Int J Clin Exp Med 2020;13(11):8585-8591
www.ijcem.com /ISSN:1940-5901/IJCEM0115410

Original Article

Clinical application of magnetic resonance imaging (MRI) in the reconstruction of anterior cruciate ligament tears in the knee joint

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Received June 1, 2020; Accepted August 26, 2020; Epub November 15, 2020; Published November 30, 2020

Abstract: Objective: This study aimed to observe the post-reconstruction effect of anterior cruciate ligament tear of knee joint with MRI. Methods: A total of 52 patients with anterior cruciate ligament (ACL) injuries were enrolled and diagnosed by MRI, and then underwent arthroscopy within 30 days. The results of the two methods were compared; indirect signs and direct signs of ACL were observed, and MRI images were judged by 3 professional physicians in our hospital. Results: The sensitivity of MRI versus arthroscopy for ACL tear examination were 95.63% and 94.25%, and the specificity were 94.26% and 92.84%, respectively, with a statistically significant difference ($P<0.05$). The sensitivity of MRI in diagnosing edema, atrophy and discontinuity were 71.16%, 53.02% and 73.89%, and the specificity were 96.94%, 96.91% and 96.81%, respectively; MRI had significantly higher accuracy than arthroscopy, and the difference was statistically significant ($P<0.05$). The specificity was higher in regarding indirect signs, e.g., meniscus, PCL index, empty intercondylar fossa sign and Notch sign. Conclusion: Various indirect signs show that MRI is significantly more accurate than arthroscopy, and such signs as edema, atrophy and discontinuity are of high diagnostic value, while meniscus, PCL index and Notch sign can be used as an auxiliary diagnostic basis.

Keywords: MRI imaging, anterior cruciate ligament, arthroscopy, clinical application value

Introduction

The Anterior cruciate ligament (ACL), also known as the cruciate ligament, is primarily located inside the knee joint between the medial posterior femoral condyle and the anterior concavity of tibial condyle [1]. The ACL is most likely to be torn in the knee joint. As reported, the incidence of ACL tear in Americans was 0.03%, while the incidence of ACL tear in athletes was higher than that in ordinary people, about 0.06% [2]. The investigation indicated that the incidence of ACL tear in Chinese athletes was 0.4%, significantly higher than that in the United States [3]. The ACL has a good cushioning effect, which can avoid sudden excessive dislocation of the tibia and ensures the normal motion of knee joint together with other structures around it [4]. An ACL tear seriously affects the stability of the joint and disrupts the normal motion of the knee joint. If treatment is not received early and multiple sprains occur in the same position, the cartilage of the knee joint will be severely injured and its structure will be severely deformed [5].

A joint subjected to serious injury will age prematurely and eventually lead to osteoarthropathy, which affects the normal work and life of patients. Surgical treatment is currently the most common clinical approach for ACL tear [6]. CT and X-ray are generally used in clinical practice for early diagnosis of ACL tears and improvement of the treatment effect; CT and X-ray have low diagnostic rates for ligament tear, so some doctors use arthroscopy for diagnosis. Some studies have shown that biopsy is required for arthroscopy diagnosis, which is traumatic [7]. MRI is a multi-directional, multi-parameter and multi-sequence examination method with high resolution and contrast, which is also non-invasive. Now MRI has become

an important diagnostic protocol for knee joint injury diseases such as ACL tear [8]. This paper analyzes the clinical application of MRI technology to ACL tears based on MRI direct signs.

Data and methods

Clinical data

A total of 100 patients diagnosed with ACL injury in our hospital from January 2016 until December 2017 were enrolled, including 48 males and 52 females, aged 15-80 years (average: 46.7 ± 8.3 years), with an injury duration of 1-24 d. Inclusion criteria: ACL patients were initially diagnosed with knee joint injury by professional doctors in our hospital [9], with clinical symptoms of knee joint ligament tear, pain, atrophy and edema of different degrees. This study was approved by our hospital and all patients signed the informed consent form.

Methods

Instruments and parameters

Normal MRI sectional anatomy of the knee joint was performed for all participants with Magnetom ESSENZA 1.5T MRI scanner (Siemens, Germany) by scanning in the sagittal plane, coronal plane and horizontal plane. During operation, the patient laid in a supine with legs straightened and knee joints externally rotated by 15°. The special surface coil for the knee joint was used, with the coil center at the lower end of the patella. MRI scanning of the whole knee joint was performed: SET1WE Sequence (TR=450 ms, TE=10-12 ms), TSE/FSE Dual Echo Sequence (TR=2300-3000 ms, TE=10-12/80-90 ms), TSE/FSE PDWI+ Fat Suppressed Sequence (TR=2200-2600 ms, TE=40-50 ms); Coronal TSE/FSE PDWI/PDWI+ Fat Suppressed Sequence (TR=2750-3050 ms, TE=50-70 ms); Cross-Sectional TSE/FSE PDWI+ Fat Suppressed Sequence (TR=3000-3200 ms, TE=50-60 ms), with slice thickness of 5 mm and interslice gap of 1 mm. All participants undergoing MRI were additionally diagnosed with arthroscopy within 30 days. The knee arthroscope produced by Xintai Hongqiang Medical Group was employed. The patient was anesthetized and lay flat for joint puncture. The arthroscope was inserted into the interior of the articular cavity for observation.

Direct signs of ACL

In this study, direct signs of the ACL were analyzed for diagnosis, including ① ACL edema: increase of ACL signal, or widening wholly or in a small area compared with normal value indicate knee joint thickening and edema; ② ACL atrophy: atrophic ACL is much thinner than normal; ③ ACL discontinuity: this appears with fracture markings, fracture gaps, or double-bundle fracture.

Indirect signs of ACL

Blumensaat angle: negative angle formed by the line parallel to the Blumensaat line intersecting the distal portion of the anterior cruciate ligament reveals ACL tear; Posterior cruciate ligament (PCL) angle: an angle of less than 105° formed by the proximal and distal portions of PCL reveals ACL tear; PCL index: the index of greater than 0.39 reveals ACL tear; Bone bruise: low signal intensity using T1WI and high signal intensity using T2WI/PDWI+ fat suppressed sequence reveal ACL tear; Notch sign: obvious change of bone bruise or deep depress of lateral femoral condyle; Visible PCL on a coronal single slice: Single-slice coronal image shows complete PCL; Meniscus posterior horn exposure sign: in the sagittal plane, the vertical line of posterior border of meniscus posterior horn is behind the vertical line of the roof of posterior border of tibia; Tibial forward displacement: in sagittal plane, the vertical line of the roof of posterior border of tibia is 7 mm or more ahead of the vertical line of the roof of posterior border of lateral femoral condyle. Empty intercondylar fossa sign: in coronal plane, the attachment site of anterior cruciate ligament on medial part of lateral femoral condyle is empty; Complete lateral collateral ligament is visualized on a coronal single slice of the lateral collateral ligament.

Criteria for judging ACL tear

In this study, three excellent radiologists in our hospital reviewed the MRI images together. They diagnosed the patients with ACL tear by carefully observing and distinguishing the direct signs on MRI images, in combination with their years of clinical review and treatment experience and the judgment criteria of direct signs of ACL. In case of disagreement, they made final diagnosis by discuss and negotia-

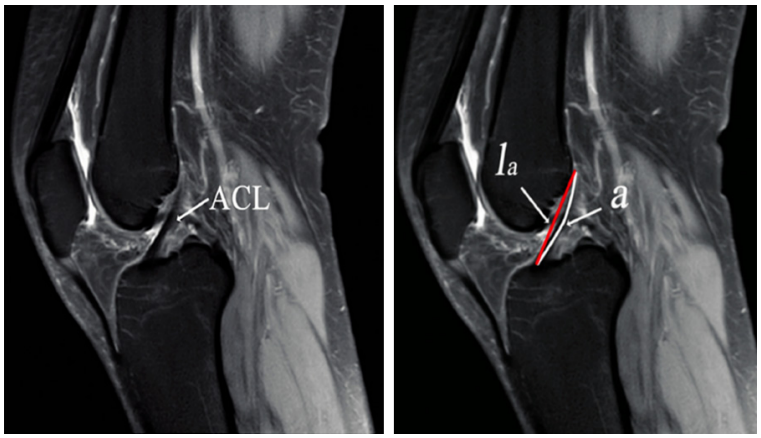


Figure 1. Measurement of anterior cruciate ligament. ACL: anterior cruciate ligament. a: ACL length, l_a: ACL attachment site to attachment site distance.

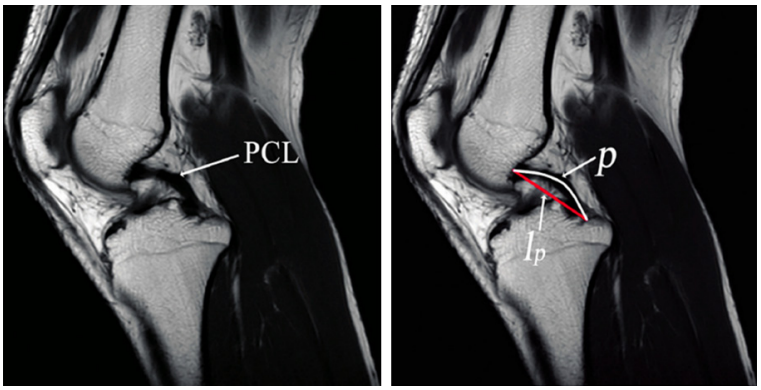


Figure 2. Measurement of posterior cruciate ligament parameters. PCL: posterior cruciate ligament. p: PCL length, l_p: PCL attachment site to attachment site distance.

Table 1. Comparison of diagnostic accuracy of ACL tear by MRI and arthroscopy

MRI diagnosis	Arthroscopic diagnosis		Total
	Tear	Normal	
Tear	18	3	21
Normal	1	30	31
Total	19	33	52
t	5.114	6.327	6.146
P	0.016	0.025	0.047

tion. Any of the signs such as ACL edema, atrophy or discontinuity was regarded as ACL tear. The sensitivity and specificity of MRI and arthroscopy were observed, and their examination results were compared. The length of anterior cruciate ligament of a, the length of posterior cruciate ligament of p of the knee joint, and the attachment site to attachment site distance of la and lp were measured, and then R and Ra were calculated by the formulas: $R=(a+p)/(l_a+l_p)$, $Ra=a/l_a$, $R_p=p/l_p$, as shown in **Figures 1** and **2**.

Statistical methods

The data were analyzed using SPSS 19.0. The measurement data were expressed as ($\bar{x} \pm s$) subject to t test and chi-squared test was used for counting, $P<0.05$ was considered statistically significant.

Results

Comparison of comprehensive diagnosis

The sensitivity and specificity of MRI for ACL tear examination were 95.63% and 94.26%, respectively. The sensitivity and specificity of arthroscopy for ACL tear examination were 94.25% and 92.84%, respectively. The accuracy of MRI was significantly higher than arthroscopy, with a statistically significant difference ($P<0.05$), as shown in **Table 1**.

Comparison between each direct sign

The examination results of each sign by arthroscopy were the same as comprehensive diagnosis. The sensitivity and specificity of MRI for edema were 71.16% and 96.94% respectively, which were significantly higher than arthroscopic diagnosis, and the difference was statistically significant ($P<0.05$), as shown in **Table 2**. The sensitivity and specificity of MRI for atrophy were 53.02% and 96.91% respectively, and the sensitivity and specificity of MRI for discontinuity sign were 73.89% and 96.81% respectively, with significantly higher accuracy than arthroscopy and statistically significant difference ($P<0.05$), as shown in **Tables 3**, **4** and **Figure 3**.

Observation of indirect signs of ACL injury by MRI and arthroscopy

Among the indirect signs by MRI, the sensitivity detection rates of Blumensaat angle, PCL

Table 2. Comparison of diagnostic accuracy of MRI and arthroscopy based on edema

MRI diagnosis	Arthroscopic diagnosis		Total
	Tear	Normal	
Tear	11	1	12
Normal	8	32	40
Total	19	33	52
t	3.271	4.270	6.893
P	0.033	0.039	0.043

Table 3. Comparison of diagnostic accuracy of x and arthroscopy based on atrophy

MRI diagnosis	Arthroscopic diagnosis		Total
	Tear	Normal	
Tear	10	1	11
Normal	9	32	41
Total	19	33	52
t	4.668	5.396	4.174
P	0.045	0.038	0.027

angle, PCL index, bone bruise, Notch sign, tibial forward displacement, meniscus posterior horn exposure sign, empty intercondylar fossa sign, visible lateral collateral ligament on a single slice and visible PCLd on a single slice were 76.92% (40/52), 67.30% (35/52), 71.15% (37/52), 69.23% (36/52), 48.07% (25/52), 67.30% (35/52), 34.61% (18/52), 63.46% (33/52), 69.23% (36/52) and 23.07% (12/52), respectively; and the specificity were 93.75% (45/48), 87.50% (42/48), 95.83% (46/48), 85.41% (41/48), 97.91% (47/48), 91.66% (44/48), 95.83% (46/48), 100% (48/48), 79.16% (38/48) and 97.91% (47/48), respectively, with a statistically significant difference ($P<0.05$), as shown in **Figure 4**.

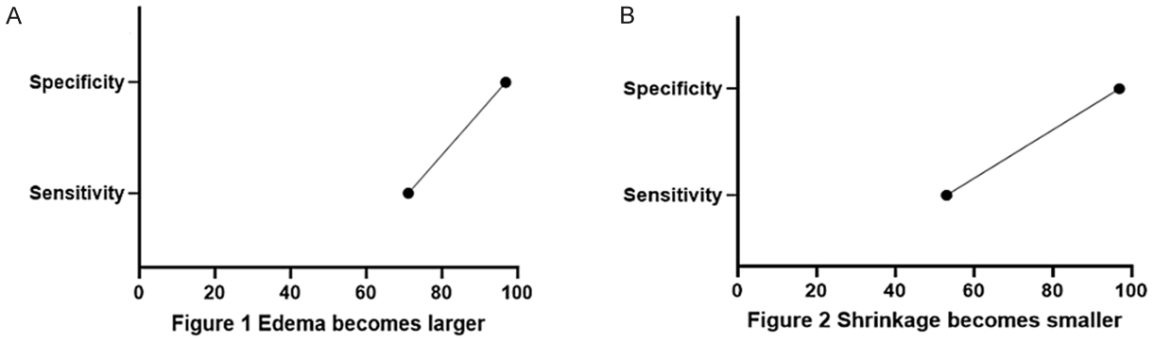
Discussion

The ACL plays a crucial role in supporting normal human activities. When the knee is extended, the joint will be flexed and relaxed to prevent backward displacement of the femur, forward displacement of the tibia and over extension and over rotation of the knee joint [10]. The ACL is the most vulnerable part of the knee joint. Various actions may lead to ACL injury in daily life, most commonly in people who participate in various competitive sports and suffer from ACL strain and tear to varying degrees [11, 12]. It is important to seek for medical treatment early to prevent repeated ligament strain or sprain. The studies have shown that, for severe ACL injury, if the injured site and the severity can be accurately diagnosed at an early stage and targeted treatment can be performed on the affected site, and the pain may be effectively relieved [13, 14]. Non-invasive MRI technology can clearly reveal the affected portion of the ACL, and it has become an important prerequisite for ACL tear reconstruction [15, 16]. MRI technology can accurately show the middle portion of the anterior cruciate ligament, which is viewed in an oblique sagittal position from the medial anterior direction to the lateral posterior direction [17, 18]. The attachment site of ACL inside the tibial condyle can be clearly viewed on the sagittal plane formed by oblique sagittal section and sagittal section. The attachment site of the ACL inside the femoral condyle can be viewed on the sagittal plane formed by an oblique sagittal section and axial section [19, 20]. Increasing literature presents MRI for ACL tear diagnosis. The sensitivity of MRI is not the same but it is in the range of 60%~90%, and its specificity is in the range of 68%~98%. The most powerful basis for ACL tear diagnosis by MRI is direct signs, mainly including: ACL discontinuity, edema, atrophy, absence, etc. [21, 22]. In this study, the diagnosis was based on direct signs of the ACL, which refers to the changes of its own characteristics. Compared with non-specific X-ray and CT used in the past, MRI can detect ACL tear in a targeted manner. CT and X-ray can only be used as auxiliary reference basis for disease diagnosis. There is a high potential for application of MRI to ACL tear reconstruction [23, 24].

Table 4. Comparison of diagnostic accuracy of MRI and arthroscopy based on discontinuity

MRI diagnosis	Arthroscopic diagnosis		Total
	Tear	Normal	
Tear	12	3	15
Normal	7	30	37
Total	19	33	52
t	4.311	6.325	4.357
P	0.025	0.037	0.029

Clinical studies have confirmed that arthroscopy is the best method to diagnose ACL injury, which requires collecting living tissues of patients, while MRI does not cause harm to



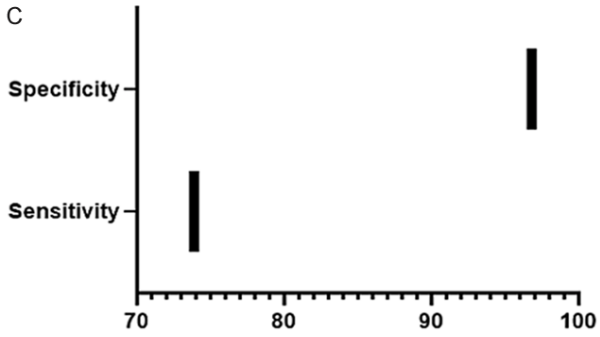


Figure 3. Sensitivity and specificity of each direct sign. The sensitivity, specificity and accuracy for edema, atrophy and discontinuity by MRI were significantly higher than arthroscopy, and the difference was statistically significant (P<0.05).

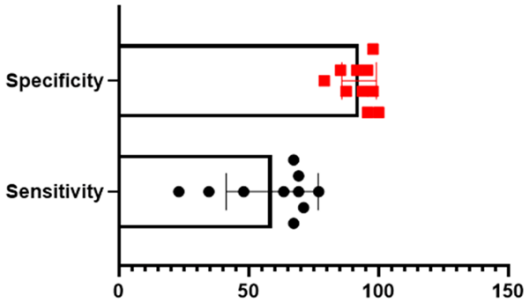


Figure 4. Indirect signs of anterior cruciate ligament injury by MRI and arthroscopy. The 10 indirect signs of anterior cruciate ligament injury of knee joint were of high sensitivity and specificity upon examination, the specificity of PCL index, Notch sign, meniscus posterior horn exposure sign and empty intercondylar fossa sign were significantly higher than that of other indirect signs, and the difference was statistically significant (P<0.05).

patients [15, 25]. This study focuses on the application of MRI in diagnosis before ACL tear reconstruction. A study reported that the accuracy rate of MRI in detecting ACL injuries was 92%-100%, and the most common part of injury was in the middle part of ligaments, accounting for about 72%, about 18% for the attachment point of the femur condyle, and 4% for the attachment point of the tibia [26]. The results showed that, among 52 participants diagnosed with ACL tear by MRI in combination with all signs, the sensitivity and specificity were 95.63% and 94.26% respectively, while the sensitivity and specificity of arthroscopy for ACL tear were 94.25% and 92.84% respectively. MRI was more accurate than arthroscopy and the difference was significant. For judgment of ACL tear by ACL edema, the sensitivity and specificity of MRI were 71.16% and 96.94% respectively. MRI was more accurate than arthroscopy and the difference was significant. For judgment of ACL tear by ACL atrophy, the sensitivity and specificity of MRI were 53.02% and 96.91% respectively. MRI was more accurate than arthroscopy and the difference was significant. For judgment of ACL tear by ACL discontinuity, the sensitivity and specificity of MRI were 73.89% and 96.81% respectively. MRI based on discontinuity was more accurate than arthroscopy and the difference was statistically significant (P<0.05), indicating that MRI is accurate and the diagnostic result is reliable. This research needs to be further expanded: joint MRI diagnosis of incomplete cruciate ligament tear still lacks typical MRI signs and diagnostic basis. It is necessary to further explore the imaging and diagnosis methods of joint MRI for incomplete cruciate ligament tear to improve the diagnostic accuracy.

In summary, the three direct manifestations and comprehensive symptoms of ACL tear have high application value and can be used as

important reference indexes for diagnosis by various detection methods. The MRI results are highly targeted and practical.

Disclosure of conflict of interest

None.

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