the infraspinatus was not measured in addition to the supraspinatus. Additionally, our study was conducted on a specific group of middle-aged tennis players. therefore, future research should include different age groups and ability levels.

5. Conclusions

The findings of this study suggest changes in pain, rotator muscle strength, core endurance, and muscle architecture evoked by core training are closely coupled. Since the structure of a muscle best reflects its functional demands, in instances of pathology, pain reduction and the maintenance or restoration of architectural parameters favorable to its function are of the utmost importance in rehabilitation. For this reason, core stability exercises can be recommended to tennis players with rotator cuff injuries as a valuable supplement to regular tennis training, based on our study findings and those of other authors.

Authors' contributions

All authors participated in creating the study's concept and design. E. M.ERSEVER collected the data, interpreted it, and drafted the manuscript. B.GOKTAS executed the statistical analysis. All authors critically revised the manuscript, read and approved the final version, and agreed to be accountable for all aspects of the work.

Congresses

This article was presented as an oral presentation at the 5th International Athletic Performance and Sports Health Congress held at Nişantaşı University, Istanbul, on 24–26 May.

Funding

The authors report no involvement in the research by the sponsor that could have influenced the outcome of this work.

Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

References

[1] Alrabaa RG, Lobao MH, Levine WN. Rotator cuff injuries in tennis players. Current reviews in musculoskeletal medicine 2020;13:734–47.
[2] BurkeWS Vangsness CT, Powers CM. Strengthening the supraspinatus: a clinical and biomechanical review. Clin Orthop Relat Res 2002;402:292–8.
[3] Reinold MM, Wilk KE, Fleisig GS, et al. Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. J Orthop Sports Phys Ther 2004;34(7):385–94.
[4] Malanga GA, Jenp YN, Growney ES, et al. EMG analysis of shoulder positioning in testing and strengthening the supraspinatus. Med Sci Sports Exerc 1996;28(6): 661–4.
[5] Jobe FW, Moynes DR. Delineation of diagnostic criteria and a rehabilitation program for rotator cuff injuries. Am J Sports Med 1982;10(6):336–9.
[6] Neer CS. Anterior acromioplasty for the chronic impingement syndrome in the shoulder 1972. J Bone Joint Surg Am 2005;87(6):1399.
[7] Kuhn JE. Exercise in the treatment of rotator cuff impingement: a systematic review and a synthesized evidence-based rehabilitation protocol. J Shoulder Elb Surg 2009;18(1):138–60.
[8] Majewska J, Kołodziej-Lackorzyńska G, Cyran-Grzebyk B, et al. Effects of core stability training on functional movement patterns in tennis players. Int J Environ Res Publ Health 2022;19(23):16033. https://doi.org/10.3390/192316033.
[9] Gomes RV, Moreira A, Lodo L, et al. Monitoring training loads, stress, immune-endocrine responses and performance in tennis players. Biol Sport 2013;30: 173–80. https://doi.org/10.5604/20831862.1059169.
[10] Brouwers J, Sotiriadou P, De Bosscher V. Sport-specific policies and factors that influence international success: The case of tennis. Sport Manag Rev 2015;18: 343–58.
[11] Fernandez-Fernandez J, Saez de Villarreal E, Sanz-Rivas D, et al. The effects of 8-week plyometric training on physical performance in young tennis players. Pediatr Exerc Sci 2016;28:77–86.
[12] Reid M, Crespo M, Santilli L, et al. The importance of the International Tennis Federation's junior boys' circuit in the development of professional tennis players. J Sports Sci 2007;25:667–72.
[13] Fu MC, Ellenbecker TS, Renstrom PA, et al. Epidemiology of injuries in tennis players. Curr Rev Musculoskelet Med 2018;11:1–5.
[14] Castillo-lozano R. Epidemiology and prevention strategies for the musculoskeletal injuries in the paddle-tennis senior players. Sci Sports 2017;32(3):e101–6.
[15] McCurdie I, Smith S, Bell PH, et al. Tennis injury data from the championships, wimbledon, from 2003 to 2012. Br J Sports Med 2017;51:607–11.
[16] Sonnery-Cottet B, Edwards TB, Noel E, et al. Rotator cuff tears in middle-aged tennis players: results of surgical treatment. Am J Sports Med 2002;30(4):558–64.
[17] Wickiewicz TL, Roy RR, Powell PL, et al. Muscle architecture of the human lower limb. Clin Orthop Relat Res 1983;179:275–83. Pubmed ID: 6617027.
[18] Van Kampen DA, van den Berg T, van der Woude HJ, et al. The diagnostic value of the combination of patient character- istics, history, and clinical shoulder tests for the diagnosis of rotator cuff tear. J Orthop Surg Res 2014;7:70. https://doi.org/10.1186/13018-014-0070.
[19] Kim S, Bleakney R, Boynton E, et al. Investigation of the static and dynamic musculotendinous architecture of supraspinatus. Clin Anat 2010;23:48–55.
[20] Powell JK, Schram B, Lewis J, et al. "You have (rotator cuff related) shoulder pain, and to treat it, I recommend exercise." A scoping review of the possible mechanisms underpinning exercise therapy. Muscoskel Sci Pract 2024;62:102646.
[21] Donatelli R, Carp K. Chapter 12—evaluation of the trunk and hip core. In: Sports-specific Rehabilitation. first ed. Amsterdam, The Netherlands: Elsevier; 2007. p. 193–222.
[22] Hibbs AE, Thompson KG, French D, et al. Optimizing performance by improving core stability and core strength. Sports Med 2008;38:995–1008.
[23] MacrinaLC Fleisig GS, Porterfield R, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional base ball pitchers. Am J Sports Med 2011;39(2):329–35.
[24] Xiao W, Geok SK, Bai X, et al. Effect of exercise training on physical fitness AmongYoungTennis players: a systematic review. Front Public Health 2022;10: 843021. https://doi.org/10.3389/2022.843021.
[25] Harrington S, Meisel C, Tate A. A cross-sectional study examining shoulder pain and disability in Division I female swimmers. J Sport Rehabil [Internet] 2014;23: 65–75. Available from: https://www.ncbi.nlm.nih.gov/pubmed/23945068.
[26] Šiupšinskas L, Garbenyť e-Apolinskieṅ T, Salatkaiť e S, et al. Association of pre-season musculoskeletal screening and functional testing with sports injuries in elite female basketball players. Sci Rep 2019;9:9286.
[27] Fernandez-Fernandez J, Granacher U, Sanz-Rivas D, et al. Sequencing effects of neuromuscular training on physical fitness in youth elite tennis players. J Strength Condit Res 2018;32:849–56. PuMed ID: 24149801.
[28] Wang T, Liu YX, Weng Z. Core strength training in university female tennis players. Revista Brasileira de Medicina do Esporte2022; 28, 651-653. PubMed ID: 24149801.
[29] Kim SY, Ko JB, Farthing J, et al. Investigation of supraspinatus muscle architecture following concentric and eccentric training. J Sci Med Sport 2015;18(4):378–82. https://doi.org/10.1016/2014.05.007.
[30] Bashir SF, Nuhmani S, Dhall R, et al. Effect of core training on dynamic balance and agility among Indian junior tennis players. J Back Musculoskelet Rehabil 2019;32: 245–52. https://doi.org/10.3233/170853.
[31] Huxel Bliven KC, Anderson BE. Core stability training for injury prevention. Sport Health 2013;5:514–22. https://doi.org/10.1177/1941738113481200. PubMed ID: 24427426.
[32] Ahmed S, Akter R, Saraswat A, et al. Core stability and its impact on upper extremity function in racket sports: a narrative review. Saudi J. Sports Med 2019; 19:31–7. https://doi.org/10.4103/1519.
[33] Cigercioglu NB, Guney-Deniz H, Unuvar E, et al. BShoulder range of motion, rotator strength, and upper-extremity functional performance in junior tennis players. J Sport Rehabil 2021;30(8):1129–37. https://doi.org/10.1123/2021-0038.
[34] Li Y. Construction of intelligent campus tennis players'body data monitoring and injury warning system based on data fusion. Rev Bras Med Esporte 2021;27:46–9.
[35] Ellenbecker TS, Davies GJ. The application of isokinetics in testing and rehabilitation of the shoulder complex. J Athl Train 2000;35(3):338–50. PubMed ID: 16558647.
[36] 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):647–53. PubMed ID: 25098662.
[37] Hinks A, Franchi MV, Power GA. The influence of longitudinal muscle fascicle growth on mechanical function. J Appl Physiol 2022;133(1):87–103. https://doi.org/10.1152/.00114.2022. PumMed ID: 35608202.
[38] Sachdeva R, Beavis C, Obaid H, et al. Surgical repair of the supraspinatus: Pre-and postoperative architectural changes in the muscle. Singap Med J 2022;63(2):97.24. https://doi.org/10.11622/2020123. PubMed ID: 32798361.
[39] Ersever EM, Guzel NA, Genç H, et al. The effects of neuromuscular electric stimulation on pain, function, muscle strength and muscle architecture in patients with rotator cuff tendinopathies. Muscles, Ligaments & Tendons Journal (MLTJ) 2022;12(4):526–33.
[40] BlazevichAJ Cannavan D, Coleman DR, et al. Influence of concentric and eccentric resistance training on architectural adaptation in human quadriceps muscles. J Appl Physiol 2007;103(5):1565–75.
[41] Potier TG, Alexander CM, Seynnes OR. Effects of eccentric strength training on biceps femoris muscle architecture and knee joint range of movement. Eur J Appl Physiol 2009;105(6):939–44.
[42] Takahashi M, Ward SR, Marchuk LL, et al. Asynchronous muscle and tendon adaptation after surgical tensioning procedures. J Bone Joint Surg Am 2010;92: 664–74.
[43] Aagaard P, Andersen JL, Dyhre-Poulsen P, et al. A mechanism for increased contractile strength of human pennate muscle in response to strength training: changes in muscle architecture. J Physiol 2001;534:613–23.
[44] Ohagan FT, Sale DG, Macdougall JD, et al. Comparative effectiveness of accommodating and weight resistance training modes. Med Sci Sports Exerc 1995; 27(8):1210–9.