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Comparative Study on the Diagnostic Efficacy of Conventional MRI Sequences and T2 Mapping Sequences in Cartilage Injury

Wang Peng, Zhi Liu, Juan Long, Chanying Wang

Xiangtan Medicine & Health Vocational College, Xiangtan 411104, Hunan, China

Abstract: Objective: To retrospectively evaluate the diagnostic efficacy of traditional MRI and T2 Mapping quantitative imaging technology for knee joint cartilage injury, clarify the differences in diagnostic value of the two imaging methods in different injury grades and different cartilage subregions, and provide evidence-based basis for the accurate diagnosis of clinical cartilage injury. Methods: Clinical and imaging data of 286 patients with knee joint lesions admitted to the Affiliated Hospital of Xiangtan Medicine and Health Vocational College from January 2020 to June 2023 were collected retrospectively. All patients underwent both traditional MRI sequences and T2 Mapping sequences. The knee joint cartilage was divided into 14 subregions. Two senior radiologists independently diagnosed the images of the two imaging technologies using a blind method and recorded the cartilage injury grades. The sensitivity, specificity, accuracy, positive predictive value, negative predictive value, and area under the receiver operating characteristic curve (AUC) of the two technologies for diagnosing cartilage injury were calculated and compared, and the differences in their diagnostic efficacy in different injury grades and different subregions were analyzed. *Results:* A total of 4004 cartilage subregions from 286 patients were included in the analysis, including 1836 injured subregions and 2168 normal subregions. The overall sensitivity (89.7%), accuracy (91.2%), and AUC (0.946) of T2 Mapping quantitative imaging for diagnosing cartilage injury were significantly higher than those of traditional MRI (76.3%, 82.5%, and 0.852 respectively), with statistically significant differences ($p < 0.001$); there was no significant difference in specificity between the two (93.5% vs 90.8%, $p = 0.062$). Subgroup analysis showed that T2 Mapping had the most significant diagnostic advantage in early cartilage injury (Grade 1), with sensitivity (78.5%) 33.2% higher than that of traditional MRI (45.3%) ($p < 0.001$). *Conclusion:* The diagnostic efficacy of T2 Mapping quantitative imaging for knee joint cartilage injury is significantly superior to that of traditional MRI, especially in the detection of early cartilage injury and accurate evaluation of weight-bearing area injury. Data verify its clinical applicability and reliability. It can be used as an important supplementary method to traditional MRI, and is recommended for the early diagnosis, grading evaluation, and clinical follow-up of cartilage injury.

Keywords: Traditional MRI; T2 Mapping; Cartilage injury; Diagnostic efficacy; Retrospective analysis

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1. Introduction

Cartilage injury is a common lesion in the fields of orthopedics and sports medicine. Its pathological process starts with biochemical changes such as cartilage matrix degradation and collagen fiber arrangement disorder, followed by gradual cartilage softening, erosion, and defect, which can eventually progress to osteoarthritis (OA), seriously affecting patients' joint function and quality of life. Early diagnosis and intervention of cartilage injury are crucial to delay disease progression and avoid irreversible damage to joint function [1].

As a non-invasive imaging examination method, traditional MRI has been widely used in the diagnosis of knee joint lesions. It evaluates the integrity of cartilage through morphological observation, relying on morphological changes such as thinning of cartilage thickness, irregular surface, and abnormal signal for diagnosis. However, early cartilage injury only shows biochemical changes (such as increased water content and collagen degradation), which are difficult to identify by traditional MRI, leading to insufficient sensitivity in early diagnosis [2].

T2 Mapping is a quantitative imaging technology based on MRI. By measuring the T2 relaxation time of cartilage tissue, it indirectly reflects the hydration state, collagen fiber arrangement, and matrix integrity of cartilage, and can detect early biochemical abnormalities before morphological changes of cartilage [3].

2. Research objects and methods

2.1. Research objects

2.1.1. Inclusion criteria

(1) Aged 20–65 years, regardless of gender;
(2) Admitted with symptoms such as knee joint pain, stiffness, and limited mobility, with clinical suspicion of cartilage injury;
(3) Underwent both traditional MRI sequences and T2 Mapping sequences, and image quality meets the analysis requirements;
(4) Have a clear diagnostic gold standard;
(5) Complete clinical and imaging data.

2.1.2. Exclusion criteria

(1) MRI images with severe artifacts affecting the observation of cartilage structure and T2 value measurement;
(2) History of knee joint surgery, infection, tumor, or congenital malformation;
(3) Long-term use of drugs that may affect cartilage metabolism such as glucocorticoids and immunosuppressants;
(4) BMI > 28 kg/m^2;
(5) Complicated with systemic diseases such as severe liver and kidney insufficiency and coagulation disorders [4].

2.2. Imaging equipment and parameters

All subjects were examined using a 1.5T magnetic resonance device. MR examinations included multiple sequences, including conventional sequences (T1-sag, fspd-sag, fspd-cor, fspd-tra) and T2 Mapping sequences.

2.3. Image analysis and diagnostic criteria

2.3.1. Image post-processing

All images were transmitted to the Siemens medical workstation (Syngo Via) for analysis. The knee joint cartilage was divided into 14 subregions: patella (medial, lateral), femur (medial anterior, medial middle, medial posterior, lateral anterior, lateral middle, lateral posterior), and tibia (medial anterior, medial middle, medial posterior, lateral anterior, lateral middle, lateral posterior). On the T2 Mapping quantitative map, the region of interest (ROI) of each subregion was manually drawn, avoiding the calcified layer and synovial fluid. The T2 value of each ROI was measured twice, and the average value was taken as the final T2 value of the subregion.

2.3.2. Diagnostic criteria

Referring to the International Cartilage Repair Society (ICRS) cartilage injury grading standard, cartilage injury was divided into 5 grades: Grade 0 (normal): normal cartilage morphology, uniform signal, T2 value within the normal reference range (mean ± 1.5SD of asymptomatic group); Grade 1 (mild injury): smooth cartilage surface, abnormal internal signal (high signal on traditional MRI, T2 value increased but < 10%); Grade 2 (moderate injury): slightly irregular cartilage surface, no significant thinning of thickness (thinning < 50%), diffuse abnormal signal (T2 value increased by 10–30%); Grade 3 (severe injury): significantly irregular cartilage surface, significant thinning of thickness (thinning ≥ 50%), but not involving the calcified layer (T2 value increased by > 30%); Grade 4 (extremely severe injury): full-thickness cartilage defect, involving the calcified layer, exposing subchondral bone (T2 value significantly increased or unmeasurable) [5].

2.3.3. Image reading process

Two physicians (Physician A and Physician B) with more than 10 years of experience in bone and joint imaging diagnosis independently read the images using a blind method. Diagnosis was made based on traditional MRI images and T2 Mapping images (including quantitative T2 values) respectively, and the injury grade of each subregion was recorded. The interval between image readings was 4 weeks to avoid memory bias. For subregions with inconsistent diagnostic results between the two, a third senior physician (15 years of experience) participated in the consultation, and the consensus opinion was taken as the final diagnostic result.

2.4. Statistical methods

SPSS 26.0 statistical software and MedCalc 19.0 software were used for data analysis. Measurement data were expressed as mean ± standard deviation ($\bar{x} \pm s$) or median (interquartile range), and intergroup comparison was performed using *t*-test or nonparametric test; count data were expressed as cases (percentage), and intergroup comparison was performed using χ^2 test. The sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV) of traditional MRI and T2 Mapping for diagnosing cartilage injury were calculated. Receiver operating characteristic (ROC) curve analysis was used to evaluate the diagnostic value of the two technologies, and the area under the curve (AUC) was calculated and *Z*-test was performed. Kappa test was used to analyze the consistency between the diagnostic results of the two technologies and the gold standard (Kappa value: < 0.4 poor consistency, 0.4–0.6 moderate consistency, 0.6–0.8 good consistency, > 0.8 excellent consistency). $p < 0.05$ was considered statistically significant.

3. Data acquisition and analysis

3.1. Image quality control

All MRI images included in the study underwent strict quality assessment. Special personnel checked the clarity, artifacts, and sequence integrity of the images. Quality assessment standards: Grade 1 (high quality): clear images without artifacts, clear display of cartilage structure and signal, and accurate division of 14 subregions; Grade 2 (qualified): slight artifacts in images, but no impact on cartilage structure recognition and subregion division; Grade 3 (unqualified): obvious artifacts in images, unable to clearly identify cartilage structure or divide subregions. Only Grade 1 and Grade 2 images were included in this study, and Grade 3 images were excluded.

3.2. Repeatability test of T2 value measurement

To verify the reliability of T2 value measurement, images of 50 randomly selected patients were remeasured by Physician A after an interval of 2 weeks, and the intraclass correlation coefficient (ICC) was calculated. The results showed that the ICC of T2 value measurement was 0.92 (95% CI: 0.88–0.95), indicating good measurement repeatability. At the same time, the ICC of T2 value measurement of the same batch of images by Physician A and Physician B was 0.89 (95% CI: 0.84–0.93), indicating good interobserver consistency.

3.3. Statistical analysis process

3.3.1. General data analysis

The sample size, patient age, gender, BMI, and distribution of injury grades of each research center were counted, and the differences in baseline characteristics between each center were compared to ensure intergroup comparability.

3.3.2. Statistical analysis of diagnostic results

The number of positive detections of traditional MRI and T2 Mapping in the total sample, each injury grade, and each cartilage subregion was counted respectively, and the corresponding diagnostic efficacy indicators (sensitivity, specificity, accuracy, PPV, NPV) were calculated.

3.3.3. ROC curve analysis

Taking the gold standard result as the dependent variable and the diagnostic results of the two technologies as independent variables, ROC curves were drawn, AUC values were calculated, and the overall diagnostic value of the two technologies was compared.

3.3.4. Consistency analysis

The Kappa values between the diagnostic results of traditional MRI and T2 Mapping and the gold standard were calculated respectively to evaluate the diagnostic consistency of the two technologies.

4. Experimental results

4.1. General data

Among the 286 patients, 152 were male (53.1%) and 134 were female (46.9%); aged 20–65 years, with an average age of (38.6 ± 10.2) years; BMI 18.5–27.9 kg/m^2, with an average of (22.3 ± 2.1) kg/m^2. The baseline data of each research center were evenly distributed, and there were no significant differences in age, gender, BMI, or composition ratio of injury grades ($p > 0.05$), indicating comparability.

4.2. Comparison of overall diagnostic efficacy of the two technologies for cartilage injury

Based on 1836 injured subregions and 2168 normal subregions confirmed by the gold standard, the overall diagnostic sensitivity, accuracy, and AUC value of T2 Mapping quantitative imaging were significantly higher than those of traditional MRI. The specificity and PPV were slightly higher than those of traditional MRI, but the differences were not statistically significant; the NPV was significantly higher than that of traditional MRI ($p < 0.05$). The specific results are shown in **Table 1**.

Table 1. Comparison of overall diagnostic efficacy of traditional MRI and T2 mapping for cartilage injury

Diagnostic indicators	Traditional MRI	T2 mapping	χ^2/Z value	*p* value
Sensitivity (%)	76.3 (1401/1836)	89.7 (1647/1836)	98.642	< 0.001
Specificity (%)	90.8 (1969/2168)	93.5 (2027/2168)	5.218	0.062
Accuracy (%)	82.5 (3370/4004)	91.2 (3674/4004)	102.357	< 0.001
PPV (%)	87.6 (1401/1600)	90.2 (1647/1826)	4.873	0.078
NPV (%)	81.2 (1969/2424)	91.8 (2027/2208)	78.429	< 0.001
AUC (95%CI)	0.852 (0.839–0.865)	0.946 (0.938–0.954)	12.368	< 0.001

Note: PPV = positive predictive value, NPV = negative predictive value, AUC = area under the receiver operating characteristic curve; the numbers in parentheses correspond to true positive/total positive, true negative/total negative, etc.

4.3. Comparison of diagnostic efficacy in different injury grades

Subgroup analysis showed that with the increase of cartilage injury grade, the diagnostic sensitivity of both technologies gradually improved, but the sensitivity of T2 Mapping in each grade was higher than that of traditional MRI, especially the difference was most significant in early injury (Grade 1) (T2 Mapping 78.5% vs traditional MRI 45.3%, $p < 0.001$); in Grade 2 and Grade 3 injuries, the sensitivity of T2 Mapping was still significantly higher than that of traditional MRI ($p < 0.001$); in Grade 4 injuries, the sensitivity of both technologies was high (> 95%), and there was no significant difference ($p = 0.321$). In terms of specificity, both technologies maintained a high level (> 85%) in each injury grade, with no significant difference ($p > 0.05$). The specific results are shown in **Table 2**.

Table 2. Comparison of diagnostic sensitivity of the two technologies in different injury grades (%)

Injury grade	Traditional MRI	T2 mapping	χ^2 value	*p* value
Grade 1 (n = 428)	45.3 (194/428)	78.5 (336/428)	106.872	< 0.001
Grade 2 (n = 615)	72.2 (444/615)	90.4 (556/615)	68.354	< 0.001
Grade 3 (n = 543)	86.2 (468/543)	94.1 (511/543)	24.189	< 0.001
Grade 4 (n = 250)	95.6 (239/250)	97.2 (243/250)	1.024	0.321

5. Discussion

5.1. Core mechanism of differences in diagnostic efficacy between traditional MRI and T2 mapping

The pathological process of cartilage injury has a typical characteristic of "biochemical changes precede morphological changes" [6]. Early cartilage injury is mainly manifested as collagen fiber rupture and proteoglycan loss in the matrix, leading to abnormal hydration state of cartilage, while there is no significant change in the surface morphology of cartilage. Traditional MRI relies on qualitative observation of cartilage morphology and signal intensity, and its signal abnormalities mainly reflect cartilage morphological changes or severe matrix damage, with insufficient sensitivity to early biochemical abnormalities [7]. In this study, the sensitivity of traditional MRI to Grade 1 cartilage injury was only 45.3%, which fully confirmed this limitation, when cartilage only has biochemical changes without morphological abnormalities, traditional MRI is difficult to identify.

The core advantage of T2 Mapping technology lies in its quantitativeness. The T2 relaxation time directly reflects the microstructure and biochemical state of cartilage tissue. The arrangement direction and density of collagen fibers in the cartilage matrix determine the size of the T2 value. When collagen fibers rupture and arrange disorderly, the transverse relaxation time of water molecules prolongs, and the T2 value increases [8]. In this study, the T2 values of the superficial cartilage of the patellofemoral joint and the central weight-bearing area of symptomatic patients were significantly increased. This change in quantitative indicators can be detected earlier than morphological abnormalities. Therefore, the sensitivity of T2 Mapping to early cartilage injury (Grade 1) is as high as 78.5%, which is significantly superior to traditional MRI [9].

5.2. Clinical significance of differences in diagnostic efficacy in different subregions

This study found that the diagnostic efficacy of both imaging technologies in the weight-bearing area was higher than that in the non-weight-bearing area, which is consistent with the clinical characteristics of higher incidence and more severe injury of cartilage in the weight-bearing area. The diagnostic sensitivity (92.3%) and accuracy (93.5%) of T2 Mapping in the weight-bearing area were significantly higher than those of traditional MRI, especially its outstanding ability to detect early injuries in the weight-bearing area. This result has important clinical significance: most patients with knee joint pain are caused by cartilage injury in the weight-bearing area. Early accurate diagnosis of weight-bearing area injury can help physicians clarify the cause of pain, formulate targeted treatment plans, and avoid the progression of injury to severe cartilage defect [10].

5.3. Research limitations and future prospects

This study has certain limitations:

(1) Retrospective study design may lead to selection bias (e.g., most included patients have obvious symptoms, and mild asymptomatic injuries may be missed);

(2) There is heterogeneity in the selection of gold standards. Some patients use clinical follow-up diagnosis instead of pathological biopsy, which may affect the diagnostic accuracy;

(3) Only data from 1.5T MRI equipment were included, and the diagnostic efficacy of T2 Mapping under 3.0T MRI equipment was not evaluated. The performance differences of equipment with different field strengths need further research;

(4) The combined diagnostic value of T2 Mapping and other quantitative sequences (such as T1 Mapping, T2* Mapping) was not explored. Combined imaging may further improve the diagnostic efficacy.

Future research can be carried out in the following directions:

(1) Conduct prospective multi-center studies, include more asymptomatic populations, and evaluate the early warning value of T2 Mapping for cartilage injury;
(2) Use arthroscopic pathological biopsy as the gold standard to further improve the reliability of research results;
(3) Compare the diagnostic efficacy of T2 Mapping under MRI equipment with different field strengths;
(4) Explore the diagnostic mode combining T2 Mapping with AI technology, and improve the diagnostic efficiency and consistency through AI automatic segmentation of cartilage subregions and measurement of T2 values;
(5) Conduct long-term follow-up studies to evaluate the monitoring value of T2 Mapping for the treatment effect of cartilage injury.

6. Conclusion

This retrospective study systematically compared the diagnostic efficacy of traditional MRI and T2 Mapping quantitative imaging for knee joint cartilage injury. The results showed that the overall diagnostic sensitivity, accuracy, and consistency with the gold standard of T2 Mapping quantitative imaging were significantly superior to those of traditional MRI, especially in the diagnosis of early cartilage injury (Grade 1) and weight-bearing area injury. There was no significant difference in specificity between the two technologies, but T2 Mapping had a higher negative predictive value, which could more reliably rule out cartilage injury. Multi-center data verified the universality and repeatability of T2 Mapping technology. Its quantitative characteristics reduce subjective diagnostic errors and provide an objective basis for the early accurate diagnosis of cartilage injury. Therefore, T2 Mapping quantitative imaging can be used as an important supplementary method to traditional MRI, and is recommended for the early diagnosis, grading evaluation, and clinical follow-up of knee joint cartilage injury, especially for patients with knee joint pain and suspected early cartilage injury.

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Disclosure statement

The authors declare no conflict of interest.

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