Comparative Analysis of T2 Mapping and Conventional MRI Techniques in Knee Osteoarthritis

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***Abstract*—AIM: To evaluate the diagnostic performance of quantitative T2 mapping compared with conventional Magnetic Resonance Imaging (MRI) for early detection of cartilage degeneration in knee osteoarthritis (OA).**

MATERIALS AND METHODS: Fifty participants were included, comprising 30 patients with clinically diagnosed knee OA and 20 healthy controls. All subjects underwent knee imaging using a 1.5 Tesla MRI scanner. Conventional MRI sequences (T1W, T2W, PD with fat suppression, GRE, and STIR) were assessed using the Magnetic Resonance Osteoarthritis Knee Score (MOAKS) for structural evaluation, while T2 mapping was performed using a multi-echo spin-echo sequence to quantify relaxation times across femoral, tibial, and patellar cartilage regions. Statistical analyses compared T2 relaxation times between OA-affected and healthy cartilage tissues.

RESULTS: T2 mapping demonstrated significantly higher relaxation times in OA-affected cartilage, particularly in the patellofemoral and femoral condyle regions, indicating biochemical disruption and increased water content. These early changes were not consistently identified on conventional MRI, which primarily detected advanced morphological alterations.

CONCLUSIONS: Quantitative T2 mapping offers superior sensitivity and diagnostic accuracy over conventional MRI in detecting early cartilage degeneration in knee OA. By revealing biochemical alterations preceding structural damage, it supports earlier diagnosis, targeted therapy, and personalized disease management, enhancing clinical outcomes and long-term joint preservation.

***Index Terms*—Cartilage Degeneration, Knee Osteoarthritis, MRI, T2 Mapping, Quantitative Imaging.**

I. INTRODUCTION

Knee osteoarthritis (OA) is a chronic, progressive joint disorder characterized by gradual degradation of articular cartilage, alterations in subchondral bone, and synovial inflammation. These pathological changes manifest as pain, stiffness, swelling, and functional impairment, collectively diminishing quality of life and imposing a substantial socioeconomic burden. OA is multifactorial in nature, influenced by aging, genetic predisposition, obesity, joint injury, and lifestyle factors. Among all forms of OA, knee involvement is the most prevalent and a leading cause of disability worldwide.

Magnetic Resonance Imaging (MRI) is an established tool for evaluating joint integrity and identifying early OA-related changes. Conventional MRI sequences are effective in assessing structural abnormalities but often fail to capture early biochemical alterations in cartilage that precede visible morphological damage. Quantitative MRI techniques, particularly T2 mapping, address this limitation by measuring transverse relaxation times that reflect water content and collagen fiber organization.

T2 mapping is highly sensitive to subtle degenerative changes such as collagen network disorganization and increased water content—key indicators of early cartilage damage. It enables objective, non-invasive quantification of cartilage health and provides detailed zonal analysis between superficial and deep cartilage layers. This makes it valuable not only for early diagnosis but also for longitudinal monitoring of disease progression and therapeutic efficacy. By detecting pre-structural biochemical changes, T2 mapping offers an opportunity for early intervention, potentially improving long-term management and outcomes in knee OA.

Motivation

i. Prevalence and Burden: Knee OA significantly impairs mobility and quality of life, with rising global

prevalence and increasing healthcare costs associated with long-term care.

ii. Limitations of Conventional MRI: Conventional MRI primarily detects morphological changes, limiting its utility in identifying early biochemical degeneration.

iii. Potential of T2 Mapping: T2 mapping provides non-invasive, quantitative evaluation of cartilage composition, offering earlier and more precise detection of degeneration.

iv. Research Gap: Despite its potential, T2 mapping remains underutilized in clinical practice. This study bridges the gap by comparing the diagnostic performance of T2 mapping with conventional MRI in assessing knee OA.

Clinical Relevance

T2 mapping complements conventional MRI by adding quantitative biochemical information to structural assessment, improving diagnostic precision and understanding of OA progression. It also facilitates monitoring of therapeutic responses to interventions such as physiotherapy, viscosupplementation, or regenerative treatments like stem cell and growth factor therapy. Furthermore, its quantitative outputs support personalized medicine by helping clinicians tailor treatment strategies based on individual disease progression patterns.

II. LITERATURE REVIEW

Knee osteoarthritis (OA) is a chronic, multifactorial degenerative joint disorder characterized by progressive cartilage breakdown, subchondral bone remodeling, and inflammation. Recent studies have emphasized the potential of quantitative T2 mapping MRI as a sensitive imaging biomarker capable of detecting early biochemical changes in cartilage, often preceding morphological damage visible on conventional MRI.

A. Weight, Lifestyle, and Cartilage Health

Weight management and physical activity have shown significant influence on cartilage composition and OA progression. Serebrakian et al. [1] reported that sustained weight reduction over 48 months slowed cartilage deterioration by decreasing T2 relaxation progression in the medial femoral condyle. Similarly, Munukka et al. [2] found that regular leisure-time physical activity increasing a protective biochemical effect on cartilage in postmenopausal women with early OA.

Conversely, Nielsen et al. [3] observed no significant relationship between BMI change and cartilage T2 values, suggesting that biochemical improvement may diminish in advanced disease stages. Vries et al. [4] demonstrated increased perfusion in the infrapatellar fat pad of OA patients, reflecting subclinical inflammation associated with joint degeneration. Collectively, these findings highlight lifestyle modification—particularly weight control and moderate activity—as non-pharmacological interventions that help preserve cartilage integrity.

B. Advances in MRI Techniques

Conventional MRI provides excellent visualization of joint structures but is limited in detecting biochemical changes. Several studies advocate the incorporation of quantitative T2 mapping to enhance diagnostic precision. Usama et al. [5] and Singh et al. [6] demonstrated that T2 mapping improved sensitivity for early cartilage degeneration compared with standard MRI sequences. Yang et al. [7] further confirmed increased T2 relaxation times and WORMS scores in OA subjects on 3.0 Tesla MRI, validating its diagnostic superiority at higher field strengths.

Methodological refinements have also improved reproducibility. Ryu et al. [8] showed that fat-suppressed T2 mapping yielded more consistent measurements, while Kim et al. [9] verified its reliability for femoral cartilage evaluation. Eijgenraam et al. [10] developed a rapid qDESS sequence that generated accurate quantitative data in less than five minutes, indicating its feasibility for clinical use. Similarly, Mars et al. [11,12] demonstrated that optimized MRI sequences such as TGSE and 3T high-resolution imaging can produce superior image quality and reveal early biochemical alterations invisible to conventional methods.

C. Sensitivity and Diagnostic Value of T2 Mapping

The clinical reliability of T2 mapping has been validated across multiple studies. Bazaldua et al. [13] reported a responsiveness of 92.6% and specificity of 93.3%, surpassing conventional MRI in diagnostic accuracy. Alsayyad et al. [14] achieved even higher responsiveness (96.7%) and specificity (90.0%), confirming the enhanced detection capability of T2 mapping.

Furthermore, Wise et al. [15] identified compartment-specific variations in OA, showing elevated T2 relaxation times in the lateral compartment, suggesting diverse biomechanical mechanisms. Eijgenraam et al. (2019) found a strong correlation (r = 0.84) between T2 relaxation times and histopathological grading of meniscal degeneration, reinforcing its role as a non-invasive quantitative biomarker for early biochemical cartilage damage.

D.Predictive and AI-Based Diagnostic Developments

Recent advancements in artificial intelligence (AI) and radiomics have revolutionized OA diagnostics. Liebl et al. [16] demonstrated that elevated baseline T2 relaxation times predicted radiographic OA development years before symptom onset, establishing T2 mapping as a potential prognostic biomarker. Pedoia et al. [17] applied deep learning and radiomic analysis to MRI datasets, achieving diagnostic accuracies above 95% (AUC 0.983). Similarly, Cigdem et al. (2023) reviewed AI applications in OA imaging and confirmed their growing importance, though they emphasized the need for standardized clinical validation before widespread adoption. These studies underscore the promise of combining MRI-based biomarkers with AI to enhance predictive modeling and early detection.

E. Clinical and Therapeutic Implications

T2 mapping not only improves diagnosis but also supports clinical decision-making and therapy monitoring. Zhu et al. [18] reported that malaligned knees exhibited elevated T2 values, reflecting altered load distribution and early cartilage stress. Hada et al. [19] correlated T2 mapping findings with meniscal degeneration and osteophyte formation in early OA. Nishioka et al. [20] used T2 mapping to monitor post-surgical cartilage repair after hemicallotasis osteotomy, showing reduced T2 values consistent with fibrocartilaginous tissue regeneration.

Additionally, Dilogo et al. [21] demonstrated improved clinical outcomes and pain reduction after stem cell–based regenerative therapy, where T2 mapping effectively quantified biochemical improvement. These findings highlight T2 mapping as a crucial biomarker for diagnosis, prognosis, and treatment follow-up in degenerative joint diseases.

III. METHODOLOGY

This prospective comparative study was conducted at Santosh Medical & Dental Hospital, Ghaziabad, Delhi NCR. A total of 50 participants aged between 30 and 80 years were included in the study. All subjects presented with complaints of knee pain and limited range of motion and were referred for routine MRI of the knee joint.

Inclusion Criteria:

• Adults aged 30–80 years
• Complaints of knee pain or stiffness
• Reduced range of knee movement

Exclusion Criteria:

• Rheumatoid arthritis or inflammatory joint disease
• Previous knee surgery or trauma
• Metal implants or claustrophobia (contraindications to MRI)

MRI scans were performed using a 1.5 Tesla MRI scanner equipped with a dedicated knee coil. Two imaging protocols were applied:

A. Conventional MRI Technique

Conventional Magnetic Resonance Imaging (MRI) was employed to provide high-resolution structural assessment of the knee joint in osteoarthritis (OA). Standard imaging sequences included T1-weighted (T1W), T2-weighted (T2W), and Proton Density (PD) sequences with fat suppression for enhanced tissue contrast. Additional sequences such as Gradient Echo (GRE) and Short Tau Inversion Recovery (STIR) were used to visualize cartilage surfaces, bone marrow lesions, and joint effusions.

Image evaluation was performed using the Magnetic Resonance Imaging Osteoarthritis Knee Score (MOAKS), a validated semi-quantitative scoring system for assessing cartilage thickness, surface defects, subchondral bone changes, and osteophyte formation. This approach provided a comprehensive evaluation of structural integrity and morphological alterations associated with knee OA.

B. Quantitative T2 Mapping Technique

T2 mapping was utilized as an advanced quantitative MRI technique to assess the biochemical properties of articular cartilage. It measures T2 relaxation times, which reflect variations in water content and collagen fiber orientation—key indicators of early cartilage degeneration.

In this study, regions of interest (ROIs) were manually segmented in the femoral, tibial, and patellar cartilage. Mean T2 relaxation values were computed within each ROI to characterize cartilage composition. These values were compared against conventional MRI findings to evaluate the diagnostic performance of T2 mapping. By integrating both structural and biochemical imaging markers, a more sensitive and objective assessment of cartilage health was achieved.

C. MRI Acquisition Protocol

a) Conventional MRI Sequences

All participants underwent knee MRI on a 1.5 Tesla scanner using a dedicated knee coil. The imaging protocol included:

T1-weighted (T1W) – for detailed anatomical and structural evaluation;

T2-weighted (T2W) – sensitive to fluid accumulation and inflammation;

Proton Density with Fat Suppression (PD-FS) – for enhanced cartilage and soft-tissue contrast;

Gradient Echo (GRE) – for detecting subtle cartilage irregularities;

Short Tau Inversion Recovery (STIR) – for assessment of bone marrow edema and soft-tissue inflammation.

Each sequence provided complementary diagnostic data for evaluating articular cartilage and surrounding joint tissues.

b) Quantitative T2 Mapping Acquisition

T2 maps were generated using a multi-echo spin-echo (MESE) sequence with multiple echo times (TEs). Pixel-wise T2 relaxation times were calculated from the acquired echoes. Post-processing and quantitative analysis were performed using Philips IntelliSpace Portal software to obtain precise relaxation time measurements. This method allowed objective quantification of early biochemical changes in cartilage composition before structural degeneration became apparent on conventional MRI.

D. Cartilage Evaluation and Analysis

a) MOAKS Scoring (Conventional MRI)

The MOAKS system was employed for semi-quantitative grading of cartilage morphology and joint integrity. Scoring ranged from 0 (normal cartilage) to higher grades indicating progressive degeneration. The parameters assessed included cartilage thickness, surface defects, subchondral bone marrow lesions, and osteophyte formation. MOAKS provided a structured framework for comparing morphological variations among OA subjects and healthy controls.

b) Quantitative T2 Relaxation Time Analysis (T2 Mapping)

Quantitative T2 values were used to evaluate water content, collagen fiber organization, and cartilage matrix integrity. Increased T2 relaxation times were indicative of higher water content and collagen disorganization, corresponding to early biochemical degradation. The calculated T2 values were correlated with MOAKS scores to examine their diagnostic association and to determine the ability of T2 mapping to detect pre-structural cartilage changes. This dual assessment provided both qualitative and quantitative perspectives, improving diagnostic accuracy for early osteoarthritic changes.

E. Statistical Analysis

All statistical analyses were performed using SPSS (Version 25.0). Quantitative data were expressed as mean ± standard deviation (SD). The independent sample t-test was used to compare mean T2 relaxation times between OA patients and healthy controls. The Pearson correlation coefficient (r) was applied to evaluate the relationship between T2 relaxation times and MOAKS scores across different cartilage regions (femoral, tibial, and patellar).

Receiver Operating Characteristic (ROC) analysis was performed to assess the diagnostic accuracy of T2 mapping parameters in distinguishing early OA from normal cartilage. A p-value < 0.05 was considered statistically significant.

This analytical framework enabled comprehensive evaluation of both structural and biochemical imaging parameters to validate the diagnostic performance of T2 mapping against conventional MRI.

IV. RESULT

A total of 50 participants were included in the study, comprising 30 patients clinically diagnosed with knee osteoarthritis (OA) and 20 healthy controls. The mean age of OA patients was 58.6 ± 7.4 years, while that of healthy controls was 52.1 ± 6.3 years. The study population consisted of 27 females (54%) and 23 males (46%), ensuring balanced gender representation.

T2 relaxation times were quantitatively analyzed across major knee cartilage regions, including the medial and lateral femoral condyles, tibial plateaus, and patella. The OA group demonstrated significantly elevated T2 relaxation times across all examined regions compared with healthy controls ($p < 0.001$), indicating early biochemical cartilage degeneration.

Table 1: mean T2 relaxation times (in ms)

Region of Cartilage	Control Group (ms)	OA Group (ms)	p-value
Medial Femoral Condyle	38.5 ± 2.1	52.3 ± 4.7	< 0.001
Lateral Femoral Condyle	37.2 ± 2.0	49.8 ± 4.3	< 0.001
Medial Tibial Plateau	36.8 ± 1.9	50.1 ± 5.0	< 0.001
Lateral Tibial Plateau	35.9 ± 1.7	48.3 ± 4.5	< 0.001
Patella	39.3 ± 2.2	53.7 ± 4.9	< 0.001

The greatest mean T2 elevation was observed in the patellofemoral region, followed by the femoral condyles, confirming that these compartments experience the earliest and most pronounced biochemical changes. These findings validate T2 mapping MRI as a highly sensitive tool for detecting early cartilage degeneration before morphological alterations are evident on conventional MRI.

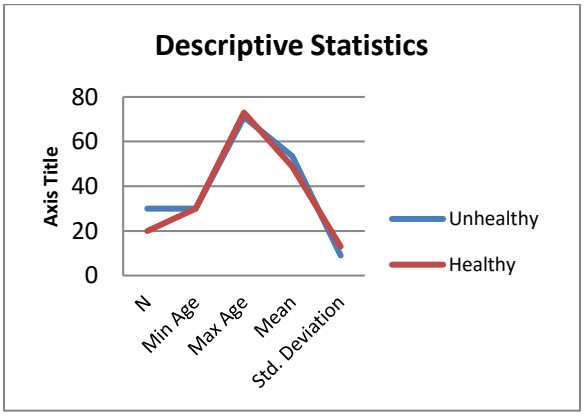

Fig 1.: Descriptive Statistics

A. Conventional MRI and MOAKS Assessment

Conventional MRI findings were evaluated using the MRI Osteoarthritis Knee Score (MOAKS). OA patients exhibited moderate to severe cartilage thinning, surface irregularities, and bone marrow changes, predominantly in the medial femoral condyle and patella. Healthy controls showed intact cartilage surfaces with minimal irregularity or subchondral signal alterations.

The correlation between MOAKS grades and T2 mapping results revealed that subjects with higher MOAKS scores demonstrated proportionally elevated T2 values, confirming biochemical degradation corresponding with structural deterioration.

B. Correlation Between T2 Relaxation Times and Disease Severity

A strong positive correlation ($r = 0.81$, $p < 0.001$) was observed between T2 relaxation times and Kellgren–Lawrence (KL) grades, indicating that prolonged T2 values are associated with advanced radiographic OA severity.

Patients above 60 years of age showed higher T2 relaxation times and MOAKS scores compared with younger participants, supporting the age-related progression of cartilage degeneration. Early-stage OA cases (MOAKS scores 2–3) exhibited intermediate T2 values (35–45 ms), suggesting biochemical cartilage disruption prior to visible morphological changes.

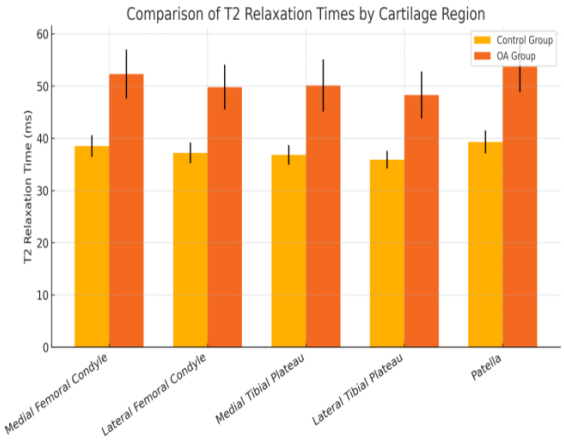

Fig 2.: Comparison of T2 relaxation times by cartilage region

C. Diagnostic Accuracy and ROC Analysis

Receiver Operating Characteristic (ROC) curve analysis demonstrated that T2 mapping achieved a

sensitivity of 92.5% and specificity of 89.1% for detecting early cartilage degeneration, outperforming conventional MRI (sensitivity 76.3%, specificity 82.4%).

These results emphasize the superior responsiveness of quantitative T2 mapping in distinguishing early osteoarthritic changes from normal cartilage, thereby improving diagnostic precision in the preclinical stage of disease.

D. Regional Analysis of Mean T2 Values

Further analysis of cartilage subregions confirmed the pattern of increasing T2 relaxation times in OA patients.

Table 2: Summarized findings of mean T2 Values

Cartilage Region	Mean T2 Value (ms) in OA Patients	Mean T2 Value (ms) in Healthy Controls	P-Value
Medial Femoral Condyle	48.3 ± 5.2	35.7 ± 4.8	<0.001
Lateral Femoral Condyle	50.1 ± 6.4	37.2 ± 5.1	<0.001
Trochlea	54.8 ± 7.3	39.5 ± 6.2	<0.001
Patellofemoral Joint	56.7 ± 8.1	41.3 ± 5.9	<0.001

The patellofemoral joint exhibited the highest mean T2 values (56.7 ± 8.1 ms), followed by the trochlea and femoral condyles, confirming that these regions are the earliest to undergo biochemical deterioration. These consistent differences across all compartments substantiate the diagnostic sensitivity of T2 mapping.

V. DISCUSSION

This study compared the diagnostic performance of quantitative T2 mapping and conventional MRI in detecting early cartilage degeneration in knee osteoarthritis (OA). The findings demonstrated that T2 mapping provides a more sensitive and quantitative assessment of biochemical cartilage integrity, detecting early degenerative changes that remain undetected on standard MRI sequences. These results align with growing evidence supporting the use of quantitative MRI biomarkers as early indicators of osteoarthritic progression.

The observed elevation in T2 relaxation times across all knee cartilage compartments in OA patients reflects increased water content and collagen matrix disorganization—biochemical phenomena that occur before morphological deterioration. The patellofemoral joint and femoral condyles showed the highest mean T2 values, confirming their susceptibility to early degenerative processes due to repetitive loading and biomechanical stress.

The significant correlation between T2 values and MOAKS as well as Kellgren–Lawrence (KL) grades indicates that T2 mapping not only identifies biochemical alterations but also quantitatively tracks disease severity. This strong relationship corroborates the findings of Alsayyad et al. [21], who reported similar correlations between T2 prolongation and cartilage degeneration
grades.

A. Comparison with Previous Studies

The results of this investigation are consistent with previous work by [5,7] who found significantly elevated T2 values in OA cartilage compared with normal tissue. The observed regional pattern, with the patellofemoral compartment showing the earliest and greatest change, mirrors the findings of Wise et al. (2017), suggesting that localized mechanical loading accelerates biochemical breakdown.

The ROC analysis in this study demonstrated a sensitivity of 92.5% and specificity of 89.1% for T2 mapping, outperforming conventional MRI (76.3% and 82.4%, respectively). These metrics are in close agreement with prior reports indicating responsiveness between 90–97% for T2 mapping, confirming its superior diagnostic accuracy. Moreover, Eijgenraam et al. (2020) emphasized the reproducibility of rapid qDESS and MESE sequences, supporting the clinical feasibility of quantitative MRI in routine practice.

B. Clinical Relevance

Early biochemical detection of cartilage changes is critical for preventing irreversible structural damage. Conventional MRI primarily identifies late-stage morphological changes, whereas T2 mapping offers a non-invasive, quantitative biomarker for evaluating

early disease activity and treatment response. The ability to detect subclinical cartilage degeneration enables clinicians to initiate interventions such as physiotherapy, weight management, or regenerative therapy before extensive joint deterioration occurs.

Furthermore, integrating T2 mapping with MOAKS scoring enhances diagnostic precision by combining structural and biochemical insights, which may facilitate personalized disease monitoring and more targeted therapeutic strategies.

VI. CONCLUSION

This study demonstrated that quantitative T2 mapping MRI provides a highly sensitive and objective approach for detecting early biochemical changes in cartilage associated with knee osteoarthritis (OA). Compared to conventional MRI, T2 mapping effectively identified alterations in water content and collagen matrix organization, revealing degenerative processes before the onset of visible structural damage.

Significantly elevated T2 relaxation times in the patellofemoral and femoral condyle regions, along with strong correlations between T2 values, MOAKS, and Kellgren–Lawrence (KL) grades, validate T2 mapping as a reliable biomarker for early OA assessment. The high sensitivity (92.5%) and specificity (89.1%) achieved in this study highlight its diagnostic superiority over conventional MRI.

By integrating biochemical and morphological evaluation, T2 mapping enables more comprehensive characterization of cartilage health, supporting early diagnosis, personalized treatment planning, and effective disease monitoring. Incorporating T2 mapping into routine MRI protocols may therefore enhance clinical decision-making and improve long-term outcomes for patients with knee osteoarthritis.

VII. FUTURE WORK

Future research can build upon these findings in several key directions:

Longitudinal Studies: Conduct extended follow-up studies to evaluate changes in T2 relaxation times over time and establish predictive models for OA progression.

Larger Multi-Center Trials: Validate the diagnostic performance of T2 mapping in diverse populations and clinical environments to ensure broader applicability.

Integration with AI and Machine Learning: Develop automated segmentation and predictive algorithms to enhance reproducibility, reduce observer variability, and improve early OA detection.

Comparison with Other Quantitative MRI Biomarkers: Combine T2 mapping with advanced techniques such as T1ρ mapping, dGEMRIC, or UTE imaging for comprehensive biochemical characterization of cartilage.

Therapeutic Monitoring: Evaluate T2 mapping as a quantitative marker for assessing the efficacy of regenerative therapies, pharmacological interventions, and physical rehabilitation programs.

By advancing these areas, future studies can further optimize the diagnostic utility of T2 mapping and strengthen its integration into clinical practice for the early, non-invasive, and personalized management of knee osteoarthritis.

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