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Original Research Article

THE RELATIONSHIP BETWEEN HAMSTRING FLEXIBILITY AND GLUTEAL MUSCLE STRENGTH IN INDIVIDUALS WITH IDIOPATHIC ANTERIOR KNEE PAIN: A CORRELATIONAL STUDY

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ABSTRACT

Background: Reduced hamstring flexibility and gluteal muscle weakness are both reported in idiopathic anterior knee pain (AKP), also termed patellofemoral pain. Hamstring shortening has been proposed as a compensation for gluteal insufficiency, but whether the two are related in AKP is unknown. The objective is to determine the relationship between hamstring flexibility and gluteal muscle strength in individuals with idiopathic AKP.

Materials and Methods: In this cross-sectional correlational study, 66 adults aged 18–35 years with idiopathic AKP were recruited by convenience sampling from the physiotherapy and orthopaedic outpatient departments. Hamstring flexibility was measured as the popliteal angle with the active knee extension (90-90) test. Gluteal strength was measured with a hand-held dynamometer during the Hip Stability Isometric Test (HipSIT) as the mean of three trials. The primary analysis was a Pearson correlation between affected-side popliteal angle and affected-side gluteal strength. Inter-rater agreement for the HipSIT was examined in 10 participants by two examiners.

Results: Participants (35 women, 31 men) had a mean age of 26.68 ± 4.79 years. On the affected side, mean popliteal angle was 40.47° ± 14.16° and mean gluteal strength was 20.79 ± 2.72 kg (non-affected side: 32.67° ± 11.95° and 22.30 ± 2.84 kg; not tested statistically). Affected-side popliteal angle and gluteal strength were not correlated ($r = -0.033$, $p = 0.790$; 95% CI −0.273 to 0.210). HipSIT inter-rater agreement was good (ICC(2,1) = 0.88, 95% CI 0.50–0.97; mean bias −0.73 kg).

Conclusion: Hamstring flexibility and gluteal muscle strength showed no linear relationship on the affected side in young adults with idiopathic AKP. Each should be assessed separately, and neither should be used to infer the other.

Keywords: anterior knee pain; patellofemoral pain; hamstring flexibility; active knee extension test; gluteal muscle strength; Hip Stability Isometric Test.

INTRODUCTION

Idiopathic anterior knee pain (AKP), now usually termed patellofemoral pain (PFP), describes pain around or behind the patella that is aggravated by activities loading the patellofemoral joint, when no other pathology explains it.[1] Among people who seek care, reported frequencies of PFP diagnosis range from 1.5% to 7.3%, with the highest rates in adolescents.[2,3] The condition was long regarded as self-limiting, yet symptoms often persist: 50% to 56% of affected adolescents still report pain two years after diagnosis.[2,3] and pain persisted in most adolescent girls followed for two to eight years.[4] Symptoms can restrict sport, work and daily activity and may recur for years.[5]

PFP typically presents as insidious, poorly localised pain in the retropatellar or peripatellar region that

worsens with squatting, prolonged sitting, stair negotiation, jumping and running.[5,6] Imaging and pathoanatomic findings correspond poorly with symptoms, so diagnosis relies on clinical features after other conditions are excluded.[7] Because no validated classification combines symptoms and examination findings, the 2019 Academy of Orthopaedic Physical Therapy clinical practice guideline proposes four impairment-based subgroups: overuse or overload, movement coordination deficits, muscle performance deficits (including gluteal weakness) and mobility impairments (including reduced hamstring flexibility).[5]

Knee extensor weakness is a prospective predictor of PFP.[8] and physically active women appear to be at higher risk.[6,9] Cross-sectional studies and systematic reviews report lower isometric strength of the hip abductors, extensors and external rotators in people with PFP.[10–12] together with slower rate of force development of the hip abductors and extensors.[13] Prospective evidence, however, shows no clear association between hip strength and later onset of PFP, which suggests that hip weakness may follow pain rather than cause it.[10]

Reduced hamstring flexibility is also common in PFP, but its cause is unclear. The hamstrings and gluteus maximus share attachments to the sacrotuberous ligament and contribute together to pelvic stability.[14] Sahrmann's movement impairment model proposes that when the gluteus maximus is under-recruited, the hamstrings dominate hip extension and may become shortened; at the knee this could raise posterior pull and patellofemoral compression.[15] Consistent with this idea, Arab et al. found shorter hamstrings in people with sacroiliac joint dysfunction who had gluteal weakness than in those without it.[16]

Gluteal strength and hamstring flexibility have therefore each been linked to AKP, but they have been studied separately. To the authors' knowledge, their relationship has not been examined in people with idiopathic AKP. If reduced flexibility reflected gluteal insufficiency, a single finding could guide treatment of both; if the two are independent, each needs its own assessment. This study aimed to determine the relationship between hamstring flexibility and gluteal muscle strength in individuals with idiopathic AKP.

MATERIALS AND METHODS

Study design and setting: This cross-sectional correlational study was conducted over six months. Participants were recruited from the physiotherapy and orthopaedic outpatient departments. The study flow and the relationship examined are shown in [Figure 1].

Participants: Adults with idiopathic AKP were enrolled by non-probability convenience sampling. Prospective participants were screened for the clinical features of idiopathic AKP against the criteria below. All procedures were explained in advance, and written informed consent was obtained from each participant before enrolment.

Inclusion criteria were age 18 to 35 years; insidious onset of prepatellar or retropatellar knee pain lasting at least six weeks; pain provoked by at least two of running, walking, hopping, squatting, stair negotiation or prolonged sitting; tenderness on patellar palpation; and pain on patellofemoral compression or resisted quadriceps contraction at 30° of knee flexion. The symptomatic limb, or the more symptomatic limb in bilateral cases, was designated the affected side.

Exclusion criteria were concomitant injury or pain arising from the lumbar spine or hip, internal derangement of the knee, knee ligament insufficiency, previous knee surgery, patellofemoral instability and patellar tendinopathy.

Sample size: The sample size was estimated a priori with G*Power (version 3.1.9.4) for a test of correlation, assuming a medium effect size (r = 0.30) and 80% power. Sixty-six participants were enrolled.

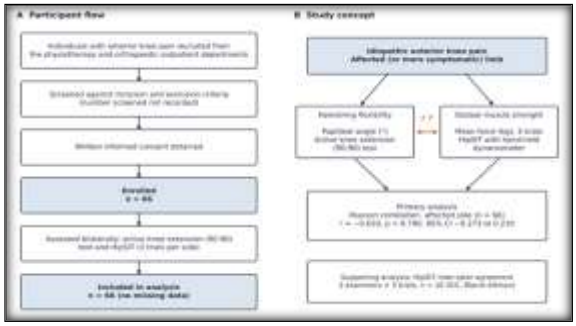


Figure 1: (A) Participant flow. The number of individuals screened and excluded was not recorded. (B) Study concept: the relationship between hamstring flexibility and gluteal muscle strength on the affected limb, with the primary and supporting analyses.

Measurement of hamstring flexibility: The straight leg raise test is widely used to assess hamstring flexibility.[17] but it does not control pelvic rotation, which affects the measured range.[18] Hamstring flexibility was therefore assessed with the active knee extension (90-90) test, which shows excellent intra-rater reliability (ICC = 0.91) in people with flexibility deficits.[19]



Figure 2: 90-90 straight leg raise (active knee extension) test.

Participants lay supine with the tested hip held at 90° of flexion and the ankle relaxed in plantar flexion [Figure 2]. The examiner monitored hip position with a full-circle goniometer throughout. Participants then actively extended the knee as far as possible, and the knee angle reached at the end of active extension was recorded with the goniometer as the popliteal angle. Both limbs were tested.

Measurement of gluteal muscle strength: Gluteal strength is usually tested in single planes, as hip abduction, external rotation or extension.[11] Because the hip stabilisers work in three dimensions, the Hip Stability Isometric Test (HipSIT) was developed to assess posterolateral hip strength in a combined, more functional position; it shows excellent intra- and inter-rater reliability.[20]

Participants lay on the side with both hips flexed to 45° and both knees flexed to 90°, with the tested limb uppermost [Figure 3]. They abducted the upper leg by about 20° while keeping the heels together. A hand-held dynamometer was placed on the lateral thigh about 5 cm proximal to the knee joint line, and participants pushed the knees apart with maximal effort while maintaining heel contact. Examiners were blinded to the affected side and watched for pelvic rotation. Three trials were performed on each side with 30-second rest intervals. Force was recorded in kilograms, and the mean of the three trials was used as the gluteal strength score.



Figure 3: Hip Stability Isometric Test (HipSIT).

Inter-rater agreement of the HipSIT: Agreement between examiners was examined in 10 participants. Two independent examiners (A and B) each recorded three consecutive maximal HipSIT trials per participant, using the protocol above.

Statistical analysis: Descriptive statistics and normality tests were performed in IBM SPSS Statistics, with significance set at $p < 0.05$. Continuous variables are reported as mean ± standard deviation (SD), median, interquartile range (IQR) and range; categorical variables as frequency and percentage. Normality was assessed with the Shapiro–Wilk test. Because affected-side popliteal angle and affected-side mean gluteal strength were approximately normally distributed, their relationship was examined with Pearson's product-moment correlation using all complete affected-side pairs in the participant-level data file. The 95% confidence interval (CI) was derived with Fisher's z transformation, and the relationship was displayed as a scatter plot with a least-squares regression line. Missing values were not imputed. Side-to-side values are reported descriptively only; no inferential side-to-side comparison was performed.

Inter-rater agreement was calculated from the trial-level data [Table 5] using each participant's mean of three trials per examiner. The intraclass correlation coefficient was calculated as ICC(2,1) (two-way random effects, absolute agreement, single rater) and ICC(3,1) (two-way mixed effects, consistency, single rater), each with 95% CI, and interpreted as poor (< 0.50), moderate (0.50–0.75), good (0.75–0.90) or excellent (> 0.90).[21] Bland–Altman analysis gave the mean bias (Examiner A − Examiner B) and 95% limits of agreement (bias ± 1.96 SD of the differences).[22] The correlation and agreement statistics were computed in Python (SciPy).

RESULTS

Participant characteristics: All 66 enrolled participants were analysed, with no missing data. The sample comprised 35 women (53.0%) and 31 men (47.0%), with a mean age of 26.68 ± 4.79 years (range 19–35) [Table 1; Figure 4 and 5].

Table 1: Demographic characteristics of participants (n = 66)

Characteristic	Value
Women, n (%)	35 (53.0)
Men, n (%)	31 (47.0)
Age, mean ± SD (years)	26.68 ± 4.79
Age, median (IQR) (years)	26.50 (8.00)
Age, range (years)	19–35

SD, standard deviation; IQR, interquartile range.

Hamstring flexibility and gluteal muscle strength: Mean popliteal angle was 40.47° ± 14.16° on the affected side and 32.67° ± 11.95° on the non-affected side. Mean gluteal strength was 20.79 ± 2.72 kg on the affected side and 22.30 ± 2.84 kg on the non-affected side [Table 2; Figure 6 and 7]. The affected side therefore had a higher mean popliteal angle and lower mean gluteal strength. These differences are descriptive and were not tested statistically.

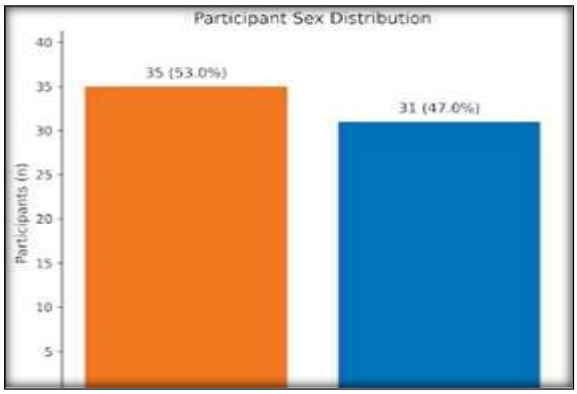


Figure 4: Gender distribution of participants (n = 66). Percentages are based on the total sample of 66 participants.

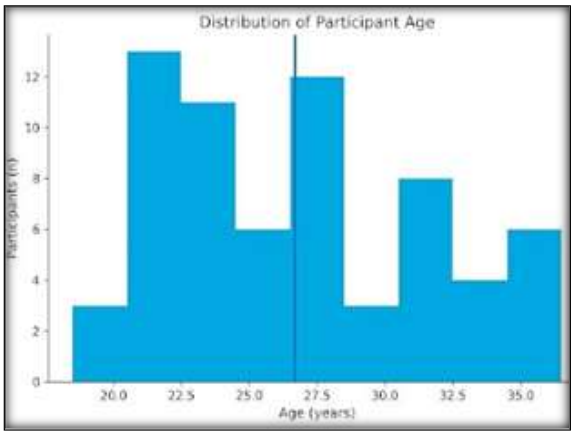


Figure 5: Age characteristics of participants (n = 66).

Table 2: Popliteal angle and gluteal muscle strength by side (n = 66)

Variable	Side	Mean ± SD	Median (IQR)	Range
Popliteal angle (°)	Affected	40.47 ± 14.16	41.00 (18.00)	11.00–68.00
Popliteal angle (°)	Non-affected	32.67 ± 11.95	33.00 (16.50)	6.00–67.00
Gluteal strength (kg)	Affected	20.79 ± 2.72	20.40 (3.75)	15.00–28.30
Gluteal strength (kg)	Non-affected	22.30 ± 2.84	22.40 (4.58)	17.40–28.90

Gluteal strength is the mean of three HipSIT trials. SD, standard deviation; IQR, interquartile range.

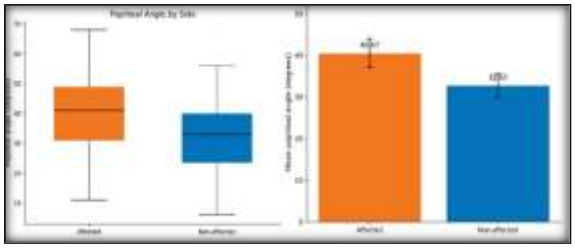


Figure 6: Popliteal angle on the affected and non-affected sides (n = 66): (A, left) box plot; (B, right) mean popliteal angle. Side-to-side differences were not tested statistically.

Normality testing: Affected-side popliteal angle (W = 0.98, p = 0.381) and affected-side mean gluteal strength (W = 0.98, p = 0.256) were approximately normally distributed. Age (p = 0.002) and the second non-affected HipSIT trial (p = 0.024) departed from normality; neither entered the correlation analysis [Table 3].

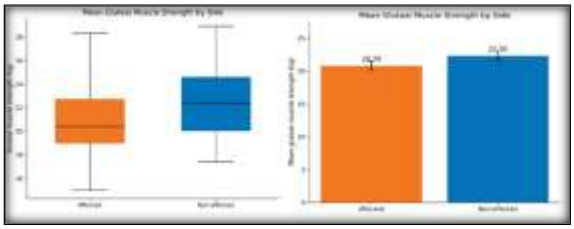


Figure 7: Gluteal muscle strength on the affected and non-affected sides (n = 66): (A, left) box plot; (B, right) mean gluteal muscle strength. Side-to-side differences were not tested statistically.

Table 3: Shapiro–Wilk tests of normality (n = 66)

Variable	W	p
Age	0.93	0.002
Affected popliteal angle	0.98	0.381
Affected gluteal strength, trial 1	0.97	0.173
Affected gluteal strength, trial 2	0.99	0.760
Affected gluteal strength, trial 3	0.97	0.074
Affected mean gluteal strength	0.98	0.256
Non-affected popliteal angle	0.98	0.560
Non-affected gluteal strength, trial 1	0.97	0.200
Non-affected gluteal strength, trial 2	0.96	0.024
Non-affected gluteal strength, trial 3	0.98	0.328
Non-affected mean gluteal strength	0.97	0.176
Popliteal angle difference (affected − non-affected)	0.98	0.453
Mean strength difference (affected − non-affected)	0.98	0.509

W, Shapiro–Wilk statistic.

Relationship between hamstring flexibility and gluteal strength: Paired affected-side records were available for all 66 participants. Affected-side popliteal angle and affected-side mean gluteal strength were not significantly correlated (r = −0.033, df = 64, p = 0.790; 95% CI −0.273 to 0.210) (Table 4; Figure 8). The regression line was almost flat (slope −0.006 kg per degree), and the confidence interval excludes moderate or strong associations in either direction.

Table 4: Pearson correlation between affected-side popliteal angle and mean gluteal muscle strength

Variable 1	Variable 2	n	r	df	95% CI	p
Affected popliteal angle	Affected mean gluteal strength	66	−0.033	64	−0.273 to 0.210	0.790

r, Pearson product–moment correlation coefficient; df, degrees of freedom; CI, confidence interval.

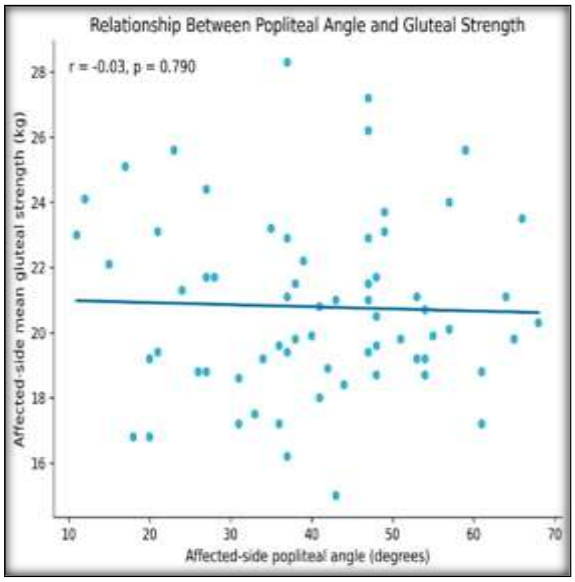


Figure 8: Relationship between affected-side popliteal angle and mean gluteal muscle strength (n = 66), with the least-squares regression line (r = −0.033, p = 0.790).

Inter-rater agreement of the HipSIT: Individual trial values ranged from 12.1 to 21.4 kg for Examiner A and from 12.1 to 22.1 kg for Examiner B [Table 5; Figure 9]. Participant mean force was 16.23 ± 2.26 kg for Examiner A and 16.96 ± 2.56 kg for Examiner B.

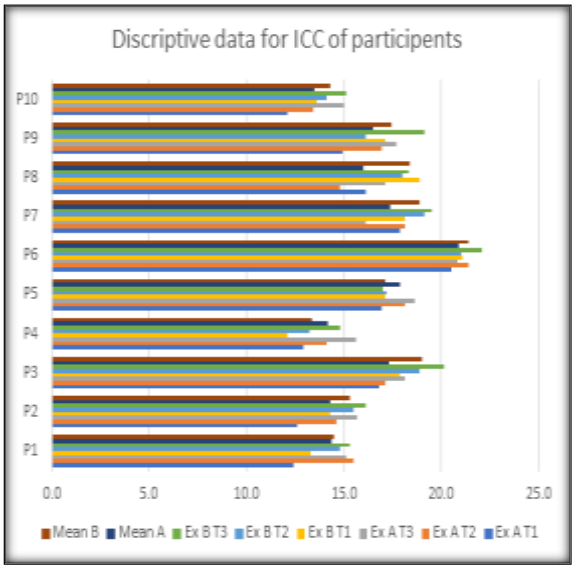


Figure 9: All measured values recorded across three trials by both examiners, alongside the participant-level mean force output (n = 10).

Table 5: HipSIT force (kg) recorded by two examiners across three trials (n = 10)

Participant	A, T1	A, T2	A, T3	B, T1	B, T2	B, T3	Mean A	Mean B
P1	12.4	15.5	15.1	13.3	14.8	15.3	14.33	14.47
P2	12.6	14.6	15.7	14.3	15.5	16.1	14.30	15.30
P3	16.8	17.1	18.1	17.9	18.9	20.1	17.33	18.97
P4	12.9	14.1	15.6	12.1	13.2	14.8	14.20	13.37
P5	16.9	18.1	18.6	17.1	17.2	17.0	17.87	17.10
P6	20.5	21.4	20.8	21.1	21.0	22.1	20.90	21.40
P7	17.9	18.1	16.1	18.1	19.1	19.5	17.37	18.90
P8	16.1	14.8	17.1	18.9	18.0	18.3	16.00	18.40
P9	14.9	16.9	17.7	17.1	16.1	19.1	16.50	17.43
P10	12.1	13.4	15.0	13.6	14.1	15.1	13.50	14.27

A, Examiner A; B, Examiner B; T, trial.

Inter-rater agreement was good, with ICC(2,1) = 0.88 (95% CI 0.50–0.97) and ICC(3,1) = 0.91 (95% CI 0.68–0.98); the examiners' means were strongly correlated (r = 0.92, p < 0.001). Bland–Altman analysis showed a mean bias of −0.73 kg (SD of differences 1.03 kg), with Examiner B recording higher values in 8 of 10 participants. The 95% limits of agreement were −2.74 to 1.28 kg, and all 10 differences fell within them [Table 6; Figure 10 and 11].

Table 6: Inter-rater agreement of the HipSIT dynamometer protocol (n = 10)

Measure	Value
Examiner A, mean ± SD (kg)	16.23 ± 2.26
Examiner B, mean ± SD (kg)	16.96 ± 2.56
ICC(2,1), absolute agreement (95% CI)	0.88 (0.50–0.97)
ICC(3,1), consistency (95% CI)	0.91 (0.68–0.98)
Pearson r	0.92 (p < 0.001)
Bland–Altman mean bias, A − B (kg)	−0.73
SD of differences (kg)	1.03
95% limits of agreement (kg)	−2.74 to 1.28

Values calculated from participant means of three trials [Table 5]. ICC, intraclass correlation coefficient; CI, confidence interval; SD, standard deviation.

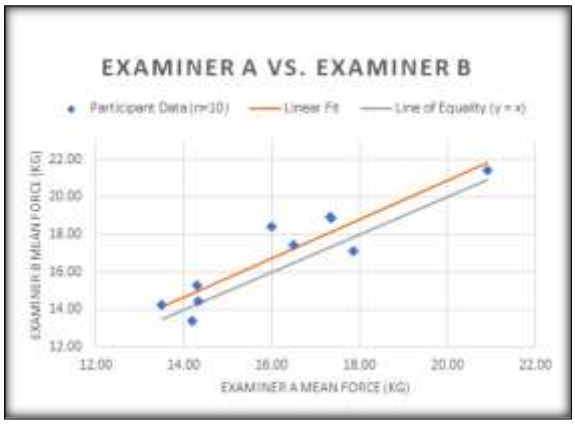


Figure 10: Scatter plot of mean force (kg) recorded by Examiner A against Examiner B (n = 10), with the linear regression fit and the line of equality (y = x).



Figure 11: Bland–Altman plot of the differences between examiners against their means (n = 10), showing the mean bias (−0.73 kg) and the 95% limits of agreement (−2.74 to 1.28 kg).

DISCUSSION

In young adults with idiopathic AKP, hamstring flexibility and gluteal muscle strength on the affected side were not linearly related ($r = -0.033$, $p = 0.790$). The 95% CI (−0.273 to 0.210) rules out a moderate or strong linear association, so in this sample neither measure gave useful information about the other. Descriptively, the affected limb had a higher mean popliteal angle and lower mean gluteal strength than the non-affected limb, but these differences were not tested and should not be read as significant.

Comparison with previous studies: The compensation hypothesis predicts that weaker gluteal muscles accompany shorter hamstrings.[14,15] The main support comes from Arab et al., who found shorter hamstrings in people with sacroiliac joint dysfunction and gluteal weakness than in those without weakness.[16] That difference was small, was absent in their other groups, and was judged by the authors to be insufficient for firm conclusions.[16] Sacroiliac joint dysfunction and AKP also differ in symptom mechanisms and loading. Our finding of no correlation in AKP suggests the association, if real, is not general across musculoskeletal conditions.

Gluteal weakness in PFP is well documented. Reviews report lower isometric hip strength in people with PFP than in pain-free controls.[10–12] and Almeida et al. found a 10% HipSIT deficit on the symptomatic limb of women with PFP.[20] Our affected-side mean was about 7% lower than the non-affected side, which is in a similar direction but was not tested statistically. Nunes et al. showed that hip strength and rate of force development deficits in women with PFP were not explained by gluteal muscle thickness or non-contractile tissue.[13] That points to neural and behavioural contributions to strength, which would not be expected to track hamstring length.

The direction of the hip strength–PFP link is also uncertain. Prospective studies show no association between hip strength and later PFP, so reduced hip strength may follow pain rather than cause it.[10] If gluteal weakness is partly a consequence of pain, there is little reason to expect it to be coupled to a structural or tolerance-based property such as hamstring extensibility.

Possible explanations for the absence of association: First, AKP is multifactorial. Local joint loading, hip and knee muscle performance, foot mechanics, activity level and pain processing all contribute.[5,6] In a heterogeneous group, flexibility and strength impairments may occur in different people, which weakens any group-level correlation even when each impairment matters for some individuals.

Second, the two measures capture different properties. Hamstring extensibility in people with pain appears to depend mainly on stretch tolerance rather than muscle stiffness.[17] whereas HipSIT force depends on voluntary effort, motor recruitment and pain-related inhibition. Static measures may also miss timing relationships: a six-week gluteal activation programme in young men with PFP changed the activation timing of both gluteus maximus and biceps femoris during stair climbing and reduced pain.[23] Any interaction between the two muscle groups may therefore lie in neuromuscular control rather than in length or maximal force.

Third, a relationship could be non-linear or present only in subgroups defined by pain severity, symptom duration, activity level or sex. Pearson's correlation detects only linear association across the whole sample.

Clinical implications: Hamstring flexibility and gluteal strength should be assessed separately in people with idiopathic AKP. A tight hamstring should not be taken as a sign of gluteal weakness, or the reverse. This supports the impairment-based approach of current guidelines, which recommend identifying each patient's predominant deficits and treating with combined hip- and knee-targeted exercise.[5] Piva et al. likewise assessed hip strength and soft-tissue flexibility as separate parts of the examination in PFP [24]. For the HipSIT, agreement between examiners was good, and the mean bias of −0.73 kg is small relative to the spread of strength

values. Even so, the limits of agreement (about −2.7 to 1.3 kg) mean that the same examiner should ideally perform repeated measurements on a patient.

Limitations: The cross-sectional design does not allow causal inference, and no healthy control group was included, so the findings cannot show whether either impairment is specific to AKP. Convenience sampling from outpatient departments may limit representativeness, and only adults aged 19 to 35 years were studied. Pain intensity, symptom duration, physical activity level and movement patterns were not recorded, so their possible influence on either variable could not be examined. Only linear association on the affected side was analysed. The reliability analysis included only 10 participants, which produced a wide confidence interval for ICC(2,1) (0.50–0.97); it assessed inter-rater agreement only and did not establish intra-rater reliability. Finally, the number of individuals screened and excluded was not recorded.

Future research: Larger and more diverse cohorts with healthy controls are needed. Future studies should relate hamstring flexibility to the strength and activation timing of individual gluteal muscles and include pain intensity, function and lower-limb biomechanics. Longitudinal and intervention studies could test whether changes in gluteal strength are followed by changes in hamstring flexibility.

CONCLUSION

In young adults with idiopathic anterior knee pain, hamstring flexibility and gluteal muscle strength on the affected side were not linearly related. The affected limb showed a higher mean popliteal angle and lower mean gluteal strength than the contralateral limb, but these differences were descriptive. Hamstring flexibility and gluteal strength should be assessed separately during physiotherapy evaluation, and neither should be used to infer the other.

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