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Influence of Severity and Duration of Anterior Knee Pain on Quadriceps Function and Self-Reported Function

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Context: Little is known about how the combination of pain severity and duration affects quadriceps function and self-reported function in patients with anterior knee pain (AKP).

Objective: To examine how severity (*low* [≤3 of 10] versus *high* [>3 of 10]) and duration (*short* [<2 years] versus *long* [>2 years]) of AKP affect quadriceps function and self-reported function.

Design: Cross-sectional study.

Setting: Laboratory.

Patients or Other Participants: Sixty patients with AKP (mean pain severity = 4 of 10 on the numeric pain rating scale, mean pain duration = 38 months) and 48 healthy control individuals. Patients with AKP were categorized into 3 subdivisions based on pain: (1) severity (low versus high); (2) duration (short versus long); and (3) severity and duration (low and short versus low and long versus high and short versus high and long).

Main Outcome Measure(s): Quadriceps maximal (maximal voluntary isometric contraction) and explosive (rate of torque development) strength, activation (central activation ratio), and endurance (average peak torque) and self-reported function (Lower Extremity Functional Scale score).

Results: Compared with the healthy control group, (1) all AKP subgroups showed less quadriceps maximal strength ($P <$ .005, $d \geq 0.78$) and activation ($P <$ .02, $d \geq 0.85$), except for the AKP subgroup with low severity and short duration of pain ($P >$ .32); (2) AKP subgroups with either high severity or long duration of pain showed less quadriceps explosive strength ($P <$ .007, $d \geq 0.74$) and endurance ($P <$ .003, $d \geq 0.79$), but when severity and duration were combined, only the AKP subgroup with high severity and long duration of pain showed less quadriceps explosive strength ($P =$ .006, $d = 1.09$) and endurance ($P =$ .0004, $d = 1.21$); and (3) all AKP subgroups showed less self-reported function ($P <$ .0001, $d \geq 3.44$).

Conclusions: Clinicians should be aware of the combined effect of severity and duration of pain and incorporate both factors into clinical practice when rehabilitating patients with AKP.

Key Words: patellofemoral pain, muscle function, patient-reported outcomes, pain level, chronic pain

Key Points

- Both the severity and duration of anterior knee pain were inversely associated with quadriceps function and self-reported function.
- Patients with both higher severity (eg, >3 of 10) and longer duration (eg, >2 years) of anterior knee pain were more likely to exhibit further deficits in quadriceps function.
- When taking a medical history before treating patients with anterior knee pain, clinicians should measure pain severity and duration and consider their combined effect.

Anterior knee pain (AKP) is a prevalent musculoskeletal complaint, accounting for 25% to 40% of all knee conditions in sports medicine clinics.[1] As the cause is multifactorial, AKP is a challenging condition for clinicians to target and treat. Pain causes a wide range of adaptations in neuromuscular activity, such as changing the onset of activation,[2] recruitment pattern,[3] and direction of contraction.[4] Hodges and Tucker[5] proposed that pain may change motoneuron-pool recruitment patterns, resulting in a redistribution of activity within and between muscles. Although these neuromuscular alterations have an immediate potential benefit in protecting against further pain and injury,[5,6] in the long term, patients may be at higher risk for increasing abnormal excessive joint loading and pain via biomechanical deviations and compensatory movements.[5,7] Similarly, AKP not only reduces physical activity levels[8] and health-related quality of life[9] by itself, but it also induces an arthrogenic muscle response, especially in the quadriceps.[10,11] Persistent quadriceps weakness and inhibition should be clinically addressed, as these have been associated with altered lower extremity biomechanics[12] and decreased self-reported function.[13] Although therapeutic interventions to reduce pain and counteract quadriceps inhibition in the short term are well documented,[10,14] the long-term outcomes of these interventions are not as effective.[15,16] For example, more than 90% of patients with AKP continued to experience pain 16 years after their diagnosis.[17]

Researchers in 2 longitudinal studies demonstrated that higher severity and longer duration of AKP predisposed individuals to an increased risk of advanced injury (eg, knee osteoarthritis) and unfavorable sequelae (eg, poor quality of life). Furthermore, the authors[18] of a previous study reported that moderate-to-severe AKP resulted in quadriceps weakness, whereas mild pain did not. As support for this evidence, several investigators have described negative relationships of AKP severity[18,19] and duration[15,16,19] on quadriceps function[18,19] and self-reported function.[15,16] For instance, clinicians may assume that the rate of development of knee-joint injury due to quadriceps weakness[10] might be minimal for patients with a lower severity of pain, a shorter duration of pain, or both. In clinical practice, patients with AKP are generally categorized into subgroups based on pain severity and duration (eg, 1.6 of 10 and 21.6 months,[20] 4.4 of 10 and 48.6 months[21]). If the magnitudes of quadriceps deficits (eg, strength deficits but normal endurance) differ among patients with AKP who have different levels of pain severity, duration, or both (eg, low severity and long duration of pain versus high severity and short duration of pain), rehabilitation strategies should be tailored to the needs of each patient. Similar to this approach, recent researchers[22] suggested that clinicians should expect that patients with AKP who have more frequent (eg, 1–2 times versus >3 times a week) pain would have greater deficits in the hip muscles. Thus, categorizing these subgroups using easily identifiable and obtainable pain-related factors may help facilitate the clinical decision-making process. According to the earlier article,[18] the cutoff value that classifies ≤3 of 10 as mild pain and >3 of 10 as moderate-to-severe pain could be clinically meaningful for quadriceps function when using a numeric pain rating scale (NPRS).[23] In terms of pain duration, no universal category scale exists. Some investigators[24,25] observed that approximately half of the patients with AKP no longer had pain 2 years later, whereas the other half continued to experience pain even after 2 years. If quadriceps function differs between patients with AKP classified by the specific period of 2 years, this may provide insight for future authors examining whether quadriceps dysfunction is a contributing factor in persistent pain.

Analyzing various characteristics of torque waveforms using force-based techniques, such as maximal voluntary isometric contraction (MVIC), rate of torque development (RTD), central activation ratio (CAR), and average peak torque (APT), would provide clinicians with further information in understanding underlying neuromuscular deficits and developing specific strengthening programs for each specific AKP subgroup. Because quadriceps strength is also negatively correlated with pain[26] and positively correlated with self-reported function,[13,26] clinicians should be encouraged to use quadriceps exercises and disinhibitory interventions during rehabilitation for AKP to improve both objective and subjective function.[27] Unfortunately, the interaction and main effects of severity and duration of AKP on quadriceps function and self-reported function have never been examined. Therefore, we aimed to explore how AKP severity (*low* [≤3 of 10] versus *high* [>3 of 10])[23,26] and duration (*short* [<2 years] versus *long* [>2 years])[24,25] affected quadriceps function and self-reported function. We hypothesized that (1) both the severity and duration of AKP would be associated with quadriceps function and self-reported function and (2) a combination of high severity and long duration of AKP would lead to additional deficits in quadriceps function and self-reported function.

METHODS

Participants

Initially, 214 volunteers aged 18 to 35 years were recruited from the university and local community via flyers and screened for eligibility, resulting in 60 patients with AKP and 48 healthy control individuals whose data were used in the final analysis (Table 1; Figure). To minimize potential confounding factors, healthy control individuals were matched on age, height, mass, body mass index, thigh circumference, and physical activity (Tables 2–5). All participants had to engage in ≥150 minutes of moderate exercise (eg, walking and light jogging) or 60 minutes of vigorous exercise (eg, running and weightlifting) per week.[26] After taking measurements, we categorized patients into 3 subdivisions based on pain (1) severity (*low* [≤3 of 10] versus *high* [>3 of 10]), (2) duration (*short* [<2 years] versus *long* [>2 years]), and (3) severity and duration (*low and short* [≤3 of 10, <2 years] versus *low and long* [≤3 of 10, >2 years] versus *high and short* [>3 of 10, <2 years] versus *high and long* [>3 of 10, >2 years]). The university's institutional review board approved the study.

Table 1. Inclusion and Exclusion Criteria

Criterion Type	Description
Inclusion criteria for anterior knee pain group	Atraumatic unilateral retropatellar or peripatellar pain ≥1 mo[19] Severity of usual pain in the past week ≥2 of 10[28] Pain of ≥2 during or after activities[27]: Prolonged sitting Kneeling Patellar compression Quadriceps contraction Stair ambulation Running Jumping Squatting
Inclusion criteria for healthy control group	No lifetime history of lower extremity or spine surgery No history of lower extremity injury or pain within 6 mo
Exclusion criteria for either group	History of knee surgery Internal derangement Ligamentous instability Other sources of anterior knee pain (eg, patellar tendinopathy) Physician-confirmed diagnosis of knee osteoarthritis Musculoskeletal or neurologic disorder Cardiovascular or respiratory disease Low back pain Hypersensitivity to electrical stimulation

Procedures

Upon arrival at the laboratory, participants read and gave informed consent. After anthropometric assessment using a bioelectrical impedance device (model InBody 770; Biospace Ltd), health history questionnaires were completed to collect the history of injuries and surgeries, physical activity, severity of typical pain in the past week[28] using the NPRS (0 = *no pain*, 10 = *worst pain imaginable*), and pain duration. We used the Lower Extremity Functional Scale (LEFS) to evaluate self-reported function.[29] Then thigh circumference (at the midpoint between the anterior-superior iliac spine and the superior pole of the patella) in centimeters was obtained using a tape measure.

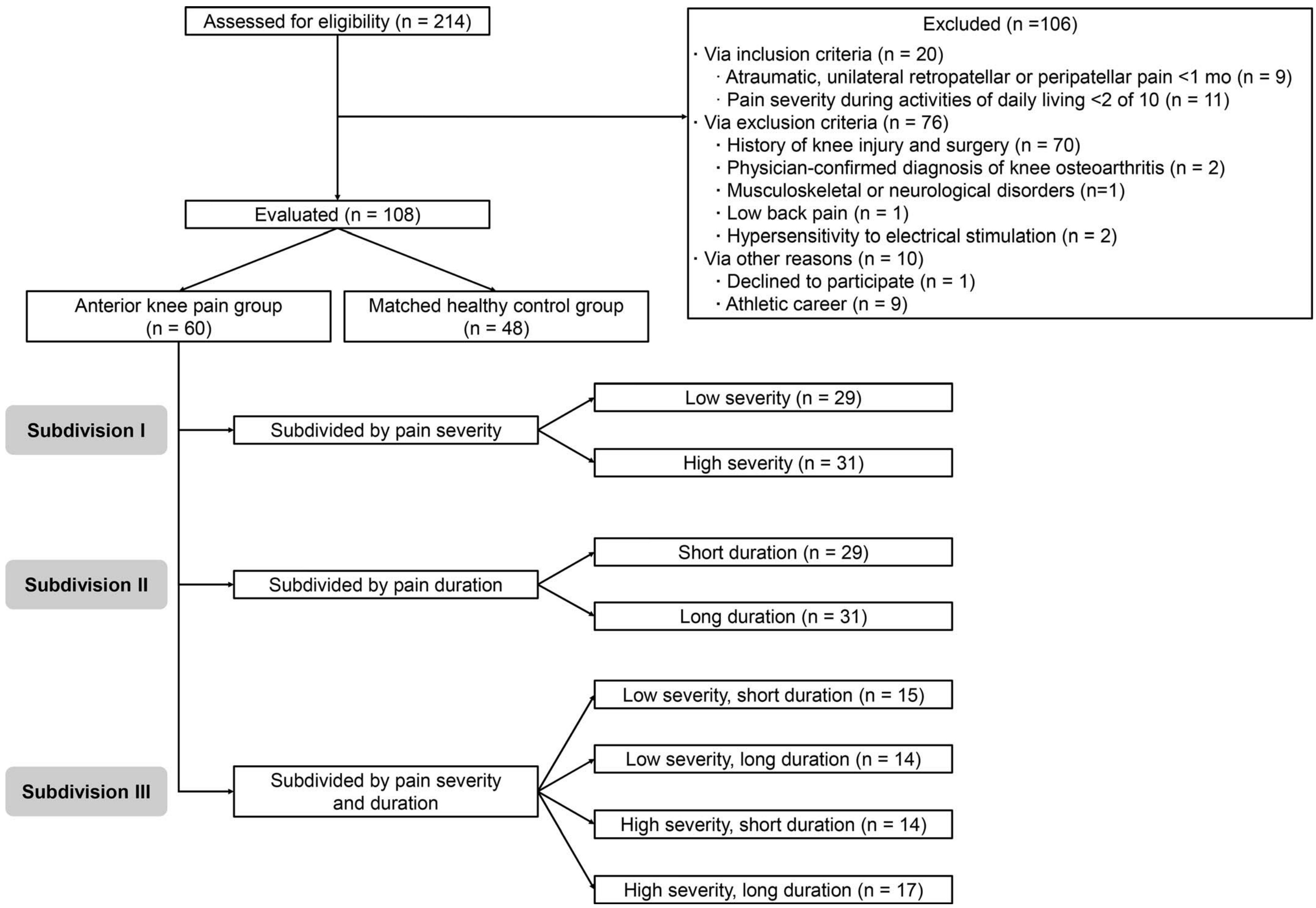

Figure. Flowchart of participant selection and subdivision.

After a 10-minute warm-up exercise on a stationary bike at a self-selected pace, the participant was seated on an isokinetic dynamometer (model 770 Norm; Cybex International). The knee and hip joints were positioned at 90° and 85°, respectively. The chest, pelvis, and thigh on the nonpainful side were secured with straps to prevent accessory motions or assistant muscle contractions. Two 7- × 12.7-cm stimulating electrodes (model Dura-Stick II; Chattanooga Group Inc) were attached to the proximal vastus lateralis and distal vastus medialis after the anterior

Table 2. Participant Demographics, Pain Severity and Duration, Quadriceps Function, and Self-Reported Function

Characteristic	Group: Anterior Knee Pain (n = 60)	Group: Healthy Control (n = 48)	*P* Value
	No.		
Sex, female/male	27/33	13/35	Not applicable
	Mean ± 95% CI		
Age, y	21.9 ± 0.7	22.5 ± 0.7	.21
Height, cm	170.4 ± 2.0	172.7 ± 2.2	.13
Mass, kg	68.6 ± 3.8	71.2 ± 3.3	.34
Body mass index, kg/m^2	23.4 ± 0.9	23.8 ± 0.8	.59
Thigh circumference, cm	54.8 ± 1.3	56.2 ± 1.4	.14
Physical activity, min/wk	247.0 ± 35.2	254.1 ± 30.8	.77
Pain severity, numeric pain rating scale	4.0 ± 0.4[a]	0.0 ± 0.0	<.0001
Pain duration, mo	38.0 ± 8.2[a]	0.0 ± 0.0	<.0001
Quadriceps maximal strength, maximal voluntary isometric contraction, N·m/kg	2.4 ± 0.2[a]	3.1 ± 0.2	<.0001
Quadriceps explosive strength, rate of torque development, N·m/s/kg	8.2 ± 0.6[a]	9.5 ± 0.6	.004
Quadriceps activation, central activation ratio	0.89 ± 0.03[a]	0.97 ± 0.01	<.0001
Quadriceps endurance, average peak torque, N·m/kg	1.6 ± 0.1[a]	1.9 ± 0.1	.001
Self-reported function, Lower Extremity Functional Scale score	55.2 ± 2.7[a]	79.1 ± 0.5	<.0001

[a] Different from the healthy control group.

Table 3. Participant Demographics, Pain Severity and Duration, Quadriceps Function, and Self-Reported Function Categorized by Pain Severity

Characteristic	Group: AKP Severity (n = 60)[a] Low (n = 29)	High (n = 31)	Healthy Control (n = 48)
		No.	
Sex, female/male	17/12	11/20	13/35
		Mean ± 95% CI	
Age, y	22.0 ± 1.0	21.7 ± 1.1	22.5 ± 0.7
Height, cm	168.9 ± 2.8	171.7 ± 2.8	172.7 ± 2.2
Mass, kg	64.2 ± 3.9[b]	72.7 ± 6.1[c]	71.2 ± 3.3
Body mass index, kg/m²	22.4 ± 0.9[b]	24.5 ± 1.5[c]	23.8 ± 0.8
Thigh circumference, cm	53.6 ± 1.7	55.8 ± 1.9	56.2 ± 1.4
Physical activity, min/wk	234.8 ± 46.8	258.4 ± 52.6	254.1 ± 30.8
Pain severity, numeric pain rating scale	2.5 ± 0.1[b,d]	5.4 ± 0.4[c,d]	0.0 ± 0.0
Pain duration, mo	33.9 ± 10.8[d]	41.9 ± 12.2[d]	0.0 ± 0.0
Quadriceps maximal strength, maximal voluntary isometric contraction, N·m/kg	2.4 ± 0.2[d]	2.4 ± 0.2[d]	3.1 ± 0.2
Quadriceps explosive strength, rate of torque development, N·m/s/kg	8.6 ± 1.0	7.8 ± 0.7[d]	9.5 ± 0.6
Quadriceps activation, central activation ratio	0.92 ± 0.03[b,d]	0.87 ± 0.04[c,d]	0.97 ± 0.01
Quadriceps endurance, average peak torque, N·m/kg	1.7 ± 0.2	1.5 ± 0.2[d]	1.9 ± 0.1
Self-reported function, Lower Extremity Functional Scale score	60.2 ± 3.1[b,d]	50.5 ± 3.6[c,d]	79.1 ± 0.5

Abbreviation: AKP, anterior knee pain.

[a] Numeric pain rating scale: ≤3 of 10, *low severity*; >3 of 10, *high severity*.
[b] Different from the AKP subgroup with a high severity of pain ($P < .05$).
[c] Different from the AKP subgroup with a low severity of pain ($P < .05$).
[d] Different from the healthy control group ($P < .05$).

thigh was shaved with a razor and cleaned with alcohol swabs. For the matched healthy control group, the *dominant leg* (defined as the leg used to kick a ball) was evaluated.

After familiarization sessions,[26] participants performed 3 trials of quadriceps MVIC with 90-second rest intervals. Visual feedback and oral encouragement ("as fast and hard as possible") were provided for each trial. When knee-extension torque reached a plateau, an electrical stimulus (100 pulses/s, 600-microsecond pulse duration, a 100-millisecond train of 10 stimuli, 125 V with a peak output current of 450 mA) was delivered to the quadriceps via 2 stimulating electrodes to recruit any remaining motor units.[11] We used the S48 Grass Stimulator with an SIU8T transformer stimulus isolation unit (Grass-Telefactor Inc) to

Table 4. Participant Demographics, Pain Severity and Duration, Quadriceps Function, and Self-Reported Function Categorized by Pain Duration

Characteristic	Group: AKP Duration (n = 60)[a] Short (n = 29)	Long (n = 31)	Healthy Control (n = 48)
		No.	
Sex, female/male	11/18	16/15	13/35
		Mean ± 95% CI	
Age, y	21.3 ± 0.8	22.4 ± 1.2	22.5 ± 0.7
Height, cm	171.6 ± 2.7	169.3 ± 3.0	172.7 ± 2.2
Mass, kg	69.0 ± 4.8	68.3 ± 5.9	71.2 ± 3.3
Body mass index, kg/m²	23.2 ± 1.1	23.7 ± 1.5	23.8 ± 0.8
Thigh circumference, cm	54.9 ± 1.6	54.6 ± 2.0	56.2 ± 1.4
Physical activity, min/wk	259.1 ± 57.3	235.6 ± 42.5	254.1 ± 30.8
Pain severity, numeric pain rating scale	4.1 ± 0.6[b]	4.0 ± 0.5[b]	0.0 ± 0.0
Pain duration, mo	11.3 ± 2.2[b,c]	63.0 ± 9.3[b,d]	0.0 ± 0.0
Quadriceps maximal strength, maximal voluntary isometric contraction, N·m/kg	2.6 ± 0.2[b]	2.3 ± 0.2[b]	3.1 ± 0.2
Quadriceps explosive strength, rate of torque development, N·m/s/kg	8.6 ± 0.8	7.8 ± 0.9[b]	9.5 ± 0.6
Quadriceps activation, central activation ratio	0.91 ± 0.04[b]	0.88 ± 0.04[b]	0.97 ± 0.01
Quadriceps endurance, average peak torque, N·m/kg	1.7 ± 0.2	1.5 ± 0.2[b]	1.9 ± 0.1
Self-reported function, Lower Extremity Functional Scale score	55.3 ± 3.8[b]	55.0 ± 3.9[b]	79.1 ± 0.5

Abbreviation: AKP, anterior knee pain.

[a] Duration: <2 y, *short*; >2 y, *long*.
[b] Different from the healthy control group ($P < .01$).
[c] Different from the AKP subgroup with a long duration of pain ($P < .0001$).
[d] Different from the AKP subgroup with a short duration of pain ($P < .0001$).

Table 5. **Participant Demographics, Pain Severity and Duration, Quadriceps Function, and Self-Reported Function Categorized by Pain Severity and Duration**

Characteristic	Group				
	AKP Severity/Duration (n = 60)[a]				
	Low/Short (n = 15)	Low/Long (n = 14)	High/Short (n = 14)	High/Long (n = 17)	Healthy Control (n = 48)
			No.		
Sex, female/male	8/7	9/5	3/11	7/10	13/35
			Mean ± 95% CI		
Age, y	21.7 ± 1.1	22.2 ± 1.6	20.8 ± 1.1	22.5 ± 1.7	22.5 ± 0.7
Height, cm	169.8 ± 3.6	168.0 ± 4.5	173.4 ± 4.0	170.3 ± 4.0	172.7 ± 2.2
Mass, kg	64.7 ± 5.8	63.8 ± 5.2	73.6 ± 7.2	72.1 ± 9.7	71.2 ± 3.3
Body mass index, kg/m^2	22.3 ± 1.2	22.5 ± 1.2	24.3 ± 1.6	24.6 ± 2.4	23.8 ± 0.8
Thigh circumference, cm	54.2 ± 2.3	53.0 ± 25	55.6 ± 2.3	56.0 ± 2.9	56.2 ± 1.4
Physical activity, min/wk	240.0 ± 76.3	229.3 ± 55.0	279.6 ± 87.7	240.9 ± 64.4	254.1 ± 30.8
Pain severity, numeric pain rating scale	2.6 ± 0.2[b,c,d]	2.5 ± 0.2[b,c,d]	5.7 ± 0.6[b,e,f]	5.2 ± 0.5[b,e,f]	0.0 ± 0.0
Pain duration, mo	11.4 ± 3.2[d,f]	58.0 ± 13.3[b,c,e]	11.3 ± 3.2[d,f]	67.1 ± 12.9[b,c,e]	0.0 ± 0.0
Quadriceps maximal strength, maximal voluntary isometric contraction, N·m/kg	2.8 ± 0.3	2.1 ± 0.2[b]	2.4 ± 0.3[b]	2.4 ± 0.3[b]	3.1 ± 0.2
Quadriceps explosive strength, rate of torque development, N·m/s/kg	8.6 ± 1.4	8.5 ± 1.5	8.6 ± 1.0	7.2 ± 1.0[b]	9.5 ± 0.6
Quadriceps activation, central activation ratio	0.95 ± 0.02	0.89 ± 0.06[b]	0.86 ± 0.07[b]	0.88 ± 0.05[b]	0.97 ± 0.01
Quadriceps endurance, average peak torque, N·m/kg	1.7 ± 0.2	1.6 ± 0.3	1.8 ± 0.2	1.3 ± 0.2[b]	1.9 ± 0.1
Self-reported function, Lower Extremity Functional Scale score	60.0 ± 4.6[b,c,d]	60.4 ± 4.3[b,c,d]	50.4 ± 5.0[b,e,f]	50.6 ± 5.2[b,e,f]	79.1 ± 0.5

Abbreviation: AKP, anterior knee pain.

[a] Numeric pain rating scale: ≤3 of 10, *low severity*; >3 of 10, *high severity*; duration: <2 y, *short*; >2 y, *long*.
[b] Different from the healthy control group ($P < .01$).
[c] Different from the AKP subgroup with a high severity/short duration of pain ($P < .01$).
[d] Different from the AKP subgroup with a high severity/long duration of pain ($P < .01$).
[e] Different from the AKP subgroup with a low severity/short duration of pain ($P < .01$).
[f] Different from the AKP subgroup with low severity/long duration of pain ($P < .01$).

generate the superimposed burst (SIB). After a 5-minute rest, quadriceps endurance was concentrically measured under isokinetic conditions at 180°/s with 20 repetitions.[30] The range of motion for the isokinetic condition was set from 90° to 20° of knee flexion.[21]

Using isometric measurements, we averaged 3 trials of quadriceps MVIC and normalized to body mass (N·m/kg). The quadriceps CAR was calculated by $F_{MVIC}/F_{MVIC+SIB}$ (ratio).[12] The quadriceps RTD was determined as the average slope (Δtorque/Δtime) of the torque-time curve over the first 200 milliseconds and normalized to body mass and time interval (N·m/s/kg).[31] Using isokinetic measurements, 1 trial of quadriceps APT that contained 20 repetitions was recorded, and the calculated mean value was normalized to body mass (N·m/kg).[30]

Statistical Analysis

Our sample size was determined using an expected mean difference in CAR of 0.11, with an SD of 0.14.[11] With $\alpha = .05$ and $\beta = 0.2$, we estimated that 14 participants in each group would be necessary.

Means and 95% CIs were calculated. Before participants were classified into subgroups by severity and duration of AKP, independent *t* tests were performed to compare participant demographics (except for sex), pain severity and duration, quadriceps function, and self-reported function. A 1-way analysis of variance and Tukey-Kramer post hoc tests were conducted when patients with AKP were categorized 3 times into either 2 or 4 subgroups (Figure) based on severity (≤3 of 10 versus >3 of 10 on NPRS)[23,26] and duration (<2 years versus >2 years)[24,25] of AKP and compared with their healthy counterparts. To assess practical significance, Cohen *d* effect sizes ($[\bar{X}_1 - \bar{X}_2]/\sigma_{pooled}$) with 95% CIs were also computed. Pearson *r* correlation coefficients were calculated to determine the bivariate correlations among outcome measurements. The statistical package SAS (version 9.4; SAS Institute) was used for all tests ($P < .05$).

RESULTS

Participant Demographics

Compared with the healthy control group, participant demographics were not different in the AKP group (P values ≥ .13; Table 2) or any AKP subgroups (P values ≥ .08; Tables 3–5). The AKP subgroup with a high severity of pain showed greater mass ($P = .04$; Table 3) and body mass index ($P = .04$; Table 3) than the AKP subgroup with a low severity of pain.

Pain Severity

Versus the healthy control group, the AKP group ($P < .0001$, d [95% CI] = 3.30 [2.72, 3.88]; Table 2) and all AKP subgroups ($P < .0001$, d [95% CI] ≥ 3.77 [2.93, 19.95]; Tables 3–5) showed more severe symptoms of pain. All AKP subgroups with a high severity of pain demonstrated more severe symptoms of pain compared with the AKP subgroups with a low severity of pain ($P < .0001$, d [95% CI] ≥ 3.67 [2.46, 5.27]; Tables 3 and 5).

Table 6. Bivariate Correlations Among Pain Severity and Duration, Quadriceps Function, and Self-Reported Function

	Pain Severity	Pain Duration	Quadriceps Maximal Strength	Quadriceps Explosive Strength	Quadriceps Activation	Quadriceps Endurance	Self-Reported Function
Pain severity	1						
Pain duration	0.53[a]	1					
Quadriceps maximal strength	−0.42[a]	−0.40[a]	1				
Quadriceps explosive strength	−0.28[b]	−0.28[b]	0.44[a]	1			
Quadriceps activation	−0.44[a]	−0.31[b]	0.47[a]	0.20[b]	1		
Quadriceps endurance	−0.31[b]	−0.36[b]	0.56[a]	0.26[b]	0.36[b]	1	
Self-reported function	−0.85[a]	−0.56[a]	0.46[a]	0.36[b]	0.51[a]	0.36[b]	1

[a] $P < .0001$.
[b] $P < .05$.

Pain Duration

Compared with the healthy control group, the AKP group ($P < .0001$, d [95% CI] = 1.58 [1.15, 2.01]; Table 2) and AKP subgroups ($P < .0001$, d [95% CI] $\geq$ 1.87 [1.26, 5.97]; Tables 3–5) exhibited longer symptoms of pain, except for the AKP subgroups with low severity and short duration ($P = .06$; Table 5) and high severity and short duration ($P = .08$; Table 5) of pain. All AKP subgroups with a long duration of pain displayed longer symptoms of pain than the AKP subgroups with a short duration of pain ($P < .0001$, d [95% CI] $\geq$ 2.49 [1.52, 3.72]; Tables 4 and 5).

Quadriceps Function

Versus the healthy control group, (1) the AKP group and AKP subgroups had less quadriceps maximal strength (AKP group: $P < .0001$, d [95% CI] = 1.06 [0.65, 1.47]; Table 2; AKP subgroups: $P < .005$, d [95% CI] $\geq$ 0.78 [0.25, 2.33]; Tables 3–5) and activation (AKP group: $P < .0001$, d [95% CI] = 0.94 [0.54, 1.34]; Table 2; AKP subgroups: $P < .02$, d [95% CI] $\geq$ 0.85 [0.32, 2.29]; Tables 3–5), except for the AKP subgroup with a low severity and short duration of pain ($P > .32$; Table 5); and (2) the AKP group and AKP subgroups with a high severity or long duration of pain showed less quadriceps explosive strength (AKP group: $P = .004$, d [95% CI] = 0.56 [0.17, 0.95]; Table 2; AKP subgroups: $P < .007$, d [95% CI] $\geq$ 0.74 [0.26, 1.27]; Tables 3 and 4) and endurance (AKP group: $P = .001$, d [95% CI] = 0.66 [0.27, 1.05]; Table 2; AKP subgroups: $P < .003$, d [95% CI] $\geq$ 0.79 [0.31, 1.42]; Tables 3 and 4). When severity and duration were combined, however, only the AKP subgroup with high severity and long duration of pain had less quadriceps explosive strength ($P = .006$, d [95% CI] = 1.09 [0.51, 1.67]; Table 5) and endurance ($P = .0004$, d [95% CI] = 1.21 [0.62, 1.80]; Table 5).

Self-Reported Function

Compared with the healthy control group, the AKP group ($P < .0001$, d [95% CI] = 2.99 [2.44, 3.54]; Table 2) and all AKP subgroups ($P < .0001$, d [95% CI] $\geq$ 3.44 [2.66, 7.25]; Tables 3–5) demonstrated less self-reported function. All AKP subgroups with a high severity of pain displayed less self-reported function than the AKP subgroups with a low severity of pain ($P < .005$, d [95% CI] $\geq$ 0.92 [0.19, 1.93]; Tables 3 and 5).

Bivariate Correlations

Pain severity and duration were positively correlated ($r = 0.53$; Table 6). Both pain severity and duration were negatively correlated with quadriceps function and self-reported function (r ranged between –0.85 and –0.28; Table 6). All quadriceps function and self-reported function values were positively correlated (r ranged between 0.20 and 0.56; Table 6).

DISCUSSION

Our purpose was to examine how each combination of severity and duration of AKP influenced quadriceps function and self-reported function. Our hypotheses were accepted: both severity and duration of AKP were inversely associated with quadriceps function and self-reported function. Also, a combination of high severity and long duration of AKP caused further deficits in quadriceps function.

To our knowledge, this is the first study to categorize patients with AKP into subdivisions based on pain severity (low [≤3 of 10] versus high [>3 of 10])[23,26] and duration (short [<2 years] versus long [>2 years])[24,25] and compare them with a healthy population. Except for the AKP subgroup with a low severity and short duration of pain (Table 5), all AKP subgroups exhibited deficits in quadriceps maximal strength (MVIC) and activation (CAR; Tables 3–5). This indicates that a combination of lower perceived (eg, ≤3 of 10) and shorter-lasting (eg, <2 years) AKP may not sufficiently contribute to quadriceps neuromuscular changes. For example, using an experimental knee pain model, investigators[32] demonstrated that pain severity of 3.2 of 10 caused quadriceps weakness, and this weakness was positively associated with pain severity. As an inverse approach, another experimental study[33] using a reduced knee pain model revealed that quadriceps strength was restored when pain severity decreased from 3.8 to 1.5 and from 3.9 to 2.2 after local anesthetic and placebo interventions, respectively. This evidence[32,33] may imply that pain beyond a certain severity level (eg, <3 of 10) is necessary for a short duration of AKP to induce quadriceps dysfunction. This is also supported by our data reflecting that the AKP subgroup with a high severity and short duration of pain (5.7 of 10 and 11.3 months, respectively; Table 5) showed deficits in quadriceps maximal strength and activation, despite having a similar pain duration as the AKP subgroup with a low severity and short duration of pain (2.6 of 10 and 11.4 months, respectively; Table 5). Yet future longitudinal research is needed to identify the intensity of AKP required to cause muscle dysfunction at any specific time point before it develops into chronic AKP. In terms of pain duration, the authors[7] of a previous study hypothesized that the degree of neural adaptation in the central nervous system due to pain is potentially influenced over time by persistent peripheral nociceptor activity. Thus, impaired muscle strength of the lower extremity could be a result of persistent AKP.[10,21] We also found that the AKP subgroup with a low severity and long duration of pain (2.5 of 10 and 58.0 months, respectively; Table 5) had less quadriceps maximal strength and activation, despite having a similar pain severity as the AKP subgroup with a low severity and short duration of pain (2.6 of 10 and 11.4 months, respectively; Table 5). Finally, all these outcomes highlight the importance of pain control in the early phase of rehabilitation to prevent or delay the progression of subsequent quadriceps impairments.

Deficits in quadriceps explosive strength (RTD) and endurance (APT) were apparent in the AKP subgroups with a high severity (Table 3) or long duration (Table 4) of pain, but when severity and duration were combined, only the AKP subgroup with a high severity and long duration of pain showed less quadriceps explosive strength and endurance (Table 5). This may indicate that additional quadriceps dysfunction is likely in patients with more severe and longer-lasting AKP. Traditionally, a general guideline for a successful return to activity is to achieve approximately 85% to 90% of the maximal strength relative to the asymptomatic limb[34]; however, evaluation of quadriceps function in various contraction modes (eg, explosive strength and endurance) that are more relevant to biomechanical factors and functional movements should be considered in clinical practice.[31,35] Quadriceps maximal strength (MVIC) was restored in 6 months (97%), whereas quadriceps explosive strength (RTD) took a longer period (ie, 12 months) to reach 90% of the preinjury level.[36] Additionally, explosive strength[36] and endurance[35] of the quadriceps were more sensitive to alterations in neuromuscular function and joint loading from a long-term perspective than isometric strength. Thus, we suggest that clinicians incorporate and analyze various characteristics of the muscle-force waveforms (eg, RTD and APT) and use this information in their clinical practice along with the MVIC to identify the specific muscle capacity to be further targeted and treated. Greater deficits in quadriceps explosive strength and endurance resulting from a high severity and long duration of pain would precipitate early onset and progression of degeneration in the knee joint.[31,35] Patients with chronic unilateral AKP (4.4 of 10 and 48.6 months, respectively) in earlier data[21] had bilateral deficits in quadriceps maximal and explosive strength, activation, and endurance, despite having a lower pain severity and shorter pain duration than the AKP subgroup with a high severity and long duration of pain (5.2 of 10 and 67.1 months, respectively; Table 5). This evidence may also support the idea that our current AKP subgroup with a high severity and long duration of pain should be evaluated and treated bilaterally.

Compared with the healthy control group, all AKP subgroups showed lower scores in self-reported function (Tables 3–5). Interestingly, the AKP subgroup with a low severity and short duration of pain did not experience any quadriceps dysfunction but had subjective functional limitations (Table 5). As the authors[37] of a previous study observed, this suggests that the perception of pain could independently exacerbate self-reported function without muscle dysfunction. Regardless of pain duration, the AKP subgroups with a high severity of pain expressed less self-reported function than the AKP subgroups with a low severity of pain (Tables 3 and 5). A direct association between pain severity and self-reported function (LEFS) in this population has been noted.[26] Our data also indicated that pain duration was moderately correlated ($r = -0.56$) with self-reported function, whereas pain severity had a strong correlation ($r = -0.85$; Table 6). Earlier investigators[27] determined that a rehabilitation program accompanied by patterned electrical neuromuscular stimulation (50-Hz pulse frequency, 70-microsecond phase duration, and 200-millisecond stimulus train on the gluteus medius, vastus medialis oblique, hamstrings, and adductors for 15 minutes before therapeutic exercise for 3 sessions over 4 weeks) reduced pain and improved self-reported function despite chronic AKP (>2 years). The clinical implication is that more attention should be paid to pain intensity, which is a controllable factor in clinical practice.

The relationships among pain severity and duration, quadriceps function, and self-reported function were characterized (Table 6). Pain severity and duration were moderately positively correlated ($r = 0.53$), in agreement with previous findings.[16] Because a cause-and-effect relationship cannot be assessed through the current (cross-sectional) study design, future researchers should evaluate whether an increase in pain leads to persistent pain or, conversely, whether persistent pain leads to an increase in pain. This may provide a deeper understanding of progressions and consequences of pain. Quadriceps function and self-reported function were inversely related to both severity and duration of AKP (Table 6), which is also in line with earlier work.[16,18,19,25] Although self-reported function could be impaired without muscle dysfunction (Table 5), the weak-to-moderate relationships ($0.36 < r < 0.51$) between these factors suggest that quadriceps-strengthening exercises[27] could be a key intervention when treating patients with AKP. Similar to our outcomes, strong negative relationships have been described between pain severity or duration and quadriceps activation (ie, Hoffmann reflex normalized by the motor response).[19] An abnormal monosynaptic stretch reflex in the spinal cord may provide useful insight into spinally mediated involuntary mechanisms as a result of pain[10,11]; however, the results of this stretch-reflex assessment—a laboratory-based technique[11,14,19] (ie, lying supine without voluntary contraction)—are difficult to apply in clinical practice or functional movements such as daily activities.[14] In addition to these data,[19] quadriceps function measures involving force-based techniques[14] (ie, maximal [MVIC] and explosive [RTD] strength, activation [CAR], and endurance [APT]) via voluntary contractions (ie, isometric and isokinetic) would offer clinicians further insight into which muscle capacity needs to be evaluated and treated before and after strengthening exercises are performed.

We analyzed a relatively homogeneous sample of participants by matching age, height, mass, body mass index, thigh circumference, and physical activity (Tables 2–5). Nevertheless, some limitations should be considered when interpreting our results. First, earlier authors[8] identified that patients with AKP were less physically active (eg, fewer steps per day and less duration) compared with their healthy counterparts. Therefore, it is difficult to generalize our results to patients with AKP who are inactive (eg, exercise <150 min/wk). Nonetheless, our patients were as physically active as the control healthy population, which allowed objective comparison. Second, our testing procedures with the SIB for quadriceps activation could have induced or increased pain perception. This type of pain directly corresponds with the outcomes, which we did not obtain. Future investigators should examine how usual pain or pain during testing is associated with the quadriceps function. Third, as in other chronic AKP studies,[19,22] recall bias as to the exact date of the atraumatic onset of pain may be a factor. Fourth, the self-reported function was measured using the LEFS, which is not specific to AKP. This was intentional to assess an overall function of the lower extremity. Additionally, the LEFS has high measurement reliability and moderate responsiveness in patients with AKP.[29] Last, because of our study design, we were unable to track and record how pain severity changed over time (ie, pain variability) and how many asymptomatic periods existed between the onset of pain and the week before testing. As the authors[38] of a recent study identified that pain variability may predict subjective function in this population, we acknowledge that this may have influenced our findings. This aspect could be examined in prospective cohort studies to understand when and how neuromuscular function and self-reported function change with time-dependent pain variability.

CONCLUSIONS

Both the severity and duration of AKP were inversely associated with quadriceps function and self-reported function. Furthermore, higher perceived (eg, >3 of 10) and longer-lasting (eg, >2 years) AKP, especially when combined, may cause additional deficits in quadriceps function. Clinicians should consider both pain severity and duration when rehabilitating patients with AKP and be especially aware of the combined effect of these factors.

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