

Research Paper: The Effect of Resistance Training on Lower Extremity Pain, Strength and Kinematical Parameters in Women With Patellofemoral Complications



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ABSTRACT

Purpose: The aim of this study was to evaluate the effect of strengthening the abductor and external rotator of the hip joint muscles on pain, thigh muscle strength, and lower limb kinematics in volleyball players with patellofemoral complications.

Methods: Twenty-four volleyball players with patellofemoral pain were randomly divided into the experimental and control groups. The experimental group received three sessions of strengthening exercises for the abductor muscles and external rotators of the hip joint using Traband for eight weeks. The control group received no training intervention. The pain was assessed by visual acuity scale, hip muscle strength by hand dynamometer, and lower limb kinematics using video analysis before and after the intervention. Samples included volleyball players with patellofemoral pain who had pain in one or both knees. If the pain was bilateral, the exercises were performed bilaterally on both lower limbs, but measurements were taken only from the lower extremity, which was most in pain. Analysis of covariance was used by SPSS software for statistical analysis.

Results: The results of this study showed that after training, in the experimental group, pain decreased and the strength of the abductor's muscles and external rotator of the hip joint muscles increased. Knee dynamic valgus and pelvic drop were observed in single-leg squat only in the experimental group.

Conclusion: The results showed that the strengthening of the hip joint can decrease the pain of volleyball players with patellofemoral, increase the strength of the muscles and change the kinematics of the lower limbs on the frontal plane, and this can be the mechanism of the effect of this intervention on the symptoms of pain.

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Highlights

- Strengthening of the hip joint can decrease the pain of volleyball players with patellofemoral complications and change the kinematics of the lower limbs on the frontal plane after eight weeks of thigh muscle resistance training.

Plain Language Summary

Recent studies have recommended the probable role of femoral muscle weakness in creating this complication and adding hip strength to conventional knee muscle training for the treatment of these patients. Each study specifically has measured the effect of a method on treatment, while the newest approaches in the treatment of patients with patellofemoral pain are more orthosis, prosthesis, reinforcement training, and tensile training. The effect of reinforcement exercises on the strength, pain, and kinematics of lower limbs of women with patellofemoral complications has been examined. Understanding factors, such as thigh muscle weaknesses may play an important role in the occurrence of patellofemoral pain syndrome. However, so far, this muscle has been not widely considered in therapeutic protocols. The mentioned study also examined the effect of the strengthening of these muscles in therapeutic protocols and contradictory results were achieved. Thus, we decided to consider the effect of reinforcement exercises on the pathway of the patellofemoral joint and control this multi-factor syndrome. The results of this study showed that after training, in the experimental group, pain decreased and the strength of the abductor's muscles and external rotator of the hip joint muscles increased. Knee dynamic valgus and pelvic drop were observed in single-leg squat only in the experimental group.

1. Introduction

Patellar thigh pain is one of the most common causes of anterior knee pain, especially among young women, which is twice as common in women as men and accounts for about 25% of knee joint problems [1]. This syndrome is a clinical condition characterized by pain in the back or under the patella that is associated with activities that involve weight bearing on the lower limbs, such as walking, running, jumping, climbing stairs, sitting for a long time, and kneeling [2]. Decreased thigh muscle strength has been considered an important factor associated with patellar pain [3]. Another accepted cause of patellofemoral pain is the abnormal deviation of the patella between the femoral gutters. [4] The cause of this deviation may be a delayed onset of vastus medialis activity relative to the vast lateral. It is likely to cause a temporary muscle imbalance in the internal-external force, which makes the patella deviate [5]. Kinematics and kinetics of the knee and hip joints, in different motor planes, can be affected by a lack of proper control of the hip muscles [6]. Improper function of these muscles is a common problem in patients with patellar pain [7], which can cause abnormal patellar outward movement [8]. This condition can be associated with kinematic changes in the hip joint in people with patellofemoral pain [9]. Due to recent attention to the abnormal kinematic role of the hip joint in patients with patellar pain, some researchers have decided to investigate the effect of strengthening the thigh

muscles on the symptoms of patellar pain in clinical and review studies [10].

Yalfani et al. examined the effect of 12 weeks of sensorimotor training on pain, strength, pelvic drop, and dynamic knee valgus in men with patellofemoral pain syndrome [11]. In this study, 32 patients with patellofemoral pain syndrome were studied. The results of this study showed that sensorimotor exercises reduced pain and facilitated the frequency and timing of muscle activation [11]. One of the reasons why some treatment protocols fail is the multifactorial nature of this syndrome [9]. It has long been the case that the treatment of this syndrome has been localized and focused on the patellofemoral joint as the site of pain [12]. Therapies have sometimes been unsuccessful in controlling pain [13]. Today, in addition to the muscles around the knee joint, the thigh area is considered the best site for treatment [14]. Recent studies have suggested the possible role of thigh muscle weakness to cause this complication and adding thigh strengthening to regular knee muscle exercises for the treatment of these patients [15].

Emamverdi et al. examined the effect of valgus control exercises on pain, strength, and performance in the active women with patellofemoral pain syndrome. Improved strength and increased functional efficiency of athletes were observed. Also, the valgus control instruction program improved performance, knee valgus angle, and strength in participants with patellofemoral pain syndrome, which can be considered by injury preven-

tion professionals [16]. Shafiee et al. reported that six weeks of the abductor and adductor muscle exercises, especially abductor's muscles, could reduce knee pain and improve joint function in patients with patellofemoral pain syndrome [17].

Silva et al. in a study entitled "The effect of neuromuscular training and strengthening of the trunk and lower limb muscles in women with patellofemoral pain" reported that trunk and lower limbs based on physiotherapy treatments can help women with patellofemoral pain [18].

Stabilization of the central trunk is mainly due to the active function of the muscular structures, creating the abdominal muscles from the front, the gluteus and parietal muscles from the back, and the pelvic floor muscles and around the thighs from the below. Definition of the body's ability to maintain the correct alignment of the lumbar-pelvic-thigh complex and the central stability of the trunk is the basis of the stability of the trunk that allows the transfer and control of force and movement to the lower parts of the motor chain, such as the knee joint [19]. So far, no study has evaluated the effect of thigh muscle strengthening exercises on strength, pain, and kinematics of lower extremities in women with patellofemoral complications. Studies that have examined the effect of the strengthening of these muscles in protocols have contradictory results. Therefore, in this study, we decided to investigate the effect of the strengthening of the abductor and external rotator cuff muscles on the amount of pain, thigh muscle strength, and lower limb kinematics in women with patellofemoral complications.

2. Materials and Methods

The method of the present study was a clinical trial and applied research in terms of purpose. It was performed in two stages of pre-test and post-test. The statistical population of this study was all female volleyball players in the age range of 18 to 25 years playing in the volleyball clubs of Tehran, Iran. A statistical sample of 24 volleyball players who were selected by available and purposeful sampling with the help of G-Power software and after screening and homogenization based on Body Mass Index (BMI), were divided into two groups of 12 players: control and experimental. In order to implement the research plan, the subjects first completed the informed consent form to participate in the research. Then, preliminary assessments, including height, weight, actual leg length, etc. were performed by valid tools and devices mentioned below.

All training sessions and kinematical parameters were held in a private club (Energy Club) from April 4 to June 10, 2021, with respect to all health Protocols. The age range was between 18 and 25 years. This age range was chosen to reduce the risk of developing osteoarthritis in people. In subjects with pain in both or one knee, if the pain was bilateral, the exercises were performed bilaterally on both lower limbs, but measurements were taken only from the lower extremity, which was more painful. If the pain in both knees were equal, data were collected only from the upper-lower limb.

To test the isometric strength of the abductor muscles of the hip joint (Figure 1), the subject stood sideways and placed the whole body in one direction. Then, to keep the body steady, they bend the lower leg slightly from the knee and keep the tested leg straight. The subject's pelvic joint was fixed by the tester and the dynamometer pad was placed above the external epicondyle of the thigh. The subject was asked to move his leg away with the maximum force exerted by the device was recorded [20].

To test the isometric strength of the external rotator of the hip joint muscles (Figure 2), the subject sat on the edge of the bed with the knee joint at a 90-degree angle of flexion and the calf hanging from the bed. To prevent any use of muscles other than the external rotator cuff muscles, the distal thigh was fixed by the tester. The dynamometer pad was placed slightly above the inner ankle of the foot and the subject tried to rotate the thigh outwards by pushing towards the pad of the device and the maximum force applied by the device was recorded [20].

In both muscle strength tests, the subject underwent these steps in three stages with an interval of one minute, and the average of these three stages was recorded as the strength of the subject's hip muscles. Then, in order to normalize the power and make a correct comparison between the two groups, the numbers obtained from the hand-held dynamometer (kg. N) were divided by the body mass (kg) and multiplied by 100.

A two-dimensional motion analysis method was used to determine the kinematics of knee and thigh joints. First, the anatomical points of each player's lower limbs were identified by a physiotherapist. These included thoracic anterior thorns on both sides, internal and external condyles of the femur, large ridges, and internal and external ankles of the target lower limb. Then, the markers on the upper anterior spines on both sides, the midpoints of the joint line of the knee and ankle joints (obtained by connecting the anatomical points and determining their central point by a tape measure), and the linear midpoint,

which was drawn from the upper anterior cruciate ligament to the middle of the patella, were attached to the thigh and the tibia protrusion on the lower limb.

Measurement of the subjects' height

To measure height, the subjects stood barefoot with their heels, hips, and head against the wall. In this case, the body weight was evenly distributed on the legs. The head and eyes were parallel to the horizon. A wall meter was used to measure height in centimeters.

Measurement of the subjects' weight

An analog scale (with a sensitivity of 0.1 kg, Germany) was used to measure the body weight of the subjects. The subjects were placed on the scales in light clothes and without shoes and their body weight was calculated in kilograms.

Pain assessment

In this study, a Visual Analog Scale (VAS) was used to assess pain. The visual acuity questionnaire is a horizontal bar measuring 100 mm or 10 cm, one end of which is zero and the other end is 10, which is the most severe pain possible. This scale is one of the most authoritative visual pain rating systems and has been widely used. Its validity and reliability are excellent with the internal reliability with an ICC (Intraclass Correlation Coefficient) value of 0.91 [21].



PHYSICAL TREATMENTS
Figure 1. Isometric strength of abductor thigh muscles

Training protocol

The subjects in the experimental group, under the direct supervision of the examiner, performed strengthening exercises of the relevant muscles for eight weeks and three sessions per week. The control group did not receive any treatment or intervention. Due to the executive restrictions on the use of free weights to increase muscle strength and ensure that the desired muscle groups are strengthened, the US-made Traband sports straps were used in four colors: red, green, purple, and black. Among the caches used in the present study, the cache with red color had the lowest resistance and the cache with black color had the highest resistance. Each training session included five minutes of warm-up, 20 minutes of resistance training, and five minutes of cooling. Exercises in each session consisted of three sets (Table 1) (4-6).

Strengthening exercises of the abductor muscles of the hip joint were performed while standing. First, the elongation was determined by measuring the abduction axis in the hip and ankle joints. Then, the subject stood on the side next to the fixed bar, so that the foot to strengthen the muscles was farther from the bar, one end of the elastic was attached to the subject's ankle and the other end was attached to the bar and fixed. The subject performed the abduction movement of the hip along with the range of motion, applying force against the training elbow.

External strengthening exercises of the rotator of the hip joint muscles were performed in a sitting position. First, the elongation was determined by measuring the distance between the axis of movement of the external



PHYSICAL TREATMENTS
Figure 2. External isometric strength test of the hip rotator cuff

Table 1. How to implement the training protocol with Traband

Week	First Set	Repeat	Second Set	Repeat	Third Set	Repeat
1-2	Red	20	Green	20	Purple	20
3-4	Red	25	Green	25	Purple	25
5-6	Green	20	Purple	20	Black	20
7-8	Green	25	Purple	25	Black	25

30 seconds of break between sets, 1-minute break at the end of the set.

PHYSICAL TREATMENTS

rotation of the thigh at the hip and knee joints. The subject then sat on the bed, with the foot close to the bar, and hung his feet from the bed, with the feet off the edge of the knee. One end of the clamp was attached to the subject’s ankle and the other end to a fixed bar.

Data analyzing

Descriptive and inferential statistics were used to analyze the data statistically. Descriptive statistics were used to calculate central indicators, dispersion of quantitative scales, charts, and tables. After checking the normality of the data by the Shapiro-Wilk test, Analysis of Covariance (ANCOVA) was used. All calculations were performed by SPSS software, v. 21 at a significant level of $P \leq 0.05$.

3. Results

The results of the Shapiro-Wilk test on the normality of the data are reported separately in Table 2. As can be seen

in Table 2, the value of the significance level of all indicators using the Shapiro-Wilk test was more than 0.05. Because one of the main assumptions for using the ANCOVA is the equality of variance (homogeneity of variance), first, the equality of variances was examined by Leven’s test.

As shown in the Table 3, slope homogeneity was not significant for all variables; thus, the concept of homogeneity of regression gradients was achieved for the variables and the hypothesis was assessed by ANCOVA. The difference in pre-test and post-test scores of the two experimental and control groups for the abductor thigh muscle significantly and the mean score of the experimental group and at the surface ($P \leq 0.01$) and Eta squares were more than the control group. Therefore, it can be said that eight weeks of resistance training of the thigh muscles had a positive and significant effect on lower limb pain in volleyball players with patellofemoral complications (Table 4).

Table 2. Shapiro-Wilk test results regarding the normal distribution of data

Variables	Z	P	Result
Age	1.67	0.331	Normal
Height	0.90	0.194	Normal
Weight	0.71	0.622	Normal
BMI	1.74	0.571	Normal
Strength of the abductor thigh muscles	0.87	0.283	Normal
Strength of the external rotator of thigh muscles	0.72	0.233	Normal
Knee valgus in the step test	0.83	0.733	Normal
Knee valgus in squat	1.22	0.156	Normal
Pelvic drop in step test	0.79	0.345	Normal
Pelvic drop in the squat	1.34	0.222	Normal
Pain	1.83	0.178	Normal

PHYSICAL TREATMENTS

Table 3. Leven's test results for t homogeneity of variances of the studied variables

Variables	F	Degree of Freedom (df 1)	Degree of Freedom (df 2)	P
Strength of the abductor thigh muscles	20.246	1	20.246	0.236
Strength of the external rotator of thigh muscles	13.676	1	13.676	0.111
Knee valgus in the step test	39.001	1	39.001	0.290
Knee valgus in squat	17.245	1	17.245	0.679
Pelvic drop in the step test	48.077	1	48.077	0.224
Pelvic drop in the squat	17.565	1	17.565	0.360
Pain	21.523	1	21.523	0.463

PHYSICAL TREATMENTS

The difference in pre-test and post-test scores of two experimental and control groups for the external rotator of the thigh muscle significantly and the mean score of the experimental group and at the surface ($P \leq 0.01$) and Eta squares were more than the control group. Therefore, it can be said that eight weeks of resistance training of the thigh muscles had a significant effect on lower limb pain in volleyball players with patellofemoral complications (Table 5).

The results showed that in the pre-test stage, the difference in mean scores of the two control and experimental groups regarding strength was not significant ($P < 0.05$).

However, for other variables, the difference in mean scores was significant ($P < 0.05$).

3. Discussion

The aim of this study was to investigate the kinematic changes of the lower extremities following an 8-week strengthening program of the abductor and external rotator of the hip joint muscles. Our findings showed a significant reduction in pain, a significant increase in the strength of the abductor and external rotator of the hip joint muscles, a reduction in the valgus angle of the knee joint in a single-legged squat, and a reduction in the sag-

Table 4. Results of pre-test and post-test of the external rotator of the thigh muscle

Variables	Source of Changes	Total Squares	Degree of Freedom (df)	Average of Squares	F	P	Eta Coefficient
Pain	Pre-test	320.60	1	320.60	6.34	0.011	0.197
	Group	341.72	1	341.72	8.77	0.011	0.680
	Error	760.56	27	36.70			
Strength	Pre-test	47.00	1	47.00	5.78	0.001	0.239
	Group	278.01	1	278.01	11.33	0.601	0.201
	Error	567.11	49	50.76			
Pelvis drop	Pre-test	210.23	1	210.23	6.34	0.001	0.510
	Group	434.21	1	434.21	7.44	0.011	0.203
	Error	793.41	29	30.54			
Knee valgus	Pre-test	276.00	1	276.00	4.44	0.032	0.320
	Group	279.11	1	279.11	2.18	0.0001	0.458
	Error	645.66	19	30.75			

PHYSICAL TREATMENTS

Table 5. Results of pre-test and post-test of the external rotator of the thigh muscle

Variables	Source of changes	Total Squares	Degree of Freedom (df)	Average of Squares	F	P	Eta Coefficient
Pain	Pre-test	200.12	1	200.12	6.30	0.001	0.210
	Group	401.40	1	401.40	4.93	0.001	0.568
	Error	840.67	17	31.79			
Strength	Pre-test	567.11	1	567.11	7.23	0.051	0.469
	Group	560.89	1	560.89	5.34	0.001	0.236
	Error	923.67	34	56.88			
Pelvis drop	Pre-test	276.00	1	00/276	44/4	0.032	0.320
	Group	279.11	1	11/279	18/2	0.0001	0.458
	Error	645.66	19	75/30			
Knee valgus	Pre-test	276.00	1	276.00	4.44	0.032	0.320
	Group	279.11	1	279.11	2.18	0.0001	0.458
	Error	645.66	1	200.12			

PHYSICAL TREATMENTS

ging angle of the opposite pelvis while descending stairs and externally hip rotator by Traband in the experimental group. The findings of this study confirmed our hypotheses of reduced pain, increased hip muscle strength, and lower limb kinematic changes.

Weakness of the abductor's muscles can lead to excessive hip joint rotation followed by more stretching of the knees. The valgus knee can increase the external force and causes pain [11]. If the rotator of the hip joint muscles is weak, the internal rotation occurs over the thigh followed by the increased contact pressure between the outer carriage of the thigh and the outer part of the detachment, and it causes pain under the patella (Table 6) [16].

The results of the present study regarding a reduction in pain following thigh muscle strengthening exercises are consistent with the results of Salimzadeh et al. [22], Khayyambashi et al. [23], and Sahin et al. [24]. Strengthening of the abductor and external muscles of the hip joint led to control of the internal rotation and hip joint and the whisker is in a better pathway before the treatment protocol and reduced the contact with the joint surfaces of the thigh [16].

The results of the present study regarding the increased strength of both hip muscle groups are consistent with the results of Salimzadeh et al. [22], Khayambashi et al. [23], and Sahin et al. [24], but not consistent with the results of Nakagawa et al. [25], and Honarpishe et al. [26].

Table 6. The mean scores of measured variables in the groups

Variables	Groups	Mean±SD		P
		Pre-test	Post-test	
Pain	Experimental	5.96±0.65	3.08±0.68	0.004
	Control	6.87±0.35	7.320.24	0.001
Strength	Experimental	17.84±0.69	23.460.95	0.782
	Control	19.30±0.75	22.17±0.39	0.001
Knee valgus	Experimental	169.23±1.18	170.62±1.16	0.003
	Control	157.65±1.23	172.04±1.20	0.001
Pelvic drop	Experimental	5.16±0.55	4.45±0.60	0.0001
	Control	5.08±0.61	5.31±0.47	0.0001

PHYSICAL TREATMENTS

The reason for the inconsistency of the results regarding the increase in the strength of the hip muscles can be due to differences in the implementation of the training protocol and also the longer training period in the present study and the type of training protocol. Another hypothesis of this study was the improvement of the kinematics of the lower limb following the program of strengthening the abductor and external rotator of the hip joint muscles that was confirmed by the results. The analysis of the findings of this study showed the improvement of knee valgus dynamics during single-legged squat in affected women as well as the improvement of pelvic prolapse during descending stairs. Intragroup comparisons showed that all kinematic variables changed significantly over time in the experimental group, but in intergroup comparisons, the results indicated that according to the findings of Bell et al. [27] and Palmer et al. [28], valgus knee dynamics improved significantly during single-legged squat in the experimental group compared to the control group. The researchers have used combined exercises in their studies, including exercises to strengthen the hip muscles, along with strengthening the ankle muscles, stretching and functional exercises, and motor retraining.

The results of the study showed that in order to cause kinematic changes in the lower extremities and improve the symptoms of patellar pain, it is possible to achieve similar results with more complex exercises with only two simple exercises to strengthen the abductor muscles and external rotator of the hip joint rotations. Improvement of valgus dynamic angle obtained in this study is not consistent with the results of Farber et al. [29] who showed that after three weeks of strengthening exercises of the abductor hip muscles there was an improvement in lower extremity kinematics, including the valgus dynamic knee. One of the reasons for the inconsistency of the results of the two studies is the duration of the training intervention period. It is noteworthy that the exercises in Farber et al. research were performed at home without supervision for three weeks, while the reinforcing exercises of the present study were performed for eight weeks, three sessions per week, and continuously under the supervision of the examiner at the designated location.

The rate of pelvic floor prolapse decreased during single-legged squat in the experimental group, which is consistent with the results of Mascal et al. [30] and Balden et al. [31] suggesting that strengthening hip muscles, functional exercise, and gait retraining are factors associated with improvement in lower limb kinematics in patients with patellofemoral pain. In addition to the valgus dynamic variable of the knee, this change was also

controlled in the degree of pelvic prolapse. Lower limb length and pelvic width are factors that can affect the kinematics and effectiveness of various strategies on lower limb kinematics in patients with patellar pain [32, 33]. Lower limb length and pelvic width were not considered in the present study. Future research should also consider anthropometric data of the lower extremities as a component. Men and women may also use different kinematic methods to reduce the symptoms of patellar pain. For example, affected men and women may place their knees in different positions as they descend the stairs so that they can moderate the amount of pressure exerted and thus reduce symptoms [33].

Limitation of this study included age, sex, fatigue (subjects were asked not to engage in any strenuous activity for 48 hours prior to exercise), height, weight, and body mass index. It is also suggested that this study be performed in a larger community than the current study on the population of people with patellofemoral complications. Research with the same title on other age groups and other sports for example on athletes of the male sex and different age groups and other sports is suggested.

5. Conclusion

According to the results of the present study, it can be stated that therapeutic exercise based on strengthening the abductor and external rotator of the hip joint muscles of patients with patellofemoral pain may be able to reduce the dynamic valgus of the knee and the amount of pelvic prolapse on the opposite side. Then, the patients' pain will be improved. Eight weeks of abductor and external strengthening exercises of the external rotator of the hip joint are likely to cause kinematic changes in the lower extremities, and by making these changes, the effect of reducing the symptoms of patellofemoral pain following the mentioned exercises may be stable. Based on the findings of this study, it may be possible to consider the training method used, which includes strengthening the abductor and external rotator of the hip joint muscles by Trand, as an effective and integrated method in the rehabilitation of patients with patellar pain. On the other hand, due to the results of the present study and the lack of sufficient studies on gender differences in how to respond to strengthening exercises, the need for a gender-specific rehabilitation program in patients with patellar pain may be further explored.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of University Islamic Azad University, East Tehran Branch, Tehran (Code: IR.IAU.SRB.REC.1400.164).

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interests.

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