Patellofemoral Pain After Arthroscopy

Muscle Atrophy Is Not Everything

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Background: It remains unclear as to why patellofemoral pain (PFP) appears in some patients after knee arthroscopy and what influence the quadriceps muscle has on its onset.

Purpose: To compare muscle thickness, neuromuscular contractility, and quadriceps femoris muscle strength between patients who develop PFP after arthroscopic partial meniscectomy and a control group and to compare functional outcomes between these entities.

Study Design: Cohort study; Level of evidence, 3.

Methods: A prospective longitudinal cohort study was carried out on patients scheduled for arthroscopic partial meniscectomy. Patients were excluded if they had preoperative PFP, previous knee surgery, or additional surgical procedures (eg, meniscal repair or microfracture). The following were performed preoperatively: magnetic resonance imaging to quantify muscle thickness, surface electromyography to analyze electrical contractility, and an isokinetic study to assess the strength of the quadriceps femoris muscle. Patients also completed a Lysholm functional questionnaire. Six weeks after the index procedure, patients were questioned about the presence of PFP, and the same tests were repeated. The PFP group included patients who developed anterior knee pain postoperatively, while the control group included those who did not develop pain.

Results: Of 90 initial study patients, 20 were included in the PFP group (23.8%) and 64 in the control group (76.2%); 6 patients were lost to follow-up. Both study groups were comparable on all of the analyzed preoperative variables. Patients in the PFP group had worse results in terms of muscle thickness (9.67 vs 16.55 cm^2), electrical contractility (1226.30 vs 1946.11 μV), and quadriceps strength (12.27 vs 20.02 kg; all $P < .001$). They also presented worse functional results on the Lysholm score (63.05 vs 74.45; $P < .001$).

Conclusion: Patients who developed PFP after arthroscopic partial meniscectomy had more quadriceps femoris muscle atrophy as well as a greater decrease in electrical contractility and muscle strength at 6 weeks postsurgically as compared with a control group. The PFP group also had worse postoperative functional results.

Keywords: patellofemoral pain; anterior knee pain; knee arthroscopy; meniscectomy; quadriceps muscle atrophy; physical therapy

Patellofemoral pain (PFP) is among the most frequently observed pathologies in the field of orthopaedics. Its prevalence ranges from 16% to 24% of the population and is more frequent in female patients, with a 2:1 ratio.[34,41] Between 80% and 90% of patients respond favorably to nonoperative treatment, with physical therapy as its main pillar.[18] Classically, the suggested etiopathogenesis of this pain was a muscle imbalance between the vastus medialis (VM) and the vastus lateralis (VL) of the quadriceps femoris. It was assumed that hypotrophy or lack of neuromuscular activity of the VM caused a lateral patellar tilt and abnormal patellofemoral tracking, leading to excessive compressive stress to the patellar facets and PFP.[17,37] For this reason, physical therapy focuses mainly on strengthening and neurostimulation of the VM, particularly its oblique fibers (VM obliquus [VMO]), as it has been shown that VMO has the most effect on patellar alignment.[17,26,45] However, the VM/VL imbalance is not present in all patients experiencing PFP,[10] and some other reasons must be causative. In recent years, other factors have been associated with PFP, such as the neuromuscular activity of the external rotators and abductors of the hip,[46] the rotational abnormalities of the femur or tibia,[20,48] and even psychological factors (eg, anxiety, depression, and kinesiophobia).[13]

Meniscal injuries are common conditions in the knee joint, particularly in sports medicine. In many cases,

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arthroscopic resection or repair is the treatment of choice, depending on the type of tear and the patient profile.[29,33,39,43] In those cases, arthroscopic surgery is an elegant procedure that often results in remarkable improvement in joint line pain. However, a non-negligible number of patients developed characteristic and usually temporary anterior knee pain after the surgical procedure.

Postsurgical PFP may be related to the muscle loss that occurs after sugery.[16] This phenomenon has been seen in patients undergoing different types of knee surgery, such as anterior cruciate ligament (ACL) reconstruction[15] or total knee arthroplasty.[47] However, as far as we know, there are no studies analyzing postoperative PFP after an arthroscopic partial meniscectomy (APM).

Therefore, the purpose of the present study was to compare the muscle thickness, neuromuscular contractility, and strength of the quadriceps femoris of patients who develop PFP after APM and those who do not. A secondary objective was to compare the functional results in these 2 groups of patients. The hypothesis was that patients who develop PFP after surgery have greater muscle thickness loss, reduced contractility, and less muscle strength as well as worse functional results than patients who do not develop this pain.

METHODS

A prospective longitudinal cohort study was undertaken between June 2015 and December 2017 in 120 consecutive patients scheduled for APM. The study was approved by the ethics committee of our institution. The inclusion criteria were an acute symptomatic meniscal tear requiring surgery in patients aged $\geq$18 years. Patients were excluded if they had PFP before surgery, previous surgery on the involved knee (including meniscal repair), or an associated surgical procedure (eg, chondral repair, ACL reconstruction) during the index procedure. All patients underwent surgery with a maximum of 6 months of evolution since the meniscal tear. No differences were found in the time of evolution of the meniscal tear between the groups.

Of the initial 120 patients, 30 were excluded per the aforementioned criteria: 19 had PFP before surgery and 11 had an associated surgical procedure. For the latter, 7 patients had meniscal repairs with suturing; 3 had associated microfractures attributed to the incidental presence of a chondral injury; and 1 had a partial meniscal injury that was left untreated (Figure 1).

Surgical Procedure

The patients underwent surgery by the same surgical team (P.H., J.L.-B., J.F.S.-S., R.T.-C., J.C.M.) in the knee unit of our institution. All surgical procedures were carried out under spinal anesthesia (15 mg; levobupivacaine 0.5%). Given the short duration of the surgery (a mean of 20 minutes), a tourniquet was used at a pressure of 100 mm Hg above systolic pressure with prior exsanguination of the limb. There were no differences in tourniquet pressure >50 mm Hg among the patients. The APM was performed through routine anterolateral and anteromedial portals in all cases. No patient received a femoral or sciatic nerve block after the operation. No drains were left in place in any case.

Postoperative Management

The patients had surgery on a day-case basis. All patients received the same analgesic, anti-inflammatory, and anticoagulant medication during the postoperative period. All patients received a standardized physical therapy protocol based on immediate postoperative weightbearing with crutches as tolerated and without bracing until a normal gait pattern was established. Muscle function was restored using targeted strengthening exercises for the quadriceps. They started from isometric exercises and progressed to open chain exercises over the course of 6 weeks. Range of motion was not limited and progressed as tolerated.

Outcome Assessment

Patients were allocated to a group according to their response to a question regarding the presence of PFP at the preoperative visit and at 6 weeks after surgery ("Have you ever had pain in the anterior part of the knee in addition to the current pain on the medial or lateral joint line?"). The patients answered this question in writing with the rest of the outcome questionnaires.

To quantify the muscle thickness of the VM and VL muscles, magnetic resonance imaging (MRI) of the thigh was performed on all patients before surgery and 6 weeks after surgery. Those MRI scans were performed on the injured and contralateral knee. A high correlation coefficient exists between the quadriceps cross-sectional area and the total muscle volume.[27] The knees were imaged on the sagittal plane on the same 1.5-T whole-body MRI unit (GE Signa EXCITE) using a commercial receive-only extremity coil. A topogram was taken, and axial planes were programmed in a T1 fast spin echo 2-dimensional sequence (flip angle, 55°; repetition time, 580 milliseconds; minimum

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Ethical approval for this study was obtained from Clínica del Parc de Salut Mar (CEIC No. 2014/5534).

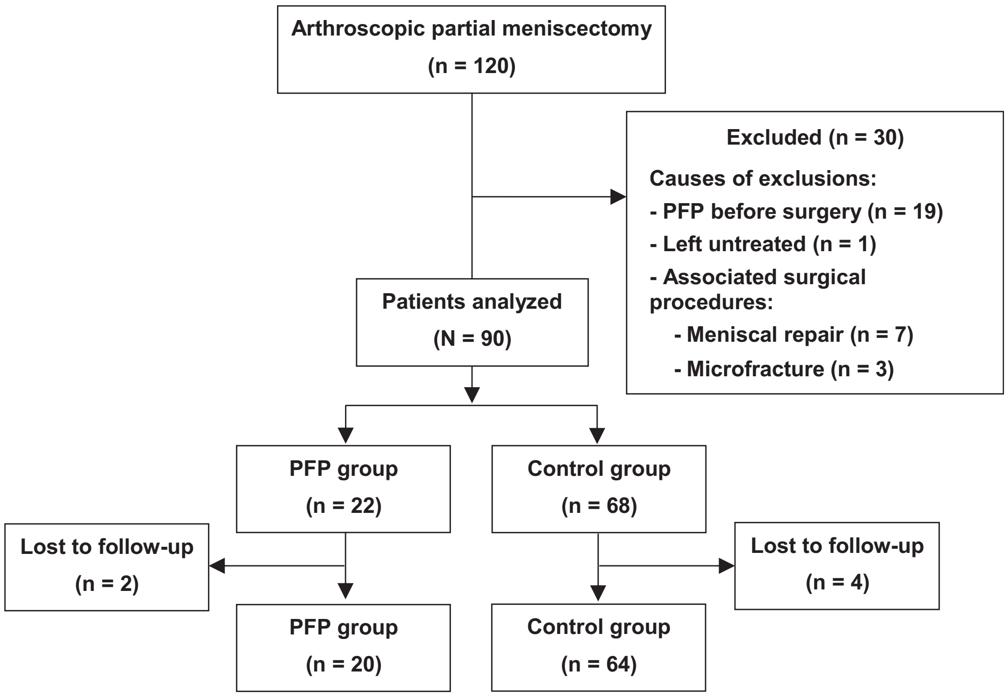

Figure 1. Flowchart of the study and enrollment of the patients. PFP, patellofemoral pain.

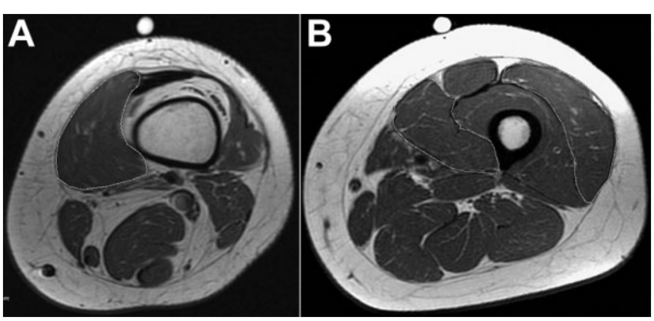

Figure 2. Axial view magnetic resonance imaging showing the cross-sectional area of the vastus medialis and vastus lateralis at (A) 3.75 cm and (B) 15 cm from the upper pole of the patella.

echo time, 11.3 milliseconds; field of view, 17 × 17 cm; 60 partitions; matrix, 448 × 288 pixels; acquisition time, 2.55 minutes). Sagittal images were obtained at a partition thickness of 6 mm, with a partition interval of 4.5 mm and an in-plane resolution of 0.31 to 0.83 mm. All the MRI assessments were performed blinded to patient identification, time sequences, and other knee structural measurements. This measurement was performed at 3.75 cm for the VM and 15 cm for the VM and VL from the upper pole of the patella, according to Wang et al[45] (Figure 2). The VL/VM ratio was calculated with those values.[31] Every MRI measurement was performed blinded by 2 independent observers (radiologists specialized in the musculoskeletal system).

Likewise, the electrical contractility of the quadriceps femoris was analyzed with surface electromyography (MegaWin), extracting muscle activity and the maximum voluntary contraction values of the VL and the VM during the preoperative period and at 6 weeks postsurgically. The Ag/AgCl surface electrodes (30-mm diameter) were distributed in the direction of the muscle fibers of the VM and VL, in accordance with the method for electrode placement in lower limb muscles for surface electromyographic recordings described by Rainoldi et al.[35] Two additional control electrodes were placed on the medial and lateral tibial plateau (Figure 3). The skin under the electrodes was cleaned with a 95% alcohol solution.

To assess the muscle performance values, an isokinetic test (Biodex dynamometer) was performed both presurgically and 6 weeks postsurgically, which provided data on muscular strength through range of motion at 60 deg/s (Figure 4). The electrophysiological and isokinetic tests were performed on both knees by the same physical therapist, who was blinded to whether the patient had PFP.

All patients completed the functional Lysholm knee score before the operation and at the control visit. This questionnaire has been validated in patients with ligamentous,[24] chondral,[25] and meniscal[2,12] injuries as well as in people with normal or healthy knees.[6,7]

Statistical Analysis

Numerical variables are expressed descriptively as means and standard deviations. Within the groups, changes (pre- vs postoperative) were evaluated through paired *t* tests. This was performed separately for the PFP group and the control group. Pre- to postoperative differences were calculated for each parameter and for every

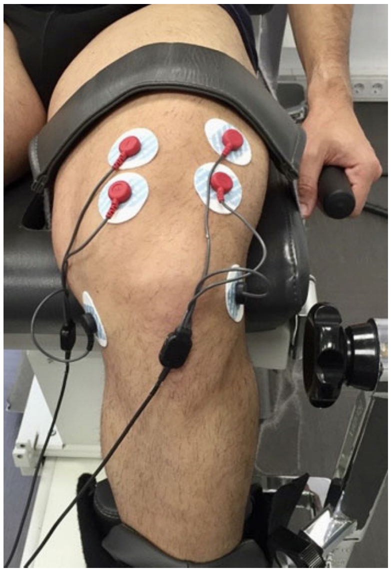

Figure 3. Electrode placement for surface electromyography in a left knee. There were 2 electrodes on the vastus medialis, 2 on the vastus lateralis, and 2 additional control electrodes on the bone surface.

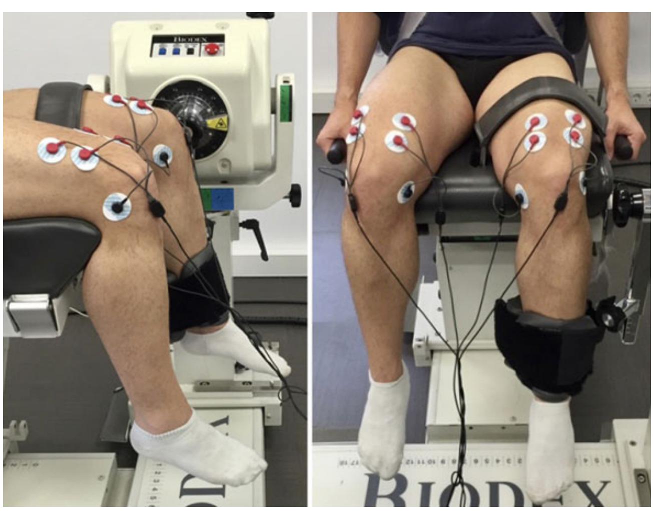

Figure 4. Isokinetic testing on a Biodex dynamometer.

patient. These differences were used to perform between-group comparisons by means of unpaired *t* tests. Stata Version 15.1 (StataCorp) was used for statistical analysis. $P < .05$ were considered statistically significant.

A sample-size calculation was made beforehand. Based on an alpha risk of .05, a beta risk of 0.2, and a relative risk of ≥0.1, a sample of 88 patients was necessary. The proportion of patients who developed PFP after surgery was estimated to be 0.25, the same as the incidence in healthy people.[41] A follow-up loss of 5% was assumed. The Poisson approximation was used.

TABLE 1
Muscle Thickness Between the Study Groups[a]

	Cross-sectional Area, cm2		
	PFP Group	Control Group	*P* Value
Preoperative			
VL$_{15cm}$	21.09 ± 3.55	22.30 ± 3.67	.072
VM$_{15cm}$	15.79 ± 2.95	17.20 ± 2.66	.127
VM$_{3.75cm}$	17.66 ± 2.62	19.25 ± 4.01	.081
VL/VM ratio[b]	1.35 ± 0.21	1.32 ± 0.26	.282
Postoperative			
VL$_{15cm}$	15.88 ± 2.47	20.72 ± 3.35	**<.001**
VM$_{15cm}$	9.06 ± 2.25	14.92 ± 2.96	**<.001**
VM$_{3.75cm}$	9.67 ± 1.84	16.55 ± 3.89	**<.001**
VL/VM ratio[b]	1.76 ± 0.25	1.63 ± 0.26	**.035**
Difference			
VL$_{15cm}$	5.11 ± 2.01	1.38 ± 1.67	**<.001**
VM$_{15cm}$	6.80 ± 1.96	2.28 ± 1.87	**<.001**
VM$_{3.75cm}$	7.80 ± 2.15	2.69 ± 3.18	**<.001**
VL/VM ratio[b]	0.77 ± 0.09	0.98 ± 0.13	**.022**

[a]Data are reported as mean ± SD. Bold *P* values indicate statistically significant difference between groups ($P < .05$). PFP, patellofemoral pain; VL, vastus lateralis; VM, vastus medialis.
[b]Cross-sectional area ratio.

RESULTS

Of the remaining 90 patients after exclusions, 6 were lost to follow-up. The losses included 2 patients from the PFP group and 4 patients from the control group. These follow-up losses were found to be nondifferential for the statistical analysis of the data, because they did not affect the demographics of the 2 groups. Of the remaining 84 patients, 20 (23.80%) were allocated to the PFP group for developing postoperative anterior knee pain, and 64 (76.20%) were considered controls. There were 55 men (65.47%) and 29 women (34.53%), and the mean ± SD age of the sample was 44.92 ± 11.01 years. Both groups were comparable in terms of all the preoperative variables analyzed.

Muscle Thickness

Although the muscle thickness was comparable between the groups preoperatively (Table 1), patients who developed PFP showed a greater decrease in muscle thickness (5.11 cm^2 for VL$_{15\ cm}$, 6.80 cm^2 for VM$_{15cm}$, and 7.80 cm^2 for VM$_{3.75cm}$ or VMO) with respect to the control group (1.38, 2.28, and 2.69 cm^2, respectively) at 6 weeks after surgery ($P < .001$ for all).

Surface Electromyography Results

Muscle activity decreased to a greater extent in the PFP group (804.25 µV in the VL and 1250.80 µV in the VM) than in the control group (486.95 and 680.82 µV) at 6 weeks after the index arthroscopy ($P = .036$ and $P < .001$, respectively).

TABLE 2
Electrical Contractility of the Femoral Quadriceps Between the Study Groups[a]

	Muscle Activity, μV		
	PFP Group	Control Group	*P* Value
Preoperative			
VL MA	2418.25 ± 940.90	2686.00 ± 984.84	.721
VM MA	2477.10 ± 936.34	2626.93 ± 914.38	.436
VL MVC	266.90 ± 70.82	264.43 ± 115.50	.784
VM MVC	271.15 ± 80.72	248.93 ± 109.19	.420
Postoperative			
VL MA	1614.00 ± 671.74	2199.05 ± 840.24	**.021**
VM MA	1226.30 ± 565.79	1946.11 ± 799.33	**<.001**
VL MVC	159.79 ± 55.94	222.33 ± 63.32	**.035**
VM MVC	122.90 ± 63.94	231.75 ± 62.83	**<.001**
Difference			
VL MA	804.25 ± 762.82	486.95 ± 421.34	**.036**
VM MA	1250.80 ± 985.02	680.82 ± 440.32	**<.001**
VL MVC	107.11 ± 99.11	42.10 ± 73.40	**.008**
VM MVC	148.25 ± 103.57	17.18 ± 80.44	**<.001**

[a]Data are reported as mean ± SD. Bold *P* values indicate statistically significant difference between groups ($P < .05$). MA, muscle activity; MVC, maximum voluntary contraction; PFP, patellofemoral pain; VL, vastus lateralis; VM, vastus medialis.

TABLE 3
Muscle Strength at 60 deg/s Between the Study Groups[a]

	Muscle Strength, kg		
	PFP Group	Control Group	*P* Value
Preoperative	23.62 ± 8.57	25.11 ± 9.17	.521
Postoperative	12.27 ± 5.59	20.02 ± 5.92	**<.001**
Difference	11.35 ± 6.78	5.09 ± 7.86	**<.001**

[a]Data are reported as mean ± SD. Bold *P* values indicate statistically significant difference between groups ($P < .05$). PFP, patellofemoral pain.

TABLE 4
Lysholm Scores Between the Study Groups[a]

	PFP Group	Control Group	*P* Value
Preoperative	59.85 ± 17.14	55.56 ± 14.16	.307
Postoperative	63.05 ± 14.70	74.45 ± 10.85	**<.001**
Difference	3.2 ± 12.95	18.89 ± 13.34	**<.001**

[a]Data are reported as mean ± SD. Bold *P* values indicate statistically significant difference between groups ($P < .05$). PFP, patellofemoral pain.

The maximum voluntary contraction analysis showed results in line with those previously mentioned (Table 2).

Isokinetic Testing Results

The preoperative isokinetic study showed muscle strength data of 23.61 kg in the PFP group and 25.11 kg in the control group ($P = .521$). It dropped to 12.27 kg in the PFP group and 20.02 kg in the control group ($P < .001$) at 6 weeks after surgery (Table 3).

Functional Results

Preoperative Lysholm scores were quite similar (PFP, 59.85; control, 55.56; $P = .307$). However, in the postoperative period, the patients who developed PFP had significant worse functional results (PFP, 63.05; control, 74.45; $P < .001$) (Table 4).

DISCUSSION

The most important finding of the current investigation is that patients who develop PFP after APM have not only greater loss of muscle thickness but also a greater decrease in muscle strength and electrical contractility of the quadriceps femoris. In that sense, the hypothesis has been confirmed.

The cause of anterior knee pain is likely to be multifactorial with a wider range of factors involved. Neuromuscular, anatomic, mechanical, and even psychological factors[13,30,32,38] have all been suggested as causative, which explains the unpredictable results of treatment. Although a holistic approach has been attempted for the treatment of these patients,[36] physical therapy continues to focus on quadriceps muscle strength to improve patellofemoral tracking and is the most commonly prescribed intervention.[19] However, recent protocols emphasize the importance of some other distant muscles, such as the abductor and external rotators of the hip, in the treatment of anterior knee pain.[22,28] These muscles decrease internal femoral rotation and excessive functional valgus during patellofemoral tracking and therefore reduce the pressure on the lateral patellar facet.[34]

Assuming that postoperative proximity inhibition is more noticeable in the thigh than in the gluteus muscle group, the present investigation has focused on the muscles around the knee.[4] In this sense, the results indicate that patients in whom PFP appears after arthroscopic surgery experience muscular atrophy of the VL and, to a greater extent, the VM. This decrease in quadriceps femoris muscle size might be related to the development of PFP. The decreased cross-sectional area of the quadriceps femoris muscle has been reported in patients with PFP as compared with asymptomatic controls.[21] Similar observations have been reported after a total knee arthroplasty. Here, strengthening of the VM optimizes patellar tracking. It is also associated with lower patellofemoral contact pressure and a reduced contact area.[26] Therefore, simple self-rehabilitation with open chain exercises to strengthen the quadriceps femoris muscle might be helpful in preventing postoperative PFP.[26,44]

Muscle atrophy is not the only condition these patients experience. They also have a decrease in quadricipital neuromuscular activity, in as much as the recruitment of muscle fibers measured by surface electromyography decreases considerably as compared with the preoperative values. Again, this is more in the VM muscle than in the VL muscle. Nevertheless, not all PFP patients demonstrate VM-VL dysfunction; this is explained by the normal physiological variability in the healthy population. Arthrogenous quadriceps muscle inhibition is associated with the severity of the anterior knee pain in patients with patellofemoral joint osteoarthritis.[8] Decreased quadriceps activation has also been observed in the acute stage of an ACL injury and in patients with ACL-deficient knees who experience instability (noncopers).[23,40] This supports the findings of studies that obtained better results in the treatment of PFP when neuromuscular control techniques (neuromuscular electrical stimulation and proprioceptive neuromuscular facilitation) were combined with muscle enhancement or strengthening techniques.[1,5,30]

A trend toward delayed activation of the VMO muscle relative to the VL muscle was seen in those patients with postoperative PFP versus those without. These differences in the activation of the quadriceps heads during contraction have also been observed among adolescent female patients with PFP when compared with healthy controls.[5,9] However, this association has not been described in patients with PFP after knee arthroscopy. The delay in VMO muscle fiber recruitment relative to the VL muscle during functional activity may adversely affect patellar tracking, thus contributing to the presence of postoperative anterior knee pain. For this reason, this study confirms the importance of VM in the PFP for the first time. Therefore, the role of the VMO in atrophy at the clinical level, which had been reviled in recent years to the detriment of the gluteal musculature, is again brought into focus.[10] Another interesting finding of the current work is the incidence of PFP after an arthroscopic meniscectomy in patients who did not previously have this pain. The 23.8% incidence of postoperative PFP is similar to that of patients after ACL reconstruction at 1- and 2-year follow-up (24% and 22%, respectively).[12] However, the shorter follow-up time in the present investigation impedes drawing any sound conclusion on this particular issue.

Intraoperative tourniquet use may be detrimental to the quadriceps femoris after knee surgery. Some studies have demonstrated that tourniquet use resulted in a significantly decreased thigh circumference as well as significant negative electromyographic changes at 3 weeks after ACL reconstruction.[3] In the present study, a tourniquet was used on all patients regardless of their group. Therefore, the tourniquet affected both groups equally and was not a confounding factor.

Some limitations can be found in the present study. First is the severity of meniscal damage and consequently the amount of meniscus removed at surgery, as it might have an impact on the degree of postoperative atrophy. Second is the duration of symptoms before surgery and the lack of follow-up after 6 weeks, which make it impossible to ascertain the evolution of these patients in the medium and long term. However, the aim of the present study was to quantify data in a relatively short period after surgery and not to ascertain the clinical evolution of these patients in the long run. Lower extremity structural anomalies on the transverse plane, including increased femoral anteversion and lateral tibial torsion, may contribute to patellofemoral malalignment, and PFP must also be considered.[11,14] These factors were not analyzed in the current study, so they might be another limitation. Last, there is the definition of PFP, which is based on the subjective presence of pain (or not) in the anterior part of the knee. This is determined by self-referral and not by more objective and specific measures or patellofemoral questionnaires, such as the patellar diagnostic test (Felson test).[42]

In light of the current results, any neuromuscular deficit observed after APM should be monitored and specific rehabilitation protocols applied to maintain functional stability of the knee to avoid any postoperative dysfunction, such as quadriceps femoris muscle atrophy or loss of strength.

CONCLUSION

The results suggest that patients who develop PFP after APM have more quadriceps femoris atrophy at 6 weeks after surgery as compared with patients who do not develop this pain. Moreover, they have decreased muscle strength and electrical contractility of the VM to a greater degree with respect to the VL. This group of patients also has worse functional results after surgery.

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REFERENCES

1. Alba-Martín P, Gallego-Izquierdo T, Plaza-Manzano G, Romero-Franco N, Núñez-Nagy S, Pecos-Martín D. Effectiveness of therapeutic physical exercise in the treatment of patellofemoral pain syndrome: a systematic review. *J Phys Ther Sci*. 2015;27(7):2387-2390.
2. Arroyo-Morales M, Martin-Alguacil J, Lozano-Lozano M, et al. The Lysholm score: cross cultural validation and evaluation of psychometric properties of the Spanish version. *PLoS One*. 2019;14(8): e0221376.
3. Baron JE, Parker EA, Duchman KR, Westermann RW. Perioperative and postoperative factors influence quadriceps atrophy and strength after ACL reconstruction: a systematic review. *Orthop J Sports Med*. 2020;8(6):232596712093029.
4. Berry PA, Teichtahl AJ, Galevska-Dimitrovska A, et al. Vastus medialis cross-sectional area is positively associated with patella cartilage and bone volumes in a pain-free community-based population. *Arthritis Res Ther*. 2008;10(6):R143.
5. Briani RV, De Oliveira Silva D, Flóride CS, et al. Quadriceps neuromuscular function in women with patellofemoral pain: influences of

the type of the task and the level of pain. *PLoS One*. 2018;13(10): e0205553.
6. Briggs KK, Kocher MS, Rodkey WG, Steadman JR. Reliability, validity, and responsiveness of the Lysholm knee score and Tegner activity scale for patients with meniscal injury of the knee. *J Bone Joint Surg Am*. 2006;88(4):698-705.
7. Briggs KK, Steadman JR, Hay CJ, Hines SL. Lysholm score and Tegner activity level in individuals with normal knees. *Am J Sports Med*. 2009;37(5):898-901.
8. Callaghan MJ, Parkes MJ, Hutchinson CE, Felson DT. Factors associated with arthrogenous muscle inhibition in patellofemoral osteoarthritis. *Osteoarthritis Cartilage*. 2014;22(6):742-746.
9. Carry PM, Kanai S, Miller NH, Polousky JD. Adolescent patellofemoral pain: a review of evidence for the role of lower extremity biomechanics and core instability. *Orthopedics*. 2010;33(7): 498-507.
10. Chester R, Smith TO, Sweeting D, Dixon J, Wood S, Song F. The relative timing of VMO and VL in the aetiology of anterior knee pain: a systematic review and meta-analysis. *BMC Musculoskelet Disord*. 2008;9:64.
11. Cibulka MT, Threlkeld-Watkins J. Patellofemoral pain and asymmetrical hip rotation. *Phys Ther*. 2005;85(11):1201-1207.
12. Culvenor AG, Øiestad BE, Holm I, Gunderson RB, Crossley KM, Risberg MA. Anterior knee pain following anterior cruciate ligament reconstruction does not increase the risk of patellofemoral osteoarthritis at 15- and 20-year follow-ups. *Osteoarthritis Cartilage*. 2017; 25(1):30-33.
13. Doménech J, Sanchis-Alfonso V, Espejo B. Changes in catastrophizing and kinesiophobia are predictive of changes in disability and pain after treatment in patients with anterior knee pain. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(10):2295-2300.
14. Erkocak OF, Altan E, Altintas M, Turkmen F, Aydin BK, Bayar A. Lower extremity rotational deformities and patellofemoral alignment parameters in patients with anterior knee pain. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(9):3011-3020.
15. Goldblatt JP, Fitzsimmons SE, Balk E, Richmond JC. Reconstruction of the anterior cruciate ligament: meta-analysis of patellar tendon versus hamstring tendon autograft. *Arthroscopy*. 2005;21(7): 791-803.
16. Grapar Žargi T, Drobnič M, Vauhnik R, Koder J, Kacin A. Factors predicting quadriceps femoris muscle atrophy during the first 12 weeks following anterior cruciate ligament reconstruction. *Knee*. 2017;24(2):319-328.
17. Hart HF, Ackland DC, Pandy MG, Crossley KM. Quadriceps volumes are reduced in people with patellofemoral joint osteoarthritis. *Osteoarthritis Cartilage*. 2012;20(8):863-868.
18. Heijden RA, Lankhorst NE, Linschoten R, Bierma-Zeinstra SMA, Middelkoop M. Exercise for treating patellofemoral pain syndrome. *Cochrane Database Syst Rev*. 2015;1:CD010387.
19. Hiemstra LA, Kerslake S, Arendt EA. Clinical rehabilitation of anterior knee pain: current concepts. *Am J Orthop*. 2017;46(2): 82-86.
20. Karaman O, Ayhan E, Kesmezacar H, Seker A, Unlu MC, Aydingoz O. Rotational malalignment after closed intramedullary nailing of femoral shaft fractures and its influence on daily life. *Eur J Orthop Surg Traumatol*. 2014;24(7):1243-1247.
21. Kaya D, Citaker S, Kerimoglu U, et al. Women with patellofemoral pain syndrome have quadriceps femoris volume and strength deficiency. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(2): 242-247.
22. Khayambashi K, Mohammadkhani Z, Ghaznavi K, Lyle MA, Powers CM. The effects of isolated hip abductor and external rotator muscle strengthening on pain, health status, and hip strength in females with patellofemoral pain: a randomized controlled trial. *J Orthop Sports Phys Ther*. 2012;42(1):22-29.
23. Knoll Z, Kocsis L, Kiss RM. Gait patterns before and after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2004;12(1):7-14.
24. Kocher MS, Steadman JR, Briggs K, Zurakowski D, Sterett WI, Hawkins RJ. Determinants of patient satisfaction with outcome after anterior cruciate ligament reconstruction. *J Bone Joint Surg Am*. 2002; 84(9):1560-1572.
25. Kocher MS, Steadman JR, Briggs KK, Sterett WI, Hawkins RJ. Reliability, validity, and responsiveness of the Lysholm knee scale for various chondral disorders of the knee. *J Bone Joint Surg Am*. 2004;86(6):1139-1145.
26. Lin Y-F, Lin J-J, Jan M-H, Wei T-C, Shih H-Y, Cheng C-K. Role of the vastus medialis obliquus in repositioning the patella: a dynamic computed tomography study. *Am J Sports Med*. 2008;36(4): 741-746.
27. Marcon M, Ciritsis B, Laux C, et al. Cross-sectional area measurements versus volumetric assessment of the quadriceps femoris muscle in patients with anterior cruciate ligament reconstructions. *Eur Radiol*. 2015;25(2):290-298.
28. Mascal CL, Landel R, Powers C. Management of patellofemoral pain targeting hip, pelvis, and trunk muscle function: 2 case reports. *J Orthop Sports Phys Ther*. 2003;33(11):647-660.
29. Matsusue Y, Thomson NL. Arthroscopic partial medial meniscectomy in patients over 40 years old: a 5- to 11-year follow-up study. *Arthroscopy*. 1996;12(1):39-44.
30. Pal S, Draper CE, Fredericson M, et al. Patellar maltracking correlates with vastus medialis activation delay in patellofemoral pain patients. *Am J Sports Med*. 2011;39(3):590-598.
31. Pan J, Stehling C, Muller-Hocker C, et al. Vastus lateralis/vastus medialis cross-sectional area ratio impacts presence and degree of knee joint abnormalities and cartilage T2 determined with 3 T MRI—an analysis from the incidence cohort of the Osteoarthritis Initiative. *Osteoarthritis Cartilage*. 2011;19(1):65-73.
32. Pattyn E, Verdonk P, Steyaert A, et al. Vastus medialis obliquus atrophy: does it exist in patellofemoral pain syndrome? *Am J Sports Med*. 2011;39(7):1450-1455.
33. Paxton ES, Stock MV, Brophy RH. Meniscal repair versus partial meniscectomy: a systematic review comparing reoperation rates and clinical outcomes. *Arthroscopy*. 2011;27(9):1275-1288.
34. Petersen W, Ellermann A, Gösele-Koppenburg A, et al. Patellofemoral pain syndrome. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(10): 2264-2274.
35. Rainoldi A, Melchiorri G, Caruso I. A method for positioning electrodes during surface EMG recordings in lower limb muscles. *J Neurosci Methods*. 2004;134(1):37-43.
36. Sanchis-Alfonso V. Holistic approach to understanding anterior knee pain: clinical implications. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(10):2275-2285.
37. Sanchis-Alfonso V.Patellofemoral pain. Article in German. *Orthopade*. 2008;37(9):835-836, 838-840.
38. Sanchis-Alfonso V, Roselló-Sastre E. Immunohistochemical analysis for neural markers of the lateral retinaculum in patients with isolated symptomatic patellofemoral malalignment: a neuroanatomic basis for anterior knee pain in the active young patient. *Am J Sports Med*. 2000; 28(5):725-731.
39. Seil R, Becker R. Time for a paradigm change in meniscal repair: save the meniscus! *Knee Surg Sports Traumatol Arthrosc*. 2016;24(5): 1421-1423.
40. Shanbehzadeh S, Mohseni Bandpei MA, Ehsani F. Knee muscle activity during gait in patients with anterior cruciate ligament injury: a systematic review of electromyographic studies. *Knee Surg Sports Traumatol Arthrosc*. 2017;25(5):1432-1442.
41. Smith BE, Selfe J, Thacker D, et al. Incidence and prevalence of patellofemoral pain: a systematic review and meta-analysis. *PLoS One*. 2018;13(1):e0190892.
42. Stefanik JJ, Neogi T, Niu J, et al. The diagnostic performance of anterior knee pain and activity-related pain in identifying knees with structural damage in the patellofemoral joint: the Multicenter Osteoarthritis Study. *J Rheumatol*. 2014;41(8):1695-1702.
43. Stein T, Mehling AP, Welsch F, von Eisenhart-Rothe R, Jäger A. Long-term outcome after arthroscopic meniscal repair versus arthroscopic

partial meniscectomy for traumatic meniscal tears. *Am J Sports Med*. 2010;38(8):1542-1548.

44. Tang SF, Chen CK, Hsu R, Chou SW, Hong WH, Lew HL. Vastus medialis obliquus and vastus lateralis activity in open and closed kinetic chain exercises in patients with patellofemoral pain syndrome: an electromyographic study. *Arch Phys Med Rehabil*. 2001;82(10): 1441-1445.
45. Wang Y, Wluka AE, Berry PA, et al. Increase in vastus medialis cross-sectional area is associated with reduced pain, cartilage loss, and joint replacement risk in knee osteoarthritis. *Arthritis Rheum*. 2012; 64(12):3917-3925.
46. Werner S. Anterior knee pain: an update of physical therapy. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(10):2286-2294.
47. Wünschel M, Leichtle U, Obloh C, Wülker N, Müller O. The effect of different quadriceps loading patterns on tibiofemoral joint kinematics and patellofemoral contact pressure during simulated partial weight-bearing knee flexion. *Knee Surg Sports Traumatol Arthrosc*. 2011; 19(7):1099-1106.
48. Yildirim AO, Aksahin E, Sakman B, et al. The effect of rotational deformity on patellofemoral parameters following the treatment of femoral shaft fracture. *Arch Orthop Trauma Surg*. 2013;133(5): 641-648.