Original Article

Supratrochlear Rim is Correlated with Isolated Patellar Chondromalacia on Magnetic Resonance Imaging of the Knee

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Purpose: To investigate the relationship between the supratrochlear rim and isolated patellar chondromalacia (PC) using magnetic resonance imaging (MRI) scans of the knee. **Methods:** Patients without patellofemoral pain (control group) and patients with patellofemoral pain and diagnosed with stage III or IV PC based on MRI (defect group) were retrospectively identified. Patients with a history of patellar subluxation were excluded. We used patient MRI scans to perform 20 anatomical measurements of the patellofemoral joint. We also performed 2 measurements of the anterior femoral curvature. A total of 30 patients (29 ± 8.7 years) were in the control group, and 20 patients were in the defect group (29.4 ± 9.7 years). **Results:** The maximum curvature ($P < .001$) and mean curvature ($P < .001$) of the anterior femoral condyle were found statistically significantly different between the groups. Patellotrochlear index ($P = .03$) and Insall-Salvati index ($P < .001$) were also found statistically significantly different between the 2 groups. Patella type III and trochlear dysplasia grade B were found more common in the defect group. **Conclusions:** In this Level III prognostic, case-control study, we have shown through MRI knee measurements that the isolated patellar chondromalacia in patients without a history of patellar subluxation and dislocation is correlated with the increased anterior femoral curvature in combination with patella alta.

Pain experienced in the anterior part of the knee is commonly referred to as *patellofemoral pain* (PFP) and is prevalent among adolescents and young adults.[1] Fifty percent of the knee pain cases in adolescents are related to PFP,[2] and 30% of adolescents are affected by knee pain.[3] PFP is also diagnosed in 1 in 6 adults with episodes of knee pain.[4] The primary method of treatment for PFP is physical therapy.[5,6] Unfortunately, prognosis of PFP is unfavorable, with as many as 40% of patients experiencing unsatisfactory outcomes up to a year after treatment.[7] Unsuccessful treatment of PFP can lead to the isolated damage of patellar cartilage called *isolated patellar chondromalacia* (PC), presented in Figure 1.[8] The etiology of isolated PC is well established in individuals with a history of patellar subluxation and dislocation in knees with severe trochlear dysplasia.[9-13] However, the cause of isolated PC in patients *without* a history of patellar subluxation and dislocation remains inconclusive.[14-17] One study suggests that isolated PC without patellar injury may be attributed to abnormalities in the structure and function of the patellofemoral joint.[18] Specifically, it is believed that isolated PC arises from the abnormal patellar tracking in the trochlear groove, resulting in irritation of highly innervated structures within the patellofemoral joint. These structures may include the subchondral bone, lateral retinaculum, or synovium.[19]

In 1961, Outerbridge[20] suggested that the abnormal tracking and alignment of the patella in patients without a history of patellar subluxation and dislocation may be caused by an increased curvature of the anterior femoral shape, specifically the supratrochlear rim. Subsequent works successfully demonstrated this correlation and proposed a surgical procedure to address

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the issue. The procedure involved removing excessive bone tissue beneath the femoral cartilage, thereby eliminating the rim and restoring a smooth condylar shape.[21-23] However, because of limited imaging technologies available at the time to visualize and analyze the supratrochlear rim, the authors were unable to quantify and objectively associate the anterior femoral shape with isolated patellofemoral pain. Instead, anatomical features other than anterior femoral shape were extensively studied as a cause of isolated patellofemoral pain. These metrics included lateral trochlear inclination (LTI),[24-30] trochlear angle,[30] patella type,[24,31-33] sulcus angle (SA),[26,30,32,34] patellar tilt,[16,25,34] Insall-Salvati (IS) index,[34,35] trochlear depth,[25,27,36] patellotrochlear index (PTI),[29,32] distance ratio between the distance from the most superior point of patella and entrance of femoral trochlea and patellar articular surface length (SP-ET index),[35] and congruence angle.[16,32] Despite extensive efforts to identify predictive anatomical features, the only anatomical feature that has shown a strong correlation with isolated patellofemoral pain is a high-lying patella, also known as *patella alta*.[29,32,34,35] There is a paucity of material available to associate abnormal tracking and alignment of the patella to isolated patellofemoral pain.

The purpose of this study was to investigate the relationship between the supratrochlear rim and isolated PC using MRI scans of the knee. We hypothesized that increased anterior femoral curvature representing the supratrochlear rim is correlated with isolated PC. Furthermore, we conducted comprehensive MRI assessments of the patellofemoral joint, focusing on measurements previously associated with isolated PC.

Methods

Patient Selection

Patients without patellofemoral pain (control group) and patients with patellofemoral pain (defect group) who presented to the author's clinic between 2021 and 2022 were retrospectively identified. To be included in the control group, knee MRIs within 6 weeks of the current injury were required to rule out patellofemoral cartilage damage. Exclusion criteria for the control group were meniscus tears exceeding 30% of the meniscal volume, multiligament injuries, arthrosis, inflammatory arthritis, or a history of patellar subluxation. To be included in the defect group, a diagnosis of stage III or IV PC based on MRI was required. Patients with a history of patellar subluxation were excluded. Patients over the age of 50 years were excluded from both groups. Both the MRI and the appointment had to take place at the same institution. Because of the retrospective character of the study, it was not required for patients to provide either written or verbal informed consent for their medical records to be used.

Seven patients from the control group have been later diagnosed with asymptomatic PC stage I or II and these patients were moved to the defect group with a new name: "PC I-IV." We compared the performed measurements between these 2 patient cohorts. To compensate for the knee injuries of patients that have been moved from one group to the other, the results are also tabulated for the groups before moving the patients with PC I-II. The demographic data has been presented in Table 1.

Anatomical Measurements

All the measurements were blinded to patient groups and performed manually using the "Markups" module in "3D Slicer," an open-source medical imaging software.[37] The anatomical structures were measured by a medical imaging scientist (A.B.) with 6 years of experience under the supervision of one orthopaedic surgeon with more than 20 years of surgical experience. The orthopaedic surgeon approved each of the performed measurements and corrected the measurements that required correction. To ensure intrarater reliability, 5 randomly selected MRI scans have been measured by the same medical imaging scientist 6 months after initial measurements. To ensure interrater reliability, the same 5 randomly selected MRI scans have been measured by the same orthopaedic surgeon 6 months after initial measurements. The results of the intra- and inter-rater reliability comparison are presented in the Results section. In total, 22 measurements of patellofemoral geometry were quantified from the MRI imaging. Fourteen of them have been measured in the sagittal plane and 8 in the axial plane. The next 2 sections present the methodology for these measurements in the sagittal and axial plane.

Sagittal Measurements

The femoral-sagittal reference plane was defined as the image plane containing the deepest point of the sulcus groove. PTI, patellar articular overlap (PAO), patellar height (PH), maximum and mean femur curvatures, sulcus groove length (SGL), SGL/PH, entrance to trochlea, SP-ET index, and ridge height have been quantified in this plane.

PTI is the ratio of PAO to the PH.[29] PH has been quantified as the length of the patellar cartilage and PAO as the line parallel to PH defining the overlap of the femoral and patellar cartilage. PTI and maximum and mean femur curvature are illustrated in Figure 2. The femoral curvature measurements have been introduced to quantify the shape of the femoral condyle and potentially detect the presence of the supratrochlear rim. The femoral curvature has been measured from the same level as the top of the patella until the end of the femoral cartilage on the condyle. Maximum curvature has been defined, accordingly to

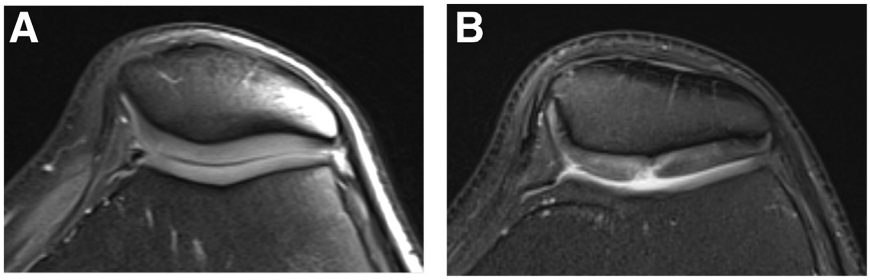

Fig 1. MRI comparison of healthy patellar cartilage of right knee (a), and patellar chondromalacia of right knee (b) in the axial plane.

common knowledge, as the smallest radius of a circle, of all circles that are tangent to a curve. Mean curvature has been defined as an average of principal curvatures at each point of the curve. SGL has been quantified along the same curve as the femur curvature but from the beginning of the femoral cartilage in the superior part of the joint (Fig 3a). Entrance to Trochlea has been quantified as a line parallel to PH defining the distance from the top of the patella to the first axial plane with the full width of the femoral cartilage, and was used to calculate the recently proposed SP-ET index (Fig 3b).[35] Ridge height is a measurement introduced in the 70s[38] and is quantified as the distance from the anterior femoral bone line to the furthest point on the anterior femoral cartilage (Fig 3 b). In the same plane, the knee flexion angle has been quantified and further used to estimate PTI at a straight knee according to the formula $cPTI = PTI - 1.3a$ presented Ahmed et al.,[39] where *cPTI* is PTI at 0° knee flexion and *a* is the measured knee flexion angle. The estimated cPTI is presented in Table 2 as "*PTI at 0° of knee flexion.*"

Patellar diagonal length and patellar tendon length were quantified in the sagittal image plane containing the tallest patellar section (Fig 3a). Insall-Salvati index was quantified as the ratio of patellar diagonal length and patellar tendon length.[40]

Axial Measurements

The femoral—axial reference plane was defined as the first superior axial image plane containing the full femoral cartilage width. Medial trochlear inclination, LTI, SA, trochlear angle, trochlear depth, and congruence angle were quantified in this plane (Fig 3c), where trochlear depth $= \frac{e+g}{2} - f$ (Fig 4c). Patellar width and patellar tilt were quantified in the axial image plane containing the widest portion of the patella (Fig 3d). For each patient, the level of trochlear dysplasia (0-D)[9] and patella type (I-III)[31] were assessed.

Statistical Analysis

We used the measurements to test the hypothesis that increased anterior femoral curvature representing the supratrochlear rim can potentially lead to isolated PC. Furthermore, we conducted comprehensive MRI assessments of the patellofemoral joint, focusing on measurements previously associated with isolated PC. The Wilcoxon signed-rank test was performed to compare the results statistically. In all tests, $P < .05$ was considered statistically significant. The 95% confidence interval was calculated for each comparison to provide a range of values that are compatible with the measurement results. The statistical analyses were performed using Matlab.

Results

A total of 23 patients (29.9 ± 8.7 years) were in the control group, and 27 patients were in the defect group (29.4 ± 9.7 years) (Fig 4). The results before moving patients from the initial control group to the defect group are also presented in Table 2 for reference.

Sagittal Measurements

Out of all measurements performed in this study, 10 have been identified as statistically significant (Table 2 in bold). From these 10, 4 had nonsignificant small differences in means between the groups (ridge height, entrance to trochlea, LTI, trochlear depth). Out of the 6 remaining measurements (Table 2 in bold and underlined), 4 of them (PTI, PTI at 0° of knee flexion, patellar tendon length, and IS Index) were statistically significantly different between the 2 groups. The last 2 remaining measurements (max curvature and mean curvature) were also found statistically significantly different between the 2 groups, with the higher curvature in the defect group (Fig 5).

Axial Measurements

No axial measurements have been found statistically different between the groups. Patella type III was found in 30%, type II in 63%, and type I in 7% of patients in the defect group ("PC I-IV"). In control group, patella

Table 1. Patient Demographics

	Gender	Age (yr)	Knee	BMI
Control Group	8F/15M	29.9 ± 8.7	12R/11L	24.8 ± 1.7
Defect Group	14F/13M	29.4 ± 9.7	15R/12L	24.7 ± 1.7

BMI, body mass index.

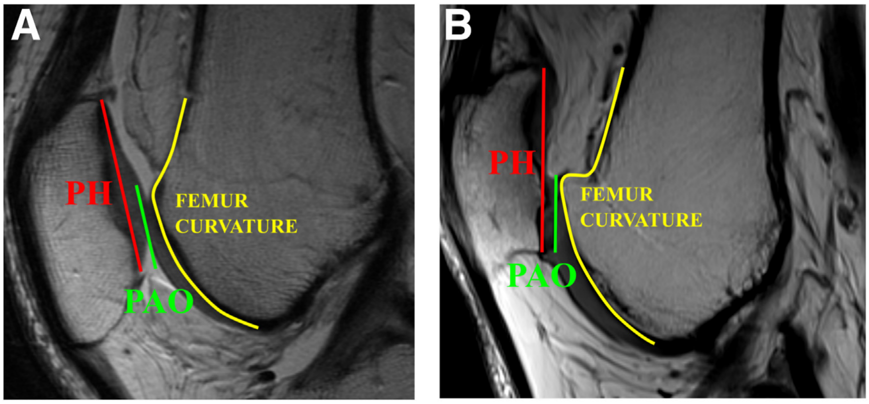

Fig 2. Measurements of the curvature and PTI in a control left knee (a) and left knee with PC (b). PH indicates patellar height; PAO, patellar articular overlap. PTI = PAO/PH.

type III was found in 0%, type II in 78%, and type I in 22% of patients in defect group ("PC I-IV"). Trochlear dysplasia grade B was found in 15%, grade A in 74%, and grade 0 in 11% of patients in defect group ("PC I-IV"). In the control group, trochlear dysplasia grade B was found in 0%, grade A in 78%, and grade 0 in 22% of patients. There were no patients with trochlear dysplasia grades C-D in either of the groups.

The analysis of the other measurements previously associated with isolated PC has determined patella alta as the only additional factor strongly correlated with isolated PC ($P < .03$). The inter- and intra-reliability analysis of the performed measurements is presented in Table 3. The only significant difference between the groups in terms of reliability is the inter-reliability in the defect group of the max curvature where the surgeons average measurement was lower than the scientists average measurement. However, the surgeons average measurement in the defect group was still significantly higher than in the control group. Confidence intervals for all the measurements included value "0," which means that there was no systematic error.

Discussion

The obtained results suggest a significant role of patella alta and supratrochlear rim in the investigated

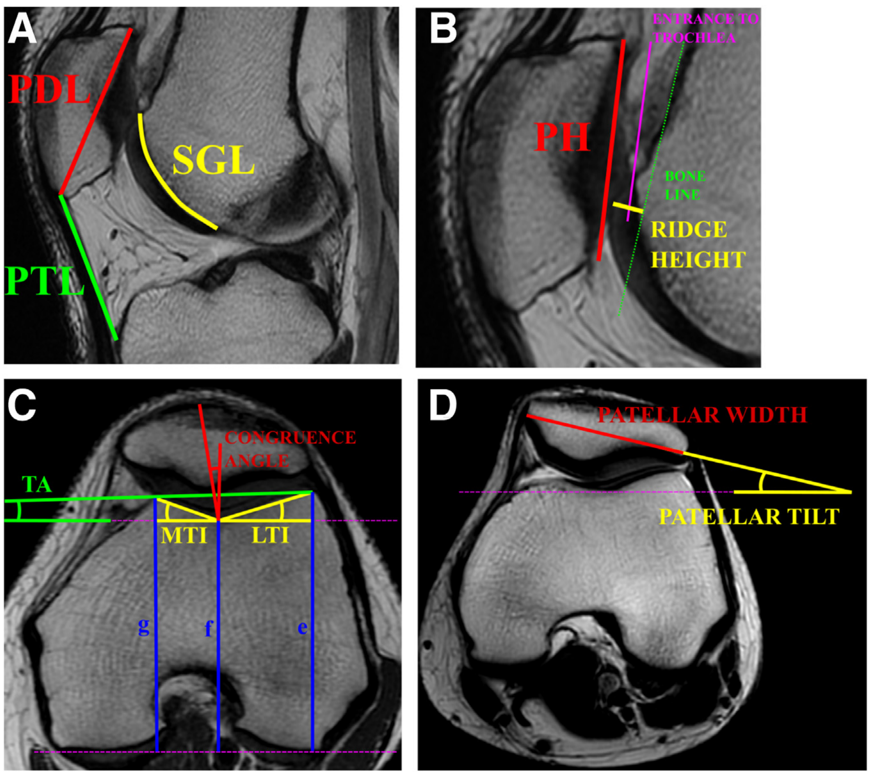

Fig 3. Measurements illustrated on right knees. PDL indicates patellar diagonal length; PTL, patellar tendon length; SGL, sulcus groove length; PH, patellar height; TA, trochlear angle; MTI, medial trochlea inclination; LTI, lateral trochlea inclination. Trochlear depth $= \frac{e+g}{2} - f$.

Table 2. Measurements Results for Both Study Groups*

Measurement	PFP (PC III-IV)	Asymptomatic (Control + PC I-II)	*P* Value	95% CI	Defect (PC I-IV)	Control	*P* Value	95% CI
Max curvature (mm^{-1})	1.9 ± 1.1	0.7 ± 0.7	**<.001***	[0.69, 1.71]	1.9 ± 1.0	0.5 ± 0.4	**<.001***	[0.95 1.85]
Mean Curvature (mm^{-1})	0.08 ± 0.02	0.06 ± 0.02	**<.001***	[0.01, 0.03]	0.08 ± 0.02	0.05 ± 0.01	**<.001***	[0.02 0.04]
PH (mm)	33.9 ± 4.6	32.1 ± 4.0	.18	[−0.67, 4.27]	33.6 ± 4.2	32.0 ± 4.2	.24	[−0.8 4.0]
SGL (mm)	33.2 ± 5.1	31.8 ± 3.8	.24	[−1.13, 3.93]	32.7 ± 4.6	31.9 ± 4.0	.58	[−1.67 3.27]
SGL/PH	0.99 ± 0.2	1.0 ± 0.1	.67	[−0.1, 0.08]	0.98 ± 0.2	1.01 ± 0.1	.30	[−0.12 0.06]
PAO (mm)	13.2 ± 4.3	14.6 ± 4.2	.50	[−3.86, 1.06]	13.1 ± 4.2	15.1 ± 4.1	.20	[−4.27 0.47]
PTI = PAO/PH	0.39 ± 0.1	0.45 ± 0.1	.06	[−0.12, −0.002]	0.39 ± 0.1	0.47 ± 0.1	**.02***	[−0.14 -0.02]
PTI at 0° of knee flexion[40]	0.28 ± 0.1	0.34 ± 0.1	.06	[−0.12, −0.002]	0.28 ± 0.1	0.35 ± 0.1	**.03***	[−0.13 -0.01]
Ridge Height [mm] [39]	4.5 ± 0.7	3.64 ± 1.5	**.002***	[0.14, 1.58]	4.6 ± 1.3	3.2 ± 1.1	**<.001***	[0.71 2.1]
Patellar diagonal length (mm)	42.9 ± 5.7	44.4 ± 3.3	.36	[−4.06, 1.06]	43.1 ± 5.2	44.6 ± 3.4	.29	[−4.05 1.05]
Patellar tendon length (mm)	50.8 ± 5.6	43.4 ± 7.8	**<.001***	[3.33, 11.47]	49.2 ± 6.4	43.1 ± 8.3	**.003***	[1.92 10.28]
Insall-Salvati Index	1.2 ± 0.2	1.0 ± 0.2	**<.001***	[0.08, 0.32]	1.2 ± 0.2	1.0 ± 0.2	**<.001***	[0.09 0.31]
Entrance to trochlea (mm)[35]	28.6 ± 5.0	25.0 ± 4.5	**.01***	[0.87, 6.33]	27.7 ± 5.2	25.0 ± 4.4	**.049***	[−0.07 5.47]
SP-ET Index[35]	0.85 ± 0.1	0.78 ± 0.1	.10	[0.01, 0.13]	0.83 ± 0.1	0.78 ± 0.1	.39	[−0.01, 0.11]
Medial trochlear inclination	21.5° ± 4.6°	21.7° ± 4.7°	.85	[−2.91, 2.51]	22.1° ± 4.8°	21.0° ± 4.4°	.67	[−1.54, 3.74]
Lateral trochlear inclination	17.5° ± 4.6°	19.6° ± 3.0°	**.03***	[−4.26, 0.06]	18.0° ± 4.4°	19.6° ± 2.8°	.11	[−3.74, 0.54]
Sulcus angle	141.1° ± 6.8°	138.7° ± 5.9°	.14	[−1.24, 6.04]	139.9° ± 6.7°	139.4° ± 6.0°	.65	[−3.15, 4.15]
Trochlear angle	3.8° ± 2.4°	3.6° ± 2.0°	.81	[−1.06, 1.46]	3.8° ± 2.3°	3.6° ± 1.9°	.85	[−1.01, 1.41]
Trochlear depth (mm)	5.7 ± 1.0	6.3 ± 1.0	**.02***	[−1.18, −0.02]	6.0 ± 1.1	6.2 ± 0.9	.20	[−0.78, 0.38]
Patellar width (mm)	44.1 ± 5.0	46.6 ± 3.9	.09	[−5.04, 0.03]	44.4 ± 4.8	46.9 ± 3.9	.10	[−5.02, 0.02]
Patellar tilt	11.0° ± 4.9°	9.9° ± 4.1°	.33	[−1.47, 3.67]	11.4° ± 5.0°	9.0° ± 3.3°	.055	[−0.06, 4.86]
Congruence angle	9.5° ± 3.7°	9.3° ± 3.7°	>.99	[−1.95, 2.35]	10.3° ± 3.6°	8.3° ± 3.6°	.06	[−0.05, 4.05]

CI, confidence interval; PAO, patellar articular overlap; PC, patellar chondromalacia; PFP, patellofemoral pain; PH, patellar height; PTI, patellotrochlear index; SGL, sulcus groove length.

*Values were given as the mean ± standard deviation. Models were compared on each metric at each location using Wilcoxon signed-rank test. The statistically significant measures have been presented in bold and out of them the ones whose means are significantly different have been underlined. The vertical line separates the measurement from before (left) and after (right) moving patients with PC I-II from the control to “PC III-IV” patient group.

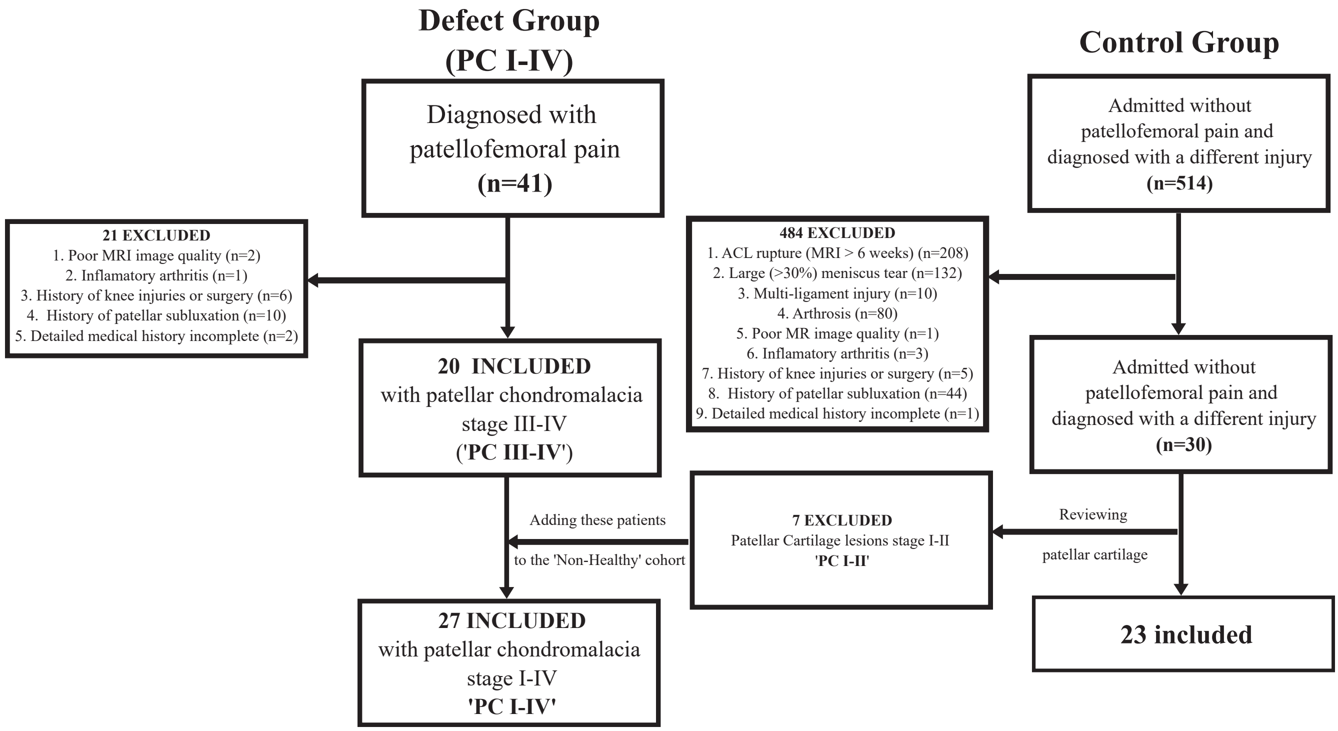

Fig 4. Patient inclusion process.

problem of PC. Four of the measurements (PTI, PTI at 0° of knee flexion, patellar tendon length, and IS index) indicate the significant role of patella alta (PTI < 30%-37%[39,41]), and max curvature together with mean curvature indicate the relationship between the PC and the shape of the femoral condyle. In patients with PC, the cartilage damage location correlated with the increased curvature of the femoral condyle. Based on these results, we conclude that the PC in patients without a history of patellar subluxations is highly likely to result from a combination of 2 factors: patella alta and the supratrochlear rim. Analyzing the results of this study, we can set a temporary benchmark of 0.9 (mm^{-1}) of maximum condylar curvature as a boundary between the knees less and more likely to develop PC. The 95% confidence interval for measurements indicating patella alta and presence of the supratrochlear rim did not contain the value "0." This indicates that there is 95% confidence of difference in means for these measurements between groups. We also observed that the supratrochlear rims mostly extend from the center of the trochlea towards the medial side, rarely extending towards the lateral side. This observation aligns with previous observations.[20-23] We presented a 3-dimensional (3D) reconstruction of the femur from 2 injured knees from the "PC I-IV" group (Fig 6) and the rim in arthroscopic and open-surgical views (Fig 7). Note the presence of the rim and the corresponding location of the damaged patellar cartilage in Figure 6. In a fully extended knee, the patella lies partially or completely proximal to the supratrochlear rim. As flexion begins the patella mounts the rim before sliding down the femoral condyles. The patellar cartilage is likely damaged by having to pass over a supratrochlear rim on the way to the trochlea. However, this study cannot prove or disprove this. It may be possible that the rim only occurs in response to patella alta. The patella starts outside the groove, for early flexion goes to enter the groove, and in doing so rubs on the supratrochlear region that responds by hypertrophying, creating a supratrochlear rim. Essentially, it is unclear what came first, the rim or patella alta.

In addition, patella type III and trochlear dysplasia grades B were found more common in the defect group. We predict that the supratrochlear rim can be an anatomical part of a trochlear dysplasia grade A and B. On the other hand, the control group had 78% patients with trochlear dysplasia grade A, which shows the supratrochlear rim is not always present in patients with minor trochlear dysplasia. The prediction of the relationship between the rim and trochlear dysplasia is, however, feasible as the supratrochlear spur is commonly detected in patients with major trochlear dysplasia and history of patellar subluxation, which is discussed later.

Our work is in accordance with the study of Mehl et al.,[42] where the authors also aimed to identify anatomical features associated with isolated cartilage defects of the patella in patients without a history of patellar dislocation. They hypothesized that several

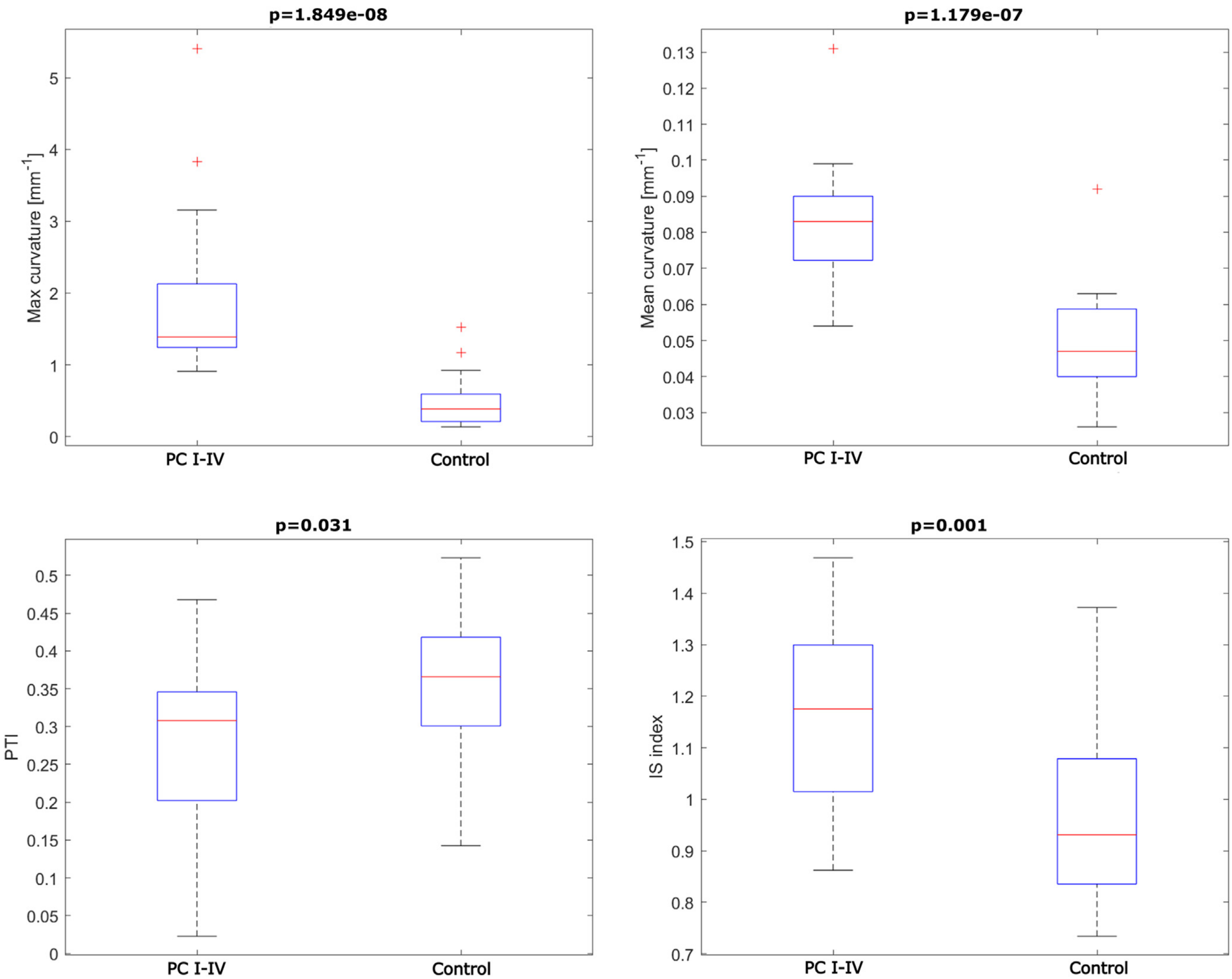

Fig 5. Boxplots of statistically significant results: Maximum Curvature, Mean Curvature, PTI at 0° flexion, Insall-Salvati Index.

abnormalities of the patellofemoral geometry can be identified in patients with isolated PC. The study concluded that trochlear dysplasia and patella alta seem to contribute to the development of patellar cartilage defects.[42] In our work, we agree with the fact that patella alta is strongly correlated with isolated PC, but in addition to Mehl et al.,[42] we found a correlation of PC with a sharp proximal edge of the condyles — supratrochlear rim. Regarding trochlear dysplasia, we found only 15% of patients with trochlear dysplasia grade B in the defect group against no such dysplasia in the control group. Mehl et al.,[42] on the other hand, found 53.5% of patients with trochlear dysplasia grades B-D in their defect group and 18.6% in the control group. Our SA measurement is most similar to their proximal osseal sulcus angle, which corresponds to trochlear dysplasia. However, their description of the proximal measurement location: "axial cut where the cartilage extends to the whole trochlea and is still in contact with the patella" is ambiguous because it is not clear how far from the start of the cartilage it was measured, and the contact with the patella can change depending on the knee flexion during the scan. Our measurement was quantified in the first proximal axial slice with full cartilage width. Our results show that the SA in patients with PC was 139.9° ± 6.7°, whereas their proximal osseal sulcus angle was 152.5° ± 6.0°. However, their proximal osseal sulcus angle in the control group was also significantly higher (149.8° ± 7.2°) than ours (139.4° ± 6.0°). Even though both studies excluded patients with a history of patellar dislocation, our study additionally excluded patients with a history of patellar subluxation. Mehl et al.[42] does not mention patients with subluxation. We predict that this difference in patient selection could have influenced a higher percentage of patients with trochlear dysplasia and, hence, higher average sulcus angle.

Table 3. Inter- and Intra-reliability Analysis[*]

	Control										Defect (PC I-IV)									
	Intra-Reliability					Inter-Reliability					Intra-Reliability					Inter-Reliability				
	Scientist Trial 1	Scientist Trial 2	95% CI	*P* Value	ICC	Scientist Trial 1	Surgeon	95% CI	*P* Value	ICC	Scientist Trial 1	Scientist Trial 2	95% CI	*P* Value	ICC	Scientist Trial 1	Surgeon	95% CI	*P* Value	ICC
Max Curvature (mm^{-1})	0.7 ± 0.3	0.7 ± 0.2	[−0.3, 0.3]	.90	0.94	0.7 ± 0.3	0.7 ± 0.2	[−0.3, 0.3]	.90	0.62	1.9 ± 0.8	1.9 ± 0.6	[−0.8, 0.8]	0.1	.97	1.9 ± 0.8	1.2 ± 0.5	[−0.1, 1.5]	.10	**0.32**
Mean Curvature (mm^{-1})	0.05 ± 0.01	0.06 ± 0.01	[−0.01, 0.01]	.80	0.91	0.05 ± 0.01	0.06 ± 0.01	[−0.02, 0.01]	.30	0.7	0.08 ± 0.01	0.08 ± 0.01	[−0.01, 0.02]	0.5	.92	0.08 ± 0.01	0.08 ± 0.02	[−0.02, 0.02]	>.99	0.9
PH (mm)	33.7 ± 5.2	33.4 ± 5.0	[−5.1, 6.3]	.60	0.98	33.7 ± 5.2	34.4 ± 5.2	[−6.9, 5.4]	.30	0.97	33.0 ± 4.8	32.0 ± 5.5	[−5.0, 7.1]	0.4	.92	33.0 ± 4.8	32.5 ± 4.7	[−5.1, 6.0]	**.04**	0.99
SGL (mm)	34.3 ± 4.8	34.4 ± 3.8	[−5.2, 4.9]	.90	0.94	34.3 ± 4.8	35.1 ± 4.5	[−6.3, 4.6]	.30	0.96	33.2 ± 4.9	33.8 ± 5.7	[−6.9, 5.6]	0.5	.94	33.2 ± 4.9	33.2 ± 5.0	[−5.9, 5.7]	.50	0.99
SGL/PH	1.02 ± 0.08	1.04 ± 0.12	[−0.1, 0.1]	.50	0.86	1.02 ± 0.08	1.03 ± 0.10	[−0.1, 0.1]	.80	0.94	1.0 ± 0.07	1.07 ± 0.14	[−0.19, 0.06]	0.4	**.40**	1.0 ± 0.07	1.02 ± 0.07	[−0.10, 0.06]	**.02**	0.97
PAO (mm)	17.9 ± 5.0	18.5 ± 4.7	[−6.3, 5.1]	.05	0.99	17.9 ± 5.0	18.5 ± 4.9	[−6.4, 5.2]	.30	0.98	12.9 ± 2.8	12.6 ± 3.1	[−3.2, 3.8]	0.5	.97	12.9 ± 2.8	12.6 ± 2.8	[−3.0, 3.6]	.10	0.99
PTI = PAO/PH	0.53 ± 0.10	0.55 ± 0.10	[−0.1, 0.1]	**.01**	0.98	0.53 ± 0.10	0.54 ± 0.11	[−0.1, 0.1]	.50	0.99	0.40 ± 0.11	0.41 ± 0.13	[−0.15, 0.14]	0.5	.99	0.40 ± 0.11	0.40 ± 0.11	[−0.13, 0.14]	.50	0.99
PTI at 0° of knee flexion[39]	0.40 ± 0.07	0.43 ± 0.08	[−0.12, 0.07]	.10	0.93	0.40 ± 0.07	0.38 ± 0.07	[−0.06, 0.11]	.10	0.91	0.30 ± 0.10	0.30 ± 0.12	[−0.14, 0.13]	0.7	.88	0.30 ± 0.10	0.26 ± 0.10	[−0.09, 0.16]	.10	0.93
Ridge height (mm)[38]	2.6 ± 1.5	3.0 ± 1.3	[−2.0, 1.3]	.40	0.84	2.6 ± 1.5	2.9 ± 1.5	[−2.0, 1.5]	.50	0.91	4.9 ± 0.3	5.1 ± 0.3	[−0.6, 0.2]	0.4	**.29**	4.9 ± 0.3	5.2 ± 0.4	[−0.7, 0.1]	.10	0.52
Patellar diagonal length (mm)	46.1 ± 3.3	46.2 ± 3.4	[−3.9, 3.9]	>.99	0.99	46.1 ± 3.3	45.7 ± 3.2	[−3.3, 3.2]	.50	0.93	43.0 ± 4.6	42.9 ± 4.5	[−5.3, 5.5]	0.6	.99	43.0 ± 4.6	42.5 ± 4.6	[−5.0, 5.9]	.10	0.99
Patellar tendon length (mm)	44.6 ± 8.2	44.9 ± 7.7	[−9.7, 9.0]	.30	0.99	44.6 ± 8.2	45.8 ± 8.5	[−11.1, 8.6]	.30	0.97	48.9 ± 3.7	49.5 ± 3.9	[−5.1, 3.8]	0.1	.98	48.9 ± 3.7	53.6 ± 6.0	[−10.5, 1.1]	.10	0.54
Insall-Salvati Index	0.96 ± 0.15	0.97 ± 0.13	[−0.17, 0.16]	.30	0.99	0.96 ± 0.15	1.0 ± 0.15	[−0.20, 0.14]	.30	0.91	1.15 ± 0.15	1.17 ± 0.15	[−0.19, 0.16]	0.2	.99	1.15 ± 0.15	1.27 ± 0.15	[−0.29, 0.05]	**.04**	0.7
Entrance to trochlea (mm)[35]	23.9 ± 2.9	24.5 ± 1.4	[−3.2, 2.1]	.50	0.8	23.9 ± 2.9	24.5 ± 1.6	[−3.3,2.2]	.60	0.75	27.5 ± 4.5	28.3 ± 4.7	[−6.2, 4.7]	0.5	.99	27.5 ± 4.5	28.2 ± 4.9	[−6.3, 4.9]	.40	0.95
SP-ET Index[35]	0.72 ± 0.06	0.75 ± 0.09	[−0.12, 0.06]	.30	0.78	0.72 ± 0.06	0.73 ± 0.11	[−0.11, 0.09]	.80	0.82	0.83° ± 0.06°	0.89° ± 0.08°	[−0.14, 0.02]	0.2	**.46**	0.83° ± 0.06°	0.87° ± 0.09°	[−0.12, 0.05]	.20	0.81
Medial trochlear inclination	20.0° ± 3.4°	19.9° ± 2.4°	[−3.6, 3.8]	.80	0.98	20.0° ± 3.4°	20.0° ± 3.2°	[−3.8, 4.0]	.80	0.98	23.5° ± 3.6°	23.2° ± 3.2°	[−3.7, 4.3]	0.3	.99	23.5° ± 3.6°	22.5° ± 3.6°	[−3.2, 5.2]	.10	0.93
Lateral trochlear inclination	17.7° ± 2.6°	18.1° ± 2.7°	[−3.4, 2.8]	.10	0.99	17.7° ± 2.6°	17.7° ± 2.7°	[−3.1, 3.2]	.90	0.97	17.6° ± 1.2°	17.7° ± 1.1°	[−1.4, 1.4]	0.9	.93	17.6° ± 1.2°	16.8° ± 2.5°	[−1.5, 3.2]	.30	0.69
Sulcus angle	142.2° ± 5.8°	142.0° ± 5.5°	[−6.4, 6.9]	.60	0.99	142.2° ± 5.8°	142.4 ± 5.8	[−7.0, 6.7]	.80	0.98	138.9° ± 3.0°	139.1 ± 2.8	[−3.7, 3.2]	0.2	.99	138.9° ± 3.0°	140.1° ± 3.4°	[−5.7, 1.9]	**.03**	0.83
Trochlear angle	3.3° ± 1.1°	3.6° ± 1.4°	[−1.8, 1.1]	.30	0.91	3.3° ± 1.1°	3.5° ± 1.0°	[−1.4, 1.1]	**.03**	0.99	2.8° ± 1.0°	3.7° ± 1.1°	[−2.0, 0.4]	0.1	.99	2.8° ± 1.0°	2.8° ± 1.0°	[−1.1, 1.3]	.3	0.99
Trochlear depth (mm)	6.0 ± 1.0	6.1 ± 0.8	[−1.2, 1.0]	0.6	0.92	6.0 ± 1.0	6.0 ± 0.9	[−1.1, 1.2]	.90	0.99	5.9 ± 0.7	6.0 ± 0.8	[−1.0, 0.7]	0.6	.79	5.9 ± 0.7	5.8 ± 1.0	[−0.9, 1.1]	.70	0.85
Patellar width (mm)	47.2 ± 4.1	46.5 ± 4.5	[−4.4, 5.7]	0.3	0.97	47.2 ± 4.1	46.8 ± 4.1	[−4.5, 5.2]	.20	0.99	45.0 ± 5.1	45.3 ± 4.5	[−6.0, 5.4]	0.6	.98	45.0 ± 5.1	45.0 ± 4.6	[−5.7, 5.8]	.90	0.99
Patellar tilt	10.8° ± 1.3°	10.8° ± 1.7°	[−1.8, 1.8]	>.99	0.73	10.8° ± 1.3°	11.7° ± 1.8°	[−2.7, 1.0]	**.04**	0.85	10.9° ± 3.9°	10.7° ± 3.6°	[−4.2, 4.6]	0.7	.98	10.9° ± 3.9°	9.6° ± 3.9°	[−3.3, 5.8]	.40	0.73
Congruence angle	9.2° ± 2.3°	9.1° ± 2.6°	[−2.8, 3.0]	.70	0.76	9.2° ± 2.3°	8.0° ± 3.3°	[−2.2, 4.5]	.30	0.76	11.4° ± 2.6°	11.0° ± 2.4°	[−2.5, 3.4]	0.1	.98	11.4° ± 2.6°	10.1° ± 3.7°	[−2.5, 5.1]	.20	0.82

CI, confidence interval; ICC, intraclass correlation coefficient; PAO, patellar articular overlap; PC, patellar chondromalacia; PH, patellar height; PFP, patellofemoral pain; PH, patellar height; PTI, patellotrochlear index; SGL, sulcus groove length.

[c]Values were given as the mean ± standard deviation. Groups were compared using t-test. '95% CI' stands for 95% confidence interval and ICC stands for intraclass correlation coefficient. *P*-value < .05 and ICC < .5 are presented in bold.

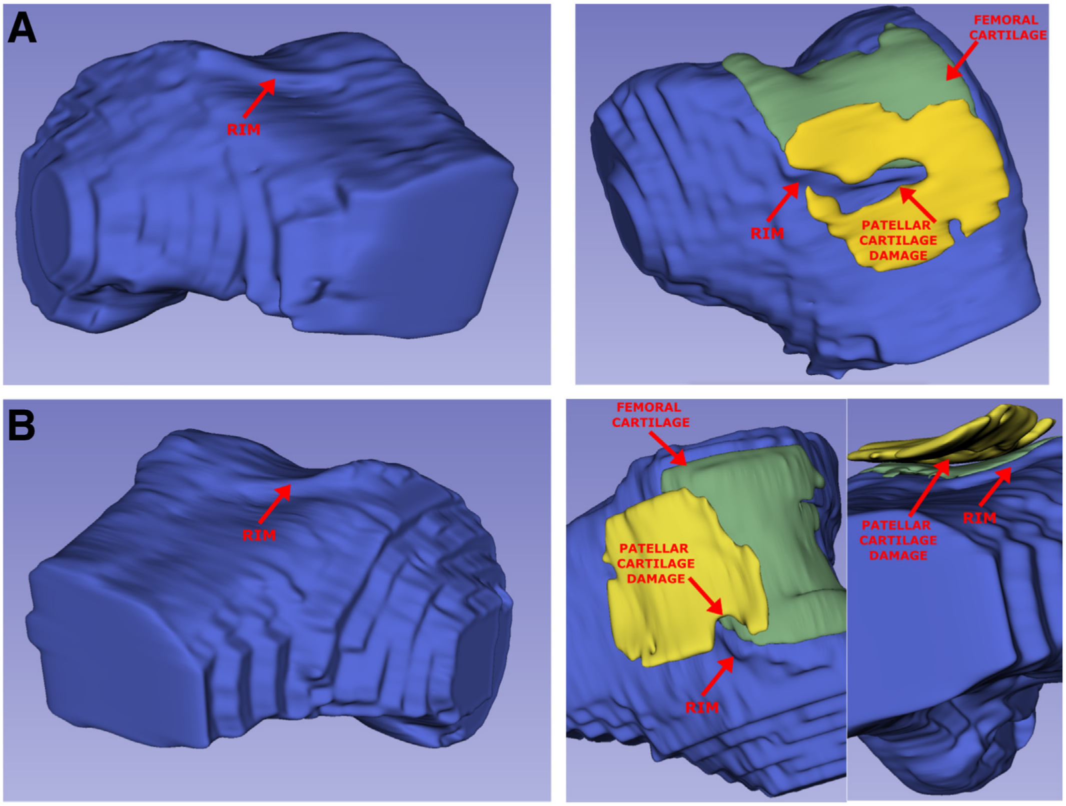

Fig 6. Examples of two knees with PC and femoral condylar rim. (A) Left illustrates a 3-dimensional (3D) reconstruction of a right femur with an indicated rim, and (a) Right is the same femur with articular cartilage displayed in green and damaged patellar cartilage in yellow. (B) Left illustrates a 3D reconstruction of a left femur with an indicated rim, and (b) right is the same left femur with articular cartilage displayed in green and damaged patellar cartilage in yellow.

The potential reason for PC in patients without a history of subluxation and dislocation may be related to a correlation between the abnormal anterior femoral shape (supratrochlear rim) and PC.[20] This correlation was later proven and a surgical procedure was proposed to remove the excessive bone tissue from underneath femoral cartilage and hence remove the rim to recover a smooth shape of the condyle.[21,22] Another study followed up with the concept of the rim as the etiology of PC and confirmed the satisfactory results of the proposed procedure.[23] In 1975 Marar et al.[38] measured the height of the condyle instead of the rim and concluded that it is not correlated with PC. Since then the role of the rim has not been well studied.[43,44] Only a limited number of works referred to Outerbridge's discovery without rejecting the idea but also without further investigation.[17,40,45]

This study also takes inspiration from numerous works that intended to identify the reason for PC in patients with a history of patellar subluxations and dislocations. The events of patellar subluxation and dislocation are related to major trochlear dysplasia

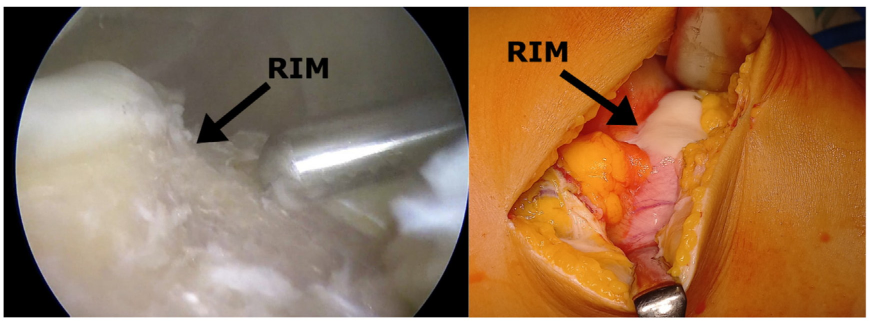

Fig 7. Supratrochlear rim in arthroscopic view of left knee (left) and in open surgery of right knee (right). Both images were taken in patients with PC without a history of patellar subluxation.

characterized by the combination of a flat or prominent trochlea. That abnormal trochlea offers inadequate patellar tracking during flexion and leads to subluxation or dislocation of the patella and eventually can cause PC.[46–50] Multiple studies, together with trochlear dysplasia, have also discovered a supratrochlear spur, also called trochlear bump/lump, which is a prominent, dysplastic beginning of the lateral femoral condyle visible in lateral x-rays, consistent with the Dejour classification of trochlear dysplasia.[9] Beaufils et al.[51] identified the supratrochlear spur as one of the important factors causing patellar subluxation and leading to PC. They measured the supratrochlear spur as the distance between a line tangential to the anterior femoral cortex, and a line parallel to this through the trochlear groove. A similar observation was we presented by van Haver et al.[52] who identified supratrochlear spur as one of the main causes of isolated PC in patients with trochlear dysplasia and a history of subluxation. These studies identified the supratrochlear spur as an interconnected part of trochlear dysplasia. We would like to highlight that the supratrochlear rim is a specific type of supratrochlear spur but not related to trochlear dysplasia. We predict that the rim might be smaller than the spur and therefore too small to participate in subluxation but large enough to cause patellar cartilage damage.

As a solution to the subluxation and PC caused by the supratrochlear spur, proximal (trochlear entrance) grooveplasty, also called bumpectomy, has been proposed to remove the spur and flatten the entry into the trochlear groove.[10,53–56] In this open procedure, the proximal trochlea is exposed, and the center of the trochlear groove is identified. The proximal trochlear cartilage is removed to then remove the supratrochlear spur with a burr and smoothen the trochlear entrance. As the next step the surrounding synovium is attached back to the margin of the articular cartilage.[56]

Currently, collagen membrane techniques are used to treat isolated PC with 10 years of promising clinical results.[57–59] The first arthroscopic patellar cartilage reconstruction with this type of membrane was presented in 2012.[59] The reconstruction results are promising but our clinical experience indicates that, in case of patellar cartilage reconstruction, this might be a treatment of the symptom, not of the underlying cause. Some of the patients we recruited have undergone patellar cartilage reconstruction. Rehabilitation did not bring satisfactory results, and these patients were still experiencing PFP after two years after the surgery even though MRI has shown good quality of the reconstruction. We predict that the mechanical conflict between the supratrochlear rim and the reconstructed patellar cartilage can be the reason for the remaining PFP in such patients.

Limitations

Because of the retrospective character of the study no standardized knee positioning was implemented before in the MRIs. Another limitation stems from the limited study size which affects the statistical power and could lead to underestimation of the group differences for some measurements. The femoral curvature measurement is performed here only on one sagittal plane. To measure it more accurately and with higher clinical relevance, the measurement should be performed in 3D along the anterior femoral surface. Additionally, the clinical data was collected only from the database of Rehasport Clinic.

Conclusions

In this case-control study, We have shown through MRI knee measurements that the isolated patellar chondromalacia in patients without a history of patellar subluxation and dislocation is correlated with the increased anterior femoral curvature in combination with patella alta.

Disclosure

The authors declare the following financial interests/personal relationships, which may be considered as potential competing interests: T.P. reports personal fees from Rehasport Clinic outside the submitted work. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

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