

# Clinical, Radiographic, and Arthroscopic Outcomes of Surgical Repair for Radial and Avulsed Lesions on the Lateral Meniscus Posterior Root During ACL Reconstruction

## A Systematic Review

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**Background:** Clinical outcomes of surgical repairs for tears of the lateral meniscus posterior root (LMPR) in patients undergoing anterior cruciate ligament (ACL) reconstruction (ACLR) have not been comprehensively investigated.

**Purpose:** To systematically review the clinical, radiographic, and arthroscopic results of surgical repairs for tears of the LMPR in patients undergoing ACLR.

**Study Design:** Systematic review; Level of evidence, 4.

**Methods:** A systematic electronic search of the PubMed and Embase databases was performed to identify studies reporting clinical, radiographic, or arthroscopic results of surgical repairs for tears of the LMPR in patients undergoing ACLR. Each included study was abstracted regarding study characteristics, patient characteristics, surgical technique, and outcome measures. The methodological quality of the included studies was analyzed according to the Methodological Index for Non-Randomized Studies (MINORS) criteria.

**Results:** Nine studies were included in this systematic review, representing a total of 215 knees in 215 patients. Overall, 123 side-to-side repairs and 89 pullout repairs were performed for tears of the LMPR during ACLR. After a mean follow-up of 33.9 months, significant improvements ( $P < .05$ ) were found in the mean Lysholm score (from 58.3 to 91.4) as well as the mean International Knee Documentation Committee subjective score (from 61.1 to 87.2). Weightbearing anteroposterior radiographs of 41 patients showed no significant narrowing of lateral joint space width. On magnetic resonance imaging scans, 31 patients demonstrated no significant progression of chondral lesions, and no significant decreases in meniscal extrusion on coronal planes were reported in another 76 patients. The complete/partial healing was 93.6% on second-look arthroscopy after side-to-side repairs for radial tears of the LMPR. The MINORS value showed a high risk of bias for all 9 studies.

**Conclusion:** Patients with tears of the LMPR associated with ACL injuries achieved favorable functional scores after ACLR and LMPR repairs, and the side-to-side repair for radial tears of the LMPR succeeded in a high meniscal healing rate of  $>90\%$ . However, the authors of this review were unable to definitively conclude whether LMPR repairs fully restore the hoop stress of the lateral meniscus.

**Keywords:** anterior cruciate ligament reconstruction; lateral meniscus; meniscal root; meniscal repair; outcomes

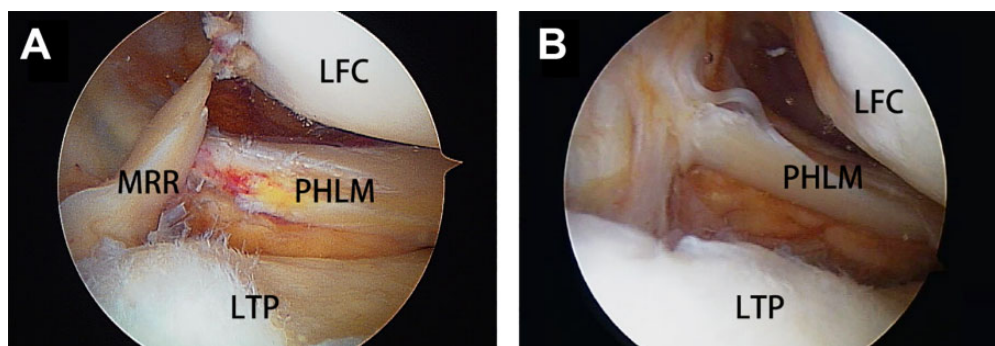
Meniscal lesions are commonly associated with anterior cruciate ligament (ACL) injuries and frequently involve the posterior horn of the lateral meniscus.<sup>5,19,26</sup> During ACL reconstruction (ACLR), tears of the lateral meniscus posterior root (LMPR) are found in up to 14% of the patients.<sup>7</sup> As

the integrity of the LMPR is critical for the meniscal function to convert the axial load to a radially directed hoop stress and control the rotational stability of ACL-deficient knees,<sup>4,9,23,28,31</sup> such particular meniscal lesions should be carefully treated during ACLR.

Some previous studies have recommended leaving tears of the LMPR in situ with a view to their spontaneous healing,<sup>14,22</sup> but corresponding results were unsatisfactory in preventing the progression of lateral joint space

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**Figure 1.** Arthroscopic views of tears of the lateral meniscus posterior root (LMPR) in 2 separate left knees. (A) A tear of the LMPR of the radial tear pattern. (B) A tear of the LMPR of the root avulsion pattern, with a meniscal root remnant completely lost. LFC, lateral femoral condyle; LTP, lateral tibial plateau; MRR, meniscal root remnant; PHLM, posterior horn of lateral meniscus.

narrowing.<sup>22</sup> Current biomechanical studies showed that the surgical repair of tears of the LMPR would better restore the normal tibiofemoral contact mechanics and knee kinematics.<sup>6,8,9,12,21,28</sup> Therefore, in recent years, interest in the surgical treatment of tears of the LMPR during ACLR has increased.

Clinically, tears of the LMPR occur with variable patterns from radial tears near the root to root avulsions (Figure 1).<sup>7,11</sup> Different surgical techniques, including the pullout repair for LMPR avulsions and the side-to-side repair for radial tears of the LMPR, have been applied in previous studies.<sup>5</sup> However, a comprehensive assessment of the available evidence on the surgical outcomes of LMPR repairs in patients undergoing ACLR is lacking.

Given this lack of data, the purpose of this study was to systematically summarize the clinical, radiographic, and arthroscopic results of surgical repairs for tears of the LMPR in patients undergoing ACLR. We hypothesized that surgically repairing tears of the LMPR during ACLR would result in good functional scores, no progression of lateral compartment degenerations, and high meniscal healing rates.

## METHODS

### Search Strategy

This systematic review was performed following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.<sup>17</sup> An electronic search of the PubMed and Embase databases was performed on July 6, 2020, to identify studies that reported

**TABLE 1**  
Study Inclusion and Exclusion Criteria<sup>a</sup>

Inclusion Criteria	Exclusion Criteria
(1) Studies with clinical, radiographic, or arthroscopic outcomes of LMPR repairs	(1) Studies unrelated to tears of the LMPR
(2) Level of evidence, 1-4	(2) Tears of the LMPR only left in situ
(3) English-language articles	(3) Tears of the LMPR without ACL injuries
(4) Studies without limits placed on the date of publication	(4) ACL injuries treated conservatively
(5) Studies published online or in print in a peer-reviewed journal	(5) Anatomic, histologic, epidemiologic, diagnostic, or biomechanical studies
	(6) Reviews, case reports, or technical notes

<sup>a</sup>ACL, anterior cruciate ligament; LMPR, lateral meniscus posterior root.

the clinical, radiographic, or arthroscopic outcomes after surgical treatments for tears of the LMPR in patients undergoing ACLR. The following terms were used for the electronic search: (*lateral meniscus posterior* OR *posterolateral meniscus*) AND (*root* OR *insertion* OR *attachment* OR *detachment*). Inclusion and exclusion criteria are detailed in Table 1.

Two authors (G.S. and Y.L.) independently screened all articles for relevance, and all articles identified by the search terms were generally reviewed and then discussed according to the inclusion or exclusion criteria. Full-text articles were then critically reviewed, and reference lists of all included studies were reviewed for potential studies

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not identified by the electronic search. If there was any disagreement among the authors about a study's inclusion, a final decision was made by the senior author (H.Z.).

### Data Extraction

Each full-text article ultimately included was abstracted regarding study characteristics, patient data, surgical techniques, and outcome measures. Original data were extracted by 1 author and verified by another (Z.Z. and Q.N., respectively). Any disagreement on the data extraction was resolved by consensus between the 2 authors.

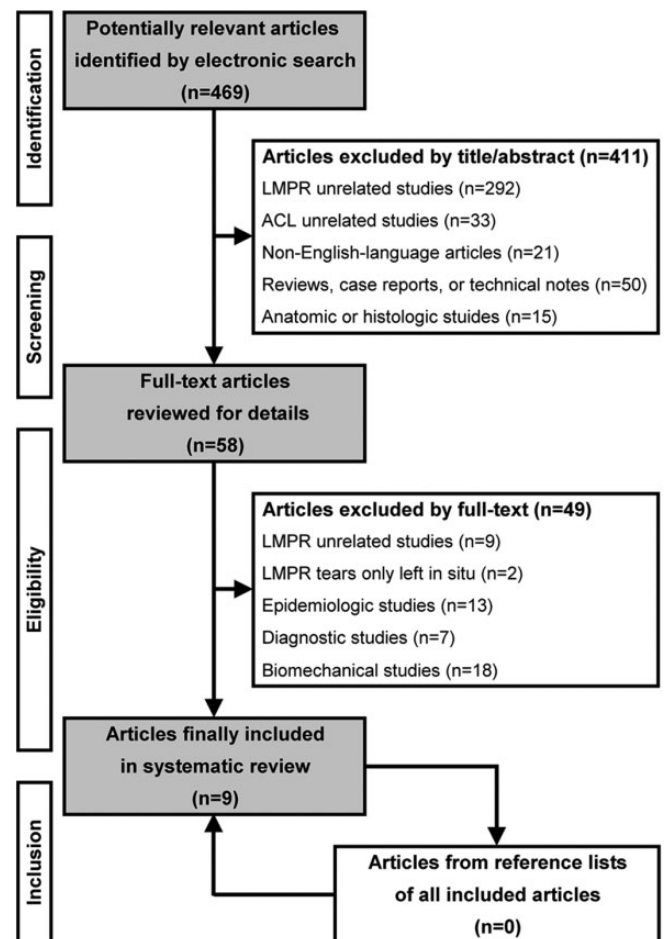
Study characteristics included author name, publication date, study design, level of evidence, number of patients/knees, and length of follow-up. Patient data consisted of sex, age, time from injury to surgery, and tear pattern of the LMPR. Surgical techniques for LMPR repairs and ACLRs were summarized according to the specific descriptions in the included studies.

Outcome measures consisted of pre- and postoperative clinical, radiographic, and arthroscopic evaluations. Clinical assessments included all subjective function scores (eg, Lysholm score, International Knee Documentation Committee [IKDC] subjective score, and Tegner score) as well as objective knee stability (eg, Lachman test, KT-1000/2000 arthrometer test, and pivot-shift test). Radiographic measurements included joint space narrowing based on weightbearing anteroposterior (AP) radiographs and cartilaginous degeneration based on magnetic resonance imaging (MRI). The lateral meniscal extrusion was also evaluated on MRI and could be measured on the coronal or sagittal plane. ACL graft and meniscal signals on follow-up MRI were extracted if recorded in original articles. The arthroscopic results were the meniscal healing status, ACL graft status, and chondral status on second-look arthroscopy.

Given the heterogeneity in patient selection, clinical interventions, and outcome measures, a quantitative comparison across studies (meta-analysis) was inappropriate. Descriptive statistics were used to report the aforementioned data.

### Quality Assessment

The methodological quality of all included studies was analyzed according to the Methodological Index for Non-Randomized Studies (MINORS).<sup>24</sup> The items in the MINORS criteria for nonrandomized studies were scored as 2 when reported and adequate, 1 when reported but inadequate, and 0 if not reported. For noncomparative studies, the ideal MINORS score was 16, and a study was considered to have a low risk of bias when it scored 13 to 15 and a high risk of bias when it scored  $\leq 12$ . In comparative studies, the corresponding thresholds were 24, 21 to 23, and  $\leq 20$ , respectively.<sup>24</sup> Two authors (Y.C. and Z.F.) independently calculated the MINORS score of each study and discussed articles in which differences existed until consensus was reached.



**Figure 2.** Flowchart of search strategy following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. ACL, anterior cruciate ligament; LMPR, lateral meniscus posterior root.

## RESULTS

### Literature Search and Quality Assessment

Of the 469 articles initially identified by electronic searches, 9 studies were ultimately included (Figure 2). Of the 9 studies included, 5 were retrospective cohort studies (level 3),<sup>10,13,18,20,30</sup> and the remaining 4 were case series (level 4).<sup>2,3,27,32</sup> The general features of each included study are summarized in Table 2.

The mean MINORS value was  $17.6 \pm 1.0$  (range, 16-19) for comparative studies and  $9.8 \pm 1.1$  (range, 8-11) for non-comparative studies. All 9 studies had a high risk of bias. The corresponding values for each study are shown in Table 2.

### Patient Characteristics

This systematic review included 215 knees in 215 patients who underwent LMPR repair and ACLR (Table 3). There were 139 (64.7%) men and 76 (35.3%) women with a mean

TABLE 2  
Study Features<sup>a</sup>

Lead Author	Year	Study Design	LOE	MINORS	Functional Score	Radiographic Evaluation	Second-Look Arthroscopy
Ahn <sup>2</sup>	2010	Case series	4	8/16	Lysholm, IKDC	Yes	Yes
Anderson <sup>3</sup>	2010	Case series	4	10/16	Lysholm, IKDC, Tegner	Yes	Yes
Song <sup>27</sup>	2014	Case series	4	11/16	Lysholm, Tegner	No	Yes
Zhuo <sup>32</sup>	2020	Case series	4	10/16	Lysholm, IKDC, Tegner	Yes	Yes
Tsuji <sup>30</sup>	2019	Cohort study <sup>b</sup>	3	19/24	None	Yes	Yes
LaPrade <sup>13</sup>	2017	Cohort study <sup>c</sup>	3	16/24	Lysholm, Tegner, WOMAC, SF-12	No	No
Krych <sup>10</sup>	2020	Cohort study <sup>c</sup>	3	18/24	Lysholm, IKDC, Tegner	No	No
Okazaki <sup>18</sup>	2020	Cohort study <sup>d</sup>	3	17/24	IKDC	Yes	No
Pan <sup>20</sup>	2015	Cohort study <sup>e</sup>	3	18/24	Lysholm, IKDC	Yes	No

<sup>a</sup>IKDC, International Knee Documentation Committee; LOE, level of evidence; MINORS, Methodological Index for Non-Randomized Studies; SF-12, 12-Item Short Form Health Survey; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

<sup>b</sup>This study compared the results of patients undergoing surgical repairs for lateral meniscus posterior root tears and patients without meniscal tears.

<sup>c</sup>This study compared the results of surgical repairs treating posterior root tears of the lateral and medial meniscus.

<sup>d</sup>This study compared the results of tears of the lateral meniscus posterior root treated by different repair techniques.

<sup>e</sup>This study compared the results of tears of the lateral meniscus posterior root treated by surgical repairs and left in situ.

TABLE 3  
Patient Characteristics<sup>a</sup>

Lead Author	Surgical Technique	No. of Patients	Sex (F/M)	Age (y)	Time From Injury to Surgery (mo)	Clinical Follow-up (mo)	Tear Pattern of the LMPR (unknown/P1/P2/P3) <sup>b</sup>
Ahn <sup>2</sup>	SSS	25	3/22	28.8 (15-58)	40.8 (0.2-216)	18.0 (12-48)	0/7/8/10
Anderson <sup>3</sup>	SSS	8	3/5	29.0 (16-58)	22.4 (0.1-216)	70.5 (29-168)	0/8/0/0
	POS	16	4/12	32.8 (17-59)	22.4 (0.1-216)	53.6 (26-116)	0/0/0/16
Song <sup>27</sup>	SSS	15	3/12	34.5 (18-56)	3.3 (1.5-12)	24.0 (12-46)	0/5/10/0
Zhuo <sup>32</sup>	SSS	26	7/19	25.4 (17-39)	3.4 ± 4.2	26.7 (24-36)	0/26/0/0
Tsuji <sup>30</sup>	SSS	41	23/18	29.5 (14-57)	4.2 (0.9-37.5)	40.8 (24-75.6)	0/41/0/0
LaPrade <sup>13</sup>	POS	10	4/6	32.2 (19.7-52.7)	NA	30.0 (24-51.6)	0/8/1/0
Krych <sup>10</sup>	POS	26	9/17	24.6	NA	41.0 (24-NA)	26/0/0/0
Okazaki <sup>18</sup>	SSS	8	4/4	27.0 ± 5.8	3.3 ± 3.8	10.0 ± 3.7	0/2/1/5
	POS	9	6/3	30.1 ± 11.8	3.9 ± 6.0	9.9 ± 3.2	0/3/1/5
Pan <sup>20</sup>	POS	31	10/21	28.0 ± 10.0	NA	37.2 (24-NA)	0/31/0/0
Overall	SSS/POS	215	76/139	28.7	13.0	33.9	26/131/21/37
	SSS	123	43/80	28.9	12.5	31.1	0/89/19/15
	POS	92	33/59	28.5	15.7	37.7	26/42/2/22

<sup>a</sup>F, female; LMPR, lateral meniscus posterior root; M, male; NA, not available; POS, pullout suture; SSS, side-to-side suture.

<sup>b</sup>P1 (pattern 1), radial tears; P2 (pattern 2), longitudinal or T-shaped tears; P3 (pattern 3), avulsed tears (aka root avulsion).

age of 28.7 years (range, 24.6-34.5 years) across all studies. Six studies reported the time from injury to initial surgery with a mean value of 13.0 months (range, 3.3-40.8 months).<sup>2,3,18,27,30,32</sup> The mean clinical follow-up period was 33.9 months (range, 9.9-70.5 months).

The morphology of tears of the LMPR was documented in 189 patients from 8 studies.<sup>2,3,13,18,20,27,30,32</sup> According to the classification systems introduced by LaPrade et al<sup>11</sup> and Ahn et al<sup>2</sup> for meniscal root tears, tear patterns of the LMPR in this systematic review were summarized as follows (Table 3): pattern 1, radial tears (131/189; 69.3%); pattern 2, longitudinal or T-shaped tears (21/189; 11.1%); and pattern 3, avulsed tears (aka root avulsion)

(37/189; 19.6%). No partial tears were included in original studies.

The integrity of the meniscofemoral ligament was assessed in 25 and 17 patients from 2 studies,<sup>2,18</sup> with incidence rates of meniscofemoral ligament tears of 8% and 41%, respectively.

### Surgical Technique

A total of 128 autologous hamstring ACLRs and 25 bone-patellar tendon-bone ACLRs were performed among the included studies; the specific techniques of the remaining 62 ACLRs were not described. There were mainly 2 surgical

techniques applied in LMPR repairs (Table 4). The side-to-side suture repair (n = 123) was performed in radial tears with a root remnant of adequate tissue quality.<sup>2,3,18,27,30,32</sup> The pullout suture repair (n = 92) was conducted in root avulsions and radial tears of an inadequate meniscal remnant, which included 56 repairs using the same tibial tunnel of ACLR and 36 repairs drilling an additional tunnel at the anatomic attachment of the LMPR.<sup>3,10,13,18,20</sup>

TABLE 4  
Surgical Technique<sup>a</sup>

Study	No. of Patients	ACL Reconstruction		LMPR Repair	
		Graft Choice	Bundle Option	Suture Technique	Pullout Tunnel
Ahn <sup>2</sup>	25	HST	SB	SSS	Not needed
Song <sup>27</sup>	15	HST	SB	SSS	Not needed
Anderson <sup>3</sup>	8	HST	SB	SSS	Not needed
	16	HST	SB	POS	ACL tunnel
Tsujii <sup>30</sup>	16	HST	TB	SSS	Not needed
	25	BPTB	Rectangular	SSS	Not needed
Zhuo <sup>32</sup>	26	NA	NA	SSS	Not needed
Okazaki <sup>18</sup>	8	HST	DB	SSS	Not needed
	9	HST	DB	POS	ACL tunnel
Pan <sup>20</sup>	31	HST	DB	POS	ACL tunnel
LaPrade <sup>13</sup>	10	NA	NA	POS	Additional tunnel
Krych <sup>10</sup>	26	NA	NA	POS	Additional tunnel

<sup>a</sup>ACL, anterior cruciate ligament; BPTB, bone–patellar tendon–bone; DB, double bundle; HST, hamstring tendon; LMPR, lateral meniscus posterior root; NA, not available; POS, pullout suture; SB, single bundle; SSS, side-to-side suture; TB, triple bundle.

Clinical Outcomes

Overall, 5 different functional scores were utilized (Table 2): the Lysholm score (7 studies<sup>2,3,10,13,20,27,32</sup>), IKDC subjective score (6 studies<sup>2,3,10,18,20,32</sup>), Tegner score (5 studies<sup>3,10,13,27,32</sup>), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score (1 study<sup>13</sup>), and 12-Item Short Form Health Survey (SF-12) score (1 study<sup>13</sup>).

All but 1 of these studies showed significant improvements (*P* < .05) in each functional score at the final follow-up compared with the preoperative status (Table 5), including the mean Lysholm score (from 58.3 to 91.4), the mean IKDC subjective score (from 61.1 to 87.2), and the Tegner score (from 2.5 to 6.0). The other 2 scores were used in only a single study.<sup>13</sup> They were the WOMAC score (from 52 to 10) and the SF-12 score (from 33.6 to 49.8).

A total of 82 patients from 3 studies were evaluated for knee stability, and all of them showed a negative Lachman or pivot-shift test at the final follow-up.<sup>3,18,30</sup> A cohort study reported no significant side-to-side differences in the KT-1000 between knees with LMPR repairs and those with an intact meniscus at 3 years after ACLR.<sup>30</sup>

Radiographic Outcomes

Radiographic evaluations were performed in 6 studies, including 1 weightbearing AP radiograph analysis on joint space width,<sup>30</sup> 1 MRI investigation on chondral status,<sup>20</sup> 3 MRI studies on meniscal extrusion,<sup>2,18,30</sup> and 2 MRI reports on meniscal healing<sup>3,32</sup> (Table 6). No study reported the ACL graft integrity based on follow-up MRI.

In 1 study, weightbearing AP radiographs showed no significant narrowing (0.04 mm) of lateral joint space width in patients undergoing side-to-side repairs for tears of the LMPR.<sup>30</sup> In another study, the chondral status on MRI scans after LMPR pullout repairs was rated as normal in 81% of patients, mild in 16% of patients, and moderate in

TABLE 5  
Functional Scores<sup>a</sup>

Study	Surgical Technique (n)	Mean Lysholm Score		Mean IKDC Subjective Score		Mean Tegner Score	
		Pre-	Post-	Pre-	Post-	Pre-	Post-
Ahn <sup>2</sup>	SSS (25)	62.3 ± 17.3	92.9 ± 3.4 <sup>b</sup>	67.0 ± 15.6	90.2 ± 7.3 <sup>b</sup>	NA	NA
Anderson <sup>3</sup>	SSS (8)	NA	86.9 ± 5.7 <sup>b</sup>	NA	81.6 ± 6.8 <sup>b</sup>	NA	6.0 ± 1.3 <sup>b</sup>
	POS (16)	NA	86.1 ± 6.5 <sup>b</sup>	NA	84.3 ± 8.3 <sup>b</sup>	NA	6.7 ± 1.2 <sup>b</sup>
Song <sup>27</sup>	SSS (15)	68.9 ± 4.3	95.6 ± 3.5 <sup>b</sup>	NA	NA	3.1 ± 0.8	6.7 ± 1.4 <sup>b</sup>
Zhuo <sup>32</sup>	SSS (26)	56.3 ± 4.6	95.1 ± 2.9 <sup>b</sup>	53.4 ± 5.3	92.1 ± 2.6 <sup>b</sup>	2.4 ± 0.6	5.6 ± 0.6 <sup>b</sup>
LaPrade <sup>13</sup>	POS (10)	35.0	75.0 <sup>b</sup>	NA	NA	2.0	4.0 <sup>b</sup>
Krych <sup>10</sup>	POS (26)	NA	93.9 <sup>b</sup>	NA	89.5 <sup>b</sup>	NA	6.5 <sup>b</sup>
Okazaki <sup>18</sup>	SSS (8)	NA	NA	63.3 ± 18.3	73.0 ± 17.7	NA	NA
	POS (9)	NA	NA	61.7 ± 18.4	70.7 ± 16.8	NA	NA
Pan <sup>20</sup>	POS (31)	59.0 ± 19.1	92.3 ± 6.3 <sup>b</sup>	62.1 ± 19.2	90.1 ± 8.6 <sup>b</sup>	NA	NA
Overall	174 SSS/POS	58.3	91.4	61.1	87.2	2.5	6.0
	82 SSS	61.4	93.6	60.5	87.9	2.7	6.0
	92 POS	53.1	89.5	62.0	86.6	2.0	6.1

<sup>a</sup>IKDC, International Knee Documentation Committee; NA, not available; POS, pullout suture; post-, postoperative; pre-, preoperative; SSS, side-to-side suture.

<sup>b</sup>Significant difference (*P* < .05) compared with preoperative status.

TABLE 6  
Radiographic Evaluations<sup>a</sup>

Study	Surgical Technique (n) <sup>b</sup>	Method	Measure	Radiographic Follow-up (mo)	Results	Significance
Okazaki <sup>18</sup>	SSS (8)	MRI	Meniscal extrusion	10.0	Coronal: increased by 1.0 ± 0.9 mm	Yes <sup>c</sup>
Ahn <sup>2</sup>	POS (9)	MRI	Meniscal extrusion	9.9	Coronal: decreased by 0.5 ± 0.7 mm	No; yes <sup>d</sup>
	SSS (18)	MRI	Meniscal extrusion	8.7	Coronal: decreased by 0.39 ± 1.13 mm; Sagittal: decreased by 1.75 ± 2.52 mm	
Tsujii <sup>30</sup>	SSS (41)	MRI	Meniscal extrusion	40.8	Coronal: decreased by 0.16 ± 0.88 mm; Sagittal: increased by 1.22 ± 1.54 mm	No
		CR	Joint space width	40.8	Decreased by 0.04 ± 0.8 mm	Yes <sup>d</sup> ; no
Pan <sup>20</sup>	POS (31)	MRI	Chondral status	37.2	Post: 81% normal, 16% mild, 3% moderate	No
Zhuo <sup>32</sup>	SSS (26)	MRI	Meniscal healing	26.7	96% complete healing, 4% failure to heal	NA
Anderson <sup>3</sup>	POS (3)	MRI	Meniscal healing	25.3	100% complete healing	NA

<sup>a</sup>CR, conventional radiograph; MRI, magnetic resonance imaging; NA, not available; POS, pullout suture; post, postoperative; SSS, side-to-side suture.

<sup>b</sup>Number of patients who underwent radiographic evaluations.

<sup>c</sup>Significant difference ( $P < .05$ ) between different repair techniques.

<sup>d</sup>Significant difference ( $P < .05$ ) between pre- and postoperative values.

TABLE 7  
Meniscal Healing on Second-Look Arthroscopy<sup>a</sup>

Study	Surgical Technique (n) <sup>b</sup>	Arthroscopic Follow-up (mo)	Healing Status on Second-Look Arthroscopy, n (%)		
			Complete Healing <sup>c</sup>	Partial Healing <sup>d</sup>	Failure to Heal <sup>e</sup>
Ahn <sup>2</sup>	SSS (9)	21.3	8 (88.9)	1 (11.1)	0 (0.0)
Anderson <sup>3</sup>	SSS (2)	49.5	2 (100.0)	0 (0.0)	0 (0.0)
	POS (3)	7.3	3 (100.0)	0 (0.0)	0 (0.0)
Song <sup>27</sup>	SSS (15)	24.0	9 (60.0)	4 (26.7)	2 (13.3)
Zhuo <sup>32</sup>	SSS (22)	13.0	19 (86.4)	3 (13.6)	0 (0.0)
Tsujii <sup>30</sup>	SSS (30)	27.6	18 (60.0)	9 (30.0)	3 (10.0)
Overall	81 SSS/POS	22.1	59 (72.8)	17 (21.0)	5 (6.2)
	78 SSS	22.6	56 (71.8)	17 (21.8)	5 (6.4)
	3 POS	7.3	3 (100.0)	0 (0.0)	0 (0.0)

<sup>a</sup>POS, pullout suture; SSS, side-to-side suture.

<sup>b</sup>Number of patients who underwent second-look arthroscopy for meniscal healing evaluations.

<sup>c</sup>Number of patients with complete healing, no visible surface defect with complete synovial coverage.

<sup>d</sup>Number of patients with partial healing, a small defect with synovial coverage over more than half of the torn area.

<sup>e</sup>Number of patients with failure to heal, a large defect with synovial coverage over less than half of the torn area.

3% patients, none of which was significantly different from their preoperative status.<sup>20</sup>

The results of lateral meniscal extrusion were reported in 3 studies.<sup>2,18,30</sup> There were no significant reductions of coronal extrusion after LMPR repairs in all 3 studies, but 1 comparative study among them showed significantly greater decreases of coronal extrusion after pullout repairs than after side-to-side repairs.<sup>18</sup> In 2 studies repairing radial tears of the LMPR by the side-to-side suture technique, the sagittal extrusion increased in 1 study but decreased in the other.<sup>2,30</sup>

The LMPR signal on follow-up MRI was reported in 2 studies.<sup>3,32</sup> Twenty-five side-to-side repairs as well as 3 pullout repairs achieved complete meniscal healing, and only 1 patient undergoing the LMPR side-to-side repair was evaluated with an abnormal hyperintense signal in the repaired site.

## Arthroscopic Outcomes

At the time of tibial hardware (for ACL graft) removal, second-look arthroscopy was performed for diagnostic purposes. The healing rate of repaired tears of the LMPR was assessed in 81 patients across 5 studies.<sup>2,3,27,30,32</sup> Meniscal healing status was classified according to consistent criteria in the 5 studies (Table 7). At a mean follow-up of 22.1 months, the healing status was rated as complete in 59 of 81, partial in 17 of 81, and failed in 5 of 81 repairs. The complete/partial healing rate was 93.8%. Specifically, 78 radial tears achieved 93.6% complete or partial healing after side-to-side repairs. All 3 root avulsions completely healed after pullout repairs.

The chondral status was evaluated arthroscopically in 1 study, and a significant progression of chondral lesions was

found in the lateral tibial plateau at 27.6 months after side-to-side repairs for radial tears of the LMPR.<sup>30</sup>

None of the included studies evaluated the ACL graft status arthroscopically.

## DISCUSSION

Despite variable outcome measures, the most important findings of this systematic review could be summarized as follows. Patients with tears of the LMPR associated with ACL injuries obtained favorable functional scores after ACLR and simultaneous LMPR repairs. Moreover, most patients in whom meniscal healing was evaluated based on second-look arthroscopy were treated with side-to-side repairs for radial tears, and the complete/partial healing rate was >90%. Additionally, with inconsistent radiographic and arthroscopic results, we were unable to definitively conclude whether LMPR repairs fully restore the hoop stress of the lateral meniscus.

Of late, the management of concomitant tears of the LMPR in ACL injuries has been a hot topic in the field of sports medicine. Authors of previous studies chose to leave the root tear in situ during ACLR.<sup>14,22</sup> In a study by Shelbourne et al,<sup>22</sup> despite improved functional scores, the mid-term radiographic follow-up results showed significant progression of lateral joint space narrowing in patients with tears of the LMPR being left in situ compared with those without meniscal lesions. Lee et al<sup>14</sup> left radial tears of the LMPR in situ in 27 patients undergoing ACLR; however, the meniscal healing rate was only 75%. Therefore, there has been great interest regarding surgical repairs of tears of the LMPR.<sup>2,3,10,13,20,27,30</sup>

A critical issue for successful repair of tears of the LMPR is proper surgical technique, and meniscal extrusion is a common and objective outcome to measure postsurgical meniscal function.<sup>1,15,18</sup> Currently, there are 2 surgical techniques with clinical follow-up records. The side-to-side technique can be used to repair radial tears with a root remnant of adequate tissue quality.<sup>2,30</sup> For cases of root avulsions or radial tears with tissue remnant of questionable quality, a transtibial pullout repair is recommended.<sup>10,13</sup> Okazaki et al<sup>18</sup> compared the efficacy of the 2 techniques in treating tears of the LMPR associated with ACL injury and found that pullout repair is better in decreasing the lateral meniscal extrusion on the coronal plane than the side-to-side technique but in a relatively short follow-up period (10 months). Meanwhile, Ahn et al<sup>2</sup> and Tsujii et al<sup>30</sup> reported no significant reduction of coronal extrusion after side-to-side repairs. Such findings indicate that extrusion reduction after LMPR repairs might not necessarily be satisfactory, but the pullout repair is likely better for the restoration of the hoop tension of the lateral meniscus. The effect of differences in repair techniques on extrusion reduction should be evaluated in a longer follow-up duration.

Although there is a broad consensus that a tear of the LMPR should be surgically repaired if confirmed during ACLR, the effectiveness of LMPR repairs still requires justification from multiple aspects. For the clinical outcomes,

this systematic review showed consistent improvements in all functional scores. The preoperative Lysholm score in 7 of the 9 included studies was around 60, which was considered to be poor and indicated severe symptoms in patients with tears of the LMPR and ACL injuries. After meniscal repair and ACLR, the mean score improved to approximately 90, indicating a significant advancement in subjective symptoms and daily activity. Such improvements were also found in terms of the IKDC subjective score and the Tegner score. Meanwhile, no residual knee mechanical instability was reported at the final follow-up.<sup>3,18,30</sup> However, because of the lack of a control group, there is no clear evidence that repairing tears of the LMPR in ACL-reconstructed knees would lead to better clinical outcomes than leaving them unrepaired.

Regarding the radiographic outcomes, a total of 72 patients showed no significant progression of joint space narrowing or chondral lesions of the lateral tibiofemoral compartment after tears of the LMPR were repaired during ACLR. Tsujii et al<sup>30</sup> found that the lateral joint space width was decreased by only 0.04 mm at a mean 3.4 years after LMPR repairs, and the amount of change was similar to that in isolated ACL-injured knees. Pan et al<sup>20</sup> reported that the postoperative chondral status was normal in 81% of patients after a mean follow-up of 3.1 years. In patients with tears of the LMPR left in situ, though, the significantly progressed lateral compartment narrowing was up to 1.0 mm,<sup>22</sup> and the postoperative chondral status was inferior to that in patients with repaired tears of the LMPR.<sup>20</sup> Such radiographic results supported the necessity of surgical repairs in terms of preventing premature osteoarthritis. However, arthroscopic results from the study of Tsujii et al<sup>30</sup> showed significantly progressed chondral lesions in the lateral tibial plateau after side-to-side repairs for tears of the LMPR, indicating that the hoop tension of the lateral meniscus might be not fully restored after LMPR repairs. Therefore, cartilaginous degeneration might progress after surgeries.

The healing capacity of surgically repaired tears of the LMPR is another important issue. In this systematic review, 78 patients who received the side-to-side repair for radial tears of the LMPR were evaluated for meniscal healing during the second-look arthroscopy. The overall healing rate of radial tears of the LMPR was 93.6%, which was more favorable compared with that of midbody radial tears of the lateral meniscus (61%).<sup>29</sup> Although the capacity of radial tears to heal was low, the bone marrow bleeding from bone tunnels during ACLR may have promoted the healing process of meniscal repair, which provided a favorable environment for meniscal healing.<sup>27,30</sup>

Several clinical studies showed that a tear of the LMPR would further destabilize the ACL-injured knee under pivot-shift loading.<sup>16,25</sup> However, the included studies failed to provide enough information about the restoration of antero-lateral rotational stability after LMPR repairs and combined ACLR. Despite the inspiring results provided by laboratory trials,<sup>8,28</sup> future studies are necessary to evaluate the effectiveness of LMPR repairs in controlling the dynamic stability of ACL-reconstructed knees in clinical scenarios.



The limitations of this systematic review were largely the result of the included studies. First, the low level of evidence and inconsistent reports of outcome measures is notable. Second, different tear patterns of the LMPR (radial/longitudinal tears near the root and root avulsions) were not clearly separated, and these are clinically unique because of anatomic characteristics and repair techniques. Third, the difference in surgical techniques of ACLR rather than LMPR repair may have a greater influence on postoperative knee stability; however, such an effect has not been clarified in this review due to the limited data available in the original studies, and it awaits further research. Despite these limitations, to our knowledge, this is the first study to systematically review clinical, radiographic, and arthroscopic results of surgical repairs for tears of the LMPR in patients undergoing ACLR. As such, this study could be helpful in directing future studies as the role of LMPR repair in ACLR is explored.

## CONCLUSION

Despite variable outcome measures in this systematic review, patients with tears of the LMPR associated with ACL injuries obtained favorable functional scores after ACLR and simultaneous LMPR repairs, and the side-to-side repair for radial tears of the LMPR achieved a high meniscal healing rate of >90%. However, with inconsistent radiographic and arthroscopic results, we are unable to definitively conclude whether LMPR repairs can fully restore the hoop stress of the lateral meniscus.

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