

Deep learning for identifying patellofemoral measurements associated with cartilage lesions on MRI

Introduction

- Management of patellofemoral joint (PFJ) osteoarthritis (OA) is often non-operative, though some patients benefit from surgical treatment such as antero-medialization osteotomy to offload stress in the PFJ.^{1,2}
- Understanding anomalies in geometric morphology contributing to PFJ cartilage loss may improve identification of patients who are most at risk for progressive degenerative changes and enable surgical correction when appropriate.
- Our aim was to develop a deep learning (DL) algorithm to segment bony and ligamentous structures in knee MRIs from a longitudinal, multi-center cohort to extract PFJ geometric measurements and determine their relationships with chondral lesions.

Methods

- We built a deep learning segmentation model to determine the locations of patella, femur, tibia, and patellar tendon within MRIs from the OsteoArthritis Initiative (**Figure 1**).
- We measured sagittal tibial tubercle trochlear groove (sTTTG) distance, tibial tubercle trochlear groove (TTTG) distance, trochlear sulcus angle, trochlear depth, Caton-Deschamps index (CDI), and flexion angle using the deep learning-generated segmentations on a subset of the OsteoArthritis Initiative with radiologist-graded PFJ cartilage gradings (N=2461) (**Figure 2**).
- We defined PFJ OA as knees with surface area of cartilage loss > 10% and at least some full thickness cartilage loss in one or more PFJ sub-compartments (anterior medial femur, anterior lateral femur, medial patella, lateral patella).
- We further correlated PFJ morphology with secondary outcomes of mean patellar cartilage thickness and mean patellar cartilage T2 relaxation time using linear regression models controlled for age, sex, and BMI.

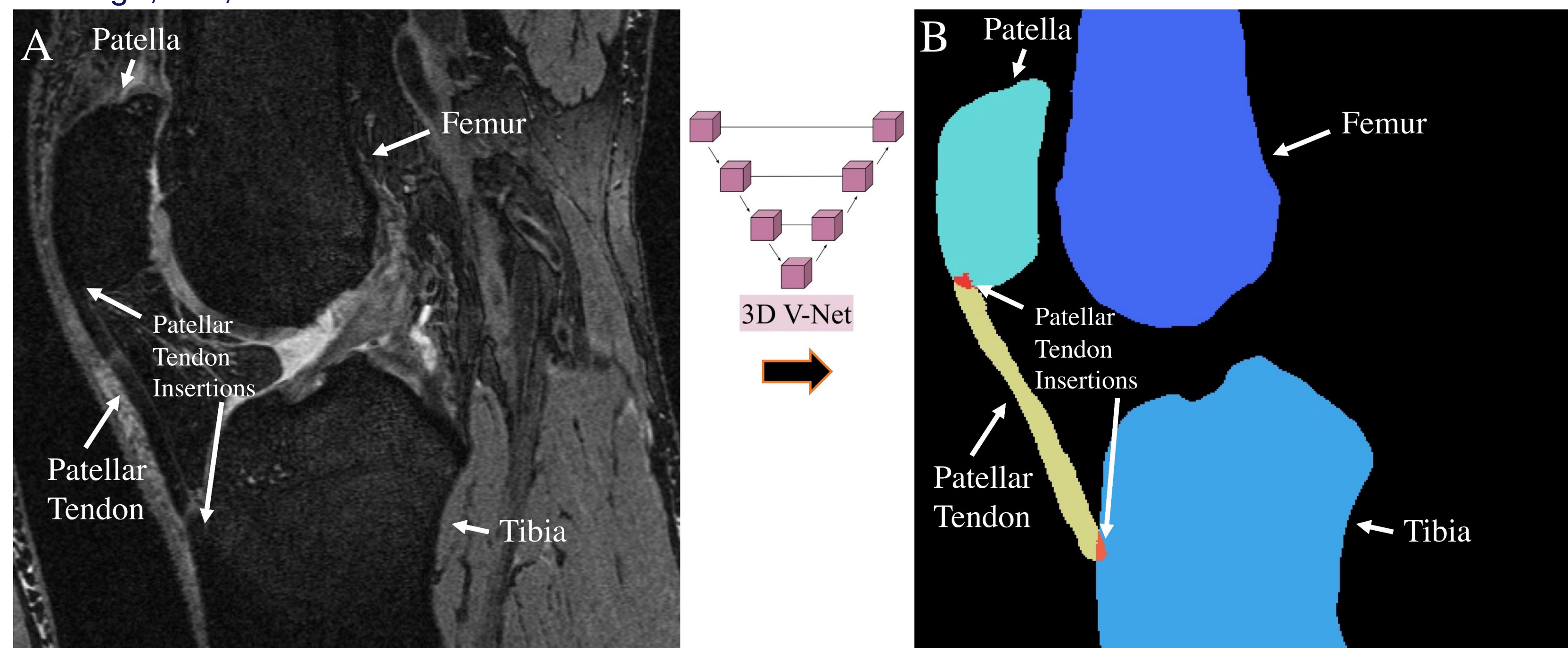


Figure 1. The deep learning segmentation algorithm receives a 3D sagittal double echo steady-state knee MRI (A) as input for 3D V-Net neural networks trained to segment patella (green), femur (dark blue), tibia (light blue), and patellar tendon (brown) masks (B). Red regions demonstrate patellar tendon insertions onto patella and tibia.

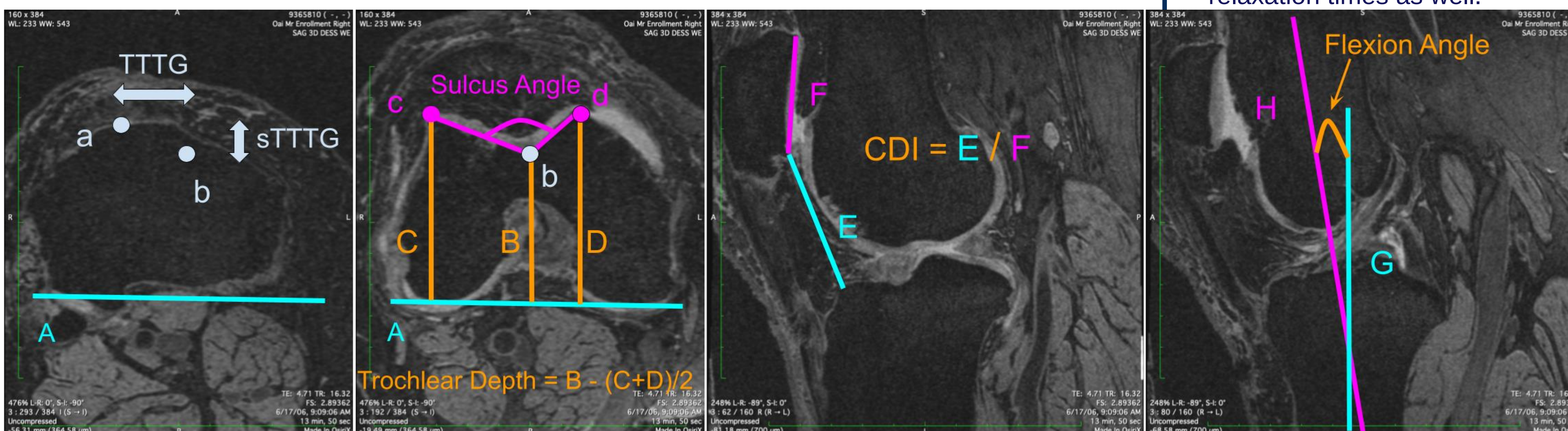


Figure 2. The anterior-posterior displacement of the tibial tubercle (point a) with respect to trochlear groove (point b), relative to the posterior condylar axis (line A) denoted the sagittal tibial tubercle trochlear groove distance (sTTTG). The medial-lateral distance, relative to the posterior condylar axis, between the tibial tubercle and trochlear groove determined the tibial tubercle trochlear groove distance (TTTG). The angle formed between the trochlear groove and the anterior-most points of the lateral femoral condyle (point c) and medial femoral condyle (point d) defined the trochlear sulcus angle. Trochlear depth was calculated by subtracting the distance from trochlear groove to posterior condylar axis (line B) from the mean distance of the lateral femoral condyle and medial femoral condyle to the posterior condylar axis (lines C and D, respectively). Caton-Deschamps index (CDI) measured the ratio of the distance between inferior patellar pole to anterior tibial plateau (line E) and the length of articulating patellar surface (line F). The angle formed between tibia diaphysis (G) and femur diaphysis (H) on mid-sagittal slice discerned flexion angle.

Results

- A total of 1626 knees did not have PFJ OA, while 835 knees possessed PFJ OA (**Table 1**).
- Subjects with PFJ OA were older, had greater female predominance, greater pain levels, and greater proportion of total knee replacement within eight years of baseline.
- Knees without PFJ OA had a greater sTTTG (11.1(12.8) mm) compared to subjects with PFJ OA (8.4(12.7) mm) ($p<0.001$), indicating a more posterior tibial tubercle for subjects with PFJ OA (mean(standard deviation)) (**Table 2**).
- Knees without PFJ OA had a lower sulcus angle (127.4(7.1) degrees v. 128.0(8.4) degrees, $p=0.01$) and greater trochlear depth (9.1(1.7) mm v. 9.0(2.0) mm, $p=0.03$) compared to subjects with PFJ OA.
- Decreased patellar cartilage thickness associated with decreased trochlear depth ($\beta=0.12$, $p=0.002$) and increased CDI ($\beta=-0.07$, $p<0.001$) (**Table 3**).
- Increased T2 relaxation time (i.e. evidence of cartilage degeneration) was significantly correlated with a lower sTTTG ($\beta=-0.08$, $p=0.01$) (i.e. more posteriorly-positioned tibial tubercle) (**Table 4**).
- A lower sulcus angle ($\beta=-0.12$, $p=0.04$) and lower CDI ($\beta=-0.12$, $p<0.001$) were associated with increased patellar cartilage T2 relaxation times as well.

Table 1. Demographics of the analytical sample stratified by patellofemoral joint osteoarthritis. Abbreviations: PFJ: patellofemoral joint, OA: osteoarthritis, KL: Kellgren-Lawrence, KOOS: Knee Injury and Osteoarthritis Outcome Score, WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index

	No PFJ OA	PFJ OA	P value
N	1626	835	
Age, years mean (SD)	62 (9)	65 (9)	<0.001
Sex Female, N (%)	868 (53)	549 (66)	<0.001
Height, cm mean (SD)	1689 (95)	1670 (95)	<0.001
Weight, kg mean (SD)	81 (16)	82 (16)	0.02
BMI, kg/m ² mean (SD)	28 (5)	29 (5)	<0.001
Baseline KL grade, N (%)			<0.001
0	723 (44)	173 (21)	
1	309 (19)	167 (20)	
2	277 (17)	274 (33)	
3	231 (14)	163 (20)	
4	86 (5)	58 (7)	
Baseline KOOS, mean(SD)	87 (17)	81 (18)	<0.001
Baseline WOMAC, mean(SD)	10 (14)	15 (16)	<0.001
Total knee replacement, N (%)	117 (7)	143 (17)	<0.001

Table 2. Patellofemoral joint geometric measurements stratified by patellofemoral joint osteoarthritis. Abbreviations: PFJ: patellofemoral joint, OA: osteoarthritis, sTTTG: sagittal tibial tubercle trochlear groove, TTTG: tibial tubercle trochlear groove, CDI: Caton-Deschamps index

	No PFJ OA	PFJ OA	P value
N	1626	835	
sTTTG, mm mean(SD)	11.1 (12.8)	8.4 (12.7)	<0.001
TTTG, mm mean(SD)	9.9 (5.3)	9.5 (6.0)	0.31
Sulcus angle, degrees mean (SD)	127.4 (7.1)	128.0 (8.4)	0.01
Trochlear depth, mm mean(SD)	9.1 (1.7)	9.0 (2.0)	0.03
CDI, mean(SD)	1.0 (0.1)	1.0 (0.2)	0.94

Table 3. Multivariate linear regression associating mean patellar cartilage thickness with PFJ geometric measurements (N=2453). Model adjusted for age, sex, and BMI.

	Beta Coefficient	P value
sTTTG	0.03	0.11
TTTG	-0.03	0.06
Sulcus angle	0.02	0.48
Trochlear depth	0.12	0.002
CDI	-0.07	<0.001

Table 4. Multivariate linear regression associating mean patellar cartilage T2 signal with patellofemoral joint geometric measurements (N=1536). Model adjusted for age, sex, and BMI.

	Beta Coefficient	P value
sTTTG	-0.08	0.01
TTTG	-0.006	0.81
Sulcus angle	-0.12	0.04
Trochlear depth	-0.11	0.08
CDI	-0.12	<0.001

Conclusions

- Our study demonstrates PFJ OA, patellar cartilage thickness, and patellar cartilage T2 relaxation time are associated with the underlying geometries within the PFJ.
- This large, longitudinal study highlights that sTTTG, a less widely studied measurement, is significantly associated with PFJ cartilage change.
- These findings may promote use of geometric measurements as prognostic indicators of PFJ OA
- Additionally, considering abnormalities in these geometric measurements may improve surgical planning for operations that offload stress on the PFJ.

References

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- Sherman SL, Humpherys J, Farr J. Optimizing patellofemoral cartilage restoration and instability with tibial tubercle osteotomy. *Arthroscopy*. 2019;35(8):2255-2256.