ADDIS ABABA UNIVERSITY

COLLEGE OF MEDICINE AND HEALTH SCIENCES

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF RADIOLOGY

PREVALENCE OF CHONDROMALACIA PATELLA AND ITS ASSOCIATION WITH PATELLOFEMORAL JOINT MORPHOLOGY AMONG ADULTS IN ETHIOPIA AT PIONEER DIAGNOSTIC CENTER: AN INSTITUTION-BASED CROSS-SECTIONAL MRI STUDY

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Prevalence of Chondromalacia Patella and Its Association with Patellofemoral Joint Morphology among Adults in Ethiopia at Pioneer Diagnostic Center: An Institution-Based Cross-Sectional MRI Study.

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December 2025

Addis Ababa, Ethiopia

DECLARATION

Letter of declaration

By signing below, I declare that this thesis is entirely my original work. I have adhered to all ethical principles throughout its preparation, including during data collection, analysis, and completion. All scholarly material included in this thesis has been properly acknowledged through citation; I have cited and referenced every source used. Every effort has been made to avoid plagiarism. This thesis is submitted in partial fulfillment of the requirements for a graduate degree from Addis Ababa University, College of Health Sciences, School of Medicine, Department of Radiology, Musculoskeletal Unit. It has not been presented or submitted, in whole or in part, to this or any other university for the award of a degree, diploma, or other qualification.

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List of acronyms and abbreviations

CP	Chondromalacia patella
MRI	Magnetic resonance imaging
ISI	Insall-Salvati index
SPSS	Statistical Package of Social Sciences

Abstract

Background

Chondromalacia patella (CP) is characterized by chondral damage of the patellar articular surface, ranging from cartilage softening to fissuring and full-thickness loss. It is a frequent cause of anterior knee pain, and has been associated with altered patellofemoral joint morphology and abnormal tracking. Despite its clinical importance, there is limited evidence from sub-Saharan Africa, and as far as our knowledge, no study from Ethiopia has yet examined the burden of CP or its morphological associations using magnetic resonance imaging (MRI).

Objective

The primary objective of this study is to determine the prevalence and severity of CP on knee MRI among adult patients. In addition, we aim to evaluate patellofemoral morphological and tracking parameters and investigate their association with CP.

Material and methods

An institution-based retrospective cross-sectional study was conducted, in which 333 knee MRI examinations were systematically sampled and reviewed. Each MRI was assessed for the presence and grading of chondromalacia patella, along with measurements of standard patellofemoral morphological parameters. To ensure reliability, both intra-observer and interobserver agreement were evaluate

Results

Chondromalacia patella was identified in 189 cases (59.8%). Both intra-observer and interobserver reliability demonstrated strong agreement. Chondromalacia patella showed a significant correlation with both sex and age. Among the patellofemoral morphological parameters assessed, only patellar height index and patellar tilt demonstrated significant associations with CP. The patellar height index was higher in the CP group (1.256 ± 0.233) compared with the non-CP group (1.19 ± 0.202) ($p = 0.007$). Similarly, the patellar tilt angle was greater in the CP group (11.45 ± 6.72°) than in those without CP (10.02 ± 6.22°) ($p = 0.047$).

Conclusion

Chondromalacia patella is a common pathology in our study population. Patellar height index and patellar tilt significantly influence the risk of patellar cartilage degeneration.

Keywords

Chondromalacia patella, patellofemoral morphology, MRI, Ethiopia

1. Introduction

1.1. Background

Chondromalacia patella (CP) refers to the abnormal softening of the hyaline cartilage of the patella, which may gradually progress to fissuring, tearing, or erosion [1]. The pathological features of CP were first described in the medical literature by Budinger et al. in 1906 based on a cadaveric study. Later, in 1992, Kelly et al**.** coined the term *chondromalacia patella*—derived from Greek, meaning "softening of cartilage"—and described chondral damage as a distinct disease entity responsible for anterior knee pain, requiring accurate diagnosis and appropriate management [1].

CP is common in young, active adult especially with activity, which result in an excessive of loading and repetitive stress in patellofemoral joint like kneeling, squatting and climbing stair. CP predominately affect female due to the wider hip which increase Q angle in quadriceps tendon result in the increase lateral pressure on patellar leading into cartilage damage [1]. Patellofemoral pain syndrome is a common orthopedic problem causing disability where majority of the cases attributed to patellar cartilage damage [2]. Multiple factors contribute to the development of chondromalacia patella, including direct trauma such as falls or blows to the knee, as well as repetitive micro-trauma from activities like stair climbing, squatting, and jumping, which can subject the patellofemoral joint to forces ranging from three to twenty times body weight [1,3,4]. Patellofemoral incongruence leads to abnormal patellar tracking, which in turn increases focal mechanical loading on the articular cartilage. This altered stress distribution predisposes to chondral damage and accelerates degenerative changes within the patellofemoral joint [1–3]. Patellofemoral incongruence affect by multiple factor including ligament integrity, quadriceps muscle imbalance as well as morphology of patellar and trochlear [1].

CP clinically presented as anterior knee pain with grinding or catching sensation especially during activity like climbing stairs, squatting or sitting for long period [1]. Epidemiological study in United Kingdom primary care setup show that patellofemoral disorder account for nearly 1 in 6 knee consultation. However, most cases are non-specifically coded as ‘anterior knee pain,’ with specific diagnoses such as chondromalacia patella being rarely recorded [5]. The finding underscore underestimation of CP in clinical practice. A validity study evaluating the Clarke’s test, which is commonly employed as a clinical diagnostic tool for chondromalacia patella, demonstrated limited diagnostic utility. When compared with arthroscopy, the test showed a sensitivity of only 39% and a specificity of 67%, indicating poor reliability in accurately identifying the condition [6].

Arthroscopy is a gold standard diagnostic method for CP by identifying for the presence of the lesion, location and severity, however due to it invasive nature it is not preferable method for routine clinical workup [1,2]. Magnetic resonance imaging (MRI) is currently the gold stander noninvasive imaging modality, which provide comprehensive evaluation of patellofemoral joint for assessing cartilage, ligament and patellofemoral morphology, which is critical for diagnosis, surgical planning and prognosis [1,7]. A systematic review assessing the diagnostic performance of MRI for detecting patellofemoral chondral defects, comparing with arthroscopy as the gold standard, demonstrated that MRI is a highly reliable and noninvasive tool. The review reported high diagnostic accuracy, along with substantial to almost perfect interobserver reliability [7]. Management of chondromalacia patellar range from primary conservative management up to surgical intervention depending on patient level of pain, severity of disease and level of activity.

Where MRI image might be the first screening imaging study, which could help with the diagnosis and assess severity of chondromalacia as well as assess for patellofemoral morphology risk factor so that management can be tailor to patient specific finding.

1.2. Significance of the Study

Chondromalacia patella is a common cause of anterior knee pain worldwide. While multiple international studies have explored its association with patellofemoral morphology using MRI, as far as the writer's knowledge there is a notable absence of data from Ethiopia and the wider SubSaharan Africa region**.** The lack of local evidence limits understanding of the burden of CP, its morphological correlates, and the potential role of MRI in diagnosis and management within this context.

As far as our knowledge this study is the first in Ethiopia to systematically investigate chondromalacia patella and its association with patellofemoral morphology using MRI. Findings from this research will provide region-specific data, contribute to filling the knowledge gap in Sub-Saharan Africa, and may inform clinical decision-making, early diagnosis, and targeted management strategies for anterior knee pain in Ethiopian populations.

2. Literature Review

2.1. Prevalence of chondromalacia patella

CP is a frequent cause of anterior knee pain, with its reported prevalence varying widely across studies due to differences in population characteristics, age distribution, sex, geographic location, and MRI field strength. A large 2022 Turkish cohort study that evaluated 562 knees using 1.5T MRI reported a high prevalence of 79.5%, supported by excellent inter-reader reliability (ICC = 0.90) [8]. In contrast, a very large Chinese study from 2016 assessing 1,703 knees using 0.2T MRI found a prevalence of 38%, with significantly higher rates in females than males (46.4% vs

28.8%, $p < 0.001$). This study also demonstrated excellent intra- and inter-observer reliability for alignment indices (ICC 0.966 and 0.939, respectively)[9].

Similarly, a 2015 Turkish cross-sectional MRI study involving 302 patients on 1.5T MRI reported a CP prevalence of 42.7%, while a 2013 Turkish series of 301 knees using the same field strength found a prevalence of 48% [2,10]. A multicenter osteoarthritis study conducted in Germany and the United States in 2012, using 1.0T MRI in an elderly population (mean age 69), reported patellofemoral cartilage damage in 36% of lateral compartments and 48% of medial compartments[11]. A 2009 U.S. study involving 100 knees showed significantly higher prevalence and severity of CP in adults aged ≥40 years compared to those <40 years (78% vs 30%). In a subset of cases validated against arthroscopy, MRI demonstrated moderate diagnostic agreement ($\kappa = 0.6219$) [12]. Additionally, a U.S. retrospective study from 2007 using 1.5T MRI on 98 knees reported a CP prevalence of 44%, with excellent reproducibility for most morphological measurements, except for the patellar facet ratio at the inferior level[13].

Collectively, these studies highlight CP as a common MRI finding, though reported prevalence varies from 30% to nearly 80%, influenced by population and MRI strength.

2.2. Patellofemoral morphology measurements

Assessment of patellofemoral morphology can be performed using both qualitative and quantitative approaches. Quantitative (numerical) measurements provide a more objective evaluation, facilitate longitudinal follow-up, and allow for clearer communication between clinicians and researchers. To date, more than 50 different measurements have been described for evaluating patellar and trochlear morphology, as well as patellofemoral tracking. However, the lack of standardization among these methods has created confusion and reduced the overall reliability of findings. In this study, we will focus on a subset of measurements that have been consistently applied across multiple publication [4].

2.3. Patellar Morphology

Morphological variations of the patella were assessed using qualitative parameters based on Baumgartl's classification. In addition, more than 11 patellar morphological measurements, including patella facet ratios, have been investigated in the literature for their potential contribution to CP [4].

In the 2022 Turkish study, patellar types were distributed as Type I (50.71%), Type II (36.7%), Type III (12.3%) and Type IV (0.3%). While no association was found in females, significant associations were noted in males and in combined sexes [8]. In the same way, A 2022 Chinese case-control study using 3.0T MRI (198 participants, 57 with early CP) demonstrated a significantly lower patellar facet ratio in the CP group (p=0.043). The study also indicates that CP is more prevalent among females [14].

The 2015 Turkish cohort reported that Type II patella was the most common (68%), while Type III patella demonstrated the highest prevalence of CP (64%) with a strong association. The study also found a higher incidence of CP among women compared to men (50% vs. 34%) [10]. The 2009 U.S. study found no correlation between patellar facet ratio across age groups [12]. The 2007 U.S. study similarly found that patellar facet ratios at multiple levels did not correlate with CP [13].

These findings suggest inconsistent evidence, with some studies supporting an association between patellar type or facet ratio and CP, while others show no correlation.

2.4. Trochlear Morphology

Trochlear dysplasia is frequently implicated in the development of CP, with the Dejour classification identifying patients at high risk [15]. More than 38 different measurements of trochlear morphology have been described in the literature, among which sulcus angle, trochlear depth, and lateral trochlear inclination are the most frequently associated with CP[4].

The 2022 Turkish cohort identified lateral trochlear inclination as the strongest predictor of CP, whereas sulcus angle and medial inclination were not significant [8]. Building on this, the 2022 Chinese case–control study using 3.0T MRI demonstrated significant associations between CP and shallow trochlear depth ($p < 0.001$), a wider sulcus angle ($p = 0.010$), and a reduced trochlear facet ratio ($p = 0.01$) . Notably, lateral trochlear inclination showed the weakest association in this study ($p = 0.040$) [14]. Supporting these results, a 2019 U.S. study of 235 patients also reported that CP was associated with an increased sulcus angle ($p = 0.0002$) and reduced trochlear depth ($p = 0.0003$) [15] .

However, some studies present a more selective pattern of associations. A 2014 German case–control study comparing 43 arthroscopy-confirmed severe defects with matched controls found that only the proximal chondral sulcus angle differed significantly, while other trochlear parameters showed no meaningful variation [16]. Similarly, the 2013 Turkish study observed significantly higher sulcus angles and shallower trochlear depths among CP patients ($p < 0.01$) [2].

Consistent with the variability across studies, the 2012 multicenter osteoarthritis cohort reported that lower lateral trochlear inclination had the strongest correlation with patellofemoral cartilage damage, followed by a moderate association for trochlear angle, while sulcus angle showed the weakest relationship [11]. Age-stratified analysis from the 2009 U.S. cohort further demonstrated that, in younger individuals, severe cartilage defects were significantly associated with trochlear depth ($p = 0.001$), sulcus angle ($p = 0.003$), and lateral trochlear inclination ($p = 0.007$), whereas trochlear facet ratio showed no correlation. In contrast, mild defects in any age group and severe defects in patients over 40 did not exhibit significant associations with any trochlear morphological indices [12]. Likewise, the 2007 U.S. study reported no significant difference in trochlear depth between groups [13].

2.5. Patellofemoral Alignment

Over 39 indices have been described to assess patellar tracking, including patellar tilt, patellar translation, patellar height, and tibial tubercle lateralization. These parameters have been extensively investigated as key biomechanical contributors to patellofemoral stress and the development of chondromalacia patella [4].

The 2022 Turkish study reported no significant association between patellar tilt or the Insall–Salvati Index (ISI) and CP [8]. In contrast, the 2019 U.S. case–control study demonstrated a strong relationship between ISI and cartilage damage ($p = 0.0006$), although no significant difference in TT–TG distance was observed [15]. Similarly, the large 2016 Chinese cohort showed that both patella alta and patella baja were significantly associated with CP ($p < 0.001$), highlighting the broader relevance of patellar height abnormalities [9].

Complementing these results, the 2014 German study found a significantly higher ISI among patients with cartilage defects ($p = 0.01$) [16]. Earlier work, however, reported more neutral findings: the 2009 U.S. study noted no correlation between ISI and CP across age groups [12]. The 2007 U.S. study likewise found no difference in tendon-to-patella length ratio[13] .

2.6. Severity of CP

Few studies have directly addressed severity. A 2018 Turkish case only cross-sectional study of 38 MRI-confirmed CP cases divided into early and advanced disease stages found no significant morphological differences, though it's small sample size limits interpretation [17]. Similarly, The 2013 Turkish cohort reported nearly equal proportions of mild and severe CP (49.5% vs 50.5%), with no statistical difference in morphology between groups [2].

3. Objectives

3.1. General Objectives

To determine the prevalence of chondromalacia patella on knee MRI among patients presenting with knee pain in Ethiopia, and to assess its association with patellofemoral joint morphology during the period from January 1, 2024, to December 31, 2024.

3.2. Specific Objectives

- To determine the prevalence of chondromalacia patella on knee MRI.
- To classify chondromalacia patella according to the Noyes grading system.
- To assess the morphological parameters of the patellofemoral joint.
- To evaluate the association between patellofemoral morphological features and the presence of chondromalacia patella.

4. Material and methods

4.1. Study setting and study design

An institution-based retrospective cross-sectional study was conducted at a Pioneer Diagnostic Center in Addis Ababa, Ethiopia. The center is equipped with three 1.5 Tesla MRI scanners and receives a high volume of referrals from multiple hospitals and orthopedic centers within the city and other regions of the country.

4.2. Study period

The study period included between January 1, 2024 and December 31, 2024

4.3. Study population

All patients who underwent knee MRI at the diagnostic center during the specified period were included, regardless of the indication, referring facility, or clinical diagnosis.

4.4.Inclusion and exclusion criteria Inclusion Criteria

- Patients aged 15 years and older.
- Bilateral knees of the same patient within the study period will be consider as independent observations.

Exclusion Criteria

- Patients with a history of knee surgery.
- Patients with inflammatory or infectious arthritis.
- Patient is fracture involving knee joint
- MRIs demonstrating poor image quality or significant artifacts.
- Repeat imaging of the same knee within the study period will not be considered; only the initial MRI will be included.

4.5.Sample size and sampling technique

4.5.1. Sampling size

From 2,500 knee MRIs performed between January 2024 and December 2024, 333 examinations were selected. The sample size is determined using a cross-sectional study formula, applying a conservative prevalence estimate of 48% for chondromalacia patella based on a previous 1.5tesla MRI study [2].

$$n = \frac{Z^2 \cdot p \cdot (1-p)}{d^2}$$

Formula for sample size based on prevalence→
Where:

n = required sample size

Z= Z-score for desired confidence level (e.g., 1.96 for 95% confidence) p= estimated prevalence (as a decimal)

d= desired margin of error (absolute precision, in decimal form)

Given values

Prevalence: p=48%=0.48, Confidence level: 95% → Z=1.96, Margin of error d=5%=0.05 Plug values into formula→ $n = \frac{(1.96)^2 \cdot 0.48 \cdot (1-0.48)}{(0.05)^2}$

Required sample size (n0) = 384

Finite population correction formula (FPC)→ $n = \frac{n_0}{1 + \frac{n_0 - 1}{N}}$ Where:

n0 = sample size without FPC (384), N = total population (2500), n= adjusted sample size Plug values into formula → $n = \frac{384}{1 + \frac{384-1}{2500}}$

Adjusted sample size(n)= 333patients

4.5.2. Sampling technique

A systematic random sampling technique were used to select sample form sampling frame.

4.6.MRI Protocol:

All knee MRI examinations were performed using a 1.5T scanner (SIGNA Explorer, GE Medical Systems) with the patient in a supine position and the knee in full extension. Two sequences were reviewed to collect the data: sagittal FSE PD-weighted with fat suppression (TR/TE 2873/36, slice thickness 3 mm) and axial FSE PD-weighted (TR/TE 3120/35, slice thickness 3 mm). Each image were analyzed on a RadiAnt workstation using electronic calipers. Measurements were taken only from the osseous surfaces, excluding cartilage, to minimize variability [12].

4.7. Operation definition

Chondromalacia patellar presence and grade

Chondral lesions of the patellar facets will be assessed using the modified Noyes grading system. Originally introduced in 1989 for arthroscopic evaluation of articular cartilage lesions, this system has since been adapted for MRI-based classification of chondral defects [18].

Table 1: Modified Noyes classification

Grade	
0	Normal
1	Increased T2 signal intensity of morphologically normal cartilage
2a	Superficial partial-thickness cartilage defect <50% of total articular surface thickness
2b	Deep partial-thickness cartilage defect >50% of total articular surface thickness
3	Full-thickness cartilage defect

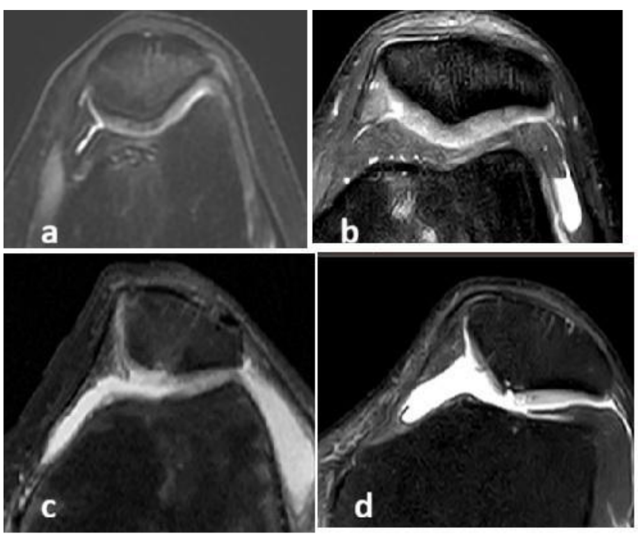

Figure 1: modified Noyes grading of chondromalacia patella: **(a)** Grade 1: Increased T2 signal intensity of morphologically normal cartilage **(b)** Grade 2a Superficial partialthickness cartilage defect <50% of total articular surface thickness **(c)** grade 2b Deep partialthickness cartilage defect >50% of total articular surface thickness **(d)** grade 3 Full-thickness cartilage defect

Patellar type

The patellae were classified into four types according to Baumgartl's classification [10,13].

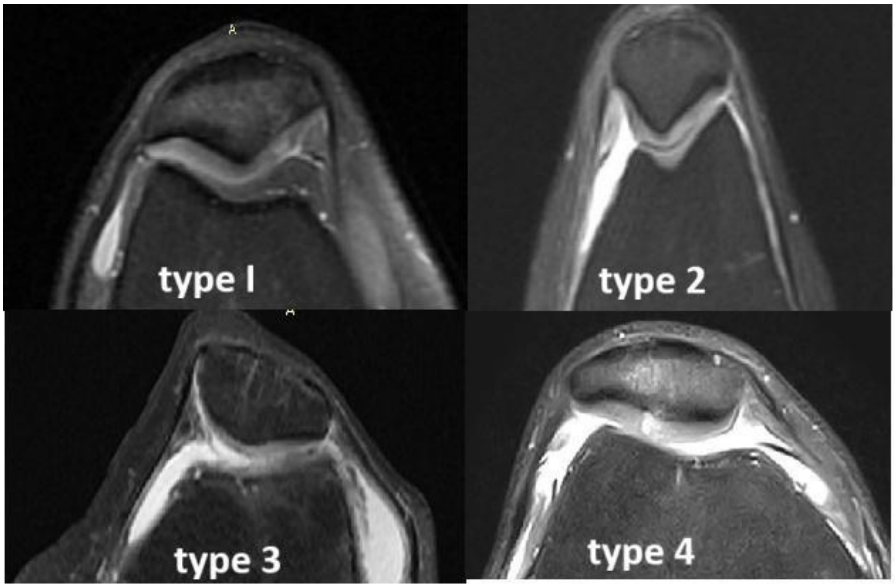

Figure 2 : Baumgartl's patellar type classification Type 1**:** Medial and lateral facets concave, equal length Type 2**:** Lateral facet more prominent; medial facet flat or concave Type 3: Medial facet small and convex Type 4 No medial facet [8]

Patellar tilt

The patellar tilt angle is measured on an axial MRI slice. First, Line 1, also known as the posterior condylar line, is drawn by connecting the posterior-most points of the medial and lateral femoral condyles, serving as the horizontal reference baseline. Next, Line 2 is drawn across the widest transverse diameter of the patella, connecting its medial and lateral borders. The patellar tilt angle is then determined as the angle formed between Line 1 and Line 2 [19].

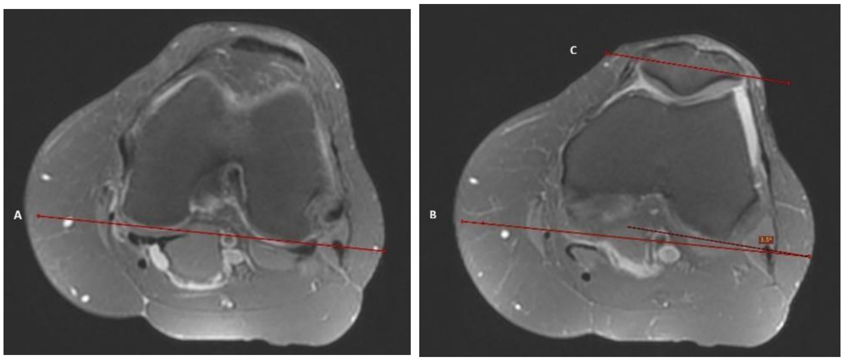

Figure 3: patellar tilt angle: (a) Line A connects the posterior-most points of the medial and lateral femoral condyles. (b) Line B, parallel to Line A, is copied onto the axial section at the widest part of the patella. Line C is drawn across the transverse diameter of the patella. The patellar tilt angle is measured between Line B and Line C."

Trochlear morphology measurement

The first proximal axial section of knee MRI where cartilaginous surface of both medial and lateral trochlear facet are fully visualized used for assessment of trochlear morphology .This level typically correspond to 2 to 3cm above tibiofemoral joint space and abnormal finding in these level highly suggestive of trochlear dysplasia. Trochlear morphology measurement which use this level includes lateral trochlear inclination, medial trochlear inclination, trochlear angle, trochlear facet ratio, trochlear depth and sulcus angle [11,20] .

Lateral trochlear inclination angle

It angle between lateral trochlear slope and posterior condylar line [11].

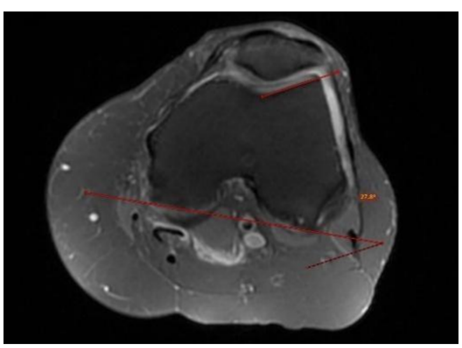

Figure 4: Lateral trochlear inclination is angle between lateral trochlear slope and posterior condylar line

Medial trochlear inclination angle

 It angle between medial trochlear slope and posterior condylar line [11].

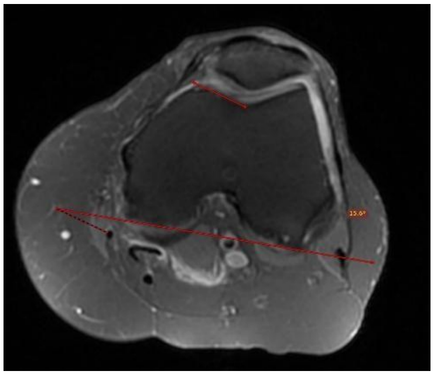

Figure 5: Medial trochlear inclination is angle between medial trochlear slope and posterior condylar line

Trochlear angle

It is angle between medial/lateral condylar slope and posterior condylar line [11].

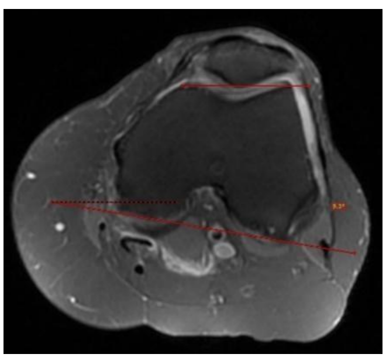

Figure 6: Trochlear angle is angle between medial/lateral condylar slope and posterior condylar line

Trochlear facet ratio

It is a ratio between medial and lateral trochlear facet [20].

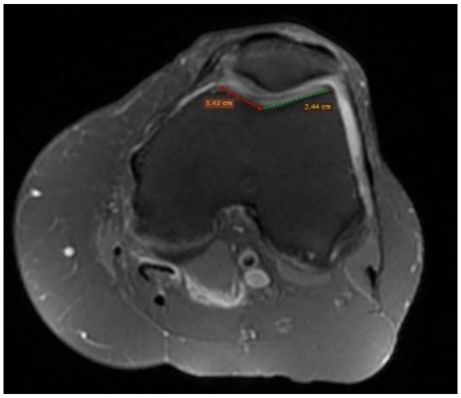

Figure 7: Trochlear facet ratio between medial and lateral trochlear facet

Sulcus angle

- It is angle between medial and lateral trochlear facet[11].

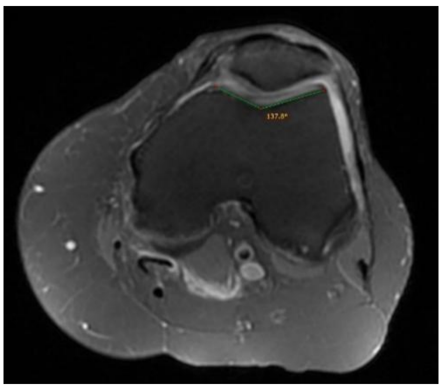

Figure 8: Sulcus angle is between medial and lateral trochlear facet

Trochlear depth

Asses using Pfirrmann method which is measuring maximal anteroposterior dimension medial as well as lateral femoral condyle and deepest point trochlear groove using posterior femoral condyle as reference line giving a, b and c measurement respectively. Then trochlear depth calculated according to the formula $([a+b]/2)-c$ [20].

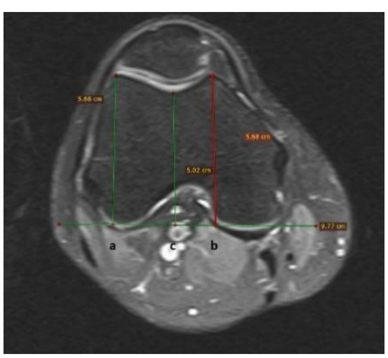

Figure 9: trochlear depth :measuring maximal anteroposterior dimension medial as well as lateral femoral condyle and deepest point trochlear groove using posterior femoral condyle as reference line giving a, b and c measurement respectively. Then trochlear depth calculated according to the formula $([a+b]/2)-c$

Tibial tuberosity to trochlear groove

The distance measured between deepest point of trochlear sulcus to the midpoint of patella tendon at it insertion on the tibial tuberosity [21].

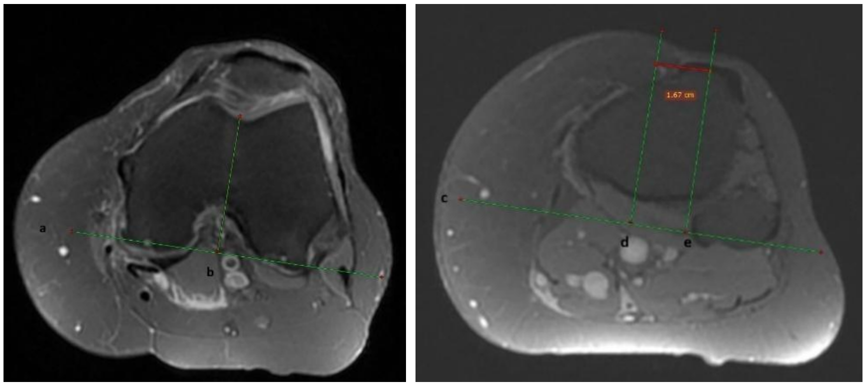

Figure 10: tibial tuberosity to trochlear groove: a distance measured between deepest point of trochlear sulcus to the midpoint of patella tendon at it insertion on the tibial tuberosity

Patellar height index (Insall-Salvati index ISI)

It is a ratio of patellar tendon length to patellar length at mid sagittal section. Patellar length measures from superior articular margin to distal anterior tip of the patella and patellar tendon length measured from distal anterior tip of the patella to tibial tuberosity[9].

Figure 11: Patellar height index (ISI) is a ratio of patellar tendon length to patellar length at mid sagittal section

4.8. Study variables

During the review of knee MRI variables, both categorical and numerical data were assessed according to the standard definitions reported in the literature, as described below.

4.8.1. Independent variable

- Chondromalacia patella present
- Grade of chondromalacia patella

4.8.2. Dependent variable

- Patellar type
- Patellar tilt
- Lateral trochlear inclination
- Medial trochlear inclination
- Trochlear angle
- Trochlear facet ratio
- Sulcus angle
- Trochlear depth
- Patellar height index

4.9. Data collection and analysis

4.9.1. Data collection

All 333 knee MRIs were reviewed by the first reader, a musculoskeletal radiology fellow, were each measurement recorded in a pre-prepared Microsoft Word table. To assess measurement reliability while maintaining workload feasibility, a random subset of 50 cases (15%) were selected for rereading. The first reader reassessed these cases after a three-week interval to minimize recall bias, allowing intra-observer reliability to be evaluated. A second reader, a senior musculoskeletal radiologist, independently reviewed the same 50 cases to assessed interobserver reliability. In cases of significant discrepancies between the two readers, a consensus decision were reached.

4.9.2. Data analysis

Data were cleaned, edited and entered into Ms. Excel first then analyzed using statistical package for social sciences (SPSS) for window version 20.

4.10. Ethical consideration

The data will be collected after obtaining ethical clearance from the radiology department ethical clearance at Tikur Anbesa specialized hospital. All clinical and radiologic information will be kept strictly confidential. Written informed consent will not be required as the study is retrospective.

4.11. Dissemination of result

The research output will be presented for department staff, in meetings and conferences. The result will be published in a reputable journal.

5. Result

A total of 333 knee MRI examinations were reviewed, comprising 139 right, 118 left and 76 bilateral studies. The study population included 142 females (42.6%) and 191 males (57.4%), with a mean age of 41.1 ± 14.13 years (range: 15–85 years).

Chondromalacia patella (CP) was identified in 189 cases (56.8%). Based on the severity we categorized (grade 1 and grade 2a = mild; grade 2b and grade 3 = severe), 114 cases (60.3%) were classified as mild, and 75 cases (39.6%) as severe. The distribution of patellar types was as follows: Type I: 94 (28.2%), Type II: 100 (30%), Type III: 137 (41.1%), and Type IV: 2 (0.6%) table 2. The overall distribution of the patellofemoral morphological variables is presented in Table 3.

Table 2: Summary of patellar type evaluation findings

	Category	Non CP group, n(%)	CP group, n (%)	Fisher's Exact	*p*-value
Patellar Type	Type I	40 (27.8%)	54 (28.6%)	Fisher	0.961
	Type II	42 (29.2 %)	58 (30.7%)		
	Type III	61 (42.4%)	76 (40.2%)		
	Type IV	1 (0.7%)	1 (0.5%)		

Table 3: Measurement outcomes of patellofemoral morphology across the study population

	Reference value from literature	**CP group**		**Non CP group**		**P value of normal**
		Mean	SD	Mean	SD	
Lateral trochlear inclination		20.957	5.19	21.056	5.145	0.863
Medial trochlear inclination		18.31	7.153	19.2	7.602	0.280
Trochlear angle		6.703	3.329	6.224	3.454	0.202
Trochlear facet ratio		0.563	0.146	0.577	0.142	0.380
Sulcus angle	<140	141.221	8.46	140.635	7.729	0.516
Trochlear depth	>3	5.159	1.445	5.387	1.452	0.155
Patellar tilt angle	<20	11.452	6.716	10.018	6.215	0.047
TT-TG distance	<15-20	13.592	5.278	13.47	5.206	0.833
Patellar height index	0.8-1.2	1.256	0.233	1.19	0.202	0.007

Reliability analysis demonstrated strong agreement. The kappa value for CP showed almost perfect intraobserver agreement ($\kappa = 0.826$) and substantial interobserver agreement ($\kappa = 0.669$) (Table 4). The intraclass correlation coefficients (ICC) for intraobserver reliability of patellofemoral morphological measurements ranged from 0.793 to 0.971, indicating good to excellent reliability. Interobserver ICC values also showed good to excellent reliability, ranging from 0.754 to 0.912 (Table 4).

Table 4: Reliability analysis: intra-observer and inter-observer kappa values and intraclass correlation coefficients

Kappa value for intra-observer and inter-observer reliably

Variable	Intra-observer K	Interpretation	Inter-observer K	interpretation
Chondromalacia patella	0.826	Almost perfect	0.669	Substantial
Severity of chondromalacia patella	0.812	Almost perfect	0.433	Moderate
Patellar type	0.845	Almost perfect	0.559	Moderate

Intra-class correlation coefficients (ICC) for intra-observer and inter-observe reliability

Variable	Intra-observer ICC	Interpretation	Inter-observer ICC	Interpretation
Lateral Trochlear Inclination	0.943	Excellent	0.874	Good
Medial trochlear inclination	0.793	Good	0.814	Good
Trochlear angle	0.869	Good	0.754	Good
Trochlear facet ratio	0.800	Good	0.765	Good
Sulcus Angle	0.808	Good	0.833	Good
Trochlear Depth	0.904	Excellent	0.818	Good
Patellar tilt angle	0.927	Excellent	0.882	Good
TT–TG Distance	0.971	Excellent	0.956	Excellent
Patellar height index	0.922	Excellent	0.852	Good

Chondromalacia patella (CP) was significantly more common in females (73.9%) than in males (44%) (p = 0.000). The mean age of patients with CP (44.46 ± 14.84 years) was significantly higher than that of those without CP (36.69 ± 13.88 years) (p=0.000), indicating an increased prevalence with advancing age. The distribution of patellar types showed no significant difference between patients with and without CP (p = 0.961) (Table 2).

Table 5: patient characteristic

		CP group	Non CP group	P value
Age, y, mean +/- SD		44.46 +/- 14.835	36.69 +/- 13.875	0.000
Sex	Male	84 (44%)	107 (56%)	0.000
	Female	105 (73.9%)	37 (26.1%)	
Side, right: left %				

Among the patellofemoral morphological parameters, patellar height index and patellar tilt angle demonstrated significant associations with CP. The patellar height index showed a stronger association, with a higher mean value in the CP group (1.256 ± 0.233) compared to the non-CP group (1.19 ± 0.202) (p = 0.007). Similarly, the patellar tilt angle was higher in the CP group (11.45 ± 6.72°) than in those without CP (10.02 ± 6.22°) (p = 0.047).The remaining morphological variables—including lateral trochlear inclination, medial trochlear inclination, trochlear angle, trochlear facet ratio, sulcus angle, trochlear depth, and TT-TG distance—showed no statistically significant association with CP (Table 3).

On subgroup analysis, patellar tilt angle demonstrated a significant association in the female cohort, with a higher mean value in the CP group (9.22 ± 6.375) compared with the non-CP group (8.08 ± 5.892) (p = 0.043). In contrast, patellar height index was the key associated parameter in the male cohort, showing a significantly higher value in the CP group (1.26 ± 0.245) compared with the non-CP group (1.188 ± 0.215) (p = 0.030). The remaining patellofemoral morphological variables showed no significant association in either sex group (Table 6).

Table 6: Patellofemoral morphology measurement outcomes in male and female participants

Sex	**Variable**	**CP group**		**Non CP group**		**P value**
		Mean	SD	Mean	SD	
Female	Lateral trochlear inclination (LTI)	21.315	4.617	22.532	4.625	0.170
	Medial trochlear inclination	18.393	7.493	20.88	6.915	0.079
	Trochlear angle	7.238	3.504	6.737	3.176	0.446
	Trochlear facet ratio	0.549	0.133	0.555	0.128	0.793
	Sulcus angle	140.7	8.265	138.77	7.05	0.208
	Trochlear depth	4.964	1.162	5.348	1.126	0.083
	patellar tilt angle	11.664	6.192	9.22	6.375	0.043
	Tibial tuberosity–trochlear groove (TT-TG) distance	12.637	4.947	11.95	3.985	0.448
	Patellar height index 1	1.252	0.225	1.194	0.161	0.152
Male	Lateral trochlear inclination (LTI)	20.51	5.825	20.545	5.237	0.965
	Medial trochlear inclination	18.227	6.746	18.618	7.771	0.715
	Trochlear angle	6.034	2.983	6.046	3.542	0.98
	Trochlear facet ratio	0.581	0.16	0.585	0.146	0.566
	Sulcus angle	141.869	8.703	141.278	7.879	0.624
	Trochlear depth	5.4	1.712	5.4	1.55	0.993
	patellar tilt angle	11.186	7.348	10.291	6.166	0.361
	Tibial tuberosity–trochlear groove (TT-TG) distance	14.787	5.462	13.996	5.485	0.323
	Patellar height index 1	1.26	0.245	1.188	0.215	0.03

Assessment of CP association across age groups (<40 years vs ≥40 years), demonstrated that only patellar height index in the younger age group showed a significant association. The patellar height index was higher in the CP group (1.304 ± 0.252) compared with the non-CP group (1.208 ± 0.207) (p = 0.007), while the other patellofemoral measurements showed no significant association in both age categories (Table 7).

Table 7: Patellofemoral morphology measurement outcomes in participants younger than 40 and those aged 40 and above

Age	Variable	CP group		Non CP group		P value
		Mean	SD	Mean	SD	
< 40	Lateral trochlear inclination (LTI)	21.454	5.197	21.036	5.4	0.604
	Medial trochlear inclination	16.669	7.237	18.112	7.396	0.196
	Trochlear angle	7.187	3.439	6.456	3.588	0.173
	Trochlear facet ratio	0.569	0.163	0.579	0.152	0.667
	Sulcus angle	142.54	8.565	141.675	7.617	0.644
	Trochlear depth	5.211	1.612	5.339	1.537	0.591
	patellar tilt angle	11.789	7.782	10.994	6.487	0.461
	Tibial tuberosity–trochlear groove (TT-TG) distance	14.81	5.385	13.521	5.189	0.109
	Patellar height index 1	1.304	0.252	1.208	0.207	0.007
>=40	Lateral trochlear inclination (LTI)	20.6	5.179	21.097	4.628	0.571
	Medial trochlear inclination	19.504	6.883	21.444	7.606	0.119
	Trochlear angle	6.355	3.218	5.744	3.142	0.274
	Trochlear facet ratio	0.559	0.133	0.573	0.118	0.635
	Sulcus angle	140.489	8.346	138.489	7.594	0.16
	Trochlear depth	5.121	1.319	5.485	1.269	0.112
	patellar tilt angle	11.21	5.858	8.002	5.111	0.001
	Tibial tuberosity–trochlear groove (TT-TG) distance	12.718	5.045	13.367	5.296	0.468
	Patellar height index 1	1.222	0.214	1.153	0.186	0.057

Evaluation of CP severity in relation to morphology also showed a significant association only with patellar height index, which was higher in the mild CP group (1.299 ± 0.231) compared with the severe CP group (1.192 ± 0.224) (p = 0.002). All other morphological parameters were not significantly associated with severity (Table 7). Spearman correlation analysis demonstrated a weak but statistically significant positive association between age and chondromalacia patella severity (ρ = 0.209, p = 0.004). This indicates that older patients tended to have higher grades of chondral damage, although the strength of the relationship was small.(Table 8)

Table 8: Patellofemoral morphology measurement outcomes in mild versus severe chondromalacia patella groups

Variable value	**Mild CP group**		**Sever CP group**		**P**
	Mean	SD	Mean	SD	
Lateral trochlear inclination (LTI)	21.125	4.875	20.702	5.659	0.585
Medial trochlear inclination	18.42	7.407	18.166	6.793	0.812
Trochlear angle	6.613	3.435	6.84	3.178	0.648
Trochlear facet ratio	0.557	0.114	0.571	0.15	0.521
Sulcus angle	140.798	8.849	141.864	7.845	0.398
Trochlear depth	5.244	1.47	5.028	1.4	0.316
patellar tilt angle	11.372	6.6	11.573	6.931	0.841
Tibial tuberosity–trochlear groove (TT-TG) distance	13.999	5.095	12.975	5.22	0.193
Patellar height index 1	1.299	0.231	1.192	0.224	0.002

6. Discussion

In our study, patellar height index and patellar tilt emerged as the key patellofemoral alignment parameters associated with chondromalacia patella. The subgroup analyses further clarified these relationships. Patellar height index functioned as a strong predictor of CP among male participants and younger individuals, and it also demonstrated a meaningful association with increasing severity of patellar chondral injury. Conversely, patellar tilt was identified as the influential factor in the female cohort, indicating that rotational malalignment may contribute more prominently to patellofemoral stress in women.

Several previous studies have similarly identified patellar height index as an important factor contributing to patellofemoral cartilage degeneration [9,12,15,16]. A retrospective cross-sectional study conducted in the United States in 2019 evaluated 235 patients, including 135 with patellofemoral cartilage lesions. That study reported significantly higher Insall–Salvati ratios in patients with cartilage damage compared to controls (1.05 ± 0.10 vs. 1.01 ± 0.15; $p = 0.0006$) [15]. Similarly, a large cross-sectional study from China in 2016 assessed 1703 knees using low-field (0.2 T) MRI and found that the Insall–Salvati ratio was significantly higher in the chondromalacia group (1.17 ± 0.17) compared to controls (1.13 ± 0.14; $p < 0.001$) [9].

A retrospective case–control study conducted in Germany in 2014 evaluated 43 patients with arthroscopically confirmed grade III–IV chondral defects and compared them with age- and sexmatched controls. The study demonstrated significantly higher Insall–Salvati ratios in the defect group compared to the control group (1.13 ± 0.18 vs. 1.02 ± 0.19; $p = 0.01$) [16].

In contrast, several studies from Turkey and the United States reported no significant association between patellar height index and chondromalacia patella [8,12,13,17]. Additionally, a Turkish crosssectional case-only study from 2018, which evaluated 38 MRI-confirmed CP patients and classified them into early and advanced stages, found no correlation between patellar height index and CP severity—contrary to the findings of our study [17].

Another significant finding in our study was the association between patellar tilt and chondromalacia patella, reflecting the influence of axial-plane rotational alignment of the patella. However, in contrast to our results, several previous studies evaluating chondromalacia in relation to patellar tilt did not demonstrate a significant association [8,16].

The vertical position of the patella relative to the femoral trochlea is critical for normal knee function. In full extension, the inferior pole of the patella lies at the superior margin of the trochlear groove, and as the knee progressively flexes, the patella gradually achieves full engagement. However, if the patella is abnormally elevated, engagement is delayed even during flexion, resulting in a reduced contact area and increased compressive forces, which can predispose to patellar cartilage degeneration. Additionally, an abnormal increase in patellar tilt angle can concentrate stress on the lateral facet of the patella, further elevating the risk of chondral damage.

In our study, patellar and trochlear morphological parameters—including patellar type, lateral trochlear inclination (LTI), sulcus angle, and trochlear depth—did not show a significant association with chondromalacia patella, despite several previous studies reporting significant relationships [2,8,11,12,14–16] . Although our sample size was relatively large and we employed standardized measurement techniques with excellent reliability, several factors may explain the absence of significant associations. One likely explanation is the composition of our study population, which included all patients presenting with knee complaints, many of which were nonspecific and not directly related to CP. This contrasts with prior studies that often evaluated more selectively targeted populations. Another possible reason is the low prevalence of severe trochlear dysplasia in our cohort, which may have limited the ability to detect a meaningful association.

Based on our data, patellar type was not associated with chondromalacia patella, whereas two MRI-based cross-sectional studies from Turkey (2022 and 2015) reported significant associations [8,10] . A plausible explanation for this discrepancy relates to the method of classification. The Baumgartl's patellar classification was originally designed for standardized axial radiographs, which provide a consistent single reference level for evaluating patellar morphology. In contrast, our assessment was performed using MRI, where patellar shape varies between the superior, mid, and inferior sections. This variability may introduce inconsistency in assigning patellar type, potentially affecting both the accuracy of classification and its observed relationship with chondral injury. Future research may benefit from using radiographic evaluation—which remains the reference standard for Baumgartl's classification—or establishing MRI-specific criteria that account for morphological variation along the patellar height.

Another important finding in our study is that age and sex emerged as key determinants in the development of patellar cartilage injury. This observation is largely consistent with the previous literature [9,10,12,14]. Although the association between chondromalacia patella severity and age in our study was relatively weak, it is still consistent with existing evidence showing that cartilage degeneration severity tends to increase with advancing age [8,12].

Our findings reveal a notably high prevalence of chondromalacia patella, consistent with reports from Western and Asian populations. The study also highlights the value of MRI as a highly sensitive diagnostic tool for detecting early patellar cartilage changes. Early identification is crucial for timely intervention in high-risk patients and can guide surgical decision-making, particularly regarding concurrent procedures to correct patellar height and tilt during cartilage repair, thereby optimizing clinical outcomes.

7. Strengths and limitation of study

This research encompassed a large sample size and employed high-quality 1.5-Tesla MRI, which offers excellent visualization of patellar cartilage and enables precise morphologic assessment. Furthermore, we performed both interobserver and intraobserver reliability analyses on a subset of participants, demonstrating strong measurement consistency. In addition, we evaluated multiple patellofemoral anatomical determinants and carried out detailed subgroup analyses to strengthen the robustness of our findings.

Despite these strengths, several limitations should be acknowledged. First, the cross-sectional study design prevents establishing causal relationships. Second, we did not have arthroscopic correlation for the diagnosis of chondromalacia patella, and MRI may underestimate low-grade chondral lesions. Finally, the study was conducted at a single center, which may limit the generalizability of our findings to the broader region.

8. Conclusion

In conclusion, alterations in patellar height significantly influence the development of patellar cartilage degeneration, while rotational malalignment, indicated by increased patellar tilt, also contributes importantly. These findings highlight the multifactorial nature of patellofemoral biomechanics and emphasize the need to consider sex- and age-related variations when assessing risk factors for chondromalacia patella.

9. Recommendation

We recommend prospective larger, multicenter studies with arthroscopic confirmation of chondral lesions to provide more robust and generalizable outcomes.

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11. Annex

11.1 Annex 1-Budget plan

Number	Items	Unit	Estimated number of items	Cost/unit	Total cost
1	Stationary (paper, pen)	pack	1	2500 ETB	2500 ETB
	Print, bind				1000 ETB
2	Data collector	person	2	10000 ETB	20000 ETB
3	Advisors	person	2	6000 ETB	120000 ETB
4	Publication fee			30000 ETB	30000 ETB
	Total				65,500 ETB

11.2 Annex 2-Data collection questioners

Knee MRI– chondromalacia & patellofemoral morphology study

Number	Variable	Measurement	Description
1	Patient Id		Number 001-384
3	Sex		Male/female
4	Age		15 above
5	Side of knee		Right/left
6	Chondromalacia (medial facet)		Grade modified Noyes (0/1/2a/2b/3)
7	Chondromalacia (lateral facet)		Grade modified Noyes (0/1/2a/2b/3)

8	Chondromalacia (median rigid)		Grade modified Noyes (0/1/2a/2b/3)
9	Sever grade of chondromalacia		Grade modified Noyes (0/1/2a/2b/3)
10	Patella type		Baumgartl's classification (Type I, II, III, IV
11	Patellar tilt angle		Measured on axial images 1 the posterior femoral condyles appear at their maximal diameter and symmetry. 2 widest transvers patellar dimension
13	Lateral trochlear inclination (LTI)		Level selection 1. The first proximal axial MR images at the level where the cartilaginous surfaces of both medial and lateral trochlear facets are fully visible 2. the posterior femoral condyles appear at their maximal diameter and symmetry. 3. Then measure angle between lateral trochlear slope and posterior condylar line
14	Medial trochlear inclination		Same level as LTI then measure angle between medial trochlear slope and posterior condylar line
15	Trochlear angle		Same level as LTI then measures angle between medial trochlear slope and posterior condylar line
16	Trochlear facet ratio		Same level as LTI Ratio between medial to lateral trochlear facet
17	Sulcus angle		Same level as LTI Angle between highest points of medial/lateral facets and deepest sulcus
18	Trochlear depth		Same level as LTI Vertical distance from deepest sulcus to posterior condylar line of lateral, medial and deep art of sulcus (Pfirrmann method) (a+b)/2-c

19	Tibial tuberosity–trochlear groove (TT-TG) distance		Horizontal distance between mid point of tibial tuberosity and deepest part of trochlear groove
23	Patellar height index 1		Mid sagittal section for the ratio of patellar tendon length to patellar ratio

 Reader comments (optional)