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Effect of excential isotonic exercises on the quadriceps muscles of the thighs on patellofemoral pain syndrome

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Abstract. *Aim:* the aim of this pilot study was to evaluate the effect of eccentric quadriceps training in patients with patellofemoral pain. *Methods.* Twenty patients (12 females and 8 males, mean age 27.50 +/-6.6 years) with patellofemoral pain syndrome were treated. Eccentric quadriceps training was performed using the Primus exercise machine from Baltimore Therapeutic Equipment (BTE). The main outcome measures were the percentage of time to goal as measured by the BTE primus, the SF-36 health questionnaire, and the Patellar-Femoral Pain Severity Scale. Statistical analysis was performed using SPSS. *Results:* All outcome measures showed significant improvements ($p<0.05$). The percentage of time to achieve the goal improved with a mean difference of 23.6, the SF-36 questionnaire showed improvements in the physical component, mental component and bodily pain scores with a mean difference of 10.9, 2.6 and 29.2 respectively, and the pain score as measured using the patella-femoral severity scale also improved with a mean difference of 3.4. *Conclusion.* It has been established that isotonic eccentric training of the quadriceps muscles of the thigh is effective in reducing pain and improving the functional status of patients with patellofemoral pain syndrome and can be offered as part of the treatment.
Keywords: quadriceps muscle, patellofemoral pain syndrome, isotonic contraction, eccentric exercises, muscle strength.

Ефект ексцентричних ізотонічних вправ на м'язи квадрицепсу стегон на синдром болю в колінах і ногах

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Резюме. *Мета статті* – оцінювання впливу ексцентричного тренування чотириголового м'яза на пацієнтів з болем у пателофеморальній ділянці. *Методи.* Проведено лікування двадцяти пацієнтів (12 жінок і 8 чоловіків, середній вік 27,50+/-6,6 років) із синдромом пателофеморального болю. Ексцентричне тренування чотириголового м'яза стегна проводилося з використанням тренажера Primus від Baltimore Therapeutic Equipment (BTE). Основними показниками результатів були відсоток часу до досягнення мети, виміряний за допомогою BTE Primus, опитувальник здоров'я SF-36 і шкала тяжкості болю в надколінку і стегнової кістки. Статистичний аналіз проводився з використанням SPSS. *Результати.* Усі показники результатів показали значні покращення ($P<0,05$). Відсоток часу досягнення мети покращився із середньою різницею у 23,6, опитувальник SF-36 показав поліпшення показників фізичного компонента, психічного компонента й тілесного болю із середньою різницею в 10,9, 2,6 і 29,2 відповідно, а показник болю, виміряний за допомогою шкали тяжкості, – у 3,4. *Висновок.* Установлено, що ізотонічна ексцентрична тренування чотириголових м'язів стегна ефективна для зменшення болю й покращення функціонального стану пацієнтів із синдромом пателофеморального болю та може бути запропонована як частина лікування.
Ключові слова: чотириголовий м'яз, синдром пателофеморального болю, ізотонічне скорочення, ексцентричні вправи, м'язова сила.

Introduction. Patellofemoral disorders are probably the most common knee pathology seen by orthopedic and sports medicine physicians [1]. Anterior knee pain is one of the most common conditions seen in the outpatient physical therapy clinic [2] and one of the most difficult to treat. Reported prevalence of patellofemoral joint pain in clinical settings ranges from 21 to 40% [3]. Patellofemoral pain syndrome (PFPS) is the most common diagnosis in outpatients with anterior knee pain [4]. It affects up to 25% of the non-athletic population, occurs in all age groups, and is more common in adolescents and young adults [5]. Patellofemoral pain is typically described as diffuse and poorly localized in the anterior aspect of the knee. Symptoms are typically aggravated by activities such as walking down stairs and are relieved by rest. The mechanism of PFPS is poorly understood; however, it has been suggested that the condition may result from abnormal muscular and biomechanical factors that alter the position of the patella within the femoral notch, contributing to increased suprapatellar-femoral contact pressure, leading to pain and dysfunction [6].

Muscle dysfunction (e.g. quadriceps weakness, abnormal firing pattern) is one of the major contributors to patellofemoral pain [4]. This is due to altered motor control of the quadriceps and decreased ability to generate force through the vastus medialis oblique (VMO) [7; 8]. Quadriceps atrophy and weakness are also commonly found in PFPS [9; 10]. Isokinetic studies have shown that peak knee extension torque values were lower in PFPS compared to healthy controls, indicating decreased quadriceps strength in subjects with PFPS [11–13].

Much of the rehabilitation of PFPS focuses on strengthening the quadriceps [14; 15]. Strengthening the quadriceps is beneficial in improving functional ability and may be especially important for individuals who want to return to more demanding activities such as running or other sports [16]. Previous studies have highlighted the importance of strengthening the quadriceps in patients with patellofemoral pain [11; 16–19]. A recent study has shown that a large number of patients with PFPS can experience significant improvements in pain, function, and quality of life, at least in the short term, with quadriceps rehabilitation, with or without a focus on selective activation of the VMO component [20].

In one study, it was observed that most patients with PFPS were unable to smoothly control the eccentric contraction of the quadriceps during stair descent or isokinetic open kinetic chain activity. There appears to be a relationship between PFPS and the control of eccentric contraction of the quadriceps [7; 8]. In another study, Tomi R. found a slight increase in average torque during eccentric contractions in a limited range in the group using eccentric contractions compared to the group using isometric contractions [21]. Therefore, there is a need for eccentric training, especially among patients with PFPS.

There are various methods of strengthening the quadriceps such as isometric exercises, isokinetic training and isotonic regimen. Since patients often complain of knee pain during dynamic phases such as stair climbing, squatting, walking and running, it seems more appropriate to strengthen the quadriceps during dynamic exercises and dynamic muscle training primarily increases dynamic function. Eccentric training can be done in an isotonic and isokinetic manner [11]. Eccentric isotonic exercises form a vital part of a muscle strengthening program since muscle weakness in the eccentric phase can lead to increased reactive forces at the patellofemoral joint. It has also been found that in patients with anterior knee pain and patellofemoral instability, concentric contraction of the quadriceps produces greater torsional motion than eccentric contraction [22]. Isotonic exercises also have the advantage of being more functional than isokinetic exercises.

To our knowledge, the effect of isotonic eccentric quadriceps exercise on patellofemoral pain syndrome has not been studied, although an association between PFPS and eccentric quadriceps contraction has been observed. Therefore, there was a need to study this aspect to help in clinical decision making. Therefore, the aim of this exploratory pilot study was to evaluate the effect of eccentric quadriceps training in patients with patellofemoral pain who complain that their pain is particularly associated with quadriceps slowness.

Methods and subjects. This was a preliminary pilot study to determine the feasibility of a subsequent randomized controlled trial. The study was approved by the institutional scientific committee and was conducted from August 2020 to August 2023. A total of 24 subjects were enrolled from the inpatient and outpatient departments of one of the hospitals in Azerbaijan, 4 patients

were lost to follow-up and were excluded from the study. Twenty patients completed the study, including 8 males and 12 females. The mean age was 27.50±6.6. Fifty percent of the patients were in the age group of 21-25 years, 35% were aged 26-30 years, and the rest were over 31 years old. The study included patients who were diagnosed with PFPS, unilateral or bilateral, by an orthopedic surgeon and who had not undergone any lower limb strengthening program within the past 6 weeks. Inclusion criteria were: (a) anterior knee pain that occurred with at least two of the following activities: climbing/descending stairs, jumping/running, squatting, kneeling, and prolonged sitting; (b) insidious onset of symptoms unrelated to the traumatic incident; (c) presence of pain when descending a 25 cm high step or squatting on both legs; and (d) pain on palpation of the patellar facets. Subjects were excluded if they had: (a) symptoms present for <1 month; (b) clinical evidence of other knee pathology (including comorbidities); (c) previous knee surgery; (d) history of patellar fracture/subluxation/dislocation; (e) current significant trauma involving other lower limb joints; (f) current use of nonsteroidal anti-inflammatory drugs or corticosteroids; (g) malignancy; (h) the presence of severe pain or discomfort during testing that prevents the person from further participating in the study.

Outcome measures were percentage time to goal, PFPS severity scale (PSS), and Short Form 36 (SF 36). All patients were trained on a Baltimore Therapeutic Equipment (BTE) Primus RS isokinetic dynamometer.

The second subscale consisted of eight items in a visual analogue scale format that asked subjects to indicate how well they were able to perform the following activities over the past week. These included: climbing stairs, squatting, walking, jogging, running/sprinting, participating in sports, sitting with bent knees (for 20 minutes), and kneeling on the floor for any period of time. The maximum score for each statement is "10" (or 10 cm), resulting in a total maximum PSS score of 100. Patient health status was assessed by completing the SF-36 Health Questionnaire. Isokinetic dynamometry was performed to assess quadriceps eccentric activity. Before exercise, all visits began with a 3-minute warm-up on a static bike, followed by a 30-second stretch of the quadriceps and hamstrings. A standard biceps brachii familiarization session was conducted, which included a detailed explanation of the differences between concentric and eccentric contractions, and subjects were given the opportunity to experience how the muscle would act during training. The same investigator conducted all studies.

The patient was seated in a therapy chair. Standard stabilization straps were placed across the distal thigh and chest. The length of the dynamometer was adjusted to the length of each patient's knee. Continuous passive motion (CPM) was used for treatment. The session began with the start of the CPM and progressed through 2 repetitions to determine the limb weight by viewing the scale on the left side of the graph. A target force was then set to be 20% greater than the highest peak of the graph (limb weight). The patient was then asked to attempt to control the limb using the set ROM to achieve a "% time on target" (percentage time on target) of 50% or greater for a 10-minute exercise duration at 10 deg/sec. Percent time on target is the percentage of the total treatment time that the patient can effectively control the target force. The computer monitor was positioned so that the patient could see it and apply force so that the graph line remained between the horizontal dotted lines on the screen. Once the target is set, the color of the feedback line on the screen indicates the direction in which the patient applies force. The red feedback line on the screen indicated that the patient was applying force to the moving device as if trying to stop it (eccentric contraction of the quadriceps). According to the SPEED (Sequential Performance of Exercises Using Experiential Decision Making) protocol for BTE technology, approximately 3-6 visits are needed to achieve this goal. Therefore, a total of six visits were scheduled. After the patient completed the training, the percentage of time to reach the goal was displayed on the screen during each visit. All patients performed the same sequence of exercises depending on the target force set for the individual. The treatment was carried out for 6 sessions over two weeks, three times a week. No other treatment was given. After the patient completed the 6 eccentric training sessions, the outcome measures (i.e., percentage of time to reach the goal, PSS, and SF-36) were recorded again. Statistical analysis was performed using SPSS 13. Statistical analysis included paired Student's t-test to determine the difference between

pre- and post-values for percentage time to goal and SF-36 health survey components. Wilcoxon signed-rank test was performed to determine the difference between pre- and post-values for pain. A probability level of $p<0.05$ was considered significant.

Results. Significant changes were observed in all outcome measures. Percentage of time to goal showed a mean increase of 23.6 (87%), which was statistically significant $P<0.001$ (Table 1). In the SF-36 Health Survey, the physical component score showed a mean increase of 10.9 (30%), the mental component score showed a mean increase of 2.6 (6%), and the bodily pain component showed a mean increase of 29.2 (64%). All of these were statistically significant at $P<0.01$. (Table 2) The pain score (PSS) showed a mean increase of 16.39 (28%), which was statistically significant (Table 3). Figure 1 shows the pain reduction in the individual components of the PSS, which showed a significant reduction in pain after exercise.

Discussion. The aim of the study was to investigate the effect of eccentric isotonic strengthening of the quadriceps in patients with patellofemoral pain. Strengthening of the quadriceps plays an important role in the treatment of patellofemoral pain syndrome [24]. This can be done either by selectively strengthening the vastus medialis (VMO) or by global strengthening of the quadriceps. Both approaches seem to be acceptable for the rehabilitation of patients with PFPS [20; 25]. However, it has been noted that it may be appropriate to perform exercises involving selective activation of the vastus medialis early in the rehabilitation process and not to focus too much on selective activation until rehabilitation has progressed, especially in more chronic cases with significant participation limitations [24]. However, quadriceps retraining has been associated with good clinical outcomes in patients with VMO disorders [26]. Many authors have focused on selective involvement of the VMO for the treatment of patellofemoral pain syndrome [2; 27–29], but some authors have concluded that the VMO cannot be selectively involved [30–32]. The available data suggest that there is considerable controversy as to whether VMO can be used in isolation [2]. It has also been noted that generalized quadriceps exercises performed without other interventions (e.g., taping, bracing) can be effective in the treatment of patellofemoral pain and may be sufficient to alleviate pain and reduce disability [33]. Therefore, focusing on the quadriceps would be a better approach rather than selective intervention. In our study, we used generalized quadriceps strengthening and obtained excellent results for all measured outcomes.

It has been observed that each unit of work performed during isotonic quadriceps contraction resulted in greater motor unit recruitment or firing rate, or both, than in the isokinetic mode. This is important in the early phase of rehabilitation when the goal is to fully recruit the motor units of injured or atrophied muscles [34].

TABLE 1 – **Changes in individual components of the patellofemoral pain severity scale**

	Mean (standard deviation)	Average difference	P-value
Before	27.10 (13.75)	-23.65	<0.001
After	50.75 (15.84		

TABLE 2 – **Changes in SF-36 Health Survey Component Values, mean(standard deviation)**

Component SF36	Physical Component Assessment Before	Physical Component Assessment After	Assessment of the mental component Before	Assessment of the mental component After	Assessment of the component of physical pain Before	Assessment of the component of physical pain After
Average So	36.69 (4,34)	47.64(3.37)	41.63(6.50)	44.28(3.12)	45.40(13.23)	74.60(11.26)
Average Difference	10.94		2.64		29.20	
P-value	**<0.001**		0.007		**<0.001**	

TABLE 3 – **Changes in pain scores according to the patellofemoral pain severity scale**

	Mean (standard deviation)	Average difference	P-value
Before	57.94(11.07)	16.39	0.001
After	41.55 (15.08)		

In our study, although none of the patients were acutely ill, we obtained good results in quadriceps performance as evidenced by the improvement in percentage of time on target. Therefore, isotonic exercise can also be proven to be functional and play an important role in daily activities in these patients. Although eccentric training was performed using exercises such as progressive lowering exercises and squats and resulted in good results, it lacked the objectivity to measure improvement in eccentric control [17]. In our study, eccentric training was performed isotonically using the BTe primus machine, which allows for objective documentation of improvement by recording an increase in percentage of time on target. Percentage of time on target, which is the percentage of total treatment time during which the subject can effectively control the target forces, also showed an increase in our study, indicating that there was an increase in eccentric muscle strength.

However, during eccentric exercise, the muscles are less active, as evidenced by EMG recordings [7]. Thus, the central nervous system can use the ability of the muscles to generate higher muscle fiber tensions during negative work and thereby reduce energy costs by reducing the number of active motor units. Thus, motor control plays an important role in rehabilitation in general and in patellofemoral joint problems in particular. Teaching the patient to better use the patellar stabilizer muscles is the main goal of many rehabilitation programs [7]. All previous studies have demonstrated the ability of the body to quickly adapt and improve strength and functionality through motor learning [35]. It has been shown that when performing exercises using biofeedback, recovery was faster compared to exercises without it [36]. In our study, feedback from the screen, allowing you to control the movement and keep it within the target range, could help our patients. The current availability of modern exercise equipment provides a promising environment for further research and clinical application.

Subjects showed improvements in physical component, mental component and bodily pain scores as shown by the SF-36 results, which can be considered clinically significant. It is likely that better eccentric control of the quadriceps leads to improvements in daily activities as shown by the improvement in the physical component score. Pain showed a significant decrease in our group. The pain relief could most likely be due to the motor control that occurred during this time period. It is unclear how exactly quadriceps training relieves pain, this is in line with a similar study previously conducted to improve quadriceps eccentric control in patellofemoral pain syndrome [7]. One reason for the pain reduction is that the increase in quadriceps strength could have changed the contact site and pressure distribution, possibly unloading sensitive areas and thus reducing pain [37]. This may also be due to adaptive changes in the muscles due to eccentric training, which may reduce tissue damage and pain in the future [31]. This study showed that when patients with patellofemoral pain train with eccentric quadriceps exercises, pain decreases, the physical and mental components of the SF-36 form show improvement, and the percentage of time the patient is able to control the target increases. Thus, isotonic eccentric quadriceps exercises should be part of the treatment protocol for the rehabilitation of patients with patellofemoral pain syndrome.

However, several limitations were noted. A control group was not included so the effects cannot be attributed to the intervention, however, it was conducted as a pilot study to see the effect of eccentric muscle strengthening in PFPS. Further studies should be conducted with a control group. Although the percentage of time to target showed significant results, the increase in eccentric control of the quadriceps could be further documented by performing functional performance tests such as the step down. The long-term effect of the intervention was also not assessed. Eccentric control of the hip muscles also appears to play a role in the treatment of PFPS, but we did not assess these muscles. Future studies could be conducted to examine isotonic eccentric control of the hip muscles in PFPS.

Conclusion. Strengthening the quadriceps is useful for improving functional capacity in patients with PFPS. Isotonic eccentric training of the quadriceps is effective in reducing pain and improving functional status in patients with patellofemoral pain syndrome and can be offered as part of treatment.

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