European Radiology (2018) 28:4669–4680
https://doi.org/10.1007/s00330-018-5460-9

MUSCULOSKELETAL

Tibial tuberosity to trochlear groove distance and its association with patellofemoral osteoarthritis-related structural damage worsening: data from the osteoarthritis initiative

Arya Haj-Mirzaian[1] · Ali Guermazi[2] · Michael Hakky[3] · Christopher Sereni[4] · Bashir Zikria[5] · Frank W. Roemer[2,6] · Miho J. Tanaka[5] · Andrew J. Cosgarea[5] · Shadpour Demehri[1]

Received: 20 January 2018 / Revised: 22 March 2018 / Accepted: 3 April 2018 / Published online: 30 April 2018

Abstract

Objectives To determine whether the tibial tuberosity-to-trochlear groove (TT-TG) distance is associated with concurrent patellofemoral joint osteoarthritis (OA)-related structural damage and its worsening on 24-month follow-up magnetic resonance imaging (MRI) in participants in the Osteoarthritis Initiative (OAI).

Methods Six hundred subjects (one index knee per participant) were assessed. To evaluate patellofemoral OA-related structural damage, baseline and 24-month semiquantitative MRI Osteoarthritis Knee Score (MOAKS) variables for cartilage defects, bone marrow lesions (BMLs), osteophytes, effusion, and synovitis were extracted from available readings. The TT-TG distance was measured in all subjects using baseline MRIs by two musculoskeletal radiologists. The associations between baseline TT-TG distance and concurrent baseline MOAKS variables and their worsening in follow-up MRI were investigated using regression analysis adjusted for variables associated with tibiofemoral and patellofemoral OA.

Results At baseline, increased TT-TG distance was associated with concurrent lateral patellar and trochlear cartilage damages, BML, osteophytes, and knee joint effusion [cross-sectional evaluations; overall odds ratio 95% confidence interval (OR 95% CI): 1.098 (1.045–1.154), $p < 0.001$]. In the longitudinal analysis, increased TT-TG distance was significantly related to lateral patellar and trochlear cartilage, BML, and joint effusion worsening (overall OR 95% CI: 1.111 (1.056–1.170), $p < 0.001$).

Conclusions TT-TG distance was associated with simultaneous lateral patellofemoral OA-related structural damage and its worsening over 24 months. Abnormally lateralized tibial tuberosity may be considered as a risk factor for future patellofemoral OA worsening.

Key Points

- *Excessive TT-TG distance on MRI is an indicator/predictor of lateral-patellofemoral-OA.*
- *TT-TG is associated with simultaneous lateral-patellofemoral-OA (6–17% chance-increase for each millimeter increase).*
- *TT-TG is associated with longitudinal (24-months) lateral-patellofemoral-OA (5–15% chance-increase for each millimeter).*

Keywords Osteoarthritis · Knee · Patella · Magnetic resonance imaging

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00330-018-5460-9) contains supplementary material, which is available to authorized users.

✉ Arya Haj-Mirzaian
arya.mirzaian@gmail.com

[1] The Russell H. Morgan Department of Radiology and Radiological Science, Johns Hopkins University School of Medicine, 601 N Caroline St, JHOC 4240, Baltimore, MD 21287, USA

[2] Department of Radiology, Boston University School of Medicine, Boston, MA, USA

[3] Department of Radiology, Florida Hospital, Maitland, FL, USA

[4] Department of Radiology, University of Massachusetts Medical School, Boston, MA, USA

[5] Department of Orthopaedic Surgery, Johns Hopkins University School of Medicine, Baltimore, MA, USA

[6] Department of Radiology, University of Erlangen-Nuremberg, Erlangen, Germany

Abbreviations

2D	Two-dimensional
ACL	Anterior cruciate ligament
ANOVA	Analysis of variance
AUC	Area under the curve
BMI	Body mass index
BML	Bone marrow lesion
CI	Confidence interval
CT	Computed tomography
DESS	Dual echo at steady state
FNIH	Foundation for the National Institute of Health
IW	Intermediate weighted
JSL	Joint space loss
KL	Kellgren-Lawrence
MOAKS	Magnetic resonance imaging osteoarthritis knee score
MPR	Multiplanar reconstruction
MRI	Magnetic resonance imaging
OA	Osteoarthritis
OAI	Osteoarthritis initiative
OR	Odds ratio
PASE	Physical activity scale for elderly
ROC	Receiver-operating characteristic
SD	Standard deviation
TSE	Turbo spin echo
TTM	Tibial tuberosity medialization (TTM)
TT-TG	Tibial tuberosity trochlear groove
WE	Water excitation
WOMAC	Western Ontario & McMaster Universities osteoarthritis index

Introduction

Patellofemoral osteoarthritis (OA) is a common debilitating disease with a prevalence of 28%-52% in the adult population based on knee radiography [1]. Compared with tibiofemoral OA, fewer data are available in the literature regarding the risk factors for patellofemoral OA development and progression. Previous studies have suggested that abnormal patellofemoral morphology and associated patellofemoral maltracking may lead to the alteration in the joint contact area and pressure distribution as well as the mechanical load [2–5]. Such malalignment may impose increasing contact pressure on the lateral patellofemoral articular surface during flexion-extension motion and therefore may predispose subjects to the development and possible worsening of patellofemoral OA [2, 3]. It has also been previously suggested that simultaneous patellofemoral OA is seen in association with underlying patellofemoral malalignment such as abnormal lateralization of the tibial tuberosity [2–7].

The position of the tibial tuberosity, as an indicator of patellofemoral alignment, can contribute to the lateral force vector acting on the patella [8, 9]. The tibial tuberosity-to-trochlear groove (TT-TG) distance, as a widely used metric for determination of tibial tuberosity lateralization, measures the distance between the central midpoint of the tibial tuberosity and the deepest point of the trochlea using axial magnetic resonance imaging (MRI) or computed tomography (CT) images [10, 11]. It has been suggested that an increased TT-TG distance increases the lateral patella contact pressure and predisposes the patellofemoral joint to cartilage damage [7, 12]. Although this assumption has been primarily investigated in a limited number of cross-sectional studies, the results were not consistent [3, 4, 12, 13]. Additionally, these results only included cross-sectional analysis, and the association between the TT-TG distance and longitudinal patellofemoral OA worsening has not been previously investigated. Therefore, the clinical importance of TT-TG distance measurement as a patellofemoral OA predictor remains to be determined.

Besides the lateralization of the tibial tuberosity, there are several other patellofemoral morphological abnormalities including patella alta, trochlear dysplasia, and patellar tilt, many of which have already been shown to be associated with patellofemoral OA [5, 13, 14]. An abnormally lateralized tibial tuberosity (excessive TT-TG distance) can be corrected by surgical methods including tibial tuberosity medialization (TTM), which is currently used in the setting of patellar instability [15–18]. Additionally, surgical correction of an abnormally lateralized tibial tuberosity along with cartilage repair procedures resulted in improvements in symptoms and function in subjects with isolated patellofemoral OA [19, 20].

Thus, we aimed to determine whether the TT-TG distance is associated with concurrent patellofemoral joint OA-related structural damage and its worsening on 24-month follow-up MRI in participants in the Osteoarthritis Initiative (OAI).

Materials and methods

Study population

We used data and images from the open access data sets of the OAI cohort, which is an ongoing multicenter study of 4,796 subjects with or at risk of knee OA, who were followed for OA outcomes (for additional details refer to https://oai.epi-ucsf.org). Our study used data of the OA biomarkers consortium Foundation for the National Institute of Health (FNIH) project, which is a nested case-control study within the OAI and constitutes a group of 600 participants.

The FNIH study was designed for assessing the role of MRI-based measures over 24 months as biomarkers of tibiofemoral OA structural and symptom progression during

the 24-48 months. Eligible participants had at least one knee with tibiofemoral Kellgren-Lawrence (KL) grade of 1 (12.5%), 2 (51%), or 3 (36.5%) at baseline and had an available knee radiograph and 3-T MRI at baseline and 24-month follow-up. Subjects with total knee/hip replacement or metal implants were excluded. Knees with advanced radiographic OA or severe symptoms at baseline were also excluded (minimum medial joint space width < 1.0 mm and/or Western Ontario and McMaster Universities Osteoarthritis (WOMAC) index pain score of > 91). Index knees were selected based on radiographic and pain progression outcomes in each subject (for details: https://oai.epi-ucsf.org/datarelease/docs/FNIH).

This available database also contains robust patellofemoral structural damage determination using the semiquantitative MRI-based MOAKS (MRI Osteoarthritis Knee Score) method. With proper adjustment of statistical models for radiographic tibiofemoral OA status at baseline and follow-up, this available data set provides an opportunity to evaluate the potential risk factors of patellofemoral OA. All subjects (one index knee per participant) from the FNIH project were included in this study. Enrolled subjects underwent MRI at baseline and 24 months. Relevant existing data, MRIs, and MRI-based measurements were extracted and analyzed. A schematic diagram of our study is presented in Fig. 1.

MRI protocol

Details of the full OAI pulse sequence protocol and parameters have been previously reported (supplementary text) [21, 22].

Semiquantitative assessment of patellofemoral joint

To evaluate patellofemoral joint structural damages, available measurements of the validated semiquantitative MOAKS method were used (supplementary text) [21]. Cartilage damage, BML, and osteophyte scores were evaluated for both the medial and lateral sides of the patellar and trochlear subregions.

Cartilage lesions were scored on a 4-point scale based on the percentage of surface and full-thickness of patellar/trochlear cartilage affected by the injury (0: none, 1: < 10% of region is involved, 2: 10-75%, 3: > 75%). BML size scores ranged from 0 to 3 (0: none, 1: < 33% is involved, 2: 33-66%, 3-4: > 66%). BML numbers were also counted in each subregion. The size of osteophytes was scored using a 4-point scale (0 = none, 1 = small, 2 = medium, 3 = large). Synovitis (defined as the signal abnormalities in Hoffa's fat pad) and effusion were evaluated using a 4-point scale based on the grade of Hoffa-synovitis and the size of effusion, without contrast enhancement [23]. The presence of baseline anterior cruciate ligament (ACL) tear was also assessed on a 3-point scale (0 = none, 1 = partial tear, and 2 = complete tear). The reliability of the MOAKS method has been previously demonstrated, with the intra- and interobserver reliability of near perfect (0.71-1.0) and moderate-strong (0.64-0.93) for all patellar measures, respectively (using the kappa method) [21].

TT-TG distance measurement

Two fellowship-trained musculoskeletal radiologists (CS and MH) with three years of clinical experience in interpreting musculoskeletal MRI assessed the baseline TT-TG distance in all 600 knees in consensus. TT-TG distance (mm) was calculated on axial MRI using a previously described method [13; 14]. In brief, the TT-TG was measured as the distance between the midpoint of the patellar tendon attachment site to the tibial tuberosity and the mid-sulcal plane at the deepest point of the trochlea (Fig. 2). The reliability of the MRI-derived TT-TG distance has been previously demonstrated, with the very good intra- and interobserver reliability in measurements [24].

Statistical analysis

Baseline characteristics and factors related to patellofemoral/tibiofemoral OA including the gender, age, body mass index (BMI), WOMAC pain score, baseline tibiofemoral KL grade, knee alignment (varus/valgus/normal; based on physical examinations), ACL injury (using MOAKS), history of knee injury, kneeling activity, PASE (Physical Activity Scale for Elderly) score, and muscle strength score were evaluated [25, 26]. All further analyses were adjusted for the possible confounding effect of these variables. In this regard, all analyses were adjusted for baseline tibiofemoral KL grade, and all longitudinal analyses were also adjusted for the presence of an interval radiographic tibiofemoral joint space width loss > 0.7 mm in the 48-month follow-up (joint space loss or JSL progression) to account for the primary outcome determination in the FNIH study design for tibiofemoral radiographic progression.

In the cross-sectional part, the association between baseline TT-TG distance and baseline MOAKS variables and overall baseline patellofemoral OA disease (presence vs. absence) was assessed using the logistic regression model. Presence of patellofemoral OA was defined as subjects who had both patellar/trochlear cartilage damage and patellar/trochlear osteophytes using MOAKS [1, 27].

In the longitudinal part, we investigated whether the TT-TG distance was associated with future worsening of patellofemoral MOAKS variables using logistic regression. In this regard, subjects were dichotomized into worsening versus non-worsening groups. Worsening of MOAKS variables was defined based on the previously published method (Supplementary text) [28]. The overall relationship between TT-TG distance and worsening of patellofemoral OA was also

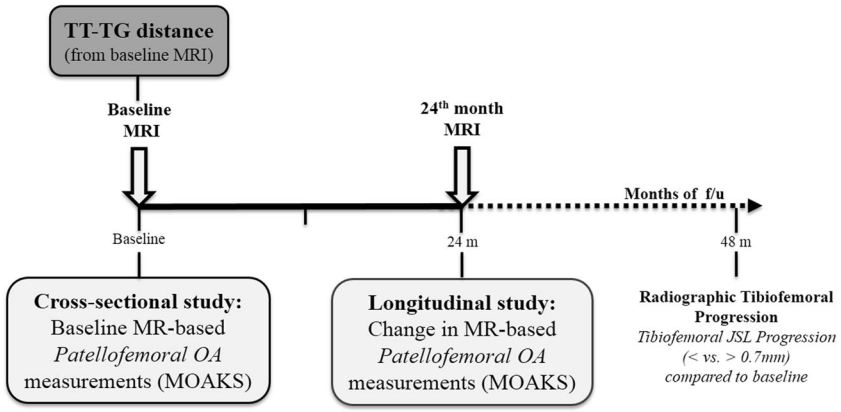

Fig. 1 Timeline of the study. *Baseline:* tibial tuberosity-to-trochlear groove (TT-TG) distance measurement; baseline MRI assessments for patellofemoral osteoarthritis (OA) including MRI Osteoarthritis Knee Score (MOAKS). *24 months:* Follow-up MRI assessments of patellofemoral OA. *48 months*: Primary FNIH outcome for tibiofemoral OA progression. Follow-up radiographic assessment of tibiofemoral joint space loss (JSL). All analyses were adjusted for 48-month JSL progression. JSL: joint space loss; f/u: follow-up; MRI: magnetic resonance imagining

explored. Subjects with any worsening change in patellar or trochlear cartilage, BML, or osteophyte MOAKS measurements were considered as worsening. Besides the regression analysis, the TT-TG distance measure was also compared between the study groups using the t-test or analysis of variance (ANOVA) method in each part of the analysis.

The areas under the receiver-operating characteristic (ROC) curve (AUCs) were evaluated to investigate predictive value of TT-TG distance for patellofemoral OA, and the optimal cutoff values of TT-TG distance with the highest Youden's Index and the best predictive ability were calculated (supplementary results).

A two-tailed p value < 5% was considered significant. Analyses were performed using SPSS (v.24, Chicago, IL, USA), STATA (v.14, College Station, TX, USA), and the R platform (v.3.2.5).

Results

Table 1 demonstrates the baseline characteristics of the study population. Six hundred participants (female: 58.8%; age: 61.5 ± 8.9 years; BMI: 30.7 ± 4.78) were included.

Table 2 shows the results of the cross-sectional study; regression analyses showed significant associations between baseline TT-TG distance and concurrent patellar and trochlear lateral surface [odds ratio (OR) 95% confidence interval (CI): 1.127(1.078–1.178)] [OR 95% CI: 1.132 (1.079–1.186)], lateral full-thickness [OR 95% CI: 1.179 (1.117–1.245)] [OR 95% CI: 1.156 (1.094–1.220)] cartilage damage, and lateral BML size [OR 95% CI: 1.158 (1.104–1.215)] [OR 95% CI: 1.150 (1.093–1.209)], and number [OR 95% CI: 1.132 (1.079–1.186)] [OR 95% CI: 1.129 (1.074–1.186)] scores, respectively. There were also significant associations between the TT-TG distance and baseline patellar and trochlear medial [OR 95% CI: 1.053 (1.008–1.101)] [OR 95% CI: 1.08 7(1.040–1.135)] and lateral [OR 95% CI: 1.119 (1.069–1.169)] [OR 95% CI: 1.151 (1.099–1.206)] osteophyte scores as well as the baseline knee effusion [OR 95% CI: 1.066 (1.022–1.112)]. On the other hand, there was a significant inverse association between the TT-TG distance and medial trochlear score [OR 95% CI: 0.941 (0.890–0.995)].

Results of the longitudinal study (Table 3) demonstrated a significant association between the baseline TT-TG distance and subsequent worsening of the lateral patellar cartilage [OR 95% CI: 1.078 (1.001–1.160)], medial and lateral trochlear

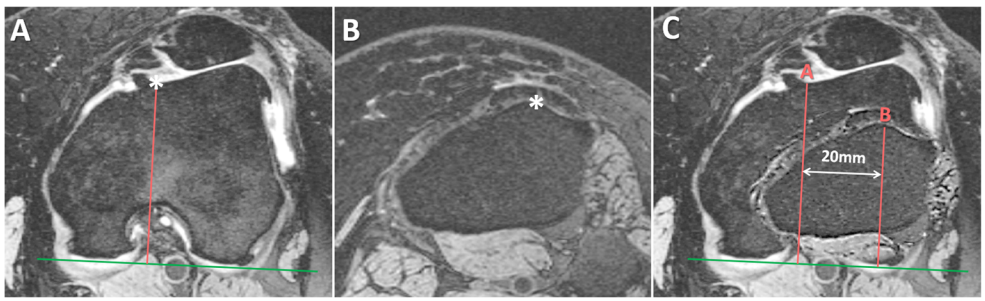

Fig. 2 TT-TG distance, the measurement was defined as the distance between the mid sulcal plane (A) and the mid tuberosity plane (B). Both lines were drawn perpendicular to baseline, joining the most posterior point of the two femoral condyles (C). Measurement is demonstrated on axial multiplanar reformations (MPRs) of the 3D dual-echo steady-state (DESS) MRI sequence

Table 1 Baseline characteristics of study subjects

Baseline	Mean ± SD or number (%)
Number	600
Gender (female)	353 (58.8%)
Age (years)	61.5 ± 8.9
BMI (kg/m^2)	30.7 ± 4.78
WOMAC pain score (range: 0-16)	2.4 ± 3.12
KL grade (range: 0-4)	
1	75 (12.5%)
2	306 (51%)
3	219 (36.5%)
Knee alignment (based on physical examination)	
Normal	165 (27.5%)
Varus	187 (31.2%)
Valgus	244 (40.7%)
ACL injury (positive MOAKS)	38 (6.4%)
Knee injury (positive)	213 (35.5%)
Kneeling (30 min per week)	0.46 ± 0.95
PASE score (range: 2-445)	164.4 ± 82.7
Muscle strength score (hours per week)	0.90 ± 1.46
MOAKS patellar scores	
Cartilage morphology scores (0/1/2/3)	
Medial	
Surface score	168 (28%)/63 (10.5%)/352 (58.7%)/17 (2.8%)
Thickness score	403 (67.2%)/64 (10.7%)/129 (21.5%)/4 (0.7%)
Lateral	
Surface score	282 (47%)/26 (4.3%)/209 (34.8%)/83 (13.8%)
Thickness score	444 (74%)/27 (4.5%)/101 (16.8%)/28 (4.7%)
BML scores (0/1/2/3-4)	
Medial	
Size score	389 (64.8%)/138 (23%)/60 (10%)/13 (2.2%)
Number score	389 (64.8%)/155 (25.8%)/54 (9%)/2 (0.3%)
Lateral	
Size score	384 (64%)/108 (18%)/84 (14%)/24 (4%)
Number score	384 (64%)/162 (27%)/41 (6.8%)/13 (2.2%)
Osteophyte score (0/1/2/3)	
Medial	252 (42%)/279 (46.5%)/68 (11.3%)/1 (0.2%)
Lateral	285 (47.5%)/ 242 (40.3%)/ 58 (9.7%)/ 15 (2.5%)
MOAKS trochlear scores	
Cartilage morphology scores (0/1/2/3)	
Medial	
Surface score	271 (45.2%)/68 (11.3%)/254 (42.3%)/7 (1.2%)
Thickness score	507 (84.5%)/29 (4.8%)/63 (10.5%)/1 (0.2%)
Lateral	
Surface score	374 (62.3%)/26 (4.3%)/172 (28.7%)/28 (4.7%)
Thickness score	454 (75.7%)/24 (4%)/115 (19.2%)/7 (1.2%)
BML scores (0/1/2/3-4)	
Medial	
Size score	441 (73.5%)/137 (22.8%)/15 (2.5%)/7 (1.2%)
Number score	445 (74.2%)/138 (23%)/14 (2.3%)/3 (0.5%)
Lateral	

Table 1 (continued)

Baseline	Mean ± SD or number (%)
Size score	426 (71%)/74 (12.3%)/75 (12.5%)/25 (4.2%)
Number score	428 (71.3%)/131 (21.8%)/30 (5%)/11 (1.8%)
Osteophyte score (0/1/2/3)	
Medial	262 (43.7%)/254 (42.3%)/72 (12%)/12 (2%)
Lateral	346 (57.7%)/155 (25.8%)/76 (12.7%)/23 (3.8%)

Data are presented as mean ± standard deviation or number (percentage %). Missing data were considered in percentage calculations. SD: standard deviation; BMI: body mass index; WOMAC: Western Ontario & McMaster Universities osteoarthritis index; KL: radiographic Kellgren and Lawrence; ACL: anterior cruciate ligament; PASE: Physical Activity Scale for the Elderly; MOAKS: MRI Osteoarthritis Knee Score; BML: bone marrow lesion

cartilage [OR 95% CI: 1.208 (1.093–1.334)] [OR 95% CI: 1.119 (1.033–1.211)], lateral patella and trochlea BML [OR 95% CI: 1.060 (1.001–1.122)] [OR 95% CI: 1.108 (1.041–1.179)], and knee effusion [OR 95% CI: 1.073 (1.018–1.131)] scores. There was a significant inverse association between the TT-TG distance and worsening of the medial trochlear BML score [OR 95% CI: 0.889 (0.817–0.967)].

Table 4 demonstrates the overall association between the presence/worsening of medial and lateral patellofemoral OA-related structural damage and baseline TT-TG distance. Analyses revealed that subjects with greater TT-TG distance had higher odds of concurrent [OR 95% CI: 1.098 (1.045–1.154)] and future worsening [OR 95% CI: 1.111 (1.056–1.170)] of lateral, but not medial, patellofemoral joint damage.

In the sub-analysis (Supplementary Fig. 1), the TT-TG distance demonstrated AUCs of 0.599 (standard error: 0.024; $p < 0.001$) for indicating future lateral patellofemoral OA-related structural damage. Based on the ROC curve analysis, the optimal cutoff values with the highest Youden Index score for the predictive value of TT-TG distance in future lateral patellofemoral OA structural damage worsening was 10.5 mm (sensitivity 55.6 %; specificity 58.4 %). Finally, the association between the TT-TG distance (categorized based on the previous 15-mm and newly suggested 10.5-mm cutoff value) and worsening of lateral patellofemoral OA-related structural damage was evaluated (Supplementary Table 1).

Discussion

In our study, we found that the TT-TG distance could be considered a marker for simultaneous lateral patellofemoral OA-related structural damage and a predictor of future worsening using the baseline and 24-month follow-up MRI data.

In 1978, Goutallier et al. initially defined the TT-TG distance using plain radiographs [29]; this has been primarily used as a metric for abnormal patellofemoral morphology in subjects with patellofemoral instability. After that, CT scans permitted its measurement in extension, and in 1992 Dejour et al. introduced the CT-derived TT-TG distance as a particular factor in patellar instability [30]. It has been suggested that the CT scan is a gold standard method for TT-TG distance determination [31, 32]. Several studies have evaluated whether TT-TG distances on CT and MRI were identical; based on these reports, it has been demonstrated that both MRI and CT can be used to measure the TT-TG distance with excellent reliability and accuracy [10, 24, 33], although these measurements may not be identical and the TT-TG distance on MRI was up to 3 mm smaller than measurements using CT scans [10, 33, 34]. In addition to TT-TG measurement, MRI can accurately demonstrate early stages and subtle features of patellofemoral OA including soft tissue and osseous structural damages [35].

It has been hypothesized that excessive TT-TG distance can lead to increased lateral patellofemoral joint contact pressure and theoretically predispose subjects to lateral patellofemoral OA and in extreme cases to lateral patellar dislocation [36, 37]. A few cross-sectional studies have investigated the relationship between the TT-TG and patellofemoral OA, but the results were controversial [3, 7, 12]. In the first investigation performed on 85 subjects with patellofemoral OA associated with varus deformity, it was reported that the CT-derived TT-TG distance was associated with the severity of lateral patellofemoral OA [12]. Thakkar et al. also found a significant association between increased TT-TG distance (using MRI) and lateral patellofemoral cartilage abnormality and knee effusion in their cross-sectional study on 32 subjects [7]. A larger cross-sectional MRI examination of 622 subjects revealed no significant difference in TT-TG distance (based on MRI) between normal knees and those with patellofemoral OA [3]. In that study, enrolled subjects were dichotomized into patellofemoral OA-positive and -negative groups (based on cartilage lesions), and detailed analysis on OA-related structural damages such as BML was not performed [3]. It has also been suggested that excessive TT-TG distance was related to knee joint effusion and superolateral Hoffa's fat pad (SHFP) edema, which have been considered prognostic factors for patellofemoral OA [7, 38–40]. Taken together, it

Table 2 Baseline cross-sectional study: association between patellofemoral joint structural damage (patellar and trochlear MOAKS variables: cartilage, BML, osteophyte, synovitis, and effusion) and baseline TT-TG distance

Baseline	Number of subjects in each score	TT-TG distance Mean (SD) for each score	ANOVA $F_{(3,596)}$, p value	OR (95% CI), p value	
				Crude	Adjusted
Cartilage morphology scores (0/1/2/3)					
Surface score					
Medial patella	168/63/352/17	10.8(4.4)/10.2(3.3)/10.3(3.4)/10.8(2.8)	0.853, 0.466	0.975 (0.934 – 1.017), 0.241	0.972 (0.927 – 1.019), 0.239
Medial trochlea	271/68/254/7	10.6(3.5)/9.9(3.7)/10.4(3.9)/10.9(2.3)	0.593, 0.620	0.990 (0.949 – 1.031), 0.618	0.980 (0.938 – 1.024), 0.374
Lateral patella	282/26/209/83	9.8(3.8)/9.1(2.55)/10.75(3.6)/12.2(3.2)	**11.15, < 0.001**	**1.125 (1.077 – 1.176), < 0.001**	**1.127 (1.078 – 1.178), < 0.001**
Lateral trochlea	374/26/172/28	9.8(3.7)/12.0(3.0)/11.1(3.4)/12.6(3.9)	**11.01, < 0.001**	**1.138 (1.087 – 1.192), < 0.001**	**1.132 (1.079 – 1.186), < 0.001**
Thickness score					
Medial patella	403/64/129/4	10.3(3.9)/10.55(3.2)/10.6(3.3)/9.75(1.7)	0.196, 0.899	1.014 (0.969 – 1.061), 0.542	1.026 (0.974 – 1.079), 0.335
Medial trochlea	507/29/63/1	10.4(3.5)/11.1(7.2)/10.0(3.1)/12.0	0.626, 0.598	0.993 (0.935 – 1.054), 0.818	0.998 (0.936 – 1.064), 0.943
Lateral patella	444/27/101/28	9.9(3.7)/11.7(3)/11.5(3.5)/13.3(3.5)	**13.21, < 0.001**	**1.172 (1.112 – 1.236), < 0.001**	**1.179 (1.117 – 1.245), < 0.001**
Lateral trochlea	454/24/115/7	10.0(3.7)/11.4(3.1)/11.8(3.4)/13.1(3.5)	**9.90, < 0.001**	**1.153 (1.095 – 1.213), < 0.001**	**1.156 (1.094 – 1.220), < 0.001**
BML scores (0/1/2/3-4)					
Size score					
Medial patella	389/138/60/13	10.4(3.9)/10.3(3.5)/10.75(3.1)/9.5(2.6)	0.482, 0.695	0.998 (0.955 – 1.044), 0.944	1.002 (0.954 – 1.052), 0.934
Medial trochlea	441/137/15/7	10.7(3.8)/9.8(3.3)/9.7(2.7)/8.6(3.0)	2.50, 0.058	**0.931 (0.882 – 0.982), 0.008**	**0.941 (0.890 – 0.995), 0.034**
Lateral patella	384/108/84/24	9.8(3.7)/10.9(3.4)/11.8(3.5)/12.9(3.1)	**12.10, < 0.001**	**1.150 (1.097 – 1.206), < 0.001**	**1.158 (1.104 – 1.215), < 0.001**
Lateral trochlea	426/74/75/25	9.9(3.3)/11.1(3.5)/12.2(5.1)/12.1(3.6)	**12.42, < 0.001**	**1.141 (1.088 – 1.198), < 0.001**	**1.150 (1.093 – 1.209), < 0.001**
Number score					
Medial patella	389/155/54/2	10.4(3.9)/10.4(3.4)/10.4(3.3)/10.5(2.1)	0.007, 0.999	0.998 (0.954 – 1.043), 0.927	1.004 (0.956 – 1.054), 0.880
Medial trochlea	445/138/14/3	10.6(3.8)/9.9(3.3)/9.1(3.1)/8.3(3.1)	2.25, 0.081	**0.934 (0.886 – 0.986), 0.013**	0.947 (0.895 – 1.002), 0.061
Lateral patella	384/162/41/13	9.8(3.7)/11.6(3.5)/10.9(3.4)/11.6(3)	**7.67, < 0.001**	**1.125 (1.076 – 1.177), < 0.001**	**1.132 (1.079 – 1.186), < 0.001**
Lateral trochlea	428/131/30/11	9.9(3.3)/11.7(4.7)/11.2(2.8)/13.5(2.3)	**8.90, < 0.001**	**1.127 (1.076 – 1.183), < 0.001**	**1.129 (1.074 – 1.186), < 0.001**
Osteophyte score (0/1/2/3)					
Medial patella	252/279/68/1	9.9(3.3)/10.6(4)/11.3(3.5)/7	**3.34, 0.019**	**1.051 (1.009 – 1.096), 0.017**	**1.053 (1.008 – 1.101), 0.022**
Medial trochlea	262/254/72/12	9.9(3.4)/10.6(3.9)/11.6(3.7)/10.8(3.9)	**4.51, 0.004**	**1.064 (1.021 – 1.108), 0.003**	**1.087 (1.040 – 1.135), < 0.001**
Lateral patella	285/242/58/15	9.8(3.7)/10.5(3.4)/12.5(3.6)/11.8(4.8)	**9.54, < 0.001**	**1.114 (1.068 – 1.163), < 0.001**	**1.119 (1.069 – 1.169), < 0.001**
Lateral trochlea	346/155/76/23	9.8(3.6)/10.6(3.6)/11.9(3.3)/13.3(3.9)	**12.74, < 0.001**	**1.145 (1.094 – 1.197), < 0.001**	**1.151 (1.099 – 1.206), < 0.001**

Table 2 (continued)

Baseline	Number of subjects in each score	TT-TG distance Mean (SD) for each score	ANOVA $F_{(3,596)}$, *p* value	OR (95% CI), *p* value	
				Crude	Adjusted
Synovitis score (0/1/2/3)	246/302/47/5	10.4(3.5)/10.2(3.3)/11.1(3.5)/13.8(17)	2.17, 0.090	1.015 (0.973 – 1.059), 0.474	1.028 (0.989 – 1.030), 0.366
Effusion score (0/1/2/3)	233/250/97/20	9.9(3.2)/10.4(3.5)/11.6(4.9)/10.4(4.2)	**4.41, 0.004**	**1.066 (1.024 – 1.111), 0.002**	**1.066 (1.022 – 1.112), 0.003**

Data are presented as mean (standard deviation) for TT-TG distance. Data were analyzed using an ordinal logistic regression model (for the association between the TT-TG distance and baseline MOAKS scores) and one-way ANOVA analysis. Logistic analysis was adjusted for baseline variables including age, BMI, gender, WOMAC pain, kneeling activity, history of knee injury, ACL tear, varus or valgus, PASE score, muscle strength, and tibiofemoral KL grade. MOAKS: MRI Osteoarthritis Knee Score; BML: bone marrow lesion; TT-TG: tibial tuberosity-trochlear groove; SD: standard deviation; SE: standard error; ANOVA: analysis of variance; BMI: body mass index; WOMAC: Western Ontario & McMaster Universities osteoarthritis index; KL: radiographic Kellgren and Lawrence; ACL: anterior cruciate ligament; PASE: Physical Activity Scale for the Elderly

Bold numbers: *p*-value <0.05

might be possible that excessive TT-TG distance leads to patellofemoral OA by inducing effusion and SHFP edema. To the best of our knowledge, no prior reports have described the predictive value of the TT-TG distance for longitudinal patellofemoral OA worsening. The results of our study not only reconfirmed the cross-sectional association between TT-TG distance and patellofemoral OA, but also demonstrated that TT-TG could be considered as an important and easily obtainable marker of future lateral patellofemoral OA. Although our results showed significant associations, the obtained ORs were not extensive. The reason was that we evaluated the continuous form of the TT-TG distance variable (not dichotomized); this means that with the OR range from 1.05-1.15 (95% CI), for each millimeter increase in TT-TG distance, there was a 5-15% increase in the odds of overall lateral patellofemoral OA worsening. The more noticeable results were also obtained after excluding subjects who had a maximum score at baseline evaluations, and therefore no subsequent progression could occur. In this study, standard OA-related structural damage including cartilage loss, BML, and formation of osteophytes was utilized for describing the patellofemoral OA using the validated MOAKS method [21, 27, 28, 41].

The non-operative medical management of patellofemoral OA includes weight loss, pharmacological pain control, physical therapies, etc. [42–44]. It has been accepted that additional correction of OA predisposing factors (such as realignment surgery) simultaneous with cartilage restoration surgery induced a significant improvement in long-term clinical results [19, 20]. In this context, Gigante et al. showed improvement of the clinical outcomes after combined distal realignment (in subjects with CT-delved TT-TG distance > 20 mm) and matrix-assisted autologous chondrocyte transplantation [45]. Previous practices have defined the cutoff value of 15 mm (using CT) in the setting of patellofemoral instability, which has primarily aimed at detection of subjects who may benefit from a realignment procedure [36, 37]. Our results showed that a TT-TG distance of 10.5 mm (based on MRI) was the optimal cutoff for predicting future patellofemoral damage worsening. Although a TT-TG distance > 15mm using CT examinations has been considered abnormal in the setting of patellofemoral instability, this value was not an optimal cutoff for indicating and predicting patellofemoral OA, which may be due to the difference in modality (CT versus MRI) or outcome of interest (patellofemoral instability versus MRI-based patellofemoral OA). The patellofemoral OA-related MRI-based structural damage worsening was not significantly different between the subjects who had a TT-TG distance of > 15 mm versus ≤ 15 mm in previous reports and our ancillary analyses [3].

Abnormally lateralized tibial tuberosity can only be corrected using surgical methods such as TTM, which is currently primarily used in the setting of patellar instability [15–18]. However,

Table 3 Follow-up study: association between patellofemoral joint structural worsening (worsening change in patellar and trochlear MOAKS variables: cartilage, BML, osteophyte, synovitis, and effusion) and baseline TT-TG distance

Change	TT-TG distance Mean (SD), number of subjects		t-test *p* value	OR (95% CI), *p* value	
	Worsening	Non-worsening		Crude	Adjusted
Cartilage morphology scores (surface/thickness change)					
Medial patella	10.4(2.6), 65	10.4(3.8), 534	0.975	1.001 (0.934 – 1.073), 0.975	1.006 (0.935 - 1.083), 0.873
Medial trochlea	13.3(8.5), 21	10.3(3.4), 579	**< 0.001**	**1.158 (1.050 – 1.277), 0.003**	**1.208 (1.093 - 1.334), < 0.001**
Lateral patella	11.4(3.5), 51	10.3(3.7), 548	**0.045**	**1.070 (1.000 – 1.146), 0.050**	**1.078 (1.001 - 1.160), 0.047**
Lateral trochlea	12.0(3.3), 37	10.3(3.7), 563	**0.007**	**1.102 (1.021 – 1.188), 0.012**	**1.119 (1.033 - 1.211), 0.006**
BML scores (size/number change)					
Medial patella	10.8(3.1), 82	10.35(3.8), 517	0.357	1.029 (0.969 – 1.092), 0.357	1.023 (0.961 - 1.088), 0.475
Medial trochlea	9.2(3.1), 64	10.6(3.8), 535	**0.005**	**0.891 (0.823 – 0.964), 0.004**	**0.889 (0.817 - 0.967), 0.006**
Lateral patella	11.1(3.4), 104	10.3(3.7), 495	**0.039**	**1.058 (1.002 – 1.117), 0.044**	**1.060 (1.001 - 1.122), 0.046**
Lateral trochlea	11.6(4.6), 89	10.2(3.5), 510	**0.001**	**1.100 (1.036 – 1.168), 0.002**	**1.108 (1.041 - 1.179), 0.001**
Osteophyte score (size change)					
Medial patella	10.0(5.0), 8	10.4(3.7), 592	0.752	0.968 (0.793 – 1.182), 0.750	0.979 (0.785 - 1.222), 0.852
Medial trochlea	8.6(2.4), 8	10.5(3.7), 592	0.169	0.854 (0.688 – 1.060), 0.152	0.810 (0.626 - 1.047), 0.108
Lateral patella	8.3(2.9), 3	10.4(3.7), 597	0.330	0.832 (0.584 – 1.185), 0.307	0.697 (0.397 - 1.224), 0.209
Lateral trochlea	12.5(4.2), 6	10.4(3.7), 594	0.165	1.099 (0.965 – 1.252), 0.153	1.138 (0.944 - 1.373), 0.176
Synovitis score					
	10.1(3), 58	10.5(3.8), 542	0.436	0.970 (0.898 – 1.047), 0.434	0.963 (0.883 - 1.050), 0.390
Effusion score					
	10.9(4.2), 154	10.2(3.5), 446	**0.044**	**1.051 (1.000 – 1.103), 0.048**	**1.073 (1.018 - 1.131), 0.008**

Data are presented as mean (standard deviation) for TT-TG distance. Data were analyzed using logistic regression model (for the association between TT-TG distance and worsening of the MOAKS scores) and t-test analysis. Logistic analysis was adjusted for baseline variables including age, BMI, gender, WOMAC pain, kneeling activity, history of knee injury, ACL tear, varus or valgus, PASE score, muscle strength, and tibiofemoral KL grade as well as radiographic tibiofemoral JSL progression. MOAKS: MRI Osteoarthritis Knee Score; BML: bone marrow lesion; TT-TG: tibial tuberosity-trochlear groove; SD: standard deviation; SE: standard error; OR: odds ratio; CI: confidence intervals; BMI: body mass index; WOMAC: Western Ontario & McMaster Universities osteoarthritis index; KL: radiographic Kellgren and Lawrence; ACL: anterior cruciate ligament; PASE: Physical Activity Scale for the Elderly; JSL: joint space loss

Bold numbers: *p*-value <0.05

the biomechanical abnormalities associated with abnormal TT-TG distance can be addressed using readily accessible and feasible nonsurgical treatments [15, 46]. One study demonstrated that while the patellar brace was being worn there was a significant improvement in tracking vector and biomechanical abnormalities [15]. Also, it has been suggested that physical therapy focusing on extensor muscle strength can be considered the initial management of biomechanical abnormalities and patellar instability caused by an excessive TT-TG distance [15, 46, 47]. According to the variety of available interventions, biomechanical abnormalities associated with the excessive TT-TG distance might be considered a potential modifiable risk factor for patellofemoral OA.

Several limitations existed in our study. First, the FNIH study outcomes were primarily designed based on tibiofemoral OA. All inclusion/exclusion criteria were related to the baseline features of the tibiofemoral joint (e.g., 12.5% of enrolled subjects had tibiofemoral KL grade < 2 when evaluating isolated patellofemoral OA) as well as the radiographic progression of the tibiofemoral joint. Also, the study groups were not matched for several characteristics related to patellofemoral OA. To address this limitation and any potential selection bias, we

Table 4 Overall associations: association between the presence and worsening of medial/lateral patellofemoral OA-related structural damages with baseline TT-TG

	TT-TG distance Mean (SD), number of subjects		t-test *p* value	OR (95% CI), *p* value	
	Positive	Negative		Crude	Adjusted
Baseline overall patellofemoral structural damage					
Medial	10.49(3.8), 384	10.46(3.5), 216	0.492	1.015 (0.969 - 1.063), 0.528	1.013 (0.965 - 1.063), 0.604
Lateral	11.08(3.6), 269	9.87(3.7), 331	**< 0.001**	**1.098 (1.046 - 1.152), < 0.001**	**1.098 (1.045 - 1.154), < 0.001**
Worsening in overall patellofemoral structural damages					
Medial	10.36(4.0), 200	10.44(3.5), 398	0.792	0.992 (0.946 - 1.039), 0.721	0.993 (0.946 - 1.042), 0.778
Lateral	11.28(4.1), 207	9.95(3.4), 392	**< 0.001**	**1.106 (1.052 - 1.163), < 0.001**	**1.111 (1.056 - 1.170), < 0.001**

Data are presented as mean (standard deviation) for TT-TG distance. Data were analyzed using logistic regression model (for the association between the TT-TG distance and patellofemoral OA-related damage presence or worsening) and t-test. Logistic analysis was adjusted for baseline variables including age, BMI, gender, WOMAC pain, kneeling activity, history of knee injury, ACL tear, varus or valgus, PASE score, muscle strength, and KL grade as well as radiographic JSL progression (for worsening change analyses). MOAKS: MRI Osteoarthritis Knee Score; OA: osteoarthritis; BML: bone marrow lesion; TT-TG: tibial tuberosity-trochlear groove; SD: standard deviation; SE: standard error; OR: odds ratio; CI: confidence intervals; BMI: body mass index; WOMAC: Western Ontario & McMaster Universities osteoarthritis index; KL: Radiographic Kellgren and Lawrence; ACL: anterior cruciate ligament; PASE: Physical Activity Scale for the Elderly; JSL: joint space loss

Bold numbers: *p*-value <0.05

assessed all possible risk/protective factors related to baseline and follow-up patellofemoral/tibiofemoral OA; all results were adjusted for the possible effect of these confounding variables such as baseline (KL grade) and follow-up (JSL progression). Second, the sample size and follow-up duration period may not be adequate, and the association between TT-TG distance and long-term OA degeneration needs to be further explored in future cohort studies. Third, there was an absence of patellofemoral joint radiographic and symptom outcome. Although knee pain measurements are available in OAI, all these evaluations could be contributed by tibiofemoral OA, and a pain-grading system specific for the patellofemoral joint was not available. Also, only posteroanterior, not lateral or axial, knee radiographs are available in OAI, which were not optimal for radiographic grading of patellofemoral OA. Fourth, the association between patellofemoral OA and other patellar morphological abnormalities including patella alta, trochlear dysplasia, and patellar tilt were not evaluated in our study as these other measurements have been previously demonstrated to be associated to patellofemoral OA [5, 13, 14]. Besides all other patellar morphological abnormalities, excessive TT-TG distance is a modifiable abnormality that can be corrected using surgical treatments, especially in patients with high-risk of OA. Finally, despite the possible relationship between the lateralized tibial tuberosity and SHFP edema, which is associated with patellofemoral OA, the role of this factor in mediating the effect of excessive TT-TG distance on OA progression was not assessed in our study [7, 38–40].

In conclusion, we showed that excessive TT-TG distance can predict the longitudinal worsening of patellofemoral OA besides its role as an indicator of patellofemoral instability syndrome. Thus, biomechanical abnormalities associated with the increased TT-TG distance can be considered a risk factor for lateral patellofemoral OA.

Funding The authors state that this work has not received any funding.

Compliance with ethical standards

Guarantor The scientific guarantor of this publication is Dr. Shadpour Demehri.

Conflict of interest The authors of this manuscript declare no relationships with any companies, whose products or services may be related to the subject matter of the article.

Statistics and biometry No complex statistical methods were necessary for this paper.

Informed consent Written informed consent was not required for this study because we used the open access OAI database. All enrolled subjects in OAI study gave informed consent.

Ethical approval Institutional Review Board approval was not required because we used the open access OAI database.

The OAI study has received ethics board approval by the institutional review board at the University of California, San Francisco (OAI Coordinating Center; Approval Number: 10-00532).

Study subjects or cohorts overlap Some study subjects or cohorts have been previously reported in the OAI database and OAI-related articles.

Methodology
- prospective
- observational
- multicenter study

References

1. Hart HF, Stefanik JJ, Wyndow N, Machotka Z, Crossley KM (2017) The prevalence of radiographic and MRI-defined patellofemoral osteoarthritis and structural pathology: a systematic review and meta-analysis. Br J Sports Med 51:1195–1208
2. Arendt EA, Berruto M, Filardo G et al (2016) Early osteoarthritis of the patellofemoral joint. Knee Surg Sports Traumatol Arthrosc 24: 1836–1844
3. Tsavalas N, Katonis P, Karantanas AH (2012) Knee joint anterior malalignment and patellofemoral osteoarthritis: an MRI study. Eur Radiol 22:418–428
4. Mehl J, Feucht MJ, Bode G, Dovi-Akue D, Südkamp NP, Niemeyer P (2016) Association between patellar cartilage defects and patellofemoral geometry: a matched-pair MRI comparison of patients with and without isolated patellar cartilage defects. Knee Surg Sports Traumatol Arthrosc 24:838–846
5. Macri EM, Stefanik JJ, Khan KK, Crossley KM (2016) Is tibiofemoral or patellofemoral alignment or trochlear morphology associated with patellofemoral osteoarthritis? A systematic review. Arthritis Care Res (Hoboken) 68:1453–1470
6. Lording T, Lustig S, Servien E, Neyret P (2014) Chondral injury in patellofemoral instability. Cartilage 5:136–144
7. Thakkar RS, Del Grande F, Wadhwa V et al (2016) Patellar instability: CT and MRI measurements and their correlation with internal derangement findings. Knee Surg Sports Traumatol Arthrosc 24: 3021–3028
8. Marquez-Lara A, Andersen J, Lenchik L, Ferguson CM, Gupta P (2017) Variability in Patellofemoral Alignment Measurements on MRI: Influence of Knee Position. AJR Am J Roentgenol 208: 1097–1102
9. Stephen JM, Lumpaopong P, Dodds AL, Williams A, Amis AA (2015) The effect of tibial tuberosity medialization and lateralization on patellofemoral joint kinematics, contact mechanics, and stability. Am J Sports Med 43:186–194
10. Schoettle PB, Zanetti M, Seifert B, Pfirrmann CWA, Fucentese SF, Romero J (2006) The tibial tuberosity–trochlear groove distance; a comparative study between CT and MRI scanning. Knee 13:26–31
11. Tanaka MJ, Elias JJ, Williams AA, Carrino JA, Cosgarea AJ (2015) Correlation between changes in tibial tuberosity–trochlear groove distance and patellar position during active knee extension on dynamic kinematic computed tomographic imaging. Arthroscopy 31: 1748–1755
12. Otsuki S, Nakajima M, Okamoto Y et al (2016) Correlation between varus knee malalignment and patellofemoral osteoarthritis. Knee Surg Sports Traumatol Arthrosc 24:176–181
13. Demehri S, Thawait GK, Williams AA et al (2014) Imaging characteristics of contralateral asymptomatic patellofemoral joints in patients with unilateral instability. Radiology 273:821–830
14. Williams AA, Elias JJ, Tanaka MJ et al (2016) The relationship between tibial tuberosity–trochlear groove distance and abnormal patellar tracking in patients with unilateral patellar instability. Arthroscopy 32:55–61
15. Becher C, Schumacher T, Fleischer B, Ettinger M, Smith T, Ostermeier S (2015) The effects of a dynamic patellar realignment brace on disease determinants for patellofemoral instability in the upright weight-bearing condition. J Orthop Surg Res 10:126
16. Saranathan A, Kirkpatrick MS, Mani S et al (2012) The effect of tibial tuberosity realignment procedures on the patellofemoral pressure distribution. Knee Surg Sports Traumatol Arthrosc 20:2054–2061
17. Mani S, Kirkpatrick MS, Saranathan A, Smith LG, Cosgarea AJ, Elias JJ (2011) Tibial tuberosity osteotomy for patellofemoral realignment alters tibiofemoral kinematics. Am J Sports Med 39: 1024–1031
18. Elias JJ, Carrino JA, Saranathan A, Guseila LM, Tanaka MJ, Cosgarea AJ (2014) Variations in kinematics and function following patellar stabilization including tibial tuberosity realignment. Knee Surg Sports Traumatol Arthrosc 22:2350–2356
19. Vasiliadis HS, Lindahl A, Georgoulis AD, Peterson L (2011) Malalignment and cartilage lesions in the patellofemoral joint treated with autologous chondrocyte implantation. Knee Surg Sports Traumatol Arthrosc 19:452–457
20. Pascual-Garrido C, Slabaugh MA, L'Heureux DR, Friel NA, Cole BJ (2009) Recommendations and treatment outcomes for patellofemoral articular cartilage defects with autologous chondrocyte implantation. Am J Sports Med 37:33S–41S
21. Hunter DJ, Guermazi A, Lo GH et al (2011) Evolution of semi-quantitative whole joint assessment of knee OA: MOAKS (MRI Osteoarthritis Knee Score). Osteoarthritis Cartilage 19:990–1002
22. Folkesson J, Dam EB, Olsen OF, Pettersen PC, Christiansen C (2007) Segmenting articular cartilage automatically using a voxel classification approach. IEEE Trans Med Imaging 26:106–115
23. Son YN, Jin W, Jahng GH et al (2018) Efficacy of double inversion recovery magnetic resonance imaging for the evaluation of the synovium in the femoro-patellar joint without contrast enhancement. Eur Radiol 28:459–467
24. Pandit S, Frampton C, Stoddart J, Lynskey T (2011) Magnetic resonance imaging assessment of tibial tuberosity–trochlear groove distance: normal values for males and females. Int Orthop 35:1799–1803
25. Cicuttini F, Spector T, Baker J (1997) Risk factors for osteoarthritis in the tibiofemoral and patellofemoral joints of the knee. J Rheumatol 24:1164–1167
26. Tangtrakulwanich B, Suwanno P (2012) Epidemiology and risk factors of patellofemoral osteoarthritis in adults: a population-based study in southern Thailand. J Med Assoc Thai 95:1048
27. Hunter D, Arden N, Conaghan P et al (2011) Definition of osteoarthritis on MRI: results of a Delphi exercise. Osteoarthritis Cartilage 19:963–969
28. Runhaar J, Schiphof D, van Meer B, Reijman M, Bierma-Zeinstra S, Oei E (2014) How to define subregional osteoarthritis progression using semi-quantitative MRI Osteoarthritis Knee Score (MOAKS). Osteoarthritis Cartilage 22:1533–1536
29. Goutallier D, Bernageau J, Lecudonnec B (1978) The measurement of the tibial tuberosity. Patella groove distanced technique and results (author's transl). Rev Chir Orthop Reparatrice Appar Mot 64: 423–428
30. Dejour H, Neyret P, Walch G (1992) Factors in patellar instability. In: Aichroth PM, Dilworth Cannon W (eds) Knee surgery current practice. Martin Dunitz Ltd, London, pp 403–412
31. Dietrich TJ, Betz M, Pfirrmann CWA, Koch PP, Fucentese SF (2014) End-stage extension of the knee and its influence on tibial tuberosity-trochlear groove distance (TTTG) in asymptomatic volunteers. Knee Surg Sports Traumatol Arthrosc 22:214–218
32. Camathias C, Pagenstert G, Stutz U, Barg A, Müller-Gerbl M, Nowakowski AM (2016) The effect of knee flexion and rotation on the tibial tuberosity-trochlear groove distance. Knee Surg Sports Traumatol Arthrosc 24:2811–2817
33. Camp CL, Stuart MJ, Krych AJ et al (2013) CT and MRI measurements of tibial tubercle–trochlear groove distances are not equivalent in patients with patellar instability. Am J Sports Med 41:1835–1840
34. Hinckel BB, Gobbi RG, Filho EN et al (2015) Are the osseous and tendinous-cartilaginous tibial tuberosity-trochlear groove distances the same on CT and MRI? Skeletal Radiol 44:1085–1093
35. Hunter DJ, Zhang W, Conaghan PG et al (2011) Systematic review of the concurrent and predictive validity of MRI biomarkers in OA. Osteoarthritis Cartilage 19:557–588

36. Dejour H, Walch G, Nove-Josserand L, Guier CH (1994) Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc 2:19–26
37. Ridley TJ, Hinckel BB, Kruckeberg BM, Agel J, Arendt EA (2016) Anatomical patella instability risk factors on MRI show sensitivity without specificity in patients with patellofemoral instability: a systematic review. J ISAKOS 1:141–152
38. Roemer FW, Guermazi A, Felson DT et al (2011) Presence of MRI-detected joint effusion and synovitis increases the risk of cartilage loss in knees without osteoarthritis at 30-month follow-up: the MOST study. Ann Rheum Dis 70:1804–1809
39. Chhabra A, Subhawong TK, Carrino JA (2011) A systematised MRI approach to evaluating the patellofemoral joint. Skeletal Radiol 40:375–387
40. Jarraya M, Guermazi A, Felson DT et al (2017) Is superolateral Hoffa's fat pad hyperintensity a marker of local patellofemoral joint disease? The MOST study. Osteoarthritis Cartilage 25:1459–1467
41. Roemer FW, Guermazi A (2014) Osteoarthritis year in review 2014: imaging. Osteoarthritis Cartilage 22:2003–2012
42. Quilty B, Tucker M, Campbell R, Dieppe P (2003) Physiotherapy, including quadriceps exercises and patellar taping, for knee osteoarthritis with predominant patello-femoral joint involvement: randomized controlled trial. J Rheumatol 30:1311–1317
43. Hunter DJ, Harvey W, Gross KD et al (2011) A randomized trial of patellofemoral bracing for treatment of patellofemoral osteoarthritis. Osteoarthritis Cartilage 19:792–800
44. Becker R, Röpke M, Krull A, Musahl V, Nebelung W (2008) Surgical treatment of isolated patellofemoral osteoarthritis. Clin Orthop Relat Res 466:443–449
45. Gigante A, Enea D, Greco F et al (2009) Distal realignment and patellar autologous chondrocyte implantation: mid-term results in a selected population. Knee Surg Sports Traumatol Arthrosc 17:2–10
46. Merchant A, Fulkerson J, Leadbetter W (2017) The diagnosis and initial treatment of patellofemoral disorders. A Am J Orthop (Belle Mead NJ) 46:68
47. Lobner S, Krauss C, Reichwein F, Patzer T, Nebelung W, Venjakob AJ (2017) Surgical treatment of patellar instability: clinical and radiological outcome after medial patellofemoral ligament reconstruction and tibial tuberosity medialisation. Arch Orthop Trauma Surg 37:1087–1095