Patellar Maltracking Persists in Adolescent Females With Patellofemoral Pain

A Longitudinal Study

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Background: Patellofemoral pain is one of the most common conditions seen in sports medicine practices, particularly among adolescent females. However, the natural history of the underlying pathology in patellofemoral pain during puberty remains poorly understood.

Purpose: The purpose of this longitudinal study is to assess changes in patellar maltracking patterns in subjects with patellofemoral pain as they mature from mid- to late adolescence.

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

Methods: Three-dimensional patellofemoral kinematic data were acquired during active knee extension-flexion using dynamic magnetic resonance imaging in 6 girls (10 knees; mean age, 14.0 years) with clinically diagnosed patellofemoral pain. The subjects then returned as late adolescents (mean age, 18.5 years) for follow-up scanning. Three-dimensional patellofemoral kinematic parameters were evaluated across the range of motion, but comparison between time points was restricted to 10° of flexion. Participation in impact and nonimpact physical activities, pain score based on the visual analog scale, and the anterior knee pain score were also compared across initial and follow-up visits.

Results: All subjects reported improved patellofemoral pain symptoms at follow-up, and one subject reported complete resolution. However, relative to the initial visit, no differences were found in patellar maltracking. There was a decrease in hours engaged in impact physical activities for all subjects at follow-up.

Conclusion: This study provides insight into the natural history of patellofemoral pain in adolescent females. The relatively unchanged patellofemoral maltracking across subjects suggests that potential anatomic and kinematic abnormalities contributing to patellofemoral pain during mid-adolescence persist during skeletal maturation. Symptom improvement for these subjects did not result from a change in patellofemoral tracking, but rather from other causes.

Keywords: knee; MRI; puberty; kinematics

Patellofemoral pain (PFP) is one of the most common causes of joint pain in female adolescents.[1,2,19,27] Despite the high prevalence, particularly among athletes, less than 5% of studies regarding PFP are focused on adolescent populations.[20,27] Among studies that do focus on adolescents, the natural history of PFP is not clear. In the landmark study by Sandow and Goodfellow,[22] PFP was labeled as a "benign, self-limiting condition." This concept has guided the clinical management of adolescents with PFP for several decades. In contrast, the recent analysis by Rathleff et al[18] found that adolescents with PFP are more likely to report persistent symptoms at 2-year follow-up among all subjects with knee pain. This study also found that subjects with PFP are more likely to discontinue sports activities relative to other subgroups with knee pain. The

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authors concluded that PFP is not a benign, self-limiting condition. Currently, it is unclear which of these 2 groups is more correct, as neither Rathleff et al[18] nor Sandow and Goodfellow[22] investigated longitudinal changes in the underlying pathologies associated with PFP.

PFP onset may follow patellar dislocation or knee trauma; however, it typically presents in patients with no history of acute injury.[24] While prolonged participation in high-impact exercise and other sports activities likely plays an important role in the etiology of nontraumatic PFP,[28-30,32] overuse cannot explain why some adolescent females develop PFP while their peers remain asymptomatic, despite equal activity levels.[18] Thus, other factors likely play an important role in the etiology of PFP, including patellar maltracking[6,11] and/or malalignment of the lower extremity (eg, femoral anteversion, laterally shifted tibial tubercle).[5,8]

A recent study[6] identified isolated pathological lateral displacement of the patella in adolescent females with PFP relative to healthy adolescent controls. Multiple subjects with PFP in this study demonstrated extreme lateral maltracking patterns (greater than 2 standard deviations [SDs] away from the average of healthy, age- and sex-matched controls). Although the lateral displacement observed in this "extreme" group was as severe as that noted in cohorts with PFP secondary to a history of patellar dislocations,[4,21] none of the study subjects reported a history of dislocation. A greater distance between the tibial tuberosity and trochlear groove (TT-TG) was also found among adolescents with PFP relative to controls, and the average closely approximated the mean value observed in adolescents with a history of patellar dislocation.[8] In a sister study (Shen et al, unpublished data, 2016), among subjects with PFP it was found that the maltracking pattern in adolescents was distinct from adults. The adolescent cohort could be discriminated from the adult cohort to an accuracy of 80% using axial plane patellar tracking (ie, medial-lateral displacement and tilt). What has not been identified, however, is if the pathologic tracking seen in adolescents with PFP resolves, persists unchanged, or evolves into patterns that resemble the adult patient with PFP over the course of skeletal maturation. Such information is crucial for determining if PFP is truly a self-limiting condition that resolves with time and for understanding the influence of onset time (pre- or postskeletal maturity) on the etiology and progression of PFP.

To compensate for this lack of knowledge, the current longitudinal study seeks to determine if patellofemoral patellar tracking changes during maturation from mid- to late-adolescence in female subjects with PFP. The null hypothesis is that the pathologic kinematics observed in a cohort of individuals with PFP during mid-adolescence persist as these subjects reach skeletal maturity in late adolescence. To further investigate the natural history of PFP, 2 additional areas of study are explored: (1) if subjects with "extreme" values of lateral displacement prior to skeletal maturity progress to episodes of patellar dislocation and (2) if the TT-TG distance changes during skeletal maturation in adolescents with PFP.

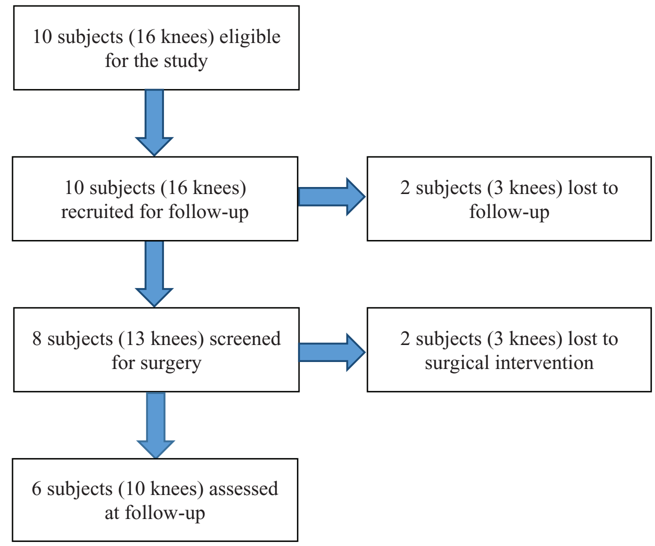

Figure 1. Flow diagram of study participants.

METHODS

Subject Recruitment

Twelve adolescent females (20 knees) diagnosed with PFP at least 6 months prior to the initial visit were enrolled in this institutional review board–approved study. Private practice orthopaedic surgeons practicing near our research facility referred these individuals. Recruitment and initial telephone screening took place between May 2009 and December 2012. The 3-dimensional (3D) patellar maltracking profile for the initial visit was acquired as part of a previous study.[6] Of the original 20 knees, data for 4 knees in this previous study were acquired 4 years prior to the rest of the participants. As such, they were not eligible for the longitudinal study. Of the 16 knees eligible for this study, 3 were excluded due to surgical intervention on the patellofemoral joint and 3 were lost to follow-up during the interim between visits (Figure 1). Thus, kinematic patterns for 10 knees (6 subjects) with PFP were analyzed in this study.

The window for follow-up was restricted to 3.5 to 5.0 years and the follow-up assessment was conducted on average 4.5 years after the initial visit. The mean age of subjects at initial evaluation was 14.0 and 18.5 years at follow-up (Table 1). PFP was defined as the onset of anterior knee pain in the absence of prior dislocation or trauma (eg, fracture, contusion, sprain). Additional exclusion criteria included the following: Beighton score[26] of ≥ 5 or clinically diagnosed generalized joint hypermobility (eg, Ehlers-Danlos syndrome); ligament, meniscus, iliotibial band, cartilage, or other lower extremity injury; prior knee surgery; contraindications to magnetic resonance imaging (MRI); and PFP onset after fusion of the epiphyseal plates.

All initial visits included a history and physical examination. At both initial and follow-up visits, all subjects underwent a focused evaluation of the knee. Acquired data

TABLE 1
Characteristics of Participants[a]

Characteristic	First Visit	Second Visit	P	95% Confidence Interval	Effect Size
Mean age, y	14.0 (1.3)	18.5 (1.0)	—	—	—
Age range, y	12-15	16-19	—	—	—
Weight, kg	52.4 (5.7)	61.0 (3.3)	—	—	—
Height, cm	156.9 (6.3)	161.1 (8.7)	—	—	—
Body mass index, kg/m^2	21.3 (2.5)	23.6 (1.5)	—	—	—
Q-angle, deg	13.1 (4.2)	15.5 (4.4)	.25	−5.38 to 1.58	0.43
J-sign	8/10 (80%)	7/10 (70%)	>.99	—	—
Lateral patellar mobility (clinical examination)	8.4 (3.7)	6.1 (4.5)	.15	−0.97 to 5.47	0.50

[a]Where appropriate, the average value is provided with 1 SD in parentheses.

included age, height, weight, body mass index, Q-angle, assessment for a J-sign, and lateral patellar hypermobility (Table 1). PFP severity was assessed using the anterior knee pain (AKP) score[13] and the visual analog scale (VAS) for pain on an average day, pain at the end of the day, and pain on performance of provocative activities. During each visit, the subject was queried for the number of hours spent participating in impact and nonimpact physical activities.

Magnetic Resonance Imaging

Dynamic, kinematic data were obtained for all subjects using cine-phase contrast (CPC) MRI techniques in a 3-T magnetic resonance scanner (Phillips Electronics). A short description of the kinematic data acquisition is provided, as a detailed explanation is available elsewhere.[23] Patients were situated supine in an magnetic resonance scanner and taught to rhythmically flex and extend at the knee at 30 cycles per minute. An auditory metronome was provided for guidance during both training and during data acquisition. Velocity data in the 3 cardinal planes were obtained and integrated to identify the position of the patella and tibia relative to the femur during the active flexion-extension cycle. Quantifying patellofemoral kinematics using CPC data has an average accuracy of 0.33 mm, with a technique precision less than 0.06 mm, and a subject repeatability of less than 0.73 mm.[3] Patellofemoral displacement was defined based on a coordinate system fixed within the femur.[23] Medial, superior, and anterior were the positive displacement directions (Figure 2). The rotation of the patella relative to the femur was defined with flexion, medial tilt, and varus (external spin) being positive.[25] The epicondylar width was used to scale all displacements, removing change in size with growth as a confounding variable.[23] Knee flexion was determined using the angle between the long axis of the femur and the anterior border of the tibia. Ten degrees of knee flexion, which corresponds to full extension clinically, was chosen for quantitative statistical analysis to enhance identification of soft tissue imbalances presenting as patellar maltracking.[10] In terminal extension, the patella is at its most superior position while the quadriceps load is still actively controlling its movement. At this location, there is minimal bony restraint from the trochlea. Thus, if present, soft tissue imbalances presenting as patellar maltracking are most apparent at this angle.

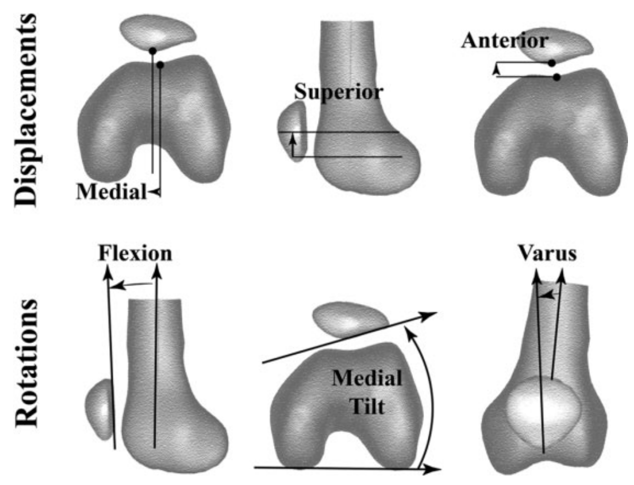

Figure 2. Patellofemoral kinematics for displacement and rotation.

Static 3D gradient recalled echo (GRE), GRE with fat-saturation, and proton density–weighted (PDW) images were also obtained using an 8-channel knee coil with the lower extremity in an anatomically neutral position. These images were reviewed by a musculoskeletal radiologist to rule out other knee pathology (eg, ligament tears, cartilage damage, osteoarthritis). The 3D GRE images (spatial resolution = $0.27 \times 0.27 \times 1.0$ mm, 512×512 pixels) were also used to measure the TT-TG distance using the current gold standard methodology.[7]

Statistical Analysis

A paired 2-tailed t test was used to compare the demographic, clinical examination, patellar tracking (at 10° of flexion), and TT-TG parameters between visits. Fisher's exact test was used to compare for the presence of the J-sign. To limit the number of statistical tests performed, height, weight, and body mass index were not compared as these parameters were expected to increase according to established growth curves. Only scores obtained on the VAS during provocative activities were compared, as this

TABLE 2
Average Patellofemoral Kinematics[a]

Kinematic Parameter	First Visit	Second Visit	P	95% Confidence Interval	Effect Size
Displacement, mm					
Medial-lateral	−3.7	−3.3	.71	−2.12 to 1.50	0.12
Superior-inferior	23.2	23.6	.75	−3.52 to 2.62	0.10
Anterior-posterior	6.6	7.3	.40	−2.47 to 1.08	0.28
Rotation, deg					
Flexion-extension	8.5	7.1	.14	−0.60 to 3.55	0.51
Medial-lateral tilt	12.7	10.8	.40	−2.88 to 6.65	0.28
Varus-valgus rotation	−1.0	−0.3	.31	−2.30 to 0.82	0.34

[a]Where appropriate, the average value is given with 1 SD in parentheses.

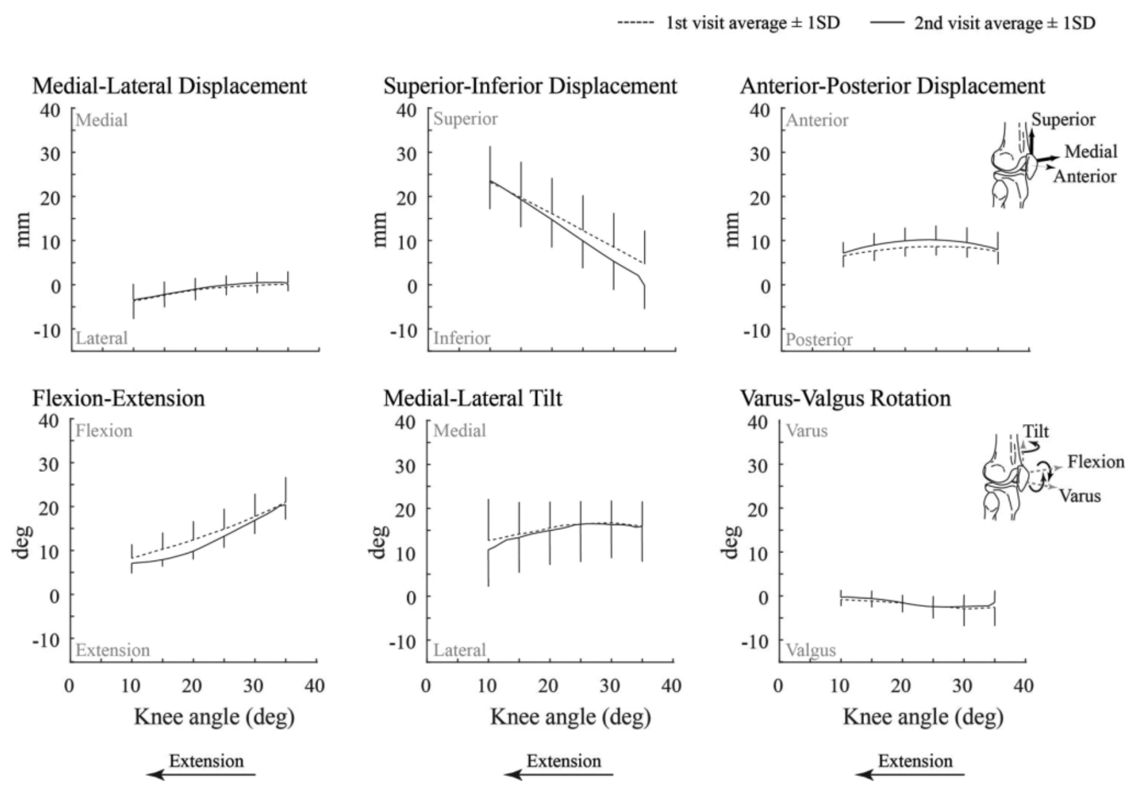

Figure 3. Average patellofemoral kinematics during the initial (dash) and follow-up visit (solid) ±1 SD.

parameter most accurately reflects the nature of PFP. A post hoc power analysis was performed.

RESULTS

The null hypothesis was accepted. No differences were observed between visits for any of the kinematic variables at 10° of knee flexion (Table 2). The largest average differences for displacement and rotational parameters were 0.7 mm and 1.9° for anterior-posterior displacement and medial-lateral tilt, respectively. Qualitatively, the average kinematic patterns across the extension movement demonstrated little change (Figure 3). The post hoc power analysis for medial-lateral displacement revealed that the power of the study was at 94%, assuming an $\alpha = 0.05$.

On initial evaluation, 5 of 10 (50%) subjects demonstrated extreme lateral displacement (greater than 2 SDs away from the average of healthy, age- and sex-matched controls) at a knee angle of 10° during extension and 5 of 10 (50%) subjects demonstrated nonextreme patterns. At follow-up, all subjects displayed the same extreme or nonextreme kinematic profile (Figure 4). Yet no subject reported a history of dislocation during either visit. Among the 3 subjects who were excluded from this study due to surgery, 2 reported that the operation was pursued to relieve pain symptoms and not due to an episode of dislocation. The third reported a long history of PFP with 1

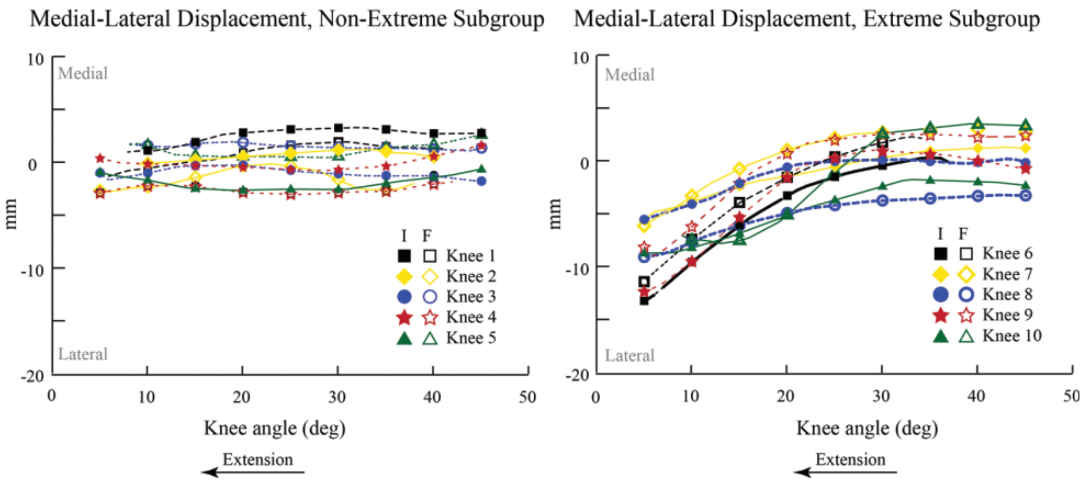

Figure 4. Individual medial-lateral patellar displacement at the initial (I) and follow-up (F) visits.

TABLE 3
Patient-Reported Pain Scores and Activity Levels[a]

Characteristic	First Visit	Second Visit	*P*	95% Confidence Interval	Effect Size
AKP score	64 (17.2)	86.6 (12.2)	.01	−38.77 to −6.43	0.99
Pain during provocative activities (VAS score out of 10)	7.4 (2.5)	4.3 (3.0)	.03	0.39 to 5.91	0.82
Hours per week participating in					
Impact physical activities	11.1 (8.5)	7.5 (10.1)	.03	0.56 to 6.64	0.85
Nonimpact physical activities	2.7 (4.0)	2.6 (2.5)	.95	−3.74 to 3.94	0.02

[a]Where appropriate, the average value is provided with 1 SD in parentheses. AKP, anterior knee pain; VAS, visual analog scale.

episode of patellar instability. However, the clinical and radiologic findings at the time of the episode did not support a diagnosis of patellar dislocation.

All subjects at follow-up reported improved PFP symptoms. The AKP scores improved by 35%, whereas the VAS for pain during provocative activities improved by 72% (Table 3). Out of 10 knees, only 1 demonstrated complete resolution, and this subject belonged to the nonextreme subgroup. Relative to the initial visit, subjects reported decreased participation in impact physical activities. Two subjects reported discontinuation of all forms of physical activity.

The average TT-TG distances observed among subjects at the initial visit and at follow-up were 11.6 and 13.0 mm, respectively ($P = .33$). Among the extreme maltrackers, the TT-TG distances at the initial visit and at follow-up were 14.8 mm (SD 2.70) and 14.2 mm (SD 3.08), respectively.

DISCUSSION

As the first longitudinal study to evaluate patellar maltracking changes in female adolescent subjects with PFP, the results of this analysis provide important clinical insights into the natural history of this pathology. The absence of any changes in the maltracking profiles through mid- to late adolescence suggests that PFP is not a benign, self-limiting condition. In addition, based on the current findings, adolescents do not transition into the more typical adult maltracking profile (Shen et al, unpublished data, 2016) nor do they transition into a more normative profile. Thus, it appears that age of onset is an important factor in the etiology of PFP. As interventions tailored to adolescent and adult maltracking patterns may improve outcomes, determining the age of onset is encouraged to guide decision making in the course of clinical care (Shen et al, unpublished data, 2016).[16]

The current analysis agrees with the landmark study by Sandow and Goodfellow[22] in that pain symptoms do improve with maturation, but strongly disputes the conclusion that this reduction in pain indicates a resolution of the underlying pathology. This prior study followed the clinical symptoms of 54 adolescent females (10-19 years old) with PFP for 2 to 8 years. At a mean follow-up of 3.8 years, they found that PFP symptoms persisted in 51 of 54 (95%) subjects; however, 25 of 54 (46%) subjects reported improvement. In a second study[15] by the same group, clinical symptoms were evaluated in a female cohort with PFP 16 years after initial presentation. PFP symptoms persisted in 49 of 63 (78%) subjects, with 45 of 63 (71%) reporting improvement. Over the course of both studies, 73% of patients with PFP eventually experienced some level of improvement without treatment, but the vast majority also reported persistent pain. Based on these clinical observations, the authors concluded that the underlying pathology also improved. The self-reported results of the present study (improved symptoms reported by all and complete resolution reported by 1 subject) closely resemble the findings of Sandow and Goodfellow.[22] However, the reduction in sports activity and absence of change in patellar maltracking that came with this improvement provide important context. The reduction in reported pain levels was not secondary to resolution of the underlying kinematic pathology and potentially came at the expense of decreased physical activity.

In agreement with the current findings, Rathleff et al[18] reported that the improvement in pain observed among adolescents with PFP likely comes at the expense of decreased time engaged in physical activities. In this previous study, 504 adolescents with various types of knee pathology were followed over the course of 2 years. Of these, 153 had a clinical diagnosis of PFP. At follow-up, 282 of 504 (56%) subjects reported persistent knee pain. However, the subgroup with PFP demonstrated a 1.26 higher relative risk for persistent pain relative to groups with the other types of knee pathology. In addition, 71% of subjects with PFP reported reduced or ceased sports activity. The subgroup with PFP participated in significantly less leisure sports activities relative to the adolescents with other knee pathologies. Based on these findings, Rathleff et al[18] concluded that PFP is not a self-limiting disorder. The chronicity of PFP symptoms for some patients may be due to the persistence of pathologic patellar tracking, as shown in the current population.

Patellofemoral shape has been shown to influence patellar tracking patterns.[12,17] During puberty, the musculoskeletal system is rapidly changing and new neuromuscular control patterns are being developed.[14] If pain onset occurs during puberty, unique musculoskeletal architecture and/or pathological control patterns may become established and cause persistent maltracking. However, the inverse of this relationship (ie, pathological musculoskeletal architecture causing PFP) may also be true. Future prospective studies are needed to determine the relationship between PFP onset and the developing musculoskeletal anatomy.

Adolescents with PFP appear to follow the typical TT-TG percentile growth chart,[8] albeit with a higher average value relative to healthy controls. The average TT-TG distance observed in this population at the initial visit exceeded the average value of age-matched healthy controls[31] and approximated the average value found in an age-matched cohort with a history of patellar dislocation.[8] The increased average TT-TG distance observed at follow-up also exceeded the average value of age-matched controls.[9] This suggests that the lateralization of the patellar tendon force might be part of the etiology of PFP in this population.

The absence of patellar dislocation in the current study population indicates that excessive lateral maltracking and/or elevated TT-TG distance will not necessarily progress to dislocation, even when these parameters approach values seen in individuals with a history of dislocation.[8,21] Future studies investigating the unique biomechanical or anatomic factors that prevent dislocation in the extreme population are in order, as the results will likely elucidate the mechanisms associated with patellar dislocation. Given the presence of lateral patellar tilt in the adolescent cohort with patellar dislocation,[21] and the absence of tilt in the current cohort with PFP, this kinematic parameter may represent a key variation in these 2 populations. Additional studies are also needed to clarify the temporal relationship between knee pain and patellar dislocation. If subjects with PFP and a history of dislocation only develop knee pain after the dislocation event, it would appear that these subjects and the current study population are distinct. However, if subjects with PFP and a prior history of dislocation develop knee pain prior to any dislocations, a spectrum of pathology likely exists between the 2 populations.

The primary limitation of this analysis is the sample size. While post hoc power analysis confirmed low probability for a type II statistical error (power = 94%), the generalizability of the study is limited. The sample size also restricted statistical testing for normality. Thus, normality was assumed based on qualitative histogram evaluation. Of note, the paired t test is robust to violations of normality and can provide valid results even when data are slightly nonnormative. Longitudinal analysis of the control group for comparison of kinematic change and participation in various forms of physical activity was not done. Yet the largest insignificant changes in tracking (0.7 mm and 1.9°) were only slightly larger than the subject reliability (0.3 mm and 1.0°) in producing patellofemoral kinematics under the same paradigm.[3] Thus, the added value of longitudinal control data is likely minimal.

The primary strength of this study is the consistent findings for the change (or lack thereof) in subjective pain levels and patellar maltracking across subjects. Another strength, particularly among studies focused on adolescents, is the acquisition of patellofemoral kinematic data during dynamic extension. Only 2 previous studies[11,21] have evaluated patellofemoral alignment in adolescents and both evaluated these parameters under static conditions. Furthermore, loading of the patella occurs mainly via quadriceps contraction and not through axial loading.[12] As such, weightbearing is likely not a primary factor in patellofemoral kinematics. Thus, the technique used in the current study was correctly designed to identify subtle abnormalities with a high level of accuracy (<0.3 mm^3).

CONCLUSION

PFP does not appear to be a benign, self-limiting condition. The isolated lateral maltracking observed in adolescents with PFP persists during maturation into late adolescence and may account for chronic symptoms. Adolescent- and adult-onset PFP demonstrate different patellar tracking patterns, which may benefit from targeted intervention specific to the abnormality. Thus, determining the age of PFP onset as part of the patient history may be important for the clinical management of this population.

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