Knee rotation in patients with and without patellofemoral instability and its correlation with patellar tendon trochlear groove distance

Himanshu Gupta[1](✉), Vineet Jain[1], Nilansh Kataria[1], Ashish Dutt Upadhyay[2], Pallav Mishra[1], Himanshu Kataria[1]
[1]Vardhman Mahavir Medical College & Safdarjung Hospital, New Delhi, India
[2]All India Institute of Medical Sciences, New Delhi, India
himanshu.aiims@gmail.com

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Abstract—Background and study aims: There are limited studies assessing the role of "knee rotation" in patellofemoral instability (PFI). Knee rotation is the external rotation of the proximal tibia with respect to distal femur. The study was performed to compare knee rotation, patellar tendon lateralisation and patellar tendon trochlear groove (PTTG) distance measured on MRI between patients with and without PFI and to assess the relative association of these factors with PFI.

Materials and methods: It was a retrospective cross-sectional study done on archival MRI films. A sample size of 20 for PFI group and 60 for control group was taken. PTTG distance, knee rotation and lateralisation of patellar tendon insertion were measured as described in literature. The knee rotation and patellar tendon lateralisation between PFI and non-PFI group were compared using t-test and their Pearson's correlation (r) with PTTG distance was calculated. Relative associations of these factors with PFI were assessed using multivariate regression.

Results: Lateralisation of patellar tendon insertion and external knee rotation were both found to be higher in PFI patients as compared to non-PFI patients. However,on taking PTTG distance into consideration, the associations of knee rotation as well as of patellar tendon lateralisation with PFI did not remain significant in generalised linear modeling. Overall, the PTTG distance showed moderate to strong correlation with the external knee rotation as well as with lateralisation of patellar tendon insertion.

Conclusions: Knee rotation was found to be significantly higher in PFI patients as compared to controls. However, PTTG distance appears to be a composite measure that takes into account the influence of both the patellar tendon lateralisation as well as knee rotation on patellofemoral biomechanics.

Keywords—Patellofemoral instability, knee rotation, patellar tendon lateralisation, PTTG distance.

1 Introduction

Lateralization of patellar tendon insertion is an important contributory factor for patellofemoral instability (PFI)[1,2]. Patellar tendon trochlear groove (PTTG) or tibial tuberosity trochlear groove (TTTG) distance is used to assess this and to decide whether a patient needs a tibial tubercle osteotomy (TTO) or not[3-8].

It was recently shown that PTTG distance not only measures the lateralization of patellar tendon (or tibial tubercle in case of TTTG), but is also influenced by external rotation of the proximal tibia with respect to distal femur, referred to as knee rotation in the existing literature[9]. Theoretically, because of the curvature of the anterior surface of the proximal tibia, "lateralization" of patellar tendon results in lateral as well as slight posterior shift of the patellar tendon insertion with respect to femur, similar to what happens to the patellar tendon insertion due to externally rotated tibia (that is, external knee rotation). Thus, knee rotation is also expected to affect the PTTG distance in the same way as patellar tendon lateralisation[10]. Further, knee rotation will also affect the vector forces of quadriceps mechanism in much the same way as patellar tendon lateralization and it could also be an etiological factor for PFI. It may be noted here that this "knee rotation" should not be confused with tibial torsion which is the relative rotation of the lower leg at the level of the ankle in reference to the rotational alignment of proximal tibia[10].

Two studies have compared the knee rotation in patients with and without patellar instability[9,10]. The proximal tibia was found to be more externally rotated in patients with patellar dislocation as compared to the control group in both the studies. However, while the knee rotation was shown to have a good positive correlation with TTTG distance in the patellar dislocation group ($r = 0.62$) in one study[9], it was found to have no correlation ($r=0.06$) with TTTG distance in another study[10]. No other study could be found in the literature assessing the relation of knee rotation with PFI or PTTG distance. Further no study could be found assessing the relative associations of increased PTTG distance and increased knee rotation with patellofemoral instability by means of a multivariate regression or linear modeling.

1.1 Study aim

The present study was conducted to assess the role of knee rotation in PFI and its association with PTTG distance, along with that of lateralisation of patellar tendon insertion. The aim of the study was:

1. To compare the knee rotation, patellar tendon lateralisation and PTTG distance, as measured on MRI, between patients with PFI and the control group (patients without PFI),
2. To assess the correlation of knee rotation and patellar tendon lateralisation with PTTG distance, in patients with PFI as well as in control group, and
3. To assess the relative associations of increased PTTG distance, increased knee rotation and increased patellar tendon lateralisation with PFI by means of generalised linear modeling.

2 Materials and methods

It was a retrospective cross-sectional study done on archival MRI films obtained from the archives of the radiology services located inside our centre. Ethical approval for use of archival data and waiver of requirement for patient consent was obtained from the Institutional Ethics Committee. The study was done in agreement with the ethical standards of the Institutional Ethics Committee.

2.1 Sample size calculation:

Sample size calculation was based on comparison of knee rotation angle. Diederichs et al reported knee rotation of 5.7º ±4.3º in normal persons and 9.4º +/- 5.0º in patients of PFI[10], that is, a difference of 3.7º in mean values. Taking the higher standard deviation of 5.0º, an effect size of 4º, alpha=0.05 and power=0.80, sample size was calculated for a 1:3 proportion of PFI and control groups. The sample size was 17 for the PFI group and 49 for the non-PFI group. A higher sample size of 20 for PFI group and 60 for control group was taken.

Tensho et al reported a correlation of 0.62 between TTTG and knee rotation[9]. For a similar correlation value, sample size calculated with alpha=0.05 and power=0.80, was 18. Hence, the chosen sample size also gives adequate power for the correlation part of the study.

2.2 Inclusion and exclusion criteria:

For the PFI group, consecutive MRI scans belonging to PFI patients, with 10 males and 10 females were retrieved- total 20 PFI patients. The inclusion criteria were (i) age between 15 to 45 years, and (ii) recurrent patellofemoral dislocation as per history records in MRI requisition form with MRI findings compatible with the diagnosis of recurrent PFI.

For the control group, 60 MRI scans (with 30 males and 30 females) were selected from the archives with age matching with the PFI patients. The exclusion criteria for the control group were (i) any history of PFI as per requisition form, or (ii) MRI findings of injury to MPFL along with osseous edema involving the anterior lateral femoral condyle and medial patellar facet suggestive of PFI.

Other common exclusion criteria for both groups were history or MRI features suggestive of injury to major ligaments of the knee other than MPFL (like ACL, PCL, MCL, LCL and PLC), previous knee surgeries, bipartite patella, grades III or IV cartilage lesions of the patella, grade III or IV osteoarthritis of the knee, fracture, metabolic disease, or tumour. Further, patients with no history of PFI but grade B or higher trochlear dysplasia were excluded from both groups.

2.3 Measurements on images:

The images were obtained in DICOM format and stored in sequentially numbered folders in a computer. Connotations related to patient identification and demographics were hidden. After the inclusion process, the personal details of the patients were not accessed, other than age and gender, to maintain patient confidentiality. All measurements were done by a consultant orthopaedic surgeon with 8 years' experience. Measurements were repeated in 20 patients (10 PFI patients and 10 control patients) after a gap of at least three weeks to assess intra-rater reliability. The assessor was blinded to the history and diagnosis at the time of taking the measurements.

Synedra View software was used for the measurement and analysis on the MRI images (Synedra Information Technologies GmbH, Austria). All the measurements were performed on Proton Density Cube sequence. The MPR images were generated from this sequence. The PTTG distance was measured as described in literature[3,4,8].

Knee rotation was measured on MRI as described in literature[9,10,11]. Briefly, an axial section through the proximal tibia was chosen with clearly recognised posterior condylar notch and the posterior tibial condylar line was drawn (Figure 1a, line AB). Similarly, an axial section through the distal femur was chosen with a well-defined Roman arch and deepest point of trochlea, and the posterior femoral condylar line was drawn (Figure 1b, line CD). Knee rotation was measured as the angle between these two lines.

For the measurement of lateralisation of patellar tendon insertion on MRI, the method described in the literature for CT measurements was used[1,9]. Briefly, a slice passing though the proximal tibia with clearly recognised posterior condylar notch was chosen and posterior tibial condylar line was drawn (Figure 2a, line AB). Lines perpendicular to this line and passing through the medial and lateral borders of the proximal tibia (lines BM and AL) were drawn to measure the total medio-lateral width 'T' of proximal tibia. Another section with complete insertion of patellar tendon was chosen and distance 't' of the centre of patellar tendon insertion was measured from the previously defined medial border of proximal tibia (Figure 2b and c). This distance was expressed as a proportion of the total medio-lateral width of proximal tibia (that is, 't' divided by 'T').

Measurements of points lying on the lateral side of the trochlear groove were given positive sign and measurements lying medial to it were given negative sign. Similarly, external rotation of proximal tibia with respect to femur was given positive sign, and internal rotation was given negative sign, as followed in existing literature.

2.4 Statistical analysis:

The mean, range, Standard Deviation (SD) and Standard Error of Mean (SEM) were calculated for all measurements. Mean was expressed as mean ±SD. The normality of data was assessed using Shapiro-Wilk test and equality of variance was assessed using F-test. Test-retest reliability was assessed using Intraclass Correlation Coefficient (ICC). The knee rotation, lateralisation of patellar tendon insertion and PTTG distance between PFI and non-PFI group were compared using t-test, as all data groups had

normal distribution. The Pearson's correlations of PTTG distance with the knee rotation, as well as with lateralisation of patellar tendon insertion, were calculated with 95% confidence intervals (95%CI). Relative associations of the three variables (that is, PTTG distance, knee rotation and lateralisation of patellar tendon insertion) with PFI were assessed using multivariate regression. The p value was set at 0.05. Statistical analysis was done on R-Commander statistical software[12,13].

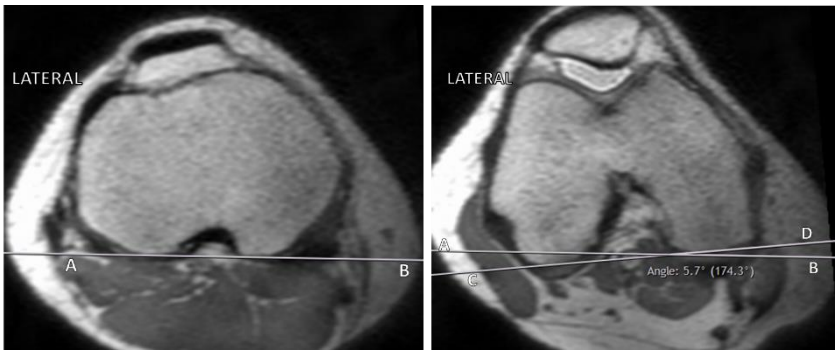

Figure 1: Measurement of knee rotation on MRI. (a) An axial section through the proximal tibia with clearly recognised posterior condylar notch was chosen. Posterior tibial condylar line AB was drawn. (b) An axial section through the distal femur with a well-defined Roman arch and deepest point of trochlea was chosen. Posterior femoral condylar line CD was drawn. Knee rotation was measured as the angle between lines AB and CD.

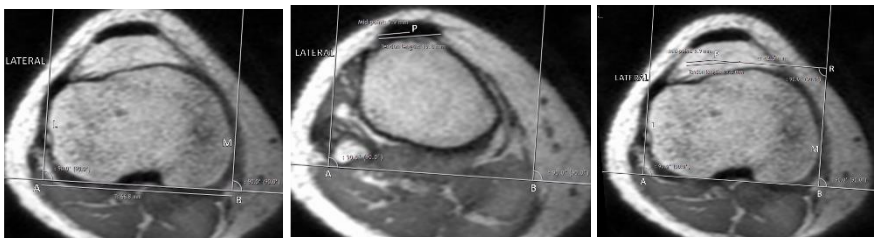

Figure 2: Measurement of lateralisation of patellar tendon insertion on MRI. (a) Posterior tibial condylar line AB was drawn. Lines BM and AL were drawn perpendicular to this line and passing tangential to the medial and lateral borders of the proximal tibia. The perpendicular distance between these two lines gave the width 'T' of proximal tibia. (b) Another axial section at the level of complete insertion of patellar tendon was chosen. The midpoint of patellar tendon, point 'P', was defined. (c) The perpendicular distance 't' of this point P was measured from the previously defined line BM.

3 Results

The mean age was 21.3 ± 3.7 (range 15-27) for PFI group and 21.6 ± 4.1 (range 15-28) for non-PFI group (table I). The groups were already matched for age and sex.

PTTG distance, lateralisation of patellar tendon insertion and external knee rotation were all found to be higher in PFI patients as compared to non-PFI patients (table II).

The mean lateralisation of patellar tendon insertion (ratio t/T) in PFI group was 0.69 ±0.03 (range 0.63 to 0.74) as compared to a mean of 0.65 ±0.03 (range 0.58 to 0.73) in non-PFI group ($p<0.001$). The mean external knee rotation in PFI group was -0.1° ± 4.3° (range -8.5° to +9.4°) as compared to a mean of -5.5° ± 4.5° (range -17.5° to +6.3°) in non-PFI group ($p<0.001$). These differences were significant for males as well as females.

In generalised linear modeling, out of the three variables assessed, only increased PTTG distance was found to be associated with PFI (table III). That is to say, when PTTG distance was considered as an associated factor for PFI, then the associations of knee rotation as well as of patellar tendon lateralisation with PFI lost their significance.

Overall, the PTTG distance showed moderate to strong correlation with the external knee rotation (Pearson's correlation coefficient =0.66, 95% CI 0.51-0.77), as well as with lateralisation of patellar tendon insertion (Pearson's coefficient=0.55, 95% CI 0.38-0.69). This correlation was also present when assessed separately in males, females, as well as in PFI patients and non-PFI patients (table IV).

Table I: Demography

	PFI	non-PFI	p value
Age, Mean±SD (Range)	21.3 ±3.7 (15 -27)	21.6 ±4.1 (15 - 28)	0.7
Sex (M:F)	10:10	30:30	
Side (R:L)	12:8	29:31	

Table II: Comparison of PFI group vs non-PFI group

	PFI patients				Non-PFI patients			
	n=	Mean ±SEM (range)	SD		n=	Mean ±SEM (range)	SD	p value
Tibial rotation (in degrees):								
All patients	20	-0.1 ±1.0 (-8.5 to 9.4)	4.3		60	-5.5 ±0.6 (-17.5 to +6.3)	4.5	<0.001
Males	10	-0.8 ±1.5 (-8.5 to 9.4)	4.9		30	-6.0 ±0.9 (-17.5 to 6.3)	5	0.01
Females	10	0.6 ±1.2 (-5.4 to 7.4)	3.7		30	-5.0 ±0.7 (-11.9 to 1.6)	3.9	0.001
Lateralisation of patellar tendon insertion (as proportion t/T; refer to text):								
All patients	20	0.69 ±0.01 (0.63-0.74)	0.03		60	0.65 ±0.004 (0.58-0.73)	0.03	<0.001
Males	10	0.68 ±0.01 (0.65-0.74)	0.03		30	0.65 ±0.01 (0.58-0.73)	0.03	0.01
Females	10	0.69 ±0.01 (0.63-0.74)	0.03		30	0.66 ±0.01 (0.59-0.72)	0.04	0.008
PTTG distance (in mm):								
All patients	20	13.0±0.5 (8.8 to 17.3)	2.2		60	6.6 ±0.4 (0.8 to 14.2)	3.2	<0.001
Males	10	12.6 ±0.8 (8.8 to 17.3)	2.6		30	6.3 ±0.7 (0.8 to 14.2)	3.7	<0.001
Females	10	13.4 ±0.5 (10.4 to 17.1)	1.7		30	6.8 ±0.5 (1.5 to 12.1)	2.6	<0.001

Table III: Generalised linear modeling for predicting presence or absence of PFI

Variable tested	Estimate	p value
PTTG distance	0.8 ±0.2	<0.001
Tibial rotation	0.02 ±0.1	0.9
Lateralisation of patellar tendon insertion (t/T)	13.3 ±15.7	0.4

(formula = PFIfactor ~ PTTG.distance + Tibial.rotation + t.T)

Table IV: Correlation of tibial rotation and patellar tendon lateralization with PTTG distance

	Correlation of tibial rotation vs PTTG	95% CI	p value	Correlation of Lateralisation of patellar tendon insertion vs PTTG	95% CI	p value
Overall	0.66	0.51 - 0.77	<0.001	0.55	0.38-0.69	<0.001
Males	0.63	0.40 - 0.79	<0.001	0.61	0.36-0.77	<0.001
Females	0.69	0.48 - 0.82	<0.001	0.5	0.22-0.70	<0.001
PFI patients	0.45	0.01 - 0.74	0.04	0.54	0.12-0.79	0.01
Non-PFI patients	0.54	0.33 - 0.70	<0.001	0.4	0.16-0.60	0.002

4 Discussion

In the present study, knee rotation as well as lateralisation of patellar tendon insertion were found to be significantly higher in PFI patients as compared to controls. Further, both these measurements correlated significantly with PTTG distance, overall as well as separately in PFI and non-PFI patients. However, in generalised linear modelling, only PTTG distance was found to be significantly associated with PFI, and in the presence of PTTG distance, the associations of knee rotation as well as of patellar tendon lateralisation with PFI did not remain significant. In other words, PTTG distance appeared as a composite measure that already takes into account the influence of both the patellar tendon lateralisation as well as knee rotation on patellofemoral biomechanics.

The knee rotation in the present study was -5.5º ±4.5º in the control group (range -17.5° to +6.3°). Previous studies have reported slightly higher values of external knee rotation in normal individuals: 5.7º ±4.3º in one study10 and 4.0º ±3.7º in another study9. A study measuring knee rotation in osteoarthritis (OA) and non-OA patients reported knee rotation of 0º ±0º in normal knee, versus 4º ±1º in OA knees11.

In literature, both lateralisation of patellar tendon insertion (tibial tuberosity lateralisation) and knee rotation have been shown to have significant positive correlation with PTTG distance9, similar to the present study. A study by Tensho et al had reported no significant difference in lateralisation of patellar tendon insertion between the PFI and control groups, and based on this, the authors had also raised concerns regarding the role of TTTG distance as a reasonable criterion for guiding surgical intervention in PFI patients [9]. On the other hand, in the present study, this factor was found to be significantly greater in PFI patients as compared to control patients, which is along expected

lines. Generally, lateralisation of patellar tendon is considered to be an established risk factor for PFI[10].

The external knee rotation was also found to be significantly greater in PFI patients than in control group in the present study (mean -0.1º ±4.3º versus -5.5º ±4.5º), and it was also found to correlate significantly with PTTG distance. Another study had reported similarly higher knee rotation in PFI patients as compared to control group (1.6 times higher), but had failed to find any correlation of knee rotation with PTTG distance (Pearson's correlation=0.06)[10]. The study by Tensho et al had reported findings on knee rotation similar to the present study, with significantly higher knee rotation in PFI patients (mean 8.5º ±7.0º versus 4.0º ±3.7º) and a correlation of 0.62 with PTTG distance in patients of PFI[9]. However, based on these findings, the authors of that study had argued that since PTTG distance is influenced more by knee rotation than by tibial tuberosity lateralisation, hence PTTG distance may not be a reasonable criterion for defining indications of medial tibial tubercle transfer[9]. We disagree with this interpretation of the authors of that study, and we believe that an increased external knee rotation would result in a lateral shifting of the patellar tendon attachment in a manner similar to that caused by an increased tibial tuberosity lateralisation. In other words, the influence of these two factors on patellofemoral biomechanics is expected to be similar as far as PFI is concerned. Hence, theoretically, a medialisation tibial tubercle osteotomy should be able to take care of this lateral shifting of patellar tendon insertion in reference to the femoral trochlear groove irrespective of whether it was caused by increased lateralisation of patellar tendon insertion or by increased knee rotation. Further, since PTTG distance has been found to positively correlate both with lateralisation of patellar tendon insertion as well as with knee rotation in the present study, hence, PTTG distance can be considered as a composite measure that takes into consideration the combined effects of both these factors. This is further supported by the results of the generalised linear modelling in the present study. When the association of all these factors with the presence or absence of PFI was assessed using generalised linear modeling, the lateralisation of patellar tendon as well as knee rotation lost their significance in the presence of PTTG distance.

Study limitations:

One limitation of the study is that only limited anatomical factors reported to be associated with PFI have been included. Other rotational malalignments of femur and tibia, that is, femoral version and tibial torsion, also constitute possible factors for PFI, although some studies have not found these torsional mal-alignments to be significantly associated with abnormal patellofemoral relationships[3,10,14]. These other torsional deformities have not been assessed in the present study, since the main purpose of this study was specifically to assess the relative association of knee rotation and lateralisation of patellar tendon insertion with PFI and PTTG distance, and the study included MRI films of only knee region.

Another limitation is that we have not defined thresholds for knee rotation for PFI and normal individuals. However, rotational alignments can show wide variations even

in healthy individuals[1,14], and in the present study also, the knee rotation showed considerable overlap between the control and PFI groups. Hence, defining thresholds may be difficult. Further, the aim of the present study was only to assess its association with PFI vis-a-vis patellar tendon lateralisation and PTTG distance.

5 Conclusion

Knee rotation was found to be significantly higher in PFI patients as compared to controls. However, when PTTG distance was taken into consideration, the associations of knee rotation as well as of patellar tendon lateralisation with PFI did not remain significant. PTTG distance appears to be a composite measure that takes into account the influence of both the patellar tendon lateralisation as well as knee rotation on patella-femoral biomechanics.

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7 Authors

Prof. Himanshu Gupta (MS Orth) is a Professor at Sports Injury Centre, Vardhman Mahavir Medical College & Safdarjung Hospital, New Delhi, India-110029. His email ID is himanshu.aiims@gmail.com

Prof. Vineet Jain (MS Orth) is a Professor at Sports Injury Centre, Vardhman Mahavir Medical College & Safdarjung Hospital, New Delhi, India-110029.

Dr. Nilansh Kataria (MBBS) was a Junior resident in Vardhman Mahavir Medical College & Safdarjung Hospital, New Delhi, India-110029. He has recently joined as Resident in Medstar Washington Hospital Center, Washington D.C., USA.

Dr. Ashish Dutt Upadhyay (PhD) is Scientist (Biostatistics) at All India Institute of Medical Sciences, New Delhi, India-110029.

Prof. Pallav Mishra (MS Orth) is a Professor at Sports Injury Centre, Vardhman Mahavir Medical College & Safdarjung Hospital, New Delhi, India-110029.

Prof. Himanshu Kataria (MS Orth) was Director-Professor at Sports Injury Centre, Vardhman Mahavir Medical College & Safdarjung Hospital, New Delhi, India-110029. He has recently joined as Director-Professor and Unit-Head in the department of Orthopedics, Lady Hardinge Medical College, Delhi, India.