A giraffe neck sign of the medial meniscus: a characteristic finding of the medial meniscus posterior root tear on magnetic resonance imaging

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Abstract

Background: The posterior root ligament of the medial meniscus (MM) has a critical role in regulating the MM movement. An accurate diagnosis of the MM posterior root tear (MMPRT) using magnetic resonance imaging (MRI) is important for preventing sequential osteoarthritis following the MMPRT. However, diagnosis of the MMPRT is relatively difficult even after using several characteristic MRI findings. The aim of this study was to identify a useful meniscal body sign of the MMPRT for improving diagnostic MRI reading.

Methods: Eighty-five patients who underwent surgical treatments for the MMPRT (39 knees) and other types of MM tears (49 knees) were included. The presence of characteristic MRI findings such as cleft sign, ghost sign, radial tear sign, medial extrusion sign, and new meniscal body shape-oriented “giraffe neck sign” was evaluated in 120 MRI examinations.

Results: Giraffe neck signs were observed in 81.7% of the MMPRTs and in 3.3% of other MM tears. Cleft, ghost, and radial tear signs were highly positive in the MMPRTs compared with other MM tears. Medial extrusion signs were frequently observed in both groups. Coexistence rates of any 2 MRI signs, except for medial extrusion sign, were 91.7% in the MMPRT group and 5% in other MM tears.

Conclusions: This study demonstrated that a new characteristic MRI finding “giraffe neck sign” was observed in 81.7% of the MMPRT. Our results suggest that the combination of giraffe neck, cleft, ghost, and radial tear signs may be important for an accurate diagnostic MRI reading of the MMPRT.

Introduction

The posterior root ligament of the medial meniscus (MM) has a critical role in regulating the MM shift during the knee motion and load bearing [1-3]. The MM posterior root tear (MMPRT), including partial, complete radial, and/or oblique tears adjacent to the posterior root ligament and attachment, leads to progressive cartilage loss, osteoarthritis, and subchondral insufficiency fracture of the knee joint by disrupting the MM functions [1]. In addition, the MMPRT leads to abnormal biomechanics of the tibiofemoral joint and the inability to convert axial loads into hoop stresses by inducing radial displacement of the MM, also called the MM extrusion [2, 3]. With a greater understanding of post-traumatic knee degradations following the MMPRT, more emphasis has been placed on accurate diagnosis and early identification of the MMPRT using magnetic resonance (MR) images [4]. Several characteristic MR findings have been reported to detect the MMPRT. A radial tear sign (radial linear defect) with complete discontinuity of the posterior root ligament and fluid gap on axial MR images has a high diagnostic sensitivity (93.3-94%) in the MMPRT [5, 6]. A ghost (or white meniscus) sign that shows a disappearance of the MM posterior root/horn on some slices of sagittal MR images can diagnose the MMPRT with a high sensitivity (96.7-100%). A cleft/truncation sign (vertical linear defect) on coronal MR images is reported to have a high sensitivity (90-100%) of the MMPRT diagnosis [5, 6]. However, these signs are extra-meniscus diagnosing criteria for the MMPRT by noticing a lack of posterior root ligament adjacent to meniscal body. Orthopaedic surgeons and radiologists usually diagnose meniscal tears with intra-meniscus signs such as fluid signal and abnormal intensity in meniscal body itself [7]. In addition, a diagnostic reading of the knee MR images is performed in variable conditions such as different MR machines, protocols, and planes. The presence of useful meniscal body sign may reduce overlooking and/or misunderstanding of the MMPRT.

A medial extrusion sign (subluxation and radial/extra-articular displacement) of the MM is also a characteristic finding on coronal MR images of patients having the MMPRT [6]. Medial extrusion of the MM is associated with a loss of medial compartment cartilage volume [8], medial joint space narrowing [9], severity of osteoarthritis as reflected by radiographic Kellgren-Lawrence grade [10, 11], degenerative knee abnormalities [12], and knee joint pain [13] in patients with osteoarthritic knees. In addition, meniscal extrusion predicts an increase in subchondral bone lesions and tibial plateau expansion in osteoarthritic knees

[14]. However, a medial extrusion sign has a lower sensitivity (63.3%) for detecting the MMPRT than the above MR-based extra-meniscus signs [6]. The aim of this study was to identify a useful meniscal body sign of the MMPRT for improving diagnostic reading of MR images.

Materials and methods

This study received the approval of our Institutional Review Board, and written informed consent was obtained from all patients. Eighty-five patients who underwent surgical treatments for the MMPRT and other types of MM tears between January 2013 and November 2016 were included (Table 1). All the patients were diagnosed having the MM tears with magnetic resonance imaging (MRI) examinations and surgical findings. Duration between MRI examination and surgery was a mean of 2.6 ± 3.1 months. The presence of the MMPRT was defined according to characteristic MRI findings (cleft /truncation sign of the MM posterior root within 9 mm from the attachment, ghost/white meniscus sign, radial tear sign, and medial extrusion sign ≥ 3 mm of the MM) [6] and new meniscal body sign (giraffe neck sign). Types of the MMPRT were determined by careful arthroscopic examinations or arthroplasty-associated direct observations (39 knees) according to the meniscal root tear classification (Table 1) [15]. Other types of MM tears were determined by arthroscopic findings and MR images (49 knees): 3 longitudinal tears, 10 horizontal tears, 11 radial tears, 13 flap tears, 9 degenerative tears, and 3 complex tears. Arthroscopic surgery of the MM was performed on 81 knees. Of these, 32 knees (39.5%) required arthroscopic treatment for the MMPRT [16]. Patients were examined by preoperative MRI scans (1-3 times). Patient demographics and clinical characteristics are shown in Table 1.

Assessments of MR images

MRI evaluation was mainly performed using an Achieva 1.5 T (Philips, Amsterdam, The Netherlands) or an EXCELART Vantage Powered by Atlas 1.5 T (Toshiba Medical Systems, Otawara, Japan) with a knee coil. Standard sequences of the Achieva included sagittal [repetition time (TR)/echo time (TE) 742/18], coronal (TR/TE 637/18), and axial (TR/TE 499/18) T2-weighted fast-field echo with a 20° flip angle (FA). Standard sequences of the Vantage included sagittal and coronal proton density fast-spin-echo (TR/TE

2,300/18), and axial T2-weighted fat suppression (TR/TE 3,500/60) with a 90° FA. Slice thickness was 3 mm with a 0.6-mm gap. Field of view (FOV) was 16 (or 17) cm with an acquisition matrix size of 205 × 256 (or 200 × 368) [17-20]. Open MRI scan was performed using an OASIS 1.2 T (Hitachi Medical, Chiba, Japan) with a coil under the 10°-flexed knee position. Standard sequences of the OASIS included sagittal and coronal (TR/TE 1,718/12) proton density-weighted images using Driven Equilibrium Pulse with a 90° FA, axial (TR/TE 4,438/84) T2-weighted multi echo with a 90° FA. The slice thickness was 4 mm with a 0-mm gap. The FOV was 16 cm with an acquisition matrix size of 320 × 416. Other MR images obtained at different hospitals were similar to those of our institution except for slice direction. A "giraffe neck sign" was determined by a lateral view of giraffe neck-like shape of the MM posterior segment on coronal MR images between 3 and 9 mm away from the posterior margin of the MM (Fig. 1a, trapezoid-like shape). Medial extrusion of the MM was measured from the medial margin of the tibial plateau to the outer border of the MM on the coronal image that crossed the midpoint of the anteroposterior length of the MM (Fig. 1b). Medial extrusion (≥ 3 mm) was defines as a positive extrusion sign. Giraffe neck sign, cleft sign, medial extrusion sign, ghost sign (Fig. 1c), and radial tear sign (Fig. 1d) were assessed on 120 MRI examinations (Table 2). Representative giraffe neck signs are shown in Figure 2 (a-d).

Statistical analysis

Data were presented as means ± standard deviations. Statistical differences in age, height, body weight, and body mass index between two groups were analyzed using Mann-Whitney U-test. Differences in gender and MRI signs between groups were compared using Fisher's exact test. Power and statistical analyses were performed using EZR (Saitama Medical Center, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing). Significance was set to $P < 0.05$. Two orthopaedic surgeons (M.F. and Y.K.) independently assessed MR images in a blinded manner. Each observer performed each evaluation twice, at least 2 weeks apart. The reliability of the MR signs was assessed by examining the inter-observer and intra-observer reliabilities. The inter-observer and intra-observer reliabilities for the assessments were determined by calculating κ coefficients and considered satisfactory (κ values > 0.80).

Results

The incidence of the MMPRT was higher in women compared with that of other MM tears (P = 0.002, Table 1). Partial stable root tears were observed in 5 knees. Remaining 34 knees showed complete MMPRTs (Table 1). Significant differences between the MMPRT and other MM tear groups were observed in age (P = 0.037), height (P = 0.002), and body mass index (P = 0.034).

Characteristic MRI signs of the MMPRT were detected in both groups. A swelled/truncated slope-like shape of the MM posterior segment on coronal MR images, named a “giraffe neck sign”, was observed in 81.7% of the MR images involved in the MMPRT patients (Table 2). On the other hand, MR images of other MM tear group rarely showed the giraffe neck sign (3.3%). Cleft, ghost, and radial tear signs were highly positive in the MMPRT group compared with other MM tears (Table 2). Cleft, ghost, and radial tear signs were detected in 81.7%, 80%, and 69.6% of the MMPRT MR images, respectively. Although medial extrusion sign was the most frequent finding in the MMPRT (90%), MR images of other MM tear group also showed the medial extrusion of the MM (80%). Statistical differences between two groups were observed in the presence of giraffe neck, cleft, ghost, and radial tear signs on MR images (P < 0.001, Table 2). No cleft signs were observed in 6 MRI scans out of the 49 scans that showed positive giraffe neck signs in the MMPRT group. Six MRI scans showed no giraffe neck sign in the cleft sign positive MMPRT patients (Table 2). In other meniscal tear group, giraffe neck signs were not correlated with cleft sign positive MRI scans.

A new meniscal body sign that showed a giraffe’s neck-like shape was observed in the MMPRT on coronal MR images (Fig. 1a, dotted area). An apparent cleft sign with a fluid gap was sometimes invisible. A medial extrusion sign of the MM was not a valuable diagnostic MRI finding of the MMPRT (Fig. 1b). A ghost sign nearby the MM posterior root was uncertain in some cases, especially in the partial root tear of the MM (Fig. 1c). Detecting a radial tear sign adjacent to the MM posterior root was difficult in some cases because of insufficient MR images (Fig. 1d).

Based on these occasional lacks of characteristic MRI signs in the MMPRT, we assessed coexistence rates of positive findings in giraffe neck, cleft, ghost, and radial tear signs (except for medial extrusion sign) between two groups. Significant differences in 1-4 positive percentages of the 4 signs were observed between the MMPRT and other MM tear groups (Table 3). The percentage involved in positive any 2 MRI signs was

91.7% in the MMPRT group. However, coexistence rate of any 2 MRI signs decreased to 81.7% without using giraffe neck sign in the MMPRT group (Table 3). Seventy-seven percent of the MRI scans in the MMPRT patients showed positive to 3 characteristic MRI signs. In other MM tear group, 5% of the MRI scans showed positive findings in any 2 MRI signs (Table 3).

Discussion

The most important finding in this study was that a new characteristic MRI finding "giraffe neck sign" showed a relatively high sensitivity (81.7%) to diagnose the MMPRT as same as cleft sign. The MMPRT diagnostic value of the giraffe neck sign was similar to those of cleft/truncation sign and ghost/white meniscus sign on MR images of various types of the MM tears. Although medial extrusion sign of the MM was highly positive in both the MMPRT and other types of MM tears, giraffe neck sign, cleft sign, ghost sign, and radial tear sign were specifically observed in the MMPRT not in other MM tears. In addition, coexistence of any 2 characteristic MRI signs except for medial extrusion sign was observed in 91.7% of the MMPRT. Our results suggest that the combination of giraffe neck, cleft, ghost, and radial tear signs may be important for an accurate diagnostic MRI reading of the MMPRT.

This study demonstrated that the incidence of the MMPRT was higher in women compared with that of other types of MM tears (Table 1). In addition, the MMPRTs were detected in older patients (mean age, 60.1 ± 10.5 years) rather than other MM tears. Several authors report that the MMPRT can occur especially in middle-aged or older female patients who have a single event of popliteal painful popping sensation during light activities such as using stairs and squatting [6, 21, 22]. Posterior segment of the MM moves 4 mm posteriorly during the knee flexion [23]. Root ligaments and attachments stabilize the complex movement of the menisci during the knee motion. The attachment of the MM posterior root (7.2 ± 2.6 mm) is shorter than all other meniscal attachments. Moreover, mechanical properties of the MM posterior root in stress relaxation (14.6 ± 1.2 N) and creep (0.17 ± 0.08 mm) are inferior to those of other meniscal roots [24]. The mechanical behavior of ligament enthesis is mostly dependent on contributions of type I and II collagens [25]. In human cadaveric knees, fibrocartilage metaplasia and calcification increase in the MM posterior roots, associated with the degree of the MMPRT (partial or complete tears). A decrease of type I collagen deposition and an increase of type II collagen synthesis is observed in the extracellular matrix of the MM posterior root in osteoarthritic knees [26]. These findings suggest that age-dependent degenerative changes in the MM posterior root and gender-related weakness of the root attachment may lead to the MMPRTs in older female patients. We consider that a lifestyle required maintaining the deep knee flexion angle may increase the risk of the MMPRT. Further investigations will be required to understand the relationships among aging, gender, compositional change in the root ligament, and the MMPRT.

Many studies have reported that the MM extrusion is associated with progression of symptomatic knee osteoarthritis [8, 10, 13]. Meniscus-to-femoral condyle congruity is essential for the development of circumferential hoop stresses and meniscal function. Abnormalities in the position of the MM and its coverage can alter the knee joint congruity and are associated with the progression of tibiofemoral osteoarthritis and cartilage degradation [8]. MRI analyses have revealed that osteonecrotic lesions of the medial femoral condyles are observed in 33% of the MMPRT patients [22]. Previous studies report that MRI-based MM extrusion ($\geq$ 3 mm) is detected in 83.3% of the MMPRT patients and 10% of patients suffering from other MM tears [6], and is more frequent in painful osteoarthritic knees than in contra-lateral painless knees [13]. In our study, medial extrusion sign of the MM was observed in 90% of the MMPRTs and 80% of other MM tears (Table 2). The difference in sensitivity of the MM extrusion sign may be partially caused by the plane setting of coronal MR images. However, we consider that medial extrusion sign is not a reliable MRI finding to diagnose the presence of the MMPRT.

Our study demonstrated that radial tear signs on axial MR images were observed in 69.6% of the MMPRT patients (Table 2). A sensitivity of radial tear sign was lower than that of other MRI signs in the MMPRT. This may be caused by a technical difficulty in obtaining appropriate axial MR images to identify the MMPRT. In addition, type 1 partial MMPRTs that have a partial continuity of the root ligament may decrease the positive rate of radial tear sign in the MMPRT patients. Diagnosis of meniscal root tears is considerably difficult, with reported detection rate of 73% to 89%, even after using characteristic MRI findings [4, 27-30]. In this study, we proposed a new meniscal body shape-oriented “giraffe neck sign” that showed a higher diagnostic value for the MMPRT than radial tear sign and medial extrusion sign (Table 2). Giraffe neck sign did not coexist with cleft sign perfectly in the MMPRT patients. We consider that the giraffe neck sign and cleft sign are two distinct valuable MRI findings for diagnosing the MMPRT. Evaluating the coexistence of any 2 reliable MRI signs increased the sensitivity to the MMPRTs up to 91.7% without augmenting the false positive rate in other MM tears (Table 3). Without using giraffe neck sign, coexistence rate of any 2 MRI signs decreased to 81.7% in the MMPRT group. Moreover, giraffe neck sign did not increase coexistence rate of 2 MRI signs in other MM tears. We consider that the giraffe neck sign may be a valuable characteristic MRI finding for diagnosing the MMPRT. It must be important to increase diagnostic options for identifying the MMPRT. There is a useful clinical sign to expect the presence of the MMPRT. The positive predictive value of the popliteal painful popping sensation in identifying the MMPRT is 96.5% and the specificity is 99.5% [21]. In the treatment of the MMPRT, early diagnosis and appropriate surgical intervention are important in obtaining a successful clinical outcome and preventing rapid progression of degenerative knee diseases [1]. However, radiologists cannot obtain information about the painful popping history and clinical findings from patients with suspected the MMPRT by themselves. Although the sensitivity of a painful popping event for the detection of a MMPRT is low (35%) [21], information of the painful popping history and evaluating the coexistence of any 2 characteristic MRI signs may be necessary for a diagnostic reading of the knee MR images to radiologist as well as orthopaedic surgeons.

There are several limitations in this study. MRI examinations were performed differently (number of examination times, variable MR machines and protocols, and duration from the onset to MRI assessment). Our study was a retrospective comparative study. Giraffe neck sign and cleft sign were occasionally observed on the same coronal MR image. There is a possibility that giraffe neck sign may depend on the presence of cleft sign in the MMPRT. We evaluated the characteristic MRI findings in a single knee flexion angle (10°) under non-weight-bearing condition. MRI assessments of the MM posterior root attachment using thin slices and appropriate planes under loading condition may enhance the diagnostic value of these characteristic MRI findings in the MMPRT.

Conclusions

This study demonstrated that a new characteristic MRI finding “giraffe neck sign” was observed in 81.7% of the MMPRT. Although medial extrusion sign of the MM was not a reliable finding to detect the

MMPRT, giraffe neck sign, cleft sign, ghost sign, and radial tear sign were specifically observed in the MMPRT not in other MM tears. In addition, coexistence of any 2 characteristic MRI signs except for medial extrusion sign was highly observed in the MMPRT. Our results suggest that the combination of giraffe neck, cleft, ghost, and radial tear signs may be important for an accurate diagnostic MRI reading of the MMPRT.

Conflict of interest

The authors have no conflict of interest.

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Figure legends

Figure 1. Characteristic signs of the MMPRT on MR images. A 35-year-old woman (the left knee). (a) A giraffe neck sign (dotted area, coronal view of the MM posterior segment). A cleft (or truncation) sign (arrow). Note that a different intensity in the meniscal body is not a horizontal tear. (b) A medial extrusion sign of the MM (dotted line, coronal view of the MM middle segment). (c) A ghost (or white meniscus) sign (dotted area, sagittal view nearby the MM posterior root). (d) A radial tear sign adjacent to the MM posterior root (dotted arrow). Note that typical fluid gap and linear defect are not observed.

Figure 2. Representative giraffe neck signs. (a) An illustration of a giraffe. Note the shape of giraffe neck (arrow). (b-d) Coronal MR images of the MMPRTs. (b) A 35-year-old woman. (c) A 49-year-old woman. (d) A 56-year-old woman. Note the meniscal body shape of the MM posterior segment.

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