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The relationship of quadriceps femoris muscle morphology and strength with patellofemoral pain syndrome and functional performance in level 1 athletes

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ABSTRACT
Background: Patellofemoral pain syndrome (PFPS) is a clinical condition characterized by anterior knee pain common in athletes. Many factors cause (PFPS), one of which is the weakness of the quadriceps femoris (QF) muscle. Weakness of the QF muscle causes the knee to be unstable, which may affect an athlete's functional performance. The purpose of this literature review was to determine the relationship of QF muscle morphology and strength to PFPS and functional performance in level 1 athletes.

Methods: This study used a literature review method. Articles were searched through PubMed and Google Scholar using the keywords "Quadriceps Femoris Morphology," "Quadriceps Muscle Strength," "Patello Femoral Pain Syndrome," "Anterior Knee Pain," and "Functional Performance." The inclusion criteria were literature published by credible institutions and related to patellofemoral pain syndrome and functional performance. The exclusion criteria were a literature that did not use ultrasound and single-leg hop test measurement tools and published more than ten years ago.

Results: From the five literature reviewed, there was a relationship between the morphology and strength of the Quadriceps Femoris muscle with Patello Femoral Pain Syndrome due to the thickness of the Quadriceps Femoris tendon and patella due to QF muscle tension and a decrease in QF muscle strength in PFPS patients. There is a relationship between the morphology and strength of the QF muscle and functional performance due to the thickness and strength of the QF muscle, which is associated with functional performance components, one of which is jumping ability.

Conclusion: This study suggested that there might be an association between QF muscle morphology and strength and PFPS, and there might be an association between QF muscle morphology and strength and functional performance. Thus, future research was needed to explore the correlation of these variables.

Keywords: athletes, functional performance, patellofemoral pain syndrome, quadriceps femoris muscle morphology, quadriceps femoris strength

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Background

An athlete is proficient in a sport or other form of physical exercise. Football, futsal, basketball, and volleyball are level 1 athletes who require good physical condition and high power strength to achieve optimal results.[1] An athlete's physical activity differs from that of a non-athlete. In certain sports, such as football and futsal, a common mechanism is landing one foot after a jump or during a rapid change of direction, so good knee stability and strength are required.[2] Overuse and large, forceful loads on the knee can result in pain and injury.[3,4] One of the most common knee injuries in athletes other than the anterior cruciate ligament (ACL) is patellofemoral pain syndrome (PFPS) in sports involving single-leg landing, change of direction, or sudden rapid descent.[5]

Anterior knee pain without additional particular disease is known as posterior PFPS, and it is often characterized by patellofemoral joint crepitation during and after weight-bearing activities, including squatting and stair climbing.[6] According to reports, knee discomfort will prevent 25% of recreational athletes with patellofemoral pain (PFP) from continuing in sports. In an observational research including 810 young basketball players, PFP was found in

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25% of the players overall—26% female and 18% male.[7] PFPS is a synonym for nonspecific PFP, runner's knee, or anterior knee pain syndrome.[8,9] PFPS is among the most frequent causes, accounting for 20-40% of anterior knee pain problems in adolescents and adults.6,10,11 PFPS is a typical injury among runners, occurring in 13.4% of 196 runners.[9] PFPS is the most prevalent cause of knee pain, affecting 220,000 people annually; the ratio of affected females to affected males is 2:1.6 PFPS is a common issue, although opinions on its etiology, diagnostic standards, and available treatments are divided.[12] Knee instability, muscular weakness, locking feeling in the knee, and discomfort when sitting with the knee flexed are the characteristics of post-partial locking syndrome (PFPS).[6]

PFPS patients usually experience physical and biomechanical changes in the patellofemoral joint, such as decreased quadriceps femoris (QF) muscle strength, decreased anatomical cross-sectional area (ACSA) of the QF muscle, decreased gastrocnemius flexibility, and hypermobility of the patellar joint.[13,14] In healthy athletes, the QF muscle has been reported to atrophy faster than other thigh muscles (e.g., hamstring).[15] A decrease in QF muscle strength can impact the functional performance of individuals, especially athletes, whose poor physical condition can reduce their functional performance.[16] The single-leg hop test evaluates functional performance in healthy and injured athletes.[17] QF muscle strength is necessary for an athlete to maintain functional performance.[18]

The causes of patellofemoral pain are multifactorial.[13] The causative factors of PFPS can be classified into three main groups, namely local joint-related factors such as patellar hypermobility, QF muscle weakness and lack of soft tissue flexibility, lower extremity biomechanics-related factors such as pelvic muscle dysfunction, irregularities in gait, and variables connected to athletic activities.[10] PFPS may be brought on by incorrect lower extremity alignment, such as increased q angle or genu valgum, structural abnormalities of the patella, weakening in the QF muscle that results in patellar instability, and overloading of the patellofemoral joint and associated soft tissue structures.[8,10,13] Furthermore, QF muscle strain, particularly during vigorous activity, may increase the pressure on the patellofemoral joint and the force that the patella exerts on the trochlea, which may be a risk factor for PFPS.[10]

The QF is a muscle group that plays an important role in maintaining knee joint stability and functions as a knee extensor.[19,20] An athlete's QF muscle strength is an important part of the athlete's functional capacity and contributes significantly to lower extremity biomechanics and performance.[21] Muscle strength is the ability of a muscle to accept a load in a given time produced by a muscle contraction.[1] Strength can be defined as the quality of power of a muscle or group of muscles in building a maximum contraction to overcome the load from within or outside.[1] Strength is directly correlated with the morphology and architecture of skeletal muscles.[22] Four muscles comprise the morphological architecture of the QF muscle: the vastus medialis, vastus lateralis, vastus intermedius, and rectus femoris.[20] When muscles contract during bodily movement, their thickness, cross-sectional area (CSA), fascicle length (FL), and pennation angle (PA) or fibre angle (PA) all play a significant role in building muscular strength.[22] Muscle strength and the QF muscle's anatomical cross-sectional area (ACSA) morphology are tightly correlated.[22,23]

Based on the above introduction, this study aims to find the relationship between ACSA muscle morphology and QF muscle strength with PFPS and functional performance. This literature review is expected to be useful for students and physiotherapists as it will provide insight into and determine and develop types of QF muscle-strengthening exercises to prevent PFPS and improve functional performance.

Methods

This research employed a literature review method, utilizing secondary data in the form of research journals sourced from various online scientific journal databases. These journals focused on the relationship between quadriceps morphology and muscle strength with patellofemoral pain syndrome and functional performance in level 1 athletes. The search for relevant literature was conducted online using PubMed and Google Scholar, with keywords including "Morphology Quadriceps Femoris," "Quadriceps Muscle Strength," "Patellofemoral Pain Syndrome," "Anterior Knee Pain," and "Functional Performance." Literature was selected based on inclusion and exclusion criteria. The inclusion criteria were literature from credible institutions and literature related to patellofemoral pain syndrome and functional performance. The exclusion criteria included literature not utilizing ultrasonography or single-leg hop tests, and literature published more than ten years ago. All selected literature met the inclusion criteria established by the author.

Results

The results of the research of Spyridon K. Methenitis et al. obtained the average CSA of the thigh muscles inParticipants with varying levels of training experience showed differences in muscle characteristics and performance metrics. For those with less than one year of training, the mean cross-sectional area (CSA) of the vastus lateralis (VL) was 134.7 cm^2, while those with one to three years of training had a CSA of 142.3 cm^2, and those with over three years had a CSA of 154.3 cm^2. The average VL thickness increased from 2.1 cm in the least experienced group to 2.3 cm and 2.6 cm in the intermediate and most experienced groups, respectively. VL fascicle length also grew from 6.4 cm to 7.1 cm and 8.8 cm across the three experience groups. Additionally, the CSA of VL muscle fibers, specifically types IIA and IIX, was higher in more experienced participants: 4,833.5 μm^2 and 4,163.6 μm^2 for the least experienced, 6,086.5 μm^2 and 4,583.2 μm^2 for the intermediate, and

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6,772.4 µm² and 4,997.4 µm² for the most experienced. Jump performance, measured through countermovement jumps and squat jumps, also improved with experience, with the least experienced participants producing 1,000.8 W and 844.4 W, the intermediate group 1,274.6 W and 1,001.8 W, and the most experienced group 1,488.8 W and 1,270.4 W, respectively. There was a significant correlation between jumping performance and VL thickness, VL fascicle length, and CSA of VL muscle fibers types IIA and IIX, with correlation coefficients ranging from $r = 0.32$ to 0.50 and $p \leq 0.05$.[24]

Research by Hande Guney et al. states that the strength of the QF muscle in the legs involved in PFPS is lower than that of healthy legs.25 The average value of QF eccentric strength is 76.8% at an angular velocity of 60 degrees and 55.6% at an angular velocity of 180 degrees. In comparison, the average value of QF concentric strength is 89.3% at an angular velocity of 60 degrees and 80.5% at an angular velocity of 180 degrees. There was a negative correlation between QF eccentric strength and knee joint position at an angular velocity of 60°/sec. There was a negative correlation between quadriceps femoris (QF) eccentric force and the target joint position angle of 20° ($r = -0.30$, $p = 0.04$), and a similar negative correlation was observed at 180°/sec ($r = -0.29$, $p = 0.04$). Additionally, QF eccentric force at 60°/sec was negatively correlated with the 60° target joint position angle ($r = -0.37$, $p = 0.01$). QF concentric strength was negatively correlated with the 20° target joint position angle at both 60°/sec ($r = -0.53$, $p < 0.001$) and 180°/sec ($r = -0.31$, $p = 0.03$). Furthermore, QF eccentric strength showed a significant negative correlation with pain during stair descent ($r = -0.49$, $p = 0.01$), squatting ($r = -0.33$, $p = 0.02$), and sitting ($r = -0.38$, $p = 0.01$) at 60°/sec. Similarly, the negative correlation between QF concentric strength and pain during stair climbing, squatting, and sitting was significant at both 60°/sec and 180°/sec (all $p < 0.05$). Overall, the Kujala score, which measures knee pain and function, was negatively correlated with QF eccentric strength across all angular velocities and with QF concentric strength only at 60°/sec ($r = -0.60$, $p < 0.001$).[25]

From the results of the study of Ahmet Özcan Kızılkaya et al., it was mentioned that individuals with PFPS exhibited significantly higher Q angle values compared to the control group across all positions: standing (17.03 ± 3.84° vs. 13.87 ± 1.75°, $p < 0.001$), supine (16.20 ± 3.74° vs. 13.45 ± 1.79°, $p = 0.001$), and sitting (16.50 ± 3.28° vs. 13.71 ± 1.72°, $p < 0.001$). Additionally, the Kujala score, which assesses knee pain and function, was significantly lower in the PFPS group (70.57 ± 8.37) compared to controls (98.58 ± 2.05, $p < 0.001$). Patellar tendon thickness was greater in the PFPS group (0.39 ± 0.08 cm) compared to the control group (0.32 ± 0.05 cm, $p < 0.001$), and quadriceps femoris (QF) thickness was also higher in the PFPS group (0.64 ± 0.10 cm) than in controls (0.52 ± 0.09 cm, $p < 0.001$). Among PFPS patients, 90% showed right-sided predominance, with the right lower extremity being affected in 73.3% of cases. The average time since symptom onset was 15 months, with symptoms typically lasting around 30 minutes and knee pain on flexion occurring after an average of 5 minutes. The median visual analog scale (VAS) score at rest was 0, while it increased to 6.5 when sitting. A significant positive correlation was found between patellar tendon thickness and VAS score at rest ($r = 0.396$, $p = 0.030$).[10]

According to research by Marwa M El Sawy et al., the VM consists of two parts: the VML, which has vertical fibers, and the vastus medialis oblique (VMO), characterized by its oblique fiber orientation. In healthy knees, the mean anatomical cross-sectional area (ACSA) of the VMO, measured via ultrasonography, varies from proximal to distal as follows: 22.5 ± 0.58 cm² at the lower end of the femoral shaft, 16.5 ± 0.8 cm² at the upper border of the patella, and 13.5 ± 1.14 cm² at the mid-patellar level (femoral condyle level). In contrast, for knees with patellofemoral pain syndrome (PFPS), the mean ACSA of the VMO was significantly reduced: 19.5 ± 0.04 cm² at the lower end of the femoral shaft, 12.7 ± 0.62 cm² at the upper border of the patella, and 9.4 ± 0.08 cm² at the mid-patellar level (femoral condyle level). All these measurements were significantly lower in PFPS knees compared to the healthy knees.[26]

From the results of research by Konstantinos Vassis et al., it was found that the average single-leg hop distance in all participants was 144.363 cm. The average extensor mean peak moment (MPM) at 60°/sec and 180°/sec in all participants was 164.705Nm and 116.012Nm. This study showed a moderate positive correlation between isokinetic strength at 60°/sec and 180°/sec ($r = 0.636$-0.673) and the SHD test. Peak QF strength characterized by the MPM extensors at 60°/sec ($r = 0.671$, $p = 0.001$) and 180°/sec ($r = 0.636$, $p = 0.001$) were significantly moderately to well positively correlated with the single-leg hop distance (SHD) test.[17]

Discussion

PFPS leads to a reduction in the strength of the leg muscles, particularly the QF muscle group. This is evident in the decreased cross-sectional area of the QF muscles, including the VMO, in the knee affected by PFPS. Weakness or reduced strength in the QF muscles can negatively impact functional performance, as these muscles play a crucial role in stabilizing the knee joint and are essential for knee extension movements involved in activities such as running, jumping, and twisting.

It was reported by Hande Guney et al. that there was a significant correlation between the functional outcome of Kujala score and pain level of VAS score with QF strength, and QF eccentric strength correlated more with patella joint position than QF concentric strength in PFPS patients.[25] In this study, there was a decrease in QF muscle strength in patients with PFPS with QF eccentric strength index ranges between 55.6% and 76.8%, while the concentric strength index for QF muscles falls between 80.5% and 89.3%. In comparison, the normative data for the QF strength index typically ranges between 84% and 96%. The pain triggered by decreased QF muscle strength is due to reduced patellofemoral joint control and increased patellofemoral reaction strength.[25] This is supported by research by Marwa M El Sawy et al., stating that the VMO is potentially more responsible for medial patella tension and is described as a medial patella stabilizer.[11] ACSA is used to represent muscle size as it has the benefit of being a predictor of isometric and isokinetic muscle strength. It was stated that ACSAVMO was significantly decreased in individuals with PFPS knees compared to healthy knees (decreases ranged from 17.2% to 36.7%).[11] In agreement with the research of Ahmet Ozcan K€ızılkaya et al., the strength of the leg muscles, particularly the QF muscle group, is reduced by PFPS. The reduction is seen in the QF muscle's cross-sectional area, which includes the vastus medialis oblique (VMO) in the knee experiencing post-polio syndrome (PFPS). Since the QF muscle is the main muscle utilized for knee extension motions in functional activities like running, jumping, and twisting, it can also impact functional performance when it becomes weaker or less strong. The QF muscle serves as an active stabilizer of the knee joint.

The study of Ahmet Ozcan K€ızılkaya et al. showed that patellar tendon thickness and QF were significantly increased in PFPS patients detected using ultrasonography. Increased tendon thickness reflects increased muscle tension that contributes to the disease pathogenesis of PFPS, so patellar tendon thickness and QF can also be used to determine the presence of PFPS.[10]

In addition to the incidence of PFPS, muscle morphology and strength are related to an athlete's functional performance.[24,26] Muscle strength is critical for performance in running, throwing, and jumping activities. Muscle strength depends on biological variables such as the amount of muscle mass, muscle architecture, muscle fiber type composition, and neural activation during functional movements. This is supported by research by Spyridon K. Methenitis et al., stating that thigh muscle CSA, VL muscle thickness, and CSA of muscle fiber types IIA and IIX of the VL muscle are contributors t**o** functional performance, including jumping strength, regardless of training background (r > 0,300). However, the VL muscle fascicle length significantly contributed to jumping performance in individuals with a long training background, possibly due to specific neural adaptations resulting in better intramuscular characteristics.[24] QF muscle strength as a knee extensor is necessary for optimal functional performance. Supported by research by Konstantinos Vassis et al., who assessed the relationship between isokinetic knee strength characteristics and single-leg jumping performance in healthy individuals, showed a significant moderate to good positive correlation between isokinetic strength at 60°/sec and 180°/sec with SHD.[17] Thus, maximal strength of the QF muscle occurs during jumping because the individual must overcome the eccentric load generated by the initial jump and immediately perform a concentric contraction for the next jump.[27]

In this study, the authors found several things that became obstacles and weaknesses of this study. The obstacles in this study include the limited number of journals that discuss the relationship between QF muscle morphology with PFPS and functional performance in level 1 athletes and the difficulty of accessing some relevant journals. However, these obstacles can be overcome well so that this research can be completed on time. The weakness of this study is that the method used is a narrative review or literature review instead of a systematic review. So, further exploration is needed regarding the relationship between muscle morphology and muscle strength with PFPS and functional performance in level 1 athletes.

Conclusion

Based on some of the literature that has been found, the researcher can conclude that there is an association between the morphology and strength of the QF muscle with PFPS, which is due to the thickness of the QF tendon and patella due to QF muscle tension, a decrease in the cross-sectional area of the VMO, and weakness or decrease in the strength of the QF muscle in PFPS patients, which can cause excessive loading and pressure on the patella so that it can cause pain. In addition, there is a relationship between QF muscle morphology strength and functional performance. QF muscle morphology can predict functional performance, namely jumping, regardless of individual background. QF muscle strength is associated with jumping performance, which is one of the components of functional performance.

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Conflict of Interest
the author states that there are no potential conflicts of interest concerning the research, authorship, or publication of this article.

Author Contributions

NPDAP developed the study design, conducted data collection, and prepared the initial manuscript; IPGSA and AANTND were responsible for data collection and provided revisions to the manuscript.

Ethical Consideration

this review study utilized publicly available published articles, so informed consent and ethical approval were unnecessary.

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