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ORIGINAL ARTICLE

The association between meniscal subluxation and cartilage degeneration

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Abstract

Purpose The menisci play a critical protective role for the knee joint through shock absorption and load distribution. We hypothesized that cartilage degeneration will be abruptly progressed if meniscal subluxation exceeds a critical point.

Methods Of 56 cases that showed medial meniscal subluxation without cartilage degeneration of ipsilateral medial femoral condyle (MFC) on initial MRI, from January 2005 to June 2007, meniscal subluxation index (MSI), the ratio of meniscal overhang to meniscal width in mid-coronal image of initial MRI, was measured. After 2 years, 40 cases were evaluated for cartilage degeneration of ipsilateral MFC on follow-up MRI. The relationship between medial MSI on initial MRI and cartilage degeneration of MFC on follow-up MRI was analyzed. Logistic regression analysis was conducted to find a critical point of meniscal subluxation related to cartilage degeneration.

Results Abrupt progression of cartilage degeneration was observed from which MSI was 0.38. Logistic regression showed that if MSI was at the critical point, which was 0.38 in our study, then the probability of cartilage degeneration to grade 3 or 4 after 2 years was 44 %. If MSI was 0.4, then the probability was 50 %. If MSI was 0.6, then the probability was 99 %.

Conclusions The results suggest the existence of critical point from which the protective function of the meniscus appears to be significantly altered, and the degree of cartilage degeneration of ipsilateral femoral condyle corresponding to the amount of medial meniscal subluxation may be predictable.

Keywords Meniscal subluxation · Cartilage degeneration · Chondromalacia · Magnetic resonance image

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Introduction

Osteoarthritis is a multifactorial disease with genetic and environmental determinants, and risk factors for it are characterized into systemic (age, gender, bone density, etc.) and local factors (malalignment, meniscal damage, etc.) [1, 2]. Progression of knee osteoarthritis is believed to result from local mechanical factors in a systemic environment. Mechanical factors are the dominant risk factors for structural progression [3], and among these, meniscus plays a critical role in tibiofemoral compartment with its shock absorbing and load distributing properties [4–7].

Meniscal subluxation results in the natural history of knee osteoarthritis, and the suggested MR definition of the meniscal subluxation is described as a distance of ≥3 mm between the peripheral border of the meniscus and the edge of the tibial plateau [8]. When hoop tension is not efficient to optimally distribute load within the knee, it was found to be associated with the increased cartilage degeneration in the same compartment [9, 10]. As available data showed that meniscal repair cannot reliably prevent the progression of osteoarthritis of knee, optimal hoop tension of menisci seems not possible to be restored whether it is degenerative or traumatic origin [11].

The association between meniscal subluxation and cartilage degeneration had been reported by previous studies [2, 5, 10], but it has not been demonstrated by prospectively designed longitudinal observational study.

The aim of our study was to demonstrate the association between meniscal subluxation and cartilage degeneration by a prospective longitudinal study of observation in patients with knee pain.

Patients and methods

Patient selection

Six hundred ninety-five patients in the database of the joint center at our hospital who underwent knee MRI between January 2005 and June 2007 were entered into this study. Inclusion criteria for this study were (1) age >40 years for both men and women, (2) without cartilage degeneration (grade <1) of medial compartment of the knee on initial MRI, (3) without advanced osteoarthritis on initial weight bearing simple radiographs, (4) with normal or degenerative meniscal tears; complex tear and horizontal tear, and (5) followed up with medical or physical treatment. Exclusion criteria included (1) cartilage degeneration of ipsilateral medial femoral condyle on initial MRI, (2) acute traumatic meniscal injuries; radial tear, vertical tear, and longitudinal tear, (3) ligaments injuries, (4) previous ipsilateral knee surgery, (5) varus or valgus malalignment, the knee was defined as varus when alignment was more than 0° in the varus direction, and valgus when it was more than 0° in the valgus direction, and (6) obesity with BMI >30.

Only medial meniscal subluxation was measured on MRI to have more homogenous group. Fifty-six cases of medial meniscal subluxation (>3 mm) were registered into this longitudinal study of observation, and among them, forty cases underwent follow-up MRI after 2 years. The relationship between medial meniscal subluxation on initial MRI and cartilage degeneration of ipsilateral medial femoral condyle on follow-up MRI was analyzed. The institutional review board approved protocols for this study.

MRI protocol

Magnetic resonance (MR) scans were performed with two 1.5 T superconducting magnets (Magenetom vision and Sonata, Siemens Medical System, Erlangen, Germany) using quadrature extremity coils. MR protocol incorporated the following sequences: fat-suppressed intermediate-weighted image (TR 2609–3200 ms/TE 45–53 ms, 4.0 mm thickness, 0.4–0.8 mm interslice gap, field-of-view (FOV) 160 × 160, matrix 256 × 179–205) in axial plane, T1-weighted image (TR 416–500 ms, TE 12–14 ms, 4.0 mm thickness, 0.4–0.8 mm interslice gap, FOV 160 × 160, matrix 256–512 × 179–198) and fat-suppressed dual-echo T2-weighted image (TR 2700–2930 ms, TE 9.5–16/76–98 ms, 4.0 mm thickness, 0.4–0.8 mm interslice gap, FOV 160 × 160, matrix 256–512 × 179–224) in sagittal plane, and dual-echo T2-weighted image (TR 2250–2700 ms, TE 11–16/79–98 ms, 3.0–4.0 mm thickness, 0.8–1.5 mm interslice gap, FOV 160 × 160, matrix 256–512 × 160–200) in coronal plane.

MRI evaluation

Review of MR images was performed by two experienced musculoskeletal radiologists (13 and 7 years in experience, respectively) in consensus with blind fashion using PACS (picture archiving and communication system, Marosis, Infinitti, Seoul, Republic of Korea) workstations.

As in the previous study of Kenny [12], on the mid-coronal image of the medial femoral condyle, subluxation of the medial meniscus was defined when the peripheral margin of the meniscus was protruded beyond the margin of medial tibial plateau except osteophyte. The measurement in millimeters was taken by first drawing a tangential vertical line at the margin of the medial tibial plateau, and second, vertical line at the outer margin of the medial meniscus parallel to the first line. The distance of two vertical lines was defined as subluxation width. Osteophyte from the margin of tibial plateau was excluded. Meniscal subluxation index was defined as the ratio of subluxation width of the meniscus divided by total width of the meniscus (Fig. 1).

Meniscal tear was defined when the intrameniscal signal extended to the articular surface or meniscal contour was deformed as shortening or blunting. Meniscal tears were classified by type and by location.

Articular cartilage of the medial femoral condyle and medial tibial plateau was evaluated using dual-echo T2-weighted image in both sagittal and coronal planes. Cartilage degeneration on the ipsilateral femoral condyle was graded on categorical scales with a modification of a previous classification system [13] (Table 1).

Statistical analysis

Descriptive statistics analyses about the meniscal subluxation and the relationship of it with the cartilage degeneration using histogram and x–y plot were performed. Data of meniscal subluxation were tested for normality using the

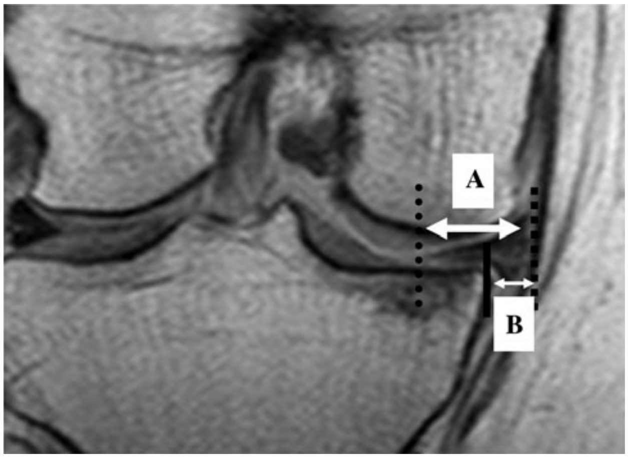

Fig. 1 The measurement was taken by first drawing a tangential *vertical line* at the margin of the medial tibial plateau (*solid line*), and second, *vertical line* at the outer margin of the medial meniscus parallel to the first *line* (*dotted line*). The distance of two *vertical lines* was defined as subluxation width (*B*). Total meniscal width was defined from inner margin (*dotted line*) to outer margin (*dotted line*) of the medial meniscus. Meniscal subluxation index was defined as subluxation width (*B*)/total meniscal length (*A*)

Table 1 Modified cartilage degeneration categorical scales

Grade	MRI findings
0	Normal cartilage
1	Focal blistering and intracartilaginous low-signal intensity area with an intact surface and bottom
2	Irregularities on the surface or bottom and loss of thickness of less than 50 %
3	Deep ulceration with loss of thickness of more than 50 %
4	Full-thickness chondral wear with exposure of subchondral bone

Kolmogorov–Smirnov test and showed normal distribution. Five cartilage degeneration groups which were graded from zero to four were categorized into two groups—group 1 contains grade 0–2; group 2 contains grade 3–4. Logistic regression analysis was performed to determine the relationship between the meniscal subluxation index (independent variable) on initial MRI and the cartilage degeneration of the ipsilateral medial femoral condyle (dependent variable) on follow-up MRI. The statistical software MedCalc® (Version 11.6; MedCalc Software, Mariakerke, Belgium) and R (Version 2.12; Comprehensive R Archive Network, Boston, MA, USA) were used for all statistical analyses.

Results

Thirty-two cases (80 %) were men and eight cases (20 %) were women, and the average ages were 62 and 60 years, respectively. Average of BMI was 24 (range from 17 to 29). Twenty-one cases (52.5 %) had complex meniscal tears, twelve cases (30.0 %) had horizontal tears, five cases (12.5 %) had only degeneration without meniscal tear, and two cases (5.0 %) had normal menisci (Table 2). Thirty-one cases (77.5 %) had meniscal lesions at posterior horn of medial meniscus, and seven cases (17.5 %) had lesions from midbody to posterior horn (Table 3).

All cases had medial meniscal subluxation, and an average of medial meniscal subluxation index was 0.44 (range from 0.08 to 0.99) (Fig. 2). Two cases (5.0 %) with normal mensci had 0.31 and 0.33 of medial meniscal subluxation index, and the cartilage degenerations of them were not seen on ipsilateral medial femoral condyle on follow-up MRI. Cartilage degeneration on the ipsilateral medial femoral condyle was observed in twenty-five cases (62.5 %); fifteen cases (37.5 %) were grade 0, one case (2.5 %) was grade 1, three cases (7.5 %) were grade 2, eleven cases (27.5 %) were grade 3, and ten cases (25.0 %) were grade 4. An average grade of cartilage degeneration of ipsilateral medial femoral condyle was 2 (Figs. 3, 4).

Table 2 Medial meniscal tears in meniscal subluxation group on initial MRI

Meniscal tear classification	Numbers	Percentage (%)
Complex tear	21	52.5
Horizontal tear	12	30.0
Degeneration without tear	5	12.5
Normal meniscus	2	5.0

Table 3 Locations of medial meniscal tears in meniscal subluxation group on initial MRI

Location	Numbers	Percentage (%)
Posterior horn only	31	77.5
Midbody to posterior horn	7	17.5

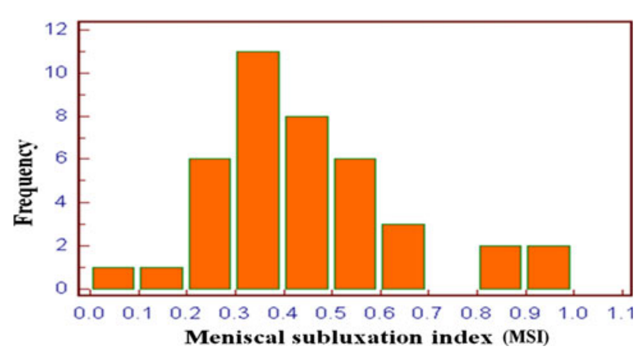

Fig. 2 The histogram of the medial meniscal subluxation index which was measured on initial MRI

Logistic regression analysis was performed to find the relation between the meniscal subluxation index and the subsequent cartilage degeneration and the optimal cutting off value of medial meniscal subluxation. The logistic regression coefficient was statistically significant. The model was checked for goodness of fit with the Hosmer and Lemeshow test and ensured that it was well specified and fit the data. The regression equation was as follows; Prob (cartilage degeneration = grade 3 or 4) = exp (−8.259 + 21.62 × Meniscal subluxation index)/[1 + exp (−8.295 + 21.162 × Meniscal subluxation index)]. And the critical point of meniscal subluxation index which was related to a sharp change of the grade of cartilage degeneration was 0.38. If meniscal subluxation index was at the critical point, the probability of cartilage degeneration to grade 3 or 4 after 2 years was 44 %. If the meniscal subluxation index was 0.4, then the probability of cartilage degeneration to grade 3 or 4 after 2 years was 50 %. If meniscal subluxation index is 0.6, then the probability of cartilage degeneration to grade 3 or 4 after 2 years was 99 % (Fig. 5).

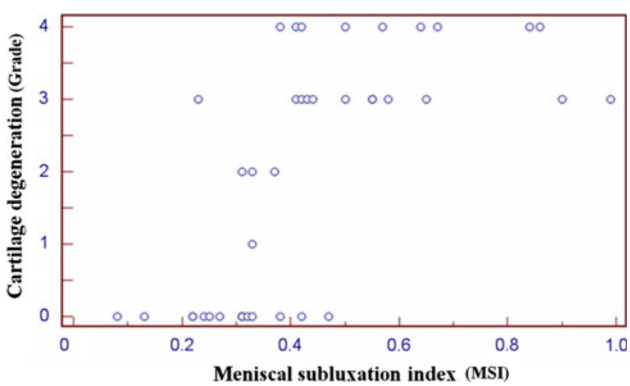

Fig. 3 Scatter plot of cartilage degeneration and meniscal subluxation index on initial MRI

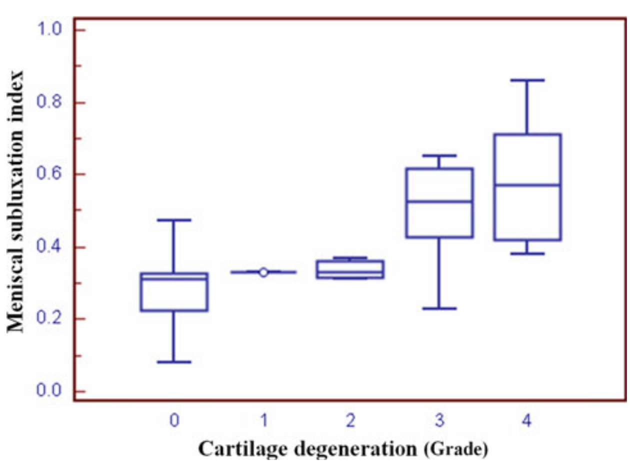

Fig. 4 Box plots of meniscal subluxation index on each grade of cartilage degeneration

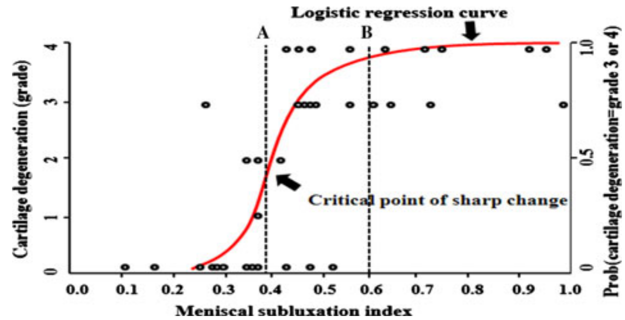

Fig. 5 Logistic regression analysis showing the relations between meniscal subluxation index and cartilage degeneration. Logistic regression *curve* (*red*) fits the relationship between the meniscal subluxation index and the probability of cartilage degeneration to grade 3 or 4 in 2 years. If the meniscal subluxation is at the critical point of meniscal subluxation index which is 0.38 (*dotted line A*), then the probability of cartilage degeneration to grade 3 or 4 after 2 years is 44 %. If the meniscal subluxation index is 0.6 (*dotted line B*), then the probability of cartilage degeneration to grade 3 or 4 after 2 years is 99 %

Discussion

Important functions of meniscus include load distribution, shock absorption, proprioception, and lubrication [14]. During load transmission, the compressive force on the meniscus results in circumferential stress that stretches the collagen bundles in a radial direction between the anterior and posterior attachments. Factors that influence resistance to hoop strain are the integrity and orientation of the meniscal collagen fibers, the attachments of anterior and posterior horns, and the intermeniscal connections [15–17].

The relationship between menisci and the knee osteoarthritis is complex, and the current structure–function relation of the meniscus suggests that a high level of congruity between the meniscus and the articulating cartilage is essential for the load distribution within the knee [17]. The loss of hoop tension of meniscus caused by disruption of circumferential fibers alters congruity between the meniscus and the articulating cartilage and leads to knee osteoarthritis. Lerer et al. [18] reported strong association between extrusion of the medial meniscus and loss of medial articular cartilage, and they suggested that extrusion of the medial meniscus preceded rather than followed. Stärke et al. [19] demonstrated that the deformation of the femoral cartilage was significantly dependent on the hoop tension applied at the meniscal horn attachment and concluded decreasing the hoop tension caused a corresponding increase in the cartilage deformation, indicating increased focal stress, and our results are consistent with these previous reports. The focus of previous research had been on the progression of cartilage degeneration related to meniscal subluxation [5, 20, 21]. They demonstrated the importance of role of the meniscus in knee kinematics, and concluded progression of cartilage degeneration was secondary to ineffective function of the meniscus within the knee joint [5, 22]. In this study, at the early period of meniscal subluxation (meniscal subluxation index between 0 to critical point of 0.38), meniscus probably could maintain its hoop tension and its congruity, so cartilage degeneration was slowly progressed. But when meniscal subluxation exceeded a critical point, cartilage degeneration was abruptly progressed, and this was because meniscus probably could not withstand the compressive force in the compartment and maintain its congruity (Fig. 5).

A biphasic behavior of menisci was investigated by some previous studies [23–25]. They reported that a meniscus was composed of two different phases and meniscal tissue followed the expected behavior of a biphasic material. And a characteristic stress-relaxation curve of meniscal tissue was demonstrated in their study. The curve showed that the load required to maintain meniscal tissue decreased abruptly as fluid expelled from the meniscal tissue. It seems that meniscal degeneration alters the composition of tissue, and this alteration combined with loss of hoop tension seems to explain abrupt cartilage degeneration after meniscal subluxation exceeded a critical point in our study. Some authors have accepted up to 3 mm of meniscal subluxation as normal, but there is no agreement with respect to the amount of meniscal subluxation that can be considered as physiological [8].

In our study, all patients with various amount of meniscal subluxation had no cartilage degeneration of the ipsilateral femoral condyle on initial MRI. This suggest that meniscal subluxation is frequent in non-arthritic knees, and some of them, as who showed advanced cartilage degeneration on follow-up MRI at 2 years in our study, have potential to develop abruptly progressed cartilage degeneration not many years after. And our results may provide information that could be helpful to prevent rapid progression of cartilage degeneration for patients with meniscal subluxation in the future study.

The strength of this study is that it has prospectively designed longitudinal observational study format. However, there are several weaknesses of this study. First, sample size is relatively small. Second, MRIs were done on symptomatic knees. Although we included the knees without cartilage degeneration and excluded many criteria, we can consider these knees as having some degree of abnormality and different activity levels. But the possible influences of these abnormalities and different activity levels on the final results were considered to be insignificant. Third, MRI used to evaluate the amount of meniscal subluxation is a static image with patient in supine position. Boxiheimer et al. reported that extrusion of medial meniscus appeared in only nine out of 22 cases, and the number of cases increased to 50 % in the loaded weight bearing position [26].

This study suggests that (1) medial meniscal subluxation is associated with cartilage degeneration of ipsilateral medial femoral condyle of the knee, (2) the amount of meniscal subluxation was related to the degree of progression of cartilage degeneration, (3) the possibility of existence of critical point of meniscal subluxation from which cartilage degeneration showed abrupt progression, and (4) the degree of cartilage degeneration of ipsilateral femoral condyle corresponding to the amount of medial meniscal subluxation may be predictable.

Conflict of interest All of the authors have nothing to declare. No financial support was received. No financial interest of any author which could create a potential conflict of interest was made.

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