

Oblique coronal and oblique sagittal MRI for diagnosis of anterior cruciate ligament tears and evaluation of anterior cruciate ligament remnant tissue

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Oblique coronal and oblique sagittal MRI for diagnosis of anterior cruciate ligament tears and evaluation of anterior cruciate ligament remnant tissue

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(d) key words:

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1 **Structured Abstract and Levels of Evidence**

2 **Background:** The purpose of this study was to investigate the efficacy of additional oblique
3 magnetic resonance imaging (MRI) for the diagnosis of anterior cruciate ligament (ACL) tear
4 and evaluation of ACL remnant tissue.

5 **Methods:** We retrospectively reviewed the records of 54 knees. Three independent readers
6 evaluated the MR images by the use of three methods: orthogonal sagittal images only
7 (method A); orthogonal sagittal and additional oblique sagittal images (method B); and
8 orthogonal sagittal and oblique coronal images (method C). The sensitivity, specificity, and
9 accuracy for the diagnosis of an ACL tear and the detection of the condition of the ACL
10 remnant tissue by the use of each method were calculated in comparison with arthroscopic
11 findings as the reference standard.

12 **Results:** The arthroscopic records revealed 27 knees with intact ACLs and 27 with torn
13 ACLs. Among the 27 knees with torn ACLs, 9 did not have continuous remnant tissue and 18
14 had certain remnant tissue attached to the femur or the posterior cruciate ligament. The
15 specificities and accuracies of methods B and C for diagnosing an ACL tear were higher than
16 those for method A. The sensitivity, specificity, and accuracy of method C for the detection of
17 ACL remnant tissue were higher than those for method A and B.

18 **Conclusions:** Additional use of oblique MRI improved the accuracy of diagnosis of ACL tear
19 and showed a reasonable level of efficacy in detecting ACL remnant tissue.

20 **Level of Evidence:** Level IV (case series)

21 **Text**

22 **Introduction**

23 Arthroscopic examination for anterior cruciate ligament (ACL) reconstruction sometimes
24 reveals that there are several types of ACL remnant tissues bridging the femur and the tibia or
25 the posterior cruciate ligament (PCL) and the tibia in the intercondylar notch^[1,2]. Recently,
26 ACL remnant tissue has attracted considerable attention in the treatment of ACL tears. When
27 performing ACL reconstruction, preserving the remnant tissue is considered to be beneficial
28 to the recovery of an ACL-deficient patient. Several factors may increase the preservation of
29 ACL remnant tissue including increased revascularization, faster remodeling of the ACL
30 construct, increased mechanical stability, and presence of neural mechanoreceptors and some
31 proprioceptive innervation in the remnant tissues^[1-5].

32 In many cases, the configuration of the ACL remnant tissue and its attachments is assessed
33 during an arthroscopic examination just before ACL reconstruction. At the preoperative
34 preparation, it is difficult to evaluate the state of ACL remnant tissue by conventional
35 magnetic resonance imaging (MRI). Because of its oblique course, visualization of the
36 complete ACL on a single image would not be expected. To achieve full-length visualization
37 of the ligament on one or more sections, the use of oblique MRI, parallel to the long axis of
38 the ACL has been advocated. These oblique images may be valuable for assessment of ACL
39 remnant tissue.

40 The purpose of this study was to investigate the efficacy of additional oblique coronal and
41 oblique sagittal MRI for the diagnosis of ACL tears and evaluation of ACL remnant tissue.

42 **Materials and methods**

43 We retrospectively reviewed the records of 54 patients (26 male and 28 female, age range:
44 12–66 years, mean age: 26.9 years) who had no history of previous knee surgery and
45 underwent both MRI of the knee and arthroscopic examination between August 2010 and
46 September 2011.

47 The MRI protocol included routine orthogonal sequences and two sets of oblique images. All
48 patients were examined using a 1.5 T MRI system (Signa; GE Healthcare, Milwaukee, WI,
49 USA). The parameters for the fast spin-echo T2-weighted orthogonal sagittal images were as
50 follows: TR/TE = 3500/85, 4-mm slice thickness, 1-mm interval. The parameters for the
51 oblique sagittal and oblique coronal T2-weighted images were as follows: TR/TE = 3500/85,
52 2-mm slice thickness, 0.5-mm interval. The oblique coronal images were obtained in the
53 plane parallel to the course of the femoral intercondylar roof on a sagittal image for section
54 positioning. The oblique sagittal images for visualization of an ACL were obtained in the
55 plane parallel to the medial border of the lateral femoral condyle on an orthogonal coronal
56 image. A single, experienced, orthopedic surgeon performed all of the arthroscopies for
57 patients suspected of having a torn ACL or other internal derangement of the knee. During the
58 diagnostic arthroscopy, damage to the ACL was evaluated by palpation with a probe.

59 MR images were reviewed retrospectively by 3 orthopedic surgeons who had at least 10
60 years' experience but were unaware of the clinical history, physical findings or arthroscopic
61 findings. Each reviewer independently evaluated the MRI images using three methods:
62 orthogonal sagittal images only (method A); orthogonal sagittal and additional oblique sagittal
63 images (method B); and orthogonal sagittal and oblique coronal images (method C). An
64 image that most clearly demonstrated the ACL or ACL remnant tissue was selected from each
65 of the 3 imaging series by an experienced, orthopedic surgeon. To avoid any recall bias, MRI
66 images were evaluated using the 3 methods separately and in a different order. The status of

67 the ACL was graded from direct signs on MR images as intact ACL, tear with continuous
68 ACL remnant tissue, or complete tear (i.e., tear without continuous remnant tissue).

69 The sensitivity, specificity, and accuracy of the diagnosis of an ACL tear and detection of the
70 condition of the ACL remnant tissue by the use of each method were calculated in comparison
71 with arthroscopic findings as the reference standard. The interobserver agreement was
72 assessed by kappa (κ) statistics, and agreements in percentages were calculated for all
73 patients. The data were analyzed using the Statistical Package for the Social Sciences (SPSS)
74 for Windows version 19.0 (SPSS Inc., Chicago, IL, USA).

75 All patients were informed that data from their cases would be submitted for publication,
76 and provided informed consent. This study was approved by the ethics committee of our
77 university.

78 **Results**

79 The arthroscopic records revealed 27 patients with intact ACLs and 27 with torn ACLs.
80 Among the 27 patients with torn ACLs, 9 did not have continuous remnant tissue (complete
81 tear) and 18 had certain remnant tissue attached to the femur or the posterior cruciate
82 ligament. Sensitivity, specificity, and accuracy values aiding the diagnosis of an ACL tear are
83 summarized in Table 1, and those aiding the detection of ACL remnant tissue are summarized
84 in Table 2. The specificities and accuracies of methods B and C for diagnosing an ACL tear
85 were higher than those for method A. The sensitivities, specificities, and accuracies for
86 methods B and C for the detection of ACL remnant tissue were higher than those for method
87 A. The sensitivity, specificity, and accuracy of method C for the detection of ACL remnant
88 tissue were higher than those for method B.

89 The interobserver variability for the diagnosis of an ACL tear is shown in Table 3, and
90 interobserver variability for the detection of ACL remnant tissue is shown in Table 4. The
91 present study showed that the highest match among readers is for method C using orthogonal
92 sagittal and oblique coronal images.

93

94 **Discussion**

95 The diagnostic accuracy of MRI for detecting an ACL tear is over 90% in patients with
96 positive abnormal direct signs such as discontinuity, disappearance, and changes in signal
97 intensity on shadows of ligament (primary signs) on MR images^[6,7]. Indirect signs (secondary
98 signs) such as bone bruising, buckling of the PCL, and anterior tibial translocation further
99 improve the accuracy^[8-10]. Standard orthogonal MRI cannot visualize the complete ACL on a
100 single image because the ACL originates from the posteromedial aspect of the lateral femoral
101 condyle and courses through the lateral intercondylar notch. Because of artifacts from the
102 popliteal artery and partial volume effects, a complete diagnosis of ACL injuries would not be
103 expected (Fig. 1). Thus, poor visualization is reported in 5%–10% of normal ACL using
104 acquired standard sagittal MRI^[11].

105 To improve the diagnostic efficacy for ACL remnant tissue, it is necessary to achieve
106 full-length visualization of the ACL by slicing along the plane parallel to the long axis of the
107 ACL (Fig. 2). The ACL arises from a semicircular attachment approximately one centimeter
108 in radius on the posteromedial corner of the medial aspect of the lateral femoral condyle,
109 which extends backward along the anteromedial aspect of the intercondylar notch to the
110 attachment on the intercondylar eminence of the tibia. The tibial attachment is approximately
111 three centimeters in anteroposterior diameter^[12,13]. Therefore, if the ACL remains, we are able
112 to obtain an oblique view of it by slicing along the ACL. In case the ACL image is unclear, a
113 bony landmark would be helpful for slicing. Diagnostic efficacy of the oblique MRI obtained
114 in this manner has been reported in previous studies^[14,15] and is consistent with our findings
115 for the diagnosis of ACL injury.

116 In acute cases of injury, bleeding or edema of the fibers of an untorn ACL often cause a
117 signal change in MRI, which makes the evaluation of ACL tears more difficult. Furthermore,
118 patients with a fibrous scar around their ACL and those with osteoarthritis are also particularly

119 prone to misdiagnosis using standard orthogonal MRI^[14]. Even in these cases, accurate
120 diagnosis can be achieved by full-length visualization of the ligament on one section.

121 Our findings showed a higher diagnostic performance and higher match rate among readers
122 for method C compared with method B. The reasons for this are that oblique coronal images
123 provide sections substantially perpendicular to the femoral attachment of the ACL, the medial
124 aspect of lateral femoral condyle. These sections more clearly show the course of the ACL
125 and its femoral attachment. In patients with an ACL tear from its femoral attachment with a
126 continuous remnant, we observed hypotonicity of ACL fibers and their attachment to the
127 lateral femoral condyle in a lower position than normal (Fig. 3). According to Staeubli et al.,
128 oblique coronal images oriented parallel to the intercondylar roof are an excellent method for
129 MRI and is the imaging modality of choice to visualize clearly the diagonal anatomical course
130 of the ACL and its relationship to the intercondylar notch and PCL^[16]. Hong et al. also
131 reported that oblique coronal images improved diagnostic accuracy of ACL injury and were
132 effective for its grading^[15]. The oblique coronal images clearly visualize the continuity,
133 tension, and changes in width and signal intensity. Thus, oblique coronal imaging is
134 considered to be the most useful MRI method for evaluating the condition of remnant tissue
135 because it enables us to evaluate directly its relationship to the medial aspect of lateral
136 femoral condyle.

137 The present study has some limitations that may affect the interpretation of our findings. The
138 interval between injury or onset of symptoms and the MRI examination and between the MRI
139 examination and arthroscopic evaluation were inconsistent. Therefore, the chronicity of an
140 ACL tear, which may affect MRI findings, was disregarded. Another limitation is the
141 difference in slice thickness being used in the orthogonal sagittal images (4 mm slice
142 thickness) and in the oblique sagittal and oblique coronal images (2 mm slice thickness). In
143 this study, we evaluated the performance of oblique MRI images only for detecting the

144 presence of remnant tissue. Further research is necessary for the detailed evaluation of
145 remnant tissue visualization patterns. More detailed information regarding ACL remnant
146 tissue obtained from oblique MRI images may be helpful in making appropriate decisions for
147 treatment of ACL injuries.

148

149 **Conclusions**

150 In conclusion, the additional use of oblique coronal and oblique sagittal MRI of the knee
151 improved the accuracy of diagnosis of an ACL tear and showed a reasonable level of efficacy
152 in detecting ACL remnant tissue. Oblique coronal images parallel to the femoral intercondylar
153 roof, which clearly depict the ACL, especially in the femoral origin area, may provide further
154 improvement in the diagnostic efficacy for ACL remnant tissue.

155

156 **Conflict of interest**

157 No conflicts of interests are declared.

158

159 **Acknowledgments**

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161

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202 resonance imaging in cruciate ligament-intact knees. *Arthroscopy.* 1999; 15: 349-359

203

204 **Tables with captions**

205 **Table 1**

206 Results for the diagnosis of an ACL tear

	Sensitivity (%)	Specificity (%)	Accuracy (%)
Method A	83.9	76.5	80.2
Method B	83.9	88.9	86.4
Method C	87.7	93.8	90.7

207 Method A indicates orthogonal sagittal images only; Method B, orthogonal sagittal and
208 additional oblique sagittal images; and Method C, orthogonal sagittal and oblique coronal
209 images.

210

211 **Table 2**

212 Results for the detection of an ACL remnant

	Sensitivity (%)	Specificity (%)	Accuracy (%)
Method A	46.3	69.4	61.7
Method B	61.1	83.3	75.9
Method C	68.5	87.0	80.9

213 Method A indicates orthogonal sagittal images only; Method B, orthogonal sagittal and
214 additional oblique sagittal images; and Method C, orthogonal sagittal and oblique coronal
215 images.

216

217 **Table 3**

218 Interobserver agreement for the diagnosis of an ACL tear

		% Agreement	κ	Interpretation
Method A	Reviewer 1 vs. Reviewer 2	74	0.481	Moderate
	Reviewer 1 vs. Reviewer 3	76	0.519	Moderate
	Reviewer 2 vs. Reviewer 3	80	0.586	Moderate
Method B	Reviewer 1 vs. Reviewer 2	78	0.550	Moderate
	Reviewer 1 vs. Reviewer 3	76	0.519	Moderate
	Reviewer 2 vs. Reviewer 3	87	0.741	Good
Method C	Reviewer 1 vs. Reviewer 2	91	0.812	Almost perfect
	Reviewer 1 vs. Reviewer 3	83	0.669	Good
	Reviewer 2 vs. Reviewer 3	85	0.707	Good

219

220

221 **Table 4**

222 Interobserver agreement for the detection of an ACL remnant

		% Agreement	κ	Interpretation
Method A	Reviewer 1 vs. Reviewer 2	59	0.343	Poor
	Reviewer 1 vs. Reviewer 3	57	0.337	Poor
	Reviewer 2 vs. Reviewer 3	63	0.436	Moderate
Method B	Reviewer 1 vs. Reviewer 2	69	0.451	Moderate
	Reviewer 1 vs. Reviewer 3	69	0.486	Moderate
	Reviewer 2 vs. Reviewer 3	70	0.517	Moderate
Method C	Reviewer 1 vs. Reviewer 2	83	0.705	Good
	Reviewer 1 vs. Reviewer 3	69	0.494	Moderate
	Reviewer 2 vs. Reviewer 3	70	0.520	Moderate

223

224

225 **Captions to illustrations**

226 **Fig. 1.**

227 On standard orthogonal sagittal MRI, it is usually difficult to visualize the complete ACL on a
228 single image. The ACL cannot be visualized throughout its entire length.

229

230 **Fig. 2.**

231 Oblique MRI parallel to the long axis of the ACL may be useful for achieving full-length
232 visualization of the ligament on one section and valuable for its assessment. The relationship
233 between the ACL and the lateral femoral condyle at the femoral insertion site can be viewed
234 directly on oblique coronal images.

235 (A) Oblique sagittal MR image. (B) Oblique coronal MR image.

236

237 **Fig. 3.**

238 An oblique coronal MR image from patient with an ACL tear from its femoral attachment
239 with a continuous remnant. Hypotonicity of ACL fibers and their attachment to the lateral
240 femoral condyle in the lower position than normal can be observed (arrow heads).

241

242 **Illustrations**

243 **Fig. 1.**



244

245

246 **Fig. 2.**

247 A

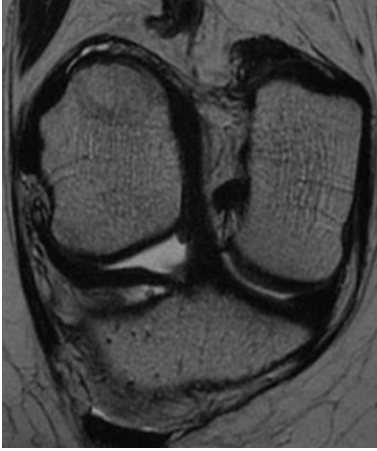


248

249

250 **Fig. 2.**

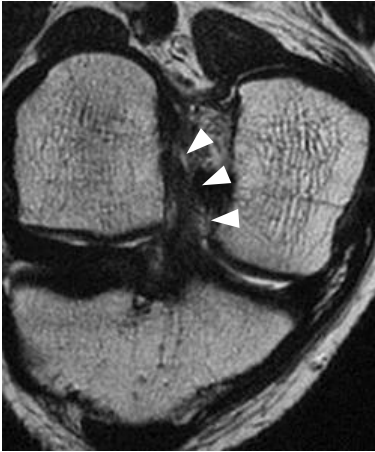
251 B



252

253

254 **Fig. 3.**



255