The Bone & Joint Journal

Supplementary Material

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Table i. Sources and range of data.

Study	Database	Publicly available?	Number of patients	Joint	OA severity at baseline	Early diagnosis	Tabular data or Imaging?	Clinical data	PROMs	Radiograph	CT	MRI	Biochemical markers	Omics data	Movement data
Al Turkestani et al (2024)[1]	Local data	No	106	TMJ	No OA to radiographic OA	No	Mixed	Yes	Yes	Yes	Yes	No	Yes	No	No
Bayramoglu et al (2024)[2]	MOST	Yes	1,832 (3,276 knees)	Patellofemoral joint (Knee)	No radiographic patellofemoral OA	No	Mixed	Yes	Yes	Yes	No	No	No	No	No
Nguyen et al (2024)[3]	OAI	Yes	8953	Knee	KL 0-4	No	Mixed	Yes	Yes	Yes	No	No	No	No	No
Nielsen et al (2024)[4]	UK Biobank	Yes	38,372	Arm, foot, spine, hip, knee, unspecified	No OA	Yes	Tabular	Yes	No	No	No	No	Yes	Yes	No
Salis et al (2024)[5]	OAI (MOST for external validation)	Yes	3114	Knee	No OA or early OA	No	Tabular	Yes	Yes	Yes	No	No	No	No	No
Chen et al (2023)[6]	OAI	Yes	3200	Knee	KL 0-1	No	Tabular	Yes	Yes	Yes	No	No	No	No	No
Dunn et al (2023)[7]	Osteoarthritis Biomarkers Consortium (OAI), (OAI and JoCo OA Project for external validation)	Yes	554	Knee	KL 2-3	No	Tabular	Yes	Yes	No	No	No	No	Yes	No
Hu et al (2023)[8]	Osteoarthritis Biomarkers	Yes	364	Knee	KL 1-3	No	Mixed	Yes	Yes	Yes	No	Yes	No	No	No

	Consortium (OAI)														
Shen et al (2023)[9]	Dryad	Yes	195	Knee	KL 2-3	No	Tabular	Yes	Yes	No	No	No	No	No	No
Widera et al (2023)[10]	MUST, HOSTAS, DIGICOD, PROCOAC, CHECK, (APPROACH for external validation)	Yes	223	Knee	JSW min 1.63mm-3.43mm	No	Tabular	Yes	Yes	Yes	No	No	No	No	No
Yin et al (2023)[11]	OAI	Yes	3583	Knee	KL 0-4	No	Imaging	No	No	Yes	No	No	No	No	No
Yoo et al (2023)[12]	Clinical Data Warehouse	No	2,151 knees	Knee	KL 0-2	Yes	Tabular	Yes	No	Yes	No	No	No	No	No
Almhdie-Imjabbar et al (2022)[13]	OAI, MOST (each also used as external dataset)	Yes	OAI: 1,888 MOST: 683	Knee	KL 2-4	No	Imaging	No	No	Yes	No	No	No	No	No
Bonakdari et al (2022)[14]	OAI (TASOAC for external validation)	Yes	901	Knee	KL 0-4	No	Tabular	Yes	No	Yes	No	No	No	Yes	No
Bonakdari et al (2022)[15]	OAI (Naproxen for external validation)	Yes	1246	Knee	Structural progressors only	No	Tabular	Yes	No	No	No	Yes	No	No	No
Guan et al (2022)[16]	OAI	Yes	6,567 knees	Knee	KL 0-4	No	Mixed	Yes	Yes	Yes	No	No	No	No	No
Hu et al (2022)[17]	OAI	Yes	4796	Knee	KL 1-4	Yes	Imaging	No	No	Yes	No	No	No	No	No
Joseph et al (2022)[18]	OAI	Yes	1044	Knee	KL 0-1	No	Tabular	Yes	Yes	Yes	No	Yes	No	No	No
Bonakdari et al (2021)[19]	OAI (Naproxen for external validation)	Yes	677	Knee	KL 1-4	Yes	Tabular	Yes	No	Yes	No	Yes	Yes	No	No
Chan et al (2021)[20]	OAI	Yes	4,181 knees	Knee	KL 0-3	Yes	Tabular	Yes	Yes	Yes	No	No	No	No	No
Cheung et al (2021)[21]	OAI	Yes	100	Knee	KL 0-4	No	Imaging	No	No	Yes	No	No	No	No	No
Lee et al (2021)[22]	OAI	Yes	2,799 (3,828 knees)	Knee	No pain	No	Mixed	Yes	No	Yes	No	Yes	No	No	No
Lu et al (2021)[23]	REP	No	654	Shoulder	No OA to symptomatic	No	Tabular	Yes	Yes	Yes	No	No	No	No	No
Ningrum et al (2021)[24]	Taiwan's National Health	No	1,201,058	Knee	N/A	No	Tabular	Yes	No	No	No	No	No	No	No

	Insurance Research and Development (NHIRD)														
Ntakolia et al (2021)[25]	OAI	Yes	3031	Knee	KL 0-4	Yes	Tabular	Yes	Yes	Yes	No	No	No	No	No
Ntakolia et al (2021)[26]	OAI	Yes	4796	Knee	KL 0 or at risk of OA	No	Tabular	Yes	Yes	Yes	No	No	No	No	No
Schiratti et al (2021)[27]	OAI	Yes	3268	Knee	KL 0-4	No	Mixed	Yes	Yes	No	No	Yes	No	No	No
Guan et al (2020)[28]	OAI	Yes	2300	Knee	KL 0-3	No	Mixed	Yes	Yes	Yes	No	No	No	No	No
Jamshidi et al (2020)[29]	OAI	Yes	4796	Knee	KL 1-4	No	Tabular	Yes	Yes	Yes	No	Yes	No	No	No
Kundu et al (2020)[30]	OAI	Yes	86	Knee	KL 0,1	Yes	Imaging	No	No	No	No	Yes	No	No	No
Morales Martinez et al (2020)[31]	OAI	Yes	41	Knee	KL 0-4	No	Imaging	No	No	No	No	Yes	No	No	No
Wang et al (2020)[32]	OAI	Yes	518	Knee	KL 0-4	No	Tabular	Yes	Yes	Yes	No	No	No	No	No
Widera et al (2020)[33]	OAI, CHECK	Yes	4467	Knee	KL 0-4	No	Tabular	Yes	Yes	Yes	No	No	No	No	No
Tiulpin et al (2019)[34]	OAI (MOST for external validation)	Yes	2,711	Knee	KL 0-3	No	Mixed	Yes	Yes	Yes	No	No	No	No	No
Ashinsky et al (2017)[35]	OAI	Yes	68	Knee	KL 0 - symptomatic	Yes	Imaging	No	No	No	No	Yes	No	No	No
Hafezi-Nejad et al (2017)[36]	Osteoarthritis Biomarkers Consortium (OAI)	Yes	600	Knee	KL 1-3	No	Tabular	Yes	Yes	Yes	No	Yes	No	No	No
Lazzarini et al (2017)[37]	PROOF	No	365	Knee	No clinical knee OA	No	Tabular	Yes	Yes	Yes	No	Yes	Yes	No	No
Marques et al (2013)[38]	Local data	No	159 (268 knees)	Knee	KL 0-4	No	Imaging	No	No	No	No	Yes	No	No	No
Woloszynski et al (2012)[39]	Local data	No	50	Knee	KL 0,2,3	No	Imaging	No	No	Yes	No	No	No	No	No

APPROACH, Applied Public-Private Research enabling OsteoArthritis Clinical Headway; CHECK, Cohort Hip and Cohort Knee; DIGICOD, DIGItal COhort Design; HOSTAS, Hand Osteoarthritis in Secondary Care; KL, Kellgren-Lawrence grade; MOST, Multicentre Osteoarthritis Study; NHIRD, National Health Insurance Research and Development; OAI, Osteoarthitis Initiative; ROCOAC, PROspective COhort of A Coruña; PROOF, PRevention of knee Osteoarthritis in Overweight Females; REP, Rochester Epidemiology Project; TASOAC, Tasmanian Older Adult Cohort.

Table ii. Summary of machine learning approaches in predicting progression of osteoarthritis.

Study	Definition of OA progression	Type of progression	Features used for progression definition	Feature extraction technique for image analysis	Predictive algorithms used	Learning type	Deep learning?	Interpretability analysis?	Validation	Metrics used to assess performance
Al Turkestani et al (2024)[1]	Four groups: 0 = asymptomatic, 1 = improved, 2 = unchanged, and 3 = worsened at 2-3 year follow up. "Asymptomatic" if there were no TMJ pain-related symptoms "Improved" if pain levels became <5 and the vertical mouth opening ≥40 mm "Worsened" if there was an increase in clinical symptoms, radiographic signs, or 3D morphological degenerative changes. Combined the healthy and improved categories into one group (recovery) and the unchanged and worsened groups into another (no recovery).	Pain or structural	Pain scores + Radiograph + CT	3D Slicer, SPHARM-PDM	Glmnet, Glmboost, HDDA, NNET, RF, XGBoost, SVM, LDA, Ensemble via Hierarchical Predictions through Nested cross-validation tool (EHPN)	Supervised	No	Yes: SHAP	CV	AUC-ROC
Bayramoglu et al (2024)[2]	Development of radiographic patellofemoral OA within 84 months: Osteophyte score ≥ 2 or the joint space narrowing (JSN) score is ≥ 1 plus any osteophyte, sclerosis or cysts ≥ 1 in the PF joint (grades 0–3; 0=normal, 1=mild, 2=moderate, 3=severe)	Structural	Radiograph	CNN	CNN + GBM	Supervised	Yes	No	CV	AUC-ROC, AUC-PRC, Brier score
Nguyen et al (2024)[3]	Changes in KL, JSL, JSM, osteophytes in the lateral/medial side of the femur (OSFL/OSFM), and osteophytes in the lateral/medial side of the tibia (OSTL/OSTM)	Structural	Radiograph	CLIMATv2 (CNN: ResNet18 and 3D-ShuffleNet2)	CLIMATv2	Unsupervised	Yes	Yes: attention maps	CV + "External" (used data collected from one center within OAI as independent dataset)	Balanced accuracy (BA)
Nielsen et al (2024)[4]	Clinical codes of OA diagnoses a maximum of 5 years after recruitment in study	Not specified	Not specified	N/A	XGBoost	Supervised	No	Yes: SHAP	CV	AUC-ROC

Salis et al (2024)[5]	A knee was classified as having esKOA if it met either of the following criteria: (1) Displaying moderate to severe KOA symptoms (defined as a combined WOMAC pain and disability score of 12 or above) in conjunction with the most severe radiographic KOA (i.e., KL grade = 4, the maximum KL grade); (2) Exhibiting intense KOA symptoms (a combined WOMAC pain and disability score of 23 or more) alongside persistent knee pain and either mild or moderate radiographic KOA (i.e., KL grade = 2 or 3); at 2-2.5 year or 4-5 year follow-up	Pain and structural	Pain scores + Radiograph	N/A	XGBoost	Supervised	No	Yes: XGBoost	Internal + Hold-out + External	AUC-ROC, F1 score
Chen et al (2023)[6]	Progression of knee pain, functional decline, and incidence of knee OA over 9 years	Pain or structural	Pain scores + Radiograph	N/A	AutoGluon (AutoML): RF, Extra trees, XGBoost, CatBoost, LightBGM, LightGBMXT, LightGBMLarge, kNN	Supervised	No	Yes: Permutation feature importance	Internal	AUC-ROC, RMSE
Dunn et al (2023)[7]	In the OABC model development cohort: - Radiographic progressors: longitudinal loss in the minimum JSW of at least 0.7 mm from baseline to 48-month follow-up in 1 index knee. In each participant, the contralateral (nonindex) knee had less or no progression over the follow-up period. - Nonprogressors: ≤0.5 mm of JSW loss from baseline to 48-month follow-up in both knees. - Pain progressors: increase of ≥9 points at 2 or more time points on the WOMAC pain subscale (normalized to a 0–100 scale) from the 24-month to 60-month pain assessment. In the JoCo OA Project validation cohort: - Radiographic progression: increase of ≥1 K/L grade in the index knee between 2 visits. - Nonprogressors: no evidence	Pain and structural	Pain scores + Radiograph	N/A	Glmnet	Supervised	No	No	CV + External	Accuracy, AUC-ROC, Sensitivity, Specificity, F1-score, Diagnostic OR

	for progression at any study time point. In the OAI validation cohor: - Radiographic progression: similar to the OABC, except that 0.7 mm of JSW loss had to occur within the first 24 months and remain narrowed at the 48-month follow-up visit.									
Hu et al (2023)[8]	Either one of: Structural progression: loss in medial minimum JSW of ≥0.7 mm from baseline to 24, 36, or 48 months. Pain progression: persistent increase from baseline to 24, 36, or 48 months of ≥9 points on a 0–100 normalized score	Pain or structural	Pain scores + Radiograph	3D DenseNets, ResNet	CNN	Unsupervised	Yes	Yes: GradCAM	CV	AUC-ROC
Shen et al (2023)[9]	Transition from KL grade 2 to 3	Structural	Radiograph	N/A	Glmnet/LASSO	Supervised	No	Yes: Nomogram	Internal + Hold-out	AUC-ROC, F1-score, Precision, Recall
Widera et al (2023)[10]	One non-progressive category (N) and three progressive categories related to pain (P), structure (S), and combined pain and structure (P + S). S category if the minimum JSW decreased by at least 0.3 mm per year. P category if: - the pain increased at least by the minimal clinically important difference per year (5 points on a 0–100 scale) and was substantial at the end of a period (at least 40 points). - for a rapid pain increase of at least 10 points per year, the end pain threshold was lower (at least 35 points). - substantial pain (at least 40 points) was sustained at both the start and the end of a period. P + S category if criteria for both P and S were satisfied N category if neither of them was satisfied.	Pain and structural	Pain scores + Radiograph	N/A	RF	Supervised	No	No	CV + External	F1 score, AUC-ROC
Yin et al (2023)[11]	Non-progression was defined as no change in KL grade or a change from KL grade 0 to KL	Structural	Radiograph	Bilateral Knee Neural	Bilateral Knee Neural Network (BikNet)	Supervised	Yes	Yes: GradCAM	Internal + Hold-out	AUC-ROC, Sensitivy, Specificity

	grade 1, while progression was defined as an increase in KL grade of at least one or the receipt of TKA during the follow-up period (48 months)			Network (BikNet)						
Yoo et al (2023)[12]	Progression rate of OA: time elapsed for a KL grade change of more than 2 from no radiologic or early OA (K-L grades 0–2) (rapid: ≤7 years; slow: >7 years).	Structural	Radiograph	N/A	RF, XGBoost	Supervised	No	No	CV	Accuracy, Recall, F1 score, AUC-ROC, Specificity, Error rate
Almhdie-Imjabbar et al (2022)[13]	An increase in the OARSI medial joint space narrowing (mJSN) grades over 48 months in OAI and 60 months in MOST	Structural	Radiograph	TBT, SNN	LR, DT, MLP	Supervised	Yes	No	CV + External	AUC-ROC
Bonakdari et al (2022)[14]	Probability values of being structural progressors (PVBSP) generated using ML, based on baseline medial minimum joint space width, mean cartilage thickness of peripheral, medial and central tibial plateaus as assessed by quantitative MRI, the medial joint space narrowing (JSN) as a score, and the outcome JSN ≥ 1 at 48 months.	Structural	Radiograph + MRI	N/A	SVM, kNN, RF, DT, ELM, SA-ELM, DT-SAELM	Supervised	No	No	CV + External	Accuracy
Bonakdari et al (2022)[15]	Cartilage volume loss (CVL) at one year	Structural	MRI	N/A	ANFIS (best model), RF, M5Rules, M5P, MLP	Supervised	No	No	Internal + External	Correlation coefficient (R), Root mean square error (RMSE), Mean absolute error (MAE)
Guan et al (2022)[16]	Pain progression: 9 point or greater increase in WOMAC pain score between baseline and two or more follow-up time over the first 48-months.	Pain	Pain scores	CNN	RF,LR, ANN, CNN	Supervised	Yes	No	Internal + Hold-out	AUC-ROC, Sensitivity, Specificity
Hu et al (2022)[17]	KL grade progression	Structural	Radiograph	A-ENN	A-ENN	Unsupervised	Yes	No	Internal + Hold-out	Accuracy
Joseph et al (2022)[18]	KL grade 2–4 OA in the right knee over 8 years	Structural	Radiograph	N/A	Xgboost	Supervised	No	No	CV + Hold-out	AUC-ROC
Bonakdari et al (2021)[19]	Probability values of being structural progressors (PVBSP) generated using ML, based on baseline medial minimum joint space width, mean cartilage thickness of peripheral, medial and central tibial plateaus as assessed by quantitative MRI,	Structural	Radiograph + MRI	N/A	kNN, RF, DT, ELM, SVM	Supervised	No	Yes: SVM	Internal + Hold-out + External	Percent estimation

	the medial joint space narrowing (JSN) as a score, and the outcome JSN ≥ 1 at 48 months.									
Chan et al (2021)[20]	Both pain and radiographic progression Pain progression: persistent increase of at least 9 points under a normalized scale from 0 to 100 of McMaster Universities Osteoarthritis Index (WOMAC) Pain Score. Radiographic progression: loss in the medial knee joint space width (JSW) of at least 0.7mm.	Pain and structural	Pain scores + Radiograph	N/A	LR, DT, MLP	Supervised	Yes	Yes: DeepLIFT	Hold-out	AUC-ROC, Accuracy, Precision, Recall, F1-score
Cheung et al (2021)[21]	Increase in KL-grade from the unaffected (KL 0 and 1) to the confirmed case (KL 2 to 4) within 48 months.	Structural	Radiograph	CNN	XGBoost	Supervised	Yes	No	CV	AUC-ROC, F1 score
Lee et al (2021)[22]	Trajectory of the KOOS pain score over 8 years	Pain	Pain scores	3D DenseNet (CNN)	CNN	Supervised	Yes	No	Hold-out	AUC-ROC, Accuracy, Sensitivity, Specificity
Lu et al (2021)[23]	Development of symptomatic OA, defined as the presence of progressive degenerative changes within the glenohumeral joint on radiograph, accompanied by pain that the treating physician attributed to the osteoarthritis.	Pain and structural	Pain scores + Radiograph	N/A	XGBoost, SVM, RF, elastic net penalized regression, LR	Supervised	No	Yes: LIME	CV	AUC-ROC, Brier
Ningrum et al (2021)[24]	Incidence of knee OA in the next year (defined by ICD-9-CM codes)	Not specified	Not specified	N/A	CNN, ANN	Supervised	Yes	No	Internal + Hold-out	AUC-ROC, Sensitivity, Specificity, Precision
Ntakolia et al (2021)[25]	Joint space narrowing	Structural	Radiograph + MRI	N/A	RF, MLP, XGBoost, LR, SVM, kNN, DT	Supervised	No	Yes: Beeswarm plot	CV	Accuracy
Ntakolia et al (2021)[26]	Davies Bouldin index: four clusters were identified in most of the methods, grouping the patients to those with zero, low, medium, and high alterations in JSM measures	Structural	Radiograph	N/A	GBM, LR, NN, NBG, RF, SVM	Supervised	No	Yes: SHAP	CV	Accuracy
Schiratti et al (2021)[27]	JSN at 12 months lower than – 0.5 mm	Structural	Radiograph	EfficientNet-B0 network	MLP	Supervised (weakly)	Yes	Yes: GradCAM	CV	AUC-ROC, Precision, Recall
Guan et al (2020)[28]	Definitive progression of medial joint space loss (greater than or equal to 0.7mm decrease) on longitudinal bilateral standing posterior-anterior knee X-rays between baseline and 48-month follow-up	Structural	Radiograph	CNN	RF, LR, ANN, CNN	Supervised	Yes	No	Internal + Hold-out	AUC-ROC, Sensitivity, Specificity

Jamshidi et al (2020)[29]	Four binary outcomes to predict OA progressors: incidence of cartilage volume loss in medial tibial plateau at 96 months and 48 months, KL grade≥ 2 at 48 months and medial JSN≥ 1 at 48 months.	Structural	Radiograph + MRI	N/A	H2O AutoML (DRF, GLM, XGBoost, GBM, MLP, stacked ensemble)	Supervised	No	Yes: sPLS	CV + Hold-out	AUC -ROC, Sensitivity, Specificity
Kundu et al (2020)[30]	Non-progressors: total WOMAC score <10 and KL score ≤1 at baseline, with 36-mo change in WOMAC score <10 and no risk factors for OA progression. The symptomatic OA progression cohort: same initial baseline criteria, but with a change in WOMAC score >10 at 3y follow-up indicating progression to symptomatic OA.	Pain	Pain scores	TBM	pLDA, RF, SVM	Supervised	No	Yes: 3D TBM	Hold-out	Accuracy, Sensitivity, Specificity, Cohen's kappa
Morales Martinez et al (2020)[31]	Development of radiographic OA (KL>=2) over 8 year follow up	Structural	Radiograph	Bone segmentation, 3D V-Net	CNN	Supervised	Yes	No	Internal + Hold-out	AUC-ROC
Wang et al (2020)[32]	KL grade at next visit over 5 year follow-up	Structural	Radiograph	N/A	Time series analysis: LSTM	Supervised	Yes	Yes: FCI with DAGs	CV	AUC-ROC, Accuracy
Widera et al (2020)[33]	Multi-class predictions One non-progressive category (N) and three progressive categories related to pain (P), structure (S), and combined pain and structure (P + S). S category if the minimum JSW decreased by at least 0.3 mm per year. P category if: - the pain increased at least by the minimal clinically important difference per year (5 points on a 0–100 scale) and was substantial at the end of a period (at least 40 points). - for a rapid pain increase of at least 10 points per year, the end pain threshold was lower (at least 35 points). - substantial pain (at least 40 points) was sustained at both the start and the end of a period. P + S category if criteria for both P and S were satisfied N category if neither of them was satisfied.	Pain and structural	Pain scores + Radiograph	N/A	LR, kNN, SVM, RF	Supervised	No	Yes: SHAP	CV	F1 score
Tiulpin et al (2019)[34]	Increase of a KL-grade within the following years:	Structural	Radiograph	CNN	GBM	Supervised	Yes	Yes: GradCAM	CV + External	AUC-ROC, Precision

	y = 0: no knee OA progression y = 1: progression within the next 60 months (fast progression) y = 2: progression after 60 months (slow progression)									
Ashinsky et al (2017)[35]	Non-progression group: baseline KL grade < 2, baseline WOMAC ≤ 10 and a 36-month change in WOMAC < 10. Symptomatic progression of OA group: baseline KL grade < 2, baseline WOMAC ≤ 10 and a 36-month change in WOMAC > 10.	Pain	Pain scores	WND-CHRM	WND-CHRM	Supervised	No	No	CV	Accuracy, Sensitivity, Specificity
Hafezi-Nejad et al (2017)[36]	Medial joint space loss > 0.7mm at 48 months	Structural	Radiograph	N/A	LR, ANN (MLP)	Supervised	Yes	Yes: MLP	Internal	AUC-ROC
Lazzarini et al (2017)[37]	Five different outcome measures of incident knee OA after 30 months: - incidence of 'combined radiographic and clinical ACR criteria' - incidence of frequent knee pain - lateral JSN of≥1.0mm - medial JSN of≥1.0mm - incidence of KL≥2	Pain and structural	Pain scores + Radiograph	N/A	RGIFE/RF	Supervised	No	Yes: Decremental analysis	CV	AUC-ROC
Marques et al (2013)[38]	Medial tibial cartilage loss at 21 months	Structural	MRI	N-jet	PLS regression	Supervised	No	No	CV	OR
Woloszynski et al (2012)[39]	Tibiofemoral JSN and osteophytes (0–3, where 0 indicates no JSN and osteophytes) in the medial and lateral compartments at 4 years according to the 1995 OARSI atlas.	Structural	Radiograph	DMC	DMC	Supervised	No	No	Internal	Accuracy, Sensitivity, Specificity

A-ENN, adversarial evolving neural network Bayes; ANFIS, adaptive neuro-fuzzy inference system; AUC ROC, area under the receiver operating characteristic curve; CNN, convolutional neural networks; DAGs, directed acyclic graphs; CV, cross-validation; DMC, dissimilarity-based multiple classifier; DRF, distributed Random Forest; DT, decision tree; ELM, extreme learning machine; FCI, fast Causal Inference; FSA, fractal signature analysis; GBM, gradient boosting machine; GLM, Bayesian generalized linear model; Glmnet, elastic net regularized; generalized logistic models, HDDA, high-dimensional discriminant analysis; kNN, k-nearest neighbour; LASSO, least absolute shrinkage and selection operator; LDA, linear discriminant analysis; LIME, local-interpretable model-agnostic explanations; LR, logistic regression ; LSTM, long short-term memory; MLP, multi-layer perceptron; NBG, naïve Bayes Gaussian; NN, neural networks; NNET, single-hidden-layer neural networks; pLDA, probabilistic linear discriminant analysis; PLS, partial least squares; RF, random forest; RGIFE, ranked guided iterative feature elimination; SA-ELM, self-adaptive extreme learning machine; SNN, Siamese neural network; sPLS, sparse partial least square; SVM, support vector machine; TBM, transport-based morphometry.

Table iii. A summary or performance in the models.

Study	Best model performance	Performance		
		Pain progression	Structural progression	Both pain and structural progression
Al Turkestani et al (2024)[1]	Accuracy 0.87 AUC-ROC 0.72 F1-score 0.82	N/A	N/A	Accuracy 0.87 AUC-ROC 0.72 F1-score 0.82
Bayramoglu et al (2024)[2]	AUC-ROC 0.865, AUC-PRC 0.447	N/A	AUC-ROC 0.865, AUC-PRC 0.447	N/A
Nguyen et al (2024)[3]	BA 0.54	N/A	BA 0.54	N/A
Nielsen et al (2024)[4]	AUC-ROC 0.72 (95%CI: 0.71–0.73)	N/A	N/A	N/A
Salis et al (2024)[5]	External validation: - right knee at 2.5 years: AUC-ROC 0.847 (95 % CI 0.811 to 0.882), F1 score 0.896 - right knee at 5 years: AUC-ROC0.853 (95 % CI 0.823 to 0.881), F1 score 0.851 - left knee at 2.5 years: AUC-ROC 0.824 (95 % CI 0.782 to 0.857), F1 score 0.756 - left knee at 5 years: AUC_ROC 0.807 (95 % CI 0.768 to 0.843), F1 score 0.877	N/A	N/A	External validation: - right knee at 2.5 years: AUC-ROC 0.847 (95 % CI 0.811 to 0.882), F1 score 0.896 - right knee at 5 years: AUC-ROC0.853 (95 % CI 0.823 to 0.881), F1 score 0.851 - left knee at 2.5 years: AUC-ROC 0.824 (95 % CI 0.782 to 0.857), F1 score 0.756 - left knee at 5 years: AUC_ROC 0.807 (95 % CI 0.768 to 0.843), F1 score 0.877
Chen et al (2023)[6]	Pain: RMSE 2.27 (SD = 0.16) right knee, 2.30 (SD = 0.13) left knee Functional decline: RMSE 7.01 (SD = 0.65) right knee, 7.33 (SD = 0.59) left knee Incidence of OA: AUC-ROC 0.78 to 0.81	RMSE 2.27 (SD = 0.16) right knee, 2.30 (SD = 0.13) left knee	AUC-ROC 0.78-0.81	N/A
Dunn et al (2023)[7]	Radiographic-only progression: - Accuracy 0.870 ± 0.008 - AUC-ROC 0.940 ± 0.004 - Sensitivity 0.88 ± 0.01 - Specificity 0.88 ± 0.01 - F1-score 0.78 ± 0.01 - Diagnostic OR 83 ± 12 Pain-only progression: - Accuracy 0.890 ± 0.009 - AUC-ROC 0.970 ± 0.004 - Sensitivity 0.92 ± 0.01 - Specificity 0.89 ± 0.01 - F1-score 0.83 ± 0.02 - Diagnostic OR 120 ± 20 Pain + radiographic progression: - Accuracy 0.720 ± 0.007 - AUC-ROC 0.790 ± 0.006 - Sensitivity 0.70 ± 0.01 - Specificity 0.74 ± 0.01 - F1-score 0.74 v 0.01 - Diagnostic OR 7.4 ± 0.4	Pain-only progression: - Accuracy 0.890 ± 0.009 - AUC-ROC 0.970 ± 0.004 - Sensitivity 0.92 ± 0.01 - Specificity 0.89 ± 0.01 - F1-score 0.83 ± 0.02 - Diagnostic OR 120 ± 20	Radiographic-only progression: - Accuracy 0.870 ± 0.008 - AUC-ROC 0.940 ± 0.004 - Sensitivity 0.88 ± 0.01 - Specificity 0.88 ± 0.01 - F1-score 0.78 ± 0.01 - Diagnostic OR 83 ± 12	Pain + radiographic progression: - Accuracy 0.720 ± 0.007 - AUC-ROC 0.790 ± 0.006 - Sensitivity 0.70 ± 0.01 - Specificity 0.74 ± 0.01 - F1-score 0.74 v 0.01 - Diagnostic OR 7.4 ± 0.4

	Any progression: - Accuracy 0.780 ± 0.004 - AUC-ROC 0.860 ± 0.004 - Sensitivity 0.78 ± 0.04 - Specificity 0.78 v 0.01 - F1-score 0.85 v 0.03 - Diagnostic OR 15 ± 1.0			
Hu et al (2023)[8]	AUC-ROC 0.664 (95% CI: 0.585–0.743) at baseline, 0.739 (95% CI: 0.703–0.775) at 12 months, and 0.775 (95% CI: 0.686–0.865) at 24 months	N/A	N/A	N/A
Shen et al (2023)[9]	AUC-ROC: Internal 0.896 (95% CI 0.87–0.945), Hold-out 0.876 (95% CI 0.767–0.984) F1 score: 0.690 Precision: 0.667 Recall: 0.714	N/A	AUC-ROC: Internal 0.896 (95% CI 0.87–0.945), Hold-out 0.876 (95% CI 0.767–0.984) F1 score: 0.690 Precision: 0.667 Recall: 0.714	N/A
Widera et al (2023)[10]	F1 score 0.60 (95% CI, 0.53–0.67) AUC-ROC(P) 0.86 (95% CI, 0.81–0.90) AUC-ROC(S) 0.61 (95% CI, 0.52–0.70)	AUC-ROC(P) 0.86 (95% CI, 0.81–0.90)	AUC-ROC(S) 0.61 (95% CI, 0.52–0.70)	N/A
Yin et al (2023)[11]	Pain + radiographic progression: - Accuracy 0.720 ± 0.007 - AUC-ROC 0.790 ± 0.006 - Sensitivity 0.70 ± 0.01 - Specificity 0.74 ± 0.01 - F1-score 0.74 v 0.01 - Diagnostic OR 7.4 ± 0.4 Any progression: - Accuracy 0.780 ± 0.004 - AUC-ROC 0.860 ± 0.004 - Sensitivity 0.78 ± 0.04 - Specificity 0.78 v 0.01 - F1-score 0.85 v 0.03 - Diagnostic OR 15 ± 1.0	N/A	AUC-ROC: 0.761 (0.728-0.795) Sensitivity: 0.665 (0.603-0.728) Specificity: 0.774 (0.753-0.797)	N/A
Yoo et al (2023)[12]	Accuracy 0.710 Recall 0.542 F1 score 0.637 Specificity 0.859 Error rate 0.290	N/A	Accuracy 0.710 Recall 0.542 F1 score 0.637 Specificity 0.859 Error rate 0.290	N/A
Almhdie-Imjabbar et al (2022)[13]	AUC-ROC 0.75 in OAI AUC-ROC 0.81 in MOST	N/A	AUC-ROC 0.75 in OAI AUC-ROC 0.81 in MOST	N/A
Bonakdari et al (2022)[14]	CV: Average Accuracy 0.951 ± 0.021 External validation: 0.905	N/A	CV: Average Accuracy 0.951 ± 0.021 External validation: 0.905	N/A
Bonakdari et al (2022)[15]	External validation: R: 0.78-0.94 for men, 0.47-0.90 for females	N/A	External validation: R: 0.78-0.94 for men, 0.47-0.90 for females	N/A
Guan et al (2022)[16]	AUC-ROC 0.807 (Sensitivity 0. 723 and Specificity 0.809) for all knees AUC-ROC 0.776 (Sensitivity 0.677 and Specificity 0.830) for KL 0 and 1 knees AUC-ROC 0.841 (Sensitivity 0.828 and Specificity 0.745) for KL 2, 3, and 4 knees	AUC-ROC 0.807 (Sensitivity 0. 723 and Specificity 0.809) for all knees AUC-ROC 0.776 (Sensitivity 0.677 and Specificity 0.830) for KL 0 and 1 knees AUC-ROC 0.841 (Sensitivity 0.828 and Specificity 0.745) for KL 2, 3, and 4 knees	N/A	N/A

	AUC-ROC 0.877 (Sensitivity0.825 and Specificity 0.800) for KL 2 knees AUC-ROC 0.794 (Sensitivity 0.778 and Specificity 0.744) for KL 3 and 4 knees	AUC-ROC 0.877 (Sensitivity0.825 and Specificity 0.800) for KL 2 knees AUC-ROC 0.794 (Sensitivity 0.778 and Specificity 0.744) for KL 3 and 4 knees		
Hu et al (2022)[17]	Overall accuracy 0.627	N/A	Overall accuracy 0.627	N/A
Joseph et al (2022)[18]	CV: AUC-ROC 0.792, 95% CI 0.694 to 0.890	N/A	CV: AUC-ROC 0.792, 95% CI 0.694 to 0.890	N/A
Bonakdari et al (2021)[19]	Training stage: - men: about 82% of progressors and 92% of no-progressors correctly estimated. - women: 97% and 76%. Test stage: - men: 81% and 98%. - women: 97% and 88% External validation: - men: 92%, and 100%. - women: 94% and 83%.	N/A	Training stage: - men: about 82% of progressors and 92% of no-progressors correctly estimated. - women: 97% and 76%. Test stage: - men: 81% and 98%. - women: 97% and 88% External validation: - men: 92%, and 100%. - women: 94% and 83%.	N/A
Chan et al (2021)[20]	Onset prediction: - Accuracy 0.843 (0.823–0.863) - Precision 0.826 (0.809–0.843) -Recall 0.849 (0.830–0.868) - F1-score 0.837 (0.816–0.858) - AUC-ROC 0.843 (0.824–0.862) Deterioration prediction - Accuracy 0.744 (0.724–0.764) - Precision 0.943 (0.920–0.966) - Recall 0.709 (0.690–0.728) - F1-score 0.810 (0.790–0.83) - AUC-ROC 0.765 (0.756–0.774)	N/A	N/A	Onset prediction: - Accuracy 0.843 (0.823–0.863) - Precision 0.826 (0.809–0.843) -Recall 0.849 (0.830–0.868) - F1-score 0.837 (0.816–0.858) - AUC-ROC 0.843 (0.824–0.862) Deterioration prediction - Accuracy 0.744 (0.724–0.764) - Precision 0.943 (0.920–0.966) - Recall 0.709 (0.690–0.728) - F1-score 0.810 (0.790–0.83) - AUC-ROC 0.765 (0.756–0.774)
Cheung et al (2021)[21]	16-point JSWs: AUC-ROC 0.551 ± 0.024, F1 score 0.480 ± 0.041 64-point JSWs: AUC-ROC 0.621	N/A	16-point JSWs: AUC-ROC 0.551 ± 0.024, F1 score 0.480 ± 0.041 64-point JSWs: AUC-ROC 0.621	N/A
Lee et al (2021)[22]	AUC-ROC 0.794 (95% CI: 0.761, 0.823) Sensitivity 0.498 (0.468, 0.619) SPecificity 0.851 (0.833, 0.867) Accuracy 0.810 (0.790, 0.830)	AUC-ROC 0.794 (95% CI: 0.761, 0.823) Sensitivity 0.498 (0.468, 0.619) SPecificity 0.851 (0.833, 0.867) Accuracy 0.810 (0.790, 0.830)	N/A	N/A
Lu et al (2021)[23]	AUC-ROC 0.78 Brier score 0.05	N/A	N/A	AUC-ROC 0.78 Brier score 0.05
Ningrum et al (2021)[24]	AUC-ROC: 0.97 Sensitivity (Recall): 0.89 Specificity: 0.93 Precision: 0.80	N/A	N/A	N/A
Ntakolia et al (2021)[25]	Accuracy 0.7655 +/- 0.0068	N/A	Accuracy 0.7655 +/- 0.0068	N/A
Ntakolia et al (2021)[26]	Accuracy 0.833	N/A	Accuracy 0.833	N/A

Schiratti et al (2021)[27]	AUC-ROC 0.65 Precision 0.13 Recall 0.84	N/A	AUC-ROC 0.65 Precision 0.13 Recall 0.84	N/A
Guan et al (2020)[28]	AUC-ROC 0.863, Sensitivity and Specificity 0.805	N/A	AUC-ROC 0.863, Sensitivity and Specificity 0.805	N/A
Jamshidi et al (2020)[29]	Prop_CV_96M: - AUC-ROC 0.80 - Sensitivity 0.86 - Specificity 0.69 Prop_CV_48M: - AUC-ROC 0.70 - Sensitivity 0.79 - Specificity 0.55 KL_grade_48M: - AUC-ROC: 0.88 - Sensitivity 0.86 - Specificity 0.77 JSN_48M: - AUC-ROC 0.95 - Sensitivity 0.87 - Specificity 0.90 * Prop_CV: cartilage volume loss in medial tibial plateau at 96 and 48 months	N/A	Prop_CV_96M: - AUC-ROC 0.80 - Sensitivity 0.86 - Specificity 0.69 Prop_CV_48M: - AUC-ROC 0.70 - Sensitivity 0.79 - Specificity 0.55 KL_grade_48M: - AUC-ROC: 0.88 - Sensitivity 0.86 - Specificity 0.77 JSN_48M: - AUC-ROC 0.95 - Sensitivity 0.87 - Specificity 0.90 * Prop_CV: cartilage volume loss in medial tibial plateau at 96 and 48 months	N/A
Kundu et al (2020)[30]	Accuracy 0.78 Sensitivity 0.769 Specificity 0.79 Cohen's kappa 0.56	Accuracy 0.78 Sensitivity 0.769 Specificity 0.79 Cohen's kappa 0.56	N/A	N/A
Morales Martinez et al (2020)[31]	AUC-ROC above 0.72	N/A	AUC-ROC above 0.72	N/A
Wang et al (2020)[32]	AUC-ROC: KLG1 0.81, KLG2 0.91, KLG3 0.99, KLG4 0.98 Accuracy: 0.90	N/A	AUC-ROC: KLG1 0.81, KLG2 0.91, KLG3 0.99, KLG4 0.98 Accuracy: 0.90	N/A
Widera et al (2020)[33]	F1-score 0.689 (95% CI: 0.680, 0.698) for OAI F1- score 0.584 (95% CI: 0.560, 0.609) for CHECK	N/A	N/A	Multi-class predictions: F1-score 0.689 (95% CI: 0.680, 0.698) for OAI F1- score 0.584 (95% CI: 0.560, 0.609) for CHECK
Tiulpin et al (2019)[34]	AUC: 0.79 (0.78–0.81) Average Precision: 0.68 (0.66–0.70)	N/A	AUC: 0.79 (0.78–0.81) Average Precision: 0.68 (0.66–0.70)	N/A
Ashinsky et al (2017)[35]	Sensitivity 0.740 ± 0.013 Specificity 0.760 ± 0.013 Accuracy 0.750 ± 0.009	Sensitivity 0.740 ± 0.013 Specificity 0.760 ± 0.013 Accuracy 0.750 ± 0.009	N/A	N/A
Hafezi-Nejad et al (2017)[36]	AUC-ROC 0.669 (95% CI: 0.626–0.712)	N/A	AUC-ROC 0.669 (95% CI: 0.626–0.712)	N/A
Lazzarini et al (2017)[37]	ACR criteria (both paina nd structural progression) AUC-ROC 0.788 (95% CI 0.712-0.863) Knee pain	Knee pain AUC-ROC 0.755 (95% CI 0.680-0.830)	Lateral JSN AUC-ROC 0.731 (95% CI 0.654-0.808)	ACR criteria (both paina nd structural progression) AUC-ROC 0.788 (95% CI 0.712-0.863)

	AUC-ROC 0.755 (95% CI 0.680-0.830) Lateral JSN AUC-ROC 0.731 (95% CI 0.654-0.808) Medial JSN AUC-ROC 0.737 (95% CI 0.659-0.814) KL incidence AUC-ROC 0.823 (95% CI 0.753-0.893)		Medial JSN AUC-ROC 0.737 (95% CI 0.659-0.814) KL incidence AUC-ROC 0.823 (95% CI 0.753-0.893)	
Marques et al (2013)[38]	OR: 3.9, 95% CI: 2.4–6.5	AUC-ROC 0.755 (95% CI 0.680-0.830)	OR: 3.9, 95% CI: 2.4–6.5	N/A
Woloszynski et al (2012)[39]	Accuracy 0.80 Specificity 0.82 Sensitivity 0.7797	N/A	Accuracy 0.80 Specificity 0.82 Sensitivity 0.7797	N/A

AUC ROC, area under the receiver operating curve; N/A, not applicable.

Table iv. Risk of bias.

Author	Risk of bias				Applicability			Risk of bias	Applicability	Overall
	Participants	Predictors	Outcome	Analysis	Participants	Predictors	Outcome			
Al Turkestani et al (2024)[1]	Low	Low	High	High	Low	Low	High	High	High	High
Bayramoglu et al (2024)[2]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Nguyen et al (2024)[3]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Nielsen et al (2024)[4]	Low	Low	Unclear	High	Low	Low	Unclear	High	Unclear	High
Salis et al (2024)[5]	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Chen et al (2023)[6]	Low	Low	High	High	Low	Low	High	High	High	High
Dunn et al (2023)[7]	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Hu et al (2023)[8]	Low	Low	High	High	Low	Low	High	High	High	High
Shen et al (2023)[9]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Widera et al (2023)[10]	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Yin et al (2023)[11]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Yoo et al (2023)[12]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Almhdie-Imjabbar et al (2022)[13]	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Bonakdari et al (2022)[14]	Low	Low	High	Unlcear	Low	Low	High	High	High	High
Bonakdari et al (2022)[15]	Low	Low	Unclear	High	Low	Low	Unclear	High	Unclear	High
Guan et al (2022)[16]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Hu et al (2022)[17]	Low	Low	High	High	Low	Low	High	High	High	High
Joseph et al (2022)[18]	Low	Low	Unclear	High	Low	Low	Low	High	Low	High
Bonakdari et al (2021)[19]	Low	Low	High	High	Low	Low	High	High	High	High
Chan et al (2021)[20]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Cheung et al (2021)[21]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Lee et al (2021)[22]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Lu et al (2021)[23]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Ningrum et al (2021)[24]	Low	Low	High	Unclear	Low	Low	High	High	High	High
Ntakolia et al (2021)[25]	Low	Low	Unclear	High	Low	Low	Unclear	High	Unclear	High
Ntakolia et al (2021)[26]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Schiratti et al (2021)[27]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Guan et al (2020)[28]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Jamshidi et al (2020)[29]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Kundu et al (2020)[30]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Morales Martinez et al (2020)[31]	Low	Low	Unclear	High	Low	Low	Low	High	Low	High
Wang et al (2020)[32]	Low	Low	High	High	Low	Low	High	High	High	High
Widera et al (2020)[33]	Low	Low	Low	High	Low	Low	Low	High	Low	High

Tiulpin et al (2019)[34]	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
Ashinsky et al (2017)[35]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Hafezi-Nejad et al (2017)[36]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Lazzarini et al (2017)[37]	Low	Low	Low	High	Low	Low	Low	High	Low	High
Marques et al (2013)[38]	Low	Low	Unclear	High	Low	Low	Low	High	Low	High
Woloszynski et al (2012)[39]	Low	Low	Low	High	Low	Low	Low	High	Low	High

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