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Research letter

3D kinematic knee variables in people with unilateral patellofemoral pain syndrome: comparison of symptomatic and contralateral knees

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Dear Editor — Patellofemoral Pain Syndrome (PFPS) is characterised by anterior knee pain that increases when the knee is flexed and loaded [1] and may be uni- or bilateral. The pathophysiology of PFPS is multifactorial and involves static and dynamic biomechanical and neuromuscular lower-limb impairments [1,2]. Knee valgus and flexion are the most reported kinematic changes in people with PFPS [3].

Although PFPS symptoms are typically not worsened by walking, changes in 3D knee kinematics during gait have been reported [3]. People with PFPS exhibit a greater increase in knee valgus (ie, valgus thrust defined by a sudden lateral shift of the knee) [4] and less knee flexion [5] during the loading phase (0–20% of the gait cycle) than asymptomatic individuals. The loading phase imposes substantial stabilisation demands on the knee joint [6]. The increase in knee valgus during the gait-loading phase was the only kinematic parameter that differed significantly between 4 clinical phenotypes [7]. However, contrary to the consensus surrounding quadriceps weakness, the kinematic changes observed during gait loading in people with PFPS remain debated [1,3].

Most studies have compared people with PFPS to more or less matched asymptomatic controls [3,8]. Since demographic characteristics (especially weight and height) influence knee kinematics [9], differences in comparator groups could explain inconsistent findings on altered kinematic gait patterns. The contralateral limb in people with unilateral PFPS is a relevant comparator, since the demographic and morphologic variables (lower-limb length and shape) are the same for both limbs of the same person [10]. To date, no study has assessed bilateral gait kinematics in individuals with unilateral PFPS. Using the contralateral, asymptomatic limb as a comparator may increase the accuracy of determining changes in knee kinematics in people with PFPS.

The primary aim was to test the hypothesis that the increase in knee valgus during gait loading would be greater in the symptomatic than the contralateral asymptomatic knee. The secondary aim was to test the hypothesis that knee flexion range of motion (RoM) during the loading phase would be lower in the symptomatic limb.

This ancillary study is derived from the single-centre comparative, cross-sectional, non-randomised PHENOPAT study (ClinicalTrials.gov Identifier: NCT05441332). The study was approved by the Human Research Ethics Committee (Comité de Protection des Personnes CPP EST-3) N°21-12-03 [7], and reporting follows the STROBE (Appendix A) and TIDieR (Appendix B) guidelines.

The main inclusion criteria were: 1) age 18 to 70 years, and 2) diagnosis of PFPS based on symptom duration >1 month and pain rated ≥4/10 on the Numeric Rating Scale (NRS) during at least one of the following activities: stair climbing and/or descending, squatting, jumping, jogging, prolonged sitting and/or crouching and 3) unilateral symptoms. The main exclusion criteria were 1) history or presence of a neurological disorder affecting the lower limbs, 2) x-ray signs of tibiofemoral osteoarthritis, 3) history of surgery or trauma to the lower limbs <1 year previously, and 4) intra-articular knee injection <2 months previously.

The primary outcome was the difference in the mean increase in knee valgus between symptomatic and contralateral asymptomatic knees during the gait-loading phase, measured as the mean absolute difference between the peak valgus point and the valgus point at initial contact among all participants. The secondary outcome was the

Abbreviations: ADL, Activities of Daily Living; AKPS, Anterior Knee Pain Scale; FPI, Foot Posture Index; NRS, Numeric Rating scale; PFPS, Patellofemoral Pain Syndrome; RoM, Range of Motion; SF-12, 12-Item Short-Form Health Survey; SPM, Statistical Parametric Mapping

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difference in mean knee flexion RoM during loading between symptomatic and asymptomatic limbs. Three dimensional knee rotations during gait were assessed using the KneeKG® optoelectronic device (Knee3DTM Software, EMOVI).

Other variables were collected for descriptive purposes: knee mean pain intensity at rest and pain intensity during activities of daily living (ADL), the week before the test (NRS, range 0−100; 0: no pain; 100: worst pain imaginable); subjective symptoms and activity limitation using the Anterior Knee Pain Scale (AKPS, Kujala score, range 0−100; 0: maximal symptoms, 100: no symptoms); quality of life using the 12-item short-form health survey (SF-12) (physical component summary score 9.95, minimum quality of life 70.02, maximum quality of life and mental component summary score 5.89, minimum quality of life 71.97, maximum quality of life); peak knee extensor and flexor torque and knee flexor/extensor ratios at 60°s^{-1}, knee extensor and flexor total work and knee flexor/extensor total work ratio at 180°s^{-1} and peak hip abductor isometric torque (N.m) using an isokinetic dynamometer (Humac NORM, CSMi, Stoughton, MA, Software HUMAC 2009, v.9.7.1); knee medio-lateral rotation (°), foot pronation using the Foot Posture Index (FPI; −12; +12: −12: high supination, +12: high pronation, −2≤ normal scores ≤9) and the Navicular Drop test (cm), a value >1.1 cm indicating excessive foot pronation [1]. The complete set of clinical and biomechanical assessments is detailed in the study protocol [11].

JASP software (version 0.19.3.0) was used for analysis. Continuous data are expressed as means and standard deviations (SD) and medians and quartiles (Q1; Q3) to take into account both the data distribution and the need to compare our results with the literature. Differences between data are expressed as absolute difference (mean of the absolute value of the differences) and (95% CI). Categorical data are expressed as absolute and relative frequencies (*n/N*, %). Given the sample size, we used the paired Wilcoxon test to compare the data from both knees. Joint angle time series were analysed using Statistical Parametric Mapping (SPM). The SPM was computed using the SPM1D Python package (version 3.9.7) with permutation analysis (1000 permutations). All tests were two-tailed, with a P- or t-value < 0.05 considered significant.

The current study included 23 of the 45 participants in the PHENO-PAT study (all those with unilateral PFPS) (Appendix C): 13 (57%) women, mean (SD) age 39 (13.8) years, symptom duration 7.1 (8.5) years, mean NRS scores 23.0 (17.7)/100 for pain (at rest) and 37.4 (23.8)/100 for pain during ADL, mean AKPS score was 71.2 (14.7)/100 (Table 1). Mean isokinetic peak knee extensor and flexor torque, total knee extensor and flexor work, and isometric peak hip abductor torque were lower in the symptomatic than in the contralateral asymptomatic side (Table 1, Appendix D). Participants walked at their self-selected comfortable speed, which varied from 2.2 to 5 km.h^{-1}. The assessment of knee kinematics using the KneeKG required a minimum of 15 repeatable gait cycles. The average walking speed was 30 cycles per minute, and the total average duration of gait recording was 1 min.

Table 1
Demographic and clinical characteristics of participants with unilateral PFPS.

	Participants (n = 23)	
Demographic characteristics		
Women *n* (%)	13 (57%)	
Age (years), mean (SD)	39 (13.8)	
BMI (kg.m^{-2}), mean (SD)	23.3 (3.7)	
General clinical characteristics, mean (SD)		
Knee Pain at rest (NRS, 0−100)	23.0 (17.7)	
Knee pain during ADL (NRS, 0−100)	37.4 (23.8)	
AKPS (0−100)	71.2 (14.7)	
SF-12 Physical score (9.95−70.02)	43.1 (10.2)	
SF-12 Mental score (5.89−71.97)	44.0 (10.0)	
Symptoms duration (years)	7.1 (8.5)	
Knee RoM (using a goniometer) in degrees	Symptomatic knee	Contralateral asymptomatic knee
Flexion	144.4 (5.6)	144.7 (5.7)
Extension	3.4 (3.6)	3.5 (3.5)
Medio-lateral rotation	41.9 (8.4)	41.7 (8.3)
Knee extensors peak torque (Isokinetic device) 60°s^{-1} in N.m	167.6 (66.6)[a]	189.8 (52.9)[a]
Current treatments (*n*)[b]		
Physical therapy	8	
Self exercises	15	
Insoles	8	
Nonsteroidal anti-inflammatory drugs	3	
Analgesics grade I	4	
Analgesics grade II	2	

ADL, activities of daily living; AKPS, Anterior Knee Pain Scale; BMI, body mass index; NRS, Numeric Rating scale; PFPS, Patellofemoral Pain Syndrome, RoM, range of motion, SF-12, Medical Outcome Study Short Form 12;
[a]mean absolute difference 28.6, 95% CI 18.5−38.8.
[b]The total number of current treatments exceeds the number of participants because one participant could have more than one treatment for PFPS.

No significant between-knee differences were found during loading for the mean increase in knee valgus (decrease in knee varus), mean absolute difference: 1.3, 95% CI 0.7−1.8°, P = 0.70 or the mean flexion RoM, mean absolute difference: 3.0, 95% CI 1.4−4.6°, P = 0.47 (Table 2, Fig. 1a,b). The kinematic curves did not differ between knees in the coronal, sagittal, or transverse planes during the loading phase or during the whole gait cycle; all t-values were below the significance threshold (t = 2.54 in the coronal plane, t = 2.75 in the sagittal plane, and t = 2.91 in the transverse plane) (Fig. 1a−f). The SD were large for knee valgus/varus and medio-lateral rotation; they were larger in the contralateral asymptomatic than the symptomatic knees for knee valgus/varus (Fig. 1a,c).

In contrast with our hypotheses, the results of this study suggested that knee valgus and flexion RoM are not specific to the symptomatic limb. Our results partially corroborate the findings of a

Table 2
Comparison of knee kinematics during gait loading between symptomatic and contralateral asymptomatic knees.

	Outcomes		Symptomatic knee (n = 21)[a]	Contralateral asymptomatic knee (n = 21)[a]	Mean absolute difference (95% CI)	P-value
	Knee kinematics[a], in degrees					
Primary outcome	Increase in knee valgus					
		Mean (SD)	1.7 (1.9)	1.2 (1.4)	1.3 (0.7−1.8)	0.70
		Median (Q1; Q3)	**1.0 (0.0; 2.2)**	**0.9 (0.3; 1.5)**		
Secondary outcomes	Flexion RoM					
		Mean (SD)	**4.5 (3.9)**	**6.0 (4.9)**	3.0 (1.4−4.6)	0.47
		Median (Q1; Q3)	3.9 (1.1; 7.7)	6.5 (2.1; 9.4)		

RoM, range of motion.
[a] Kinematic data were missing for 2 participants: one was unable to walk on the treadmill and the data of the other were unusable. Positive values indicate increased knee valgus/decreased varus or flexion; bold values indicate the main values to consider as a function of the normality of the data distribution.

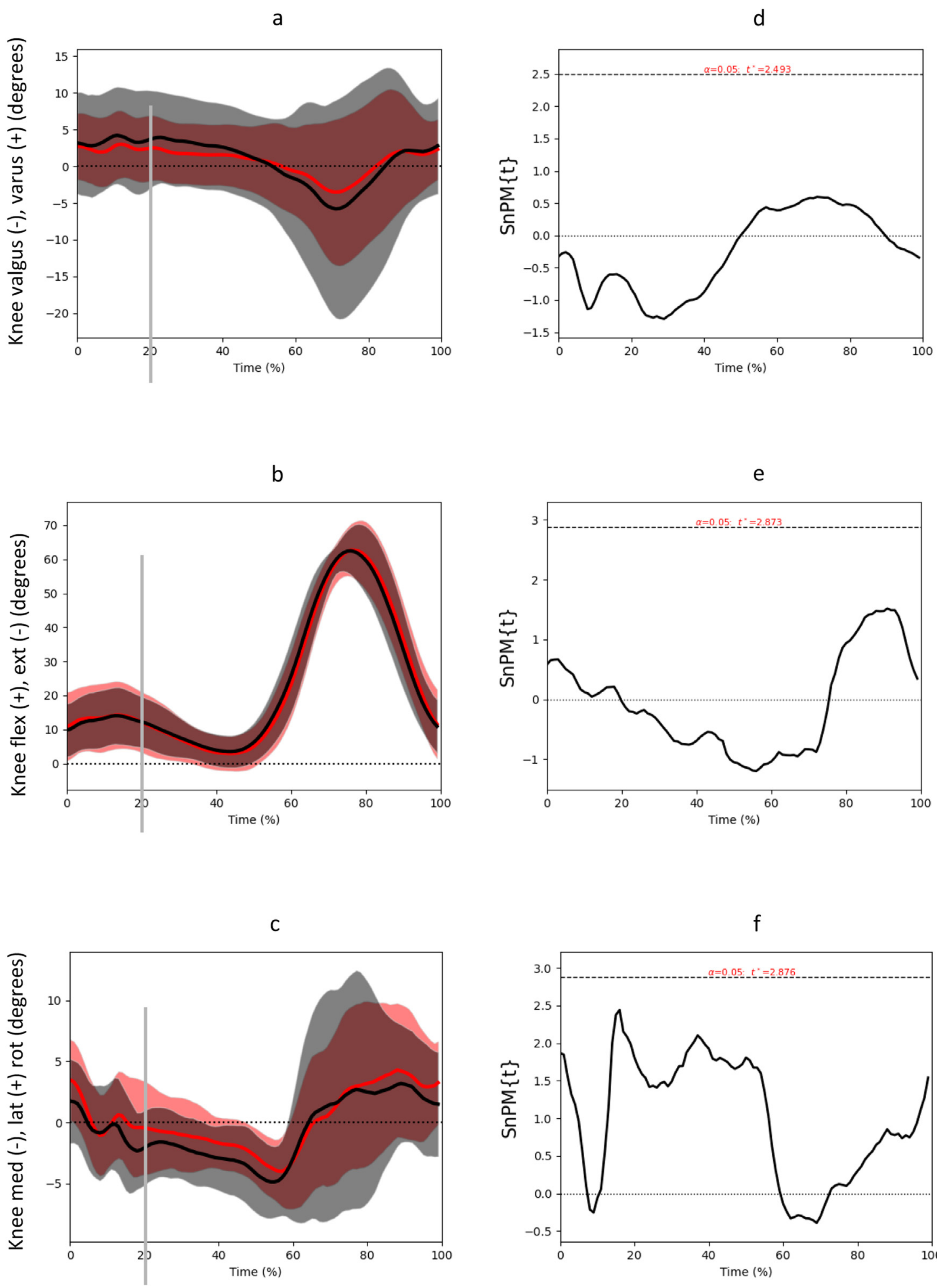

Fig. 1. a, b, c: Mean (SD) kinematic curves for the knee during gait in the coronal, sagittal and transverse planes, in red the symptomatic knees and in black the contralateral asymptomatic knees. The grey vertical line represents the end of the loading phase.

Figure 1 d, e, f: SPM results: Statistical Parametric Mapping (SPM) is a method used to analyse time series data, enabling curve comparisons. The x-axis represents the 100 points of the gait cycle, and the y-axis indicates the *t*-values computed by SPM. The dashed horizontal line represents the critical threshold corresponding to a significance level of alpha = 0.05. Regions where the *t* curve exceeds this threshold highlight parts of the gait cycle where significant differences between groups (knees with PFPS and contralateral asymptomatic knees) are observed.

large systematic review, which showed limited evidence of differences in knee abduction-adduction RoM and moderate evidence of decreased peak knee flexion between people with PFPS and asymptomatic people during gait [3]. However, the review's conclusion was drawn from only 2 studies that did not assess the loading phase specifically [3].

The lack of kinematic differences found in this study between the symptomatic and contralateral asymptomatic lower limbs could be explained by 2 specific factors: an adaptation that resulted in a between-limb kinematic symmetry of both lower limbs, especially during gait, which is a cyclical, bilateral activity, and the fact that PFPS affects both lower limbs [12]. People with unilateral PFPS have lower physical functional performance in both lower limbs than asymptomatic individuals [13]. Also, quadriceps muscle volume is reduced bilaterally in people with unilateral symptomatic PFPS [14]. A cross-sectional study involving 48 individuals with bilateral PFPS and 48 with unilateral symptoms suggested that the bilateral form may represent a progression from the unilateral form [12]. Nevertheless, the long mean duration of unilateral symptoms in the current study suggests that PFPS does not systematically become bilateral.

Most participants were women, corresponding to the sex distribution in PFPS [15]. The participants were older than those in most biomechanical studies of PFPS [3], but a large epidemiological study found several prevalence peaks of PFPS between the ages of 30 and 60 years [15]. The clinical variables were similar to previous reports on moderate pain intensity, subjective knee symptoms, and health-related quality of life in PFPS [16]. In addition to the sample and the comparator characteristics (asymptomatic contralateral side or controls), comparisons across studies are challenging due to the gait phase analysed (loading, whole stance, or the entire gait cycle), the walking speed (self-selected speed or fast walking), and heterogeneity in the biomechanical variables analysed (kinematics or kinetics) and the methods and devices used for assessment (motion capture, inertial sensors or pressure devices) [3]. Moreover, there is no consensus threshold to differentiate physiological from pathological kinematic values.

The lack of kinematic differences between the symptomatic and contralateral asymptomatic knees, despite decreased knee extensor and flexor and hip abductor strength values in the symptomatic knee, suggests that PFPS may be more associated with motor control than kinematic deficiency.

Several factors could have limited the identification of significant differences between symptomatic and contralateral asymptomatic lower limbs. The small sample size may have reduced the study's power. Considering differences in the increase in knee valgus during loading between both limbs and using a 5% alpha level and 80% power level, we estimated that the required sample size should be 161 participants. We did not consider sex, lower-limb dominance, walking speed, or clinical phenotypes, which may alter lower-limb kinematics. Studies have shown that a greater increase in knee valgus during gait is more frequent in women than men [17], stance duration is longer for the dominant lower limb than the non-dominant limb, and knee flexion amplitude increases with gait speed [18]. Additionally, the amplitude of the increase in knee valgus in the symptomatic knee during gait loading was found to be significantly higher for the most common phenotype characterised by clinical static and/or dynamic lower-limb alignment alterations [7]. The large SD in kinematic variables reflects the heterogeneity of the sample but also the clinical reality of PFPS [1].

Further studies should investigate long-term changes in individuals with unilateral PFPS to elucidate relationships among symptoms and impairments, as well as the link between unilateral and bilateral forms of PFPS. The long-term effectiveness of a bilateral rehabilitation protocol on pain and activity limitation for people with unilateral symptomatic PFPS should be assessed.

Availability of data and materials

Data are owned by the promoter Assistance Publique - Hôpitaux de Paris (AP-HP). Data cannot be shared publicly because of the AP-HP's data-sharing policy. Data are available from the AP-HP Institutional Data Access (contact via Unité de Recherche Clinique, URC, Necker-Cochin, Marie Benhammani-Godard, marie.godard@aphp.fr) for researchers who meet the criteria for access to confidential data.

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Author contribution statement

Conceptualisation. AR, MMLC, MC, CN, FR. Funding acquisition. MC, AR. Methodology. AR, MMLC, LG, NH. Data acquisition: MC, MMLC. Analysis. MC, AR, LG, MMLC, NH. Supervision. AR, MMLC, NH, GD. Writing − Original draft. Preparation MC, AR, LG. Writing − Review & Editing. MC, LG, CN, FR, GD, NH, MMLC, AR.

Declaration of generative AI and AI-assisted technologies

The authors did not use generative AI or AI-assisted technologies in the writing process.

Data availability

The authors do not have permission to share data.

Declaration of competing interest

None.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rehab.2026.102124.

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