Prevalence and Site of Medial Patellofemoral Ligament Injuries in Patients With Acute Lateral Patellar Dislocations

A Systematic Review and Meta-analysis

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Background: Medial patellofemoral ligament (MPFL) injuries are common in patients with acute lateral patellar dislocations, but the pattern of MPFL injuries is unclear, especially with respect to patient age.

Purpose: The primary aim was to determine the prevalence of MPFL injuries according to the site of injury in patients with acute lateral patellar dislocations. The secondary aim was to compare the site of MPFL injuries in patients aged ≤16 versus >16 years.

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

Methods: A systematic literature search was performed with PubMed, Embase, and CINAHL to identify articles published from January 1, 1999, to May 31, 2019, that examined the site of MPFL injuries in patients with acute patellar dislocations. The study design, sample size, age at injury, technique used for diagnosing MPFL injuries (magnetic resonance imaging, ultrasound, and/or surgery), and prevalence and site of MPFL injuries were extracted from each study. The pooled estimate of the proportion of MPFL injuries at each site was calculated (femur, patella, midsubstance, and combined sites of injury) as well as proportions stratified by age group (≤16 and >16 years).

Results: The literature search yielded 420 unique articles, of which 52 were screened for eligibility; of these, 17 were excluded. Thus, a total of 35 articles (2558 patients) were included in the final analysis. The overall prevalence of MPFL injuries was 94.7% (95% CI, 91.2%-96.8%). Most MPFL injuries occurred at the patella (37.1% [95% CI, 30.8%-43.9%]), followed by the femur (36.8% [95% CI, 31.0%-43.0%]), combined sites (25.1% [95% CI, 20.7%-30.1%]), and the midsubstance (15.6% [95% CI, 13.2%-18.4%]). In patients aged ≤16 years, most MPFL injuries occurred at the patella (39.3% [95% CI, 27.9%-51.9%]), and in patients aged >16 years, most MPFL injuries occurred at the femur (47.2% [95% CI, 40.6%-54.0%]).

Conclusion: The prevalence of MPFL injuries in patients with acute patellar dislocations varied by site of injury and by age. MPFL injuries at the patella were most prevalent overall and in children and adolescents, and MPFL injuries at the femur were more prevalent in adults.

Keywords: medial patellofemoral ligament; acute injury; patellar dislocation; meta-analysis

The annual incidence of acute lateral patellar dislocations ranges from 5.8 to 7.0 cases per 100,000 person-years in the general population and is as high as 29 cases per 100,000 person-years among those aged 10 to 17 years.[13] The majority of first-time patellar dislocations occur during sports or physical activity (60%), often resulting from a direct blow to the knee or from a noncontact injury involving external rotation of the leg while the foot is planted.[22,26,33] Other risk factors for acute patellar dislocations include female sex, family history, and patellofemoral dysplasia.[17] Alterations in osseous or soft tissue structures, such as patella alta, trochlear dysplasia, and abnormalities of the medial patellofemoral ligament (MPFL), can lead to patellar dislocations.[26] The MPFL is the primary ligamentous restraint of the patella and aids in preventing lateral patellar subluxation by providing 50% to 60% of lateral patellar translation control.[2,10] Magnetic resonance imaging (MRI) has been found to be 85% sensitive and 70% accurate for diagnosing MPFL ruptures.[32] As many as 78% to 100% of MPFLs are partially or completely ruptured on MRI after acute lateral patellar dislocations.[11] MPFL repair or reconstruction is indicated for cases with recurrent instability, native soft tissue laxity, deficient bony stabilizers, and more severe MPFL tears.[26] Repair should only be considered for patients with an initial patellar dislocation who are

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undergoing a concomitant procedure (eg, osteochondral repair) because MPFL repair has been shown to result in just as many recurrent dislocations as nonoperative management and more recurrent dislocations than MPFL reconstruction.[31,35] MPFL injuries can occur at the femoral insertion, midsubstance, patellar attachment, or more than 1 of these sites.[11,15]

MPFL injuries at the femoral attachment tend to be more common in adults, while MPFL injuries at the patellar attachment tend to be more common in children and adolescents.[10,14,26] However, most studies that have examined the prevalence of MPFL injuries by site of injury have done so using small samples of fewer than 100 patients, and only 1 small study compared the rate of MPFL injuries in children versus adults.[6] Determining the site(s) of MPFL injuries in patients with acute lateral patellar dislocations can aid in treatment planning, especially for patients deemed surgical candidates.[19]

The primary aim of this systematic review was to determine the prevalence of MPFL injuries according to the site of injury in patients with acute lateral patellar dislocations. The secondary aim was to compare the site of MPFL injuries in skeletally immature (aged ≤16 years) versus skeletally mature (aged >16 years) patients. The primary hypothesis was that the site of MPFL injuries would vary among patients with an acute lateral patellar dislocation. The secondary hypothesis was that there would be more MPFL injuries at the patella in patients aged ≤16 years and more MPFL injuries at the femur in patients aged >16 years.

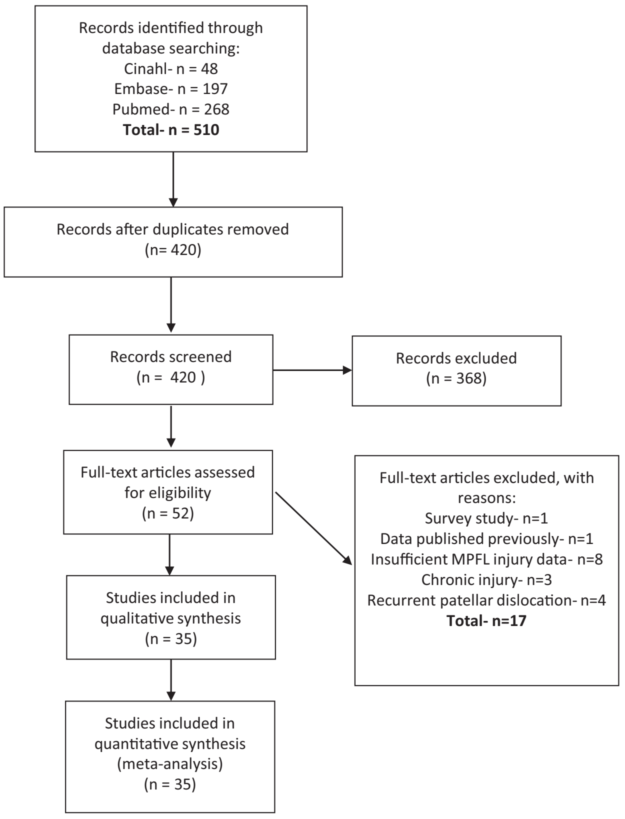

Figure 1. PRISMA (Preferred Reporting Items for Systematic Meta-Analyses) flowchart.

METHODS

Literature Search and Selection Criteria

A systematic review of the literature pertaining to the site of MPFL injuries in patients with acute lateral patellar dislocations was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. An electronic search was performed on June 27, 2019, with PubMed, Embase, and CINAHL to identify articles published from January 1, 1999, through May 31, 2019. The search terms were the following: ("medial patellofemoral ligament" OR "MPFL") AND ("tear" OR "rupture" OR "avulsion") AND/OR ("acute" OR "first" OR "initial") AND "patellar dislocation." We included articles that were written in English and reported the site of MPFL injuries in patients with a primary acute lateral patellar dislocation. We excluded articles not published in English and studies of chronic patellar dislocations, secondary patellar dislocations, insufficient MPFL injury data for extraction, and studies whose data were published previously. There were 2 authors (M.A.K. and L.M.) who independently reviewed the results of the literature search to identify articles for inclusion and exclusion. In the event of discrepancies, the advice of the senior author (J.M.M.) was sought.

Level of Evidence and Quality Assessment

The level of evidence was determined based on criteria established by the Oxford Centre for Evidence-Based Medicine.[29] The Downs and Black study quality assessment tool was used to score the methodological quality and risk of bias for each study.[12] The maximum Downs and Black score (indicating good quality/low risk of bias) was 9 for case series, 15 for observational studies, and 32 for randomized controlled trials.

Data Extraction

The same 2 reviewers independently extracted the following data from each article into a standardized spreadsheet:

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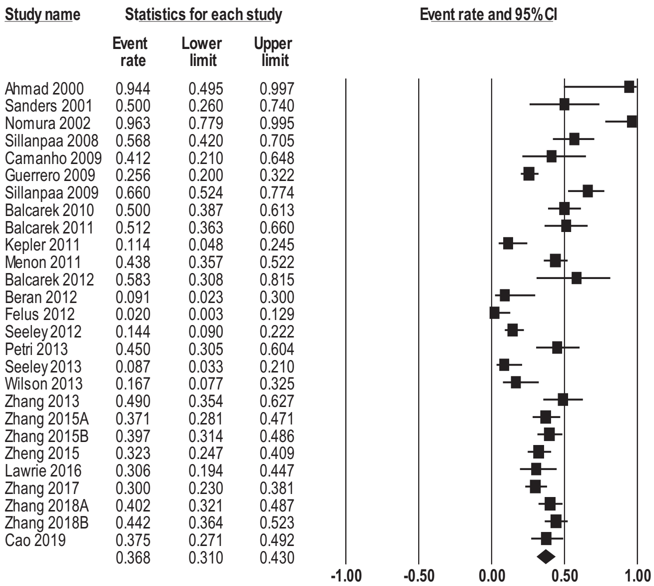

Figure 2. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries at the femur. Tests of heterogeneity: $Q = 147.8$ ($P < .001$); $I^2 = 82\%$.

study design, sample size, age at injury, method for diagnosing MPFL injuries (MRI, ultrasound, and/or surgery), overall prevalence of MPFL injuries, and site of MPFL injuries. The site of MPFL injuries included the (1) femur, (2) patella, (3) midsubstance, or (4) combined sites that involved the femur, patella, and/or midsubstance.

Statistical Analysis

The pooled estimate of the proportion of MPFL injuries at each site was calculated (femur, patella, midsubstance, and combined sites of injury) as well as the overall proportion of MPFL injuries. The proportion of MPFL injuries was also stratified by age group (≤16 and >16 years). To assess heterogeneity, the I^2 (significance level of $I^2 > 50\%$) and Cochran Q statistic (significance level of $P < .05$) were calculated. Tests of heterogeneity were found to be significant, and thus, random-effects models were used. Forest plots with proportions and 95% CIs are reported. Meta-analyses were performed with Comprehensive Meta-Analysis Software (Version 3; Biostat).

RESULTS

The initial search yielded 420 unique articles, of which 52 were screened for eligibility. Of the 52 full-text articles, 17 were excluded because they involved survey research, data were previously published, there was insufficient reporting of MPFL injury data, they included chronic injuries, or they included recurrent patellar dislocations. The final analysis included 35 articles with a total of 2558 patients (Figure 1).

As demonstrated in Appendix Table A1, the majority of included studies were level 4 evidence (n = 28; 80.0%),

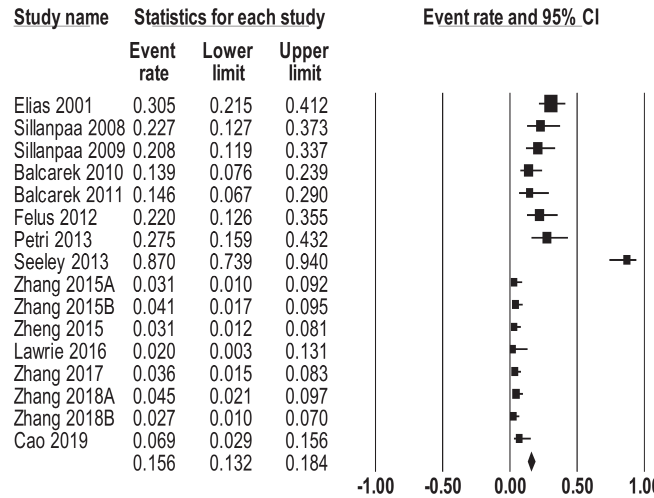

Figure 3. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries at the midsubstance. Tests of heterogeneity: $Q = 164.8$ ($P < .001$); $I^2 = 91\%$.

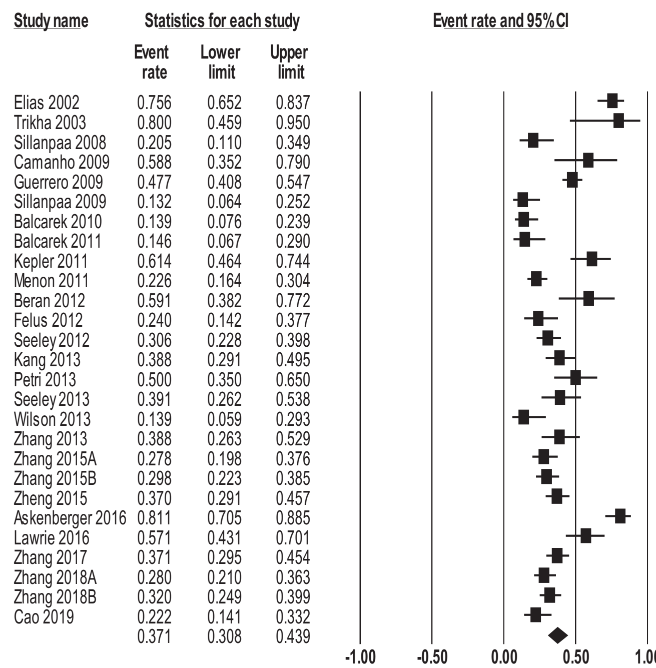

Figure 4. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries at the patella. Tests of heterogeneity: $Q = 212.1$ ($P < .001$); $I^2 = 88\%$.

followed by level 2 (n = 3; 8.6%), level 3 (n = 3; 8.6%), and level 1 (n = 1; 2.8%). Most case series (n = 27) and observational studies (n = 5) were of good quality and had a low risk of bias based on Downs and Black scores; however, the randomized controlled trials (n = 3) were of lower quality, mainly because of lack of blinding, loss to follow-up, and lack of power analysis. The mean patient age was ≤16 years

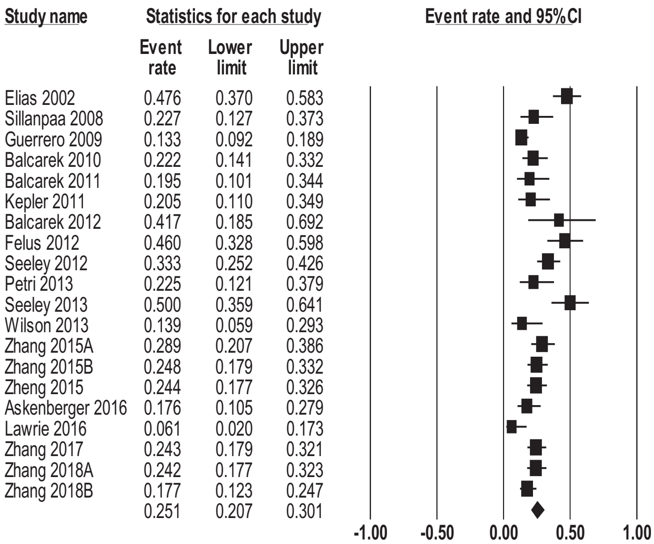

Figure 5. Forest plot illustrating the prevalence of combined sites of medial patellofemoral ligament (MPFL) injuries. Combined MPFL injuries involved the femur, midsubstance, and/or patella. Tests of heterogeneity: $Q = 82.7$ ($P < .001$); $I^2 = 77\%$.

in 10 studies (28.6%) and >16 years in 23 studies (65.7%); age was not reported in 2 studies (5.7%). Most studies diagnosed MPFL injuries on preoperative MRI (n = 25; 71.4%), followed by surgical confirmation in 9 studies (25.7%) and a diagnosis on ultrasound in 1 study (2.9%).

The overall pooled prevalence of MPFL injuries was 94.7% (95% CI, 91.2%-96.8%) and was slightly lower in studies with a mean patient age ≤16 years (90.8% [95% CI, 81.8%-95.6%]) compared with studies with a mean patient age >16 years (95.7% [95% CI, 91.2%-98.0%]) (Appendix Figures A1-A4). The site of MPFL injuries varied (Figures 2-5). Most MPFL injuries occurred at the patella (37.1% [95% CI, 30.8%-43.9%]), followed by the femur (36.8% [95% CI, 31.0%-43.0%]), combined sites (25.1% [95% CI, 20.7%-30.1%]), and the midsubstance (15.6% [95% CI, 13.2%-18.4%]).

Among studies with a mean patient age ≤16 years, most MPFL injuries occurred at the patella (39.3% [95% CI, 27.9%-51.9%]), followed by combined sites (28.7% [95% CI, 21.9%-36.5%]), the midsubstance (22.3% [95% CI, 6.0%-56.4%]), and the femur (22.0% [95% CI, 10.9%-39.3%]) (Appendix Figures A5, A7, A9, and A11). Among studies with a mean patient age >16 years, most MPFL injuries occurred at the femur (47.2% [95% CI, 40.6%-54.0%]), followed by the patella (31.3% [95% CI, 25.0%-38.4%]), combined sites (19.0% [95% CI, 15.2%-23.5%]), and the midsubstance (9.7% [95% CI, 5.5%-16.5%]) (Appendix Figures A6, A8, A10, and A12).

DISCUSSION

We found that the overall prevalence of MPFL injuries was 94.7% and conclude that disruption of the MPFL can be considered the "essential lesion" of acute lateral patellar dislocations. MPFL injuries occurred most commonly at the patellar attachment (37.1%) and femoral insertion (36.8%), followed by combined sites (25.1%) and the midsubstance (15.6%). As hypothesized, most MPFL injuries occurred at the patella in patients aged ≤16 years (39.3%) and at the femur in patients aged >16 years (47.2%).

We found that the prevalence for both femoral insertion and patellar attachment MPFL injuries were approximately 37%, with slightly more injuries at the patellar attachment. There has been conflicting evidence regarding the localization of MPFL injuries in patients with acute patellar dislocations. Historically, the femoral insertion has been thought to be the most common site of MPFL injuries. Of the 35 articles included in our systematic review, the most common site of MPFL injuries was the femoral insertion in 15 studies,[‡] the patellar attachment in 12 studies,[§] the midsubstance in 2 studies,[33,34] combined sites in 1 study,[16] and was not reported in 5 studies.[20,27,28,36,38] There are a number of factors that may account for the discrepancies in data regarding the localization of MPFL injuries, including (1) the lack of an accurate definition of a complete MPFL rupture on MRI, (2) not being able to discern the dynamic status of the ligament on MRI after a patellar dislocation, and (3) difficulty in visualizing the oblique course of the fibers of the MPFL in relation to standard planes used for MRI.[16] It has also been shown that the pattern of MPFL injuries is associated with predisposing anatomic factors for an acute patellar dislocation.[4] For instance, an injury at the patellar insertion is more likely to occur when the tibial tubercle–trochlear groove distance is increased and the values of trochlear dysplasia vary for patellar and femoral MPFL injuries. Also, variation in the diagnostic method (ie, MRI, ultrasound, surgical visualization) and small sample sizes make it difficult to compare the localization of MPFL injuries between studies.

Similar to previous research,[10,14,26] we observed an age difference in the localization of MPFL injuries, with patellar-sided injuries being more common in patients aged ≤16 years and femoral-sided injuries being more common in patients aged >16 years. To our knowledge, only 1 study directly compared the localization of MPFL injuries between children and adults with acute patellar dislocations, finding no age-based difference in MPFL injury patterns.[6] Femoral-sided injuries were most common in both children and adults in that study; however, the sample size was small (N = 43) and may not be representative of all acute patellar dislocations. On the other hand, a number of studies restricted to the recruitment of children and adolescents found patellar-sided MPFL injuries to be most common among this age group.[3,16,23,33,34,45,49] Felus and Kowalczyk[16] found that the patellar attachment was the most common site of MPFL injuries in children and adolescents, and all but 2 of the patients with patellar-sided MPFL injuries also had an avulsion fracture of the medial patellar border. The authors speculated that younger

[‡]References 1, 4-6, 9, 25, 32, 37, 39, 42-44, 46-48.
[§]References 3, 7, 8, 15, 18, 21, 23, 24, 30, 40, 45, 49.

persons may be more susceptible to patellar-sided injuries because the medial patellar border stays cartilaginous until age 16 to 18 years, unlike the distal femoral epiphysis, which ossifies around age 13 to 15 years. This chondro-osseous boundary is susceptible to tension forces, resulting in marginal avulsion fractures of the patella or detachment injuries of the MPFL at the patella in children and adolescents.[49] Seeley et al[33] found that the articular cartilage sulcus angle may be associated with the pattern of MPFL injuries in children and adolescents, such that patellar-sided injures were associated with a steeper articular sulcus angle and femoral-sided injuries were associated with a flattened articular sulcus angle. Zheng et al[49] found that 37% of 127 children and adolescents with acute patellar dislocations had a patellar-sided MPFL injury. The authors speculated that the patellar attachment of the MPFL in younger patients may be weaker and more easily injured because the fibers of the MPFL and the vastus medialis obliquus may not be fully combined yet on the patellar side; however, no anatomic studies have confirmed this hypothesis.

The operative management of MPFL ruptures is considered the gold standard for addressing recurrent instability; however, choosing between MPFL repair and reconstruction remains controversial. Similar subjective outcome scores have been demonstrated for MPFL repair and MPFL reconstruction, although MPFL repair tends to result in more recurrent dislocations.[35,41] Therefore, properly diagnosing the location and severity of MPFL injuries is essential for treatment planning and avoids a one-size-fits-all approach to surgical correction when the injury site varies significantly. According to our review, most practitioners used MRI as the diagnostic tool of choice, and this study encourages our radiology colleagues to describe specifically the site of MPFL injuries to enhance reading accuracy. We support performing MRI on patients with a patellar instability event to identify the location of MPFL injuries and to evaluate for intra-articular abnormalities. In this way, both acute and delayed surgery can be indicated appropriately.

To our knowledge, this study is the only systematic review that has examined the localization of MPFL injuries in patients with acute lateral patellar dislocations and, to date, is the largest study on this topic (N = 2558). However, this study is not without limitations. The method used for diagnosing MPFL injuries varied between studies and may have led to confounding. However, the risk of confounding is likely low because the majority of studies confirmed MPFL injuries using MRI. Patellar medial margin fractures and articular cartilage status may be associated with the MPFL injury pattern and could also be potential confounders, but this information was not reported in most studies, which precluded any further analysis. Our analyses stratified by age should be interpreted cautiously. We were unable to conduct a direct statistical comparison of injury rates between age groups. Although there were more patellar-sided injuries in patients aged ≤16 years, for instance, the 95% CI did overlap with patients aged >16 years, which suggests that this difference is not statistically significant. Most studies were level 4 case series, although we found a low risk of bias in the majority of studies, and case series are appropriate for determining prevalence rates. Finally, this study may be at risk for publication and language bias because we only included peer-reviewed articles published in English.

In conclusion, the prevalence of MPFL injuries in patients with an acute patellar dislocation varied by site of injury and by age. MPFL injuries at the patella were most prevalent overall and in children and adolescents, and MPFL injuries at the femur were more prevalent in adults.

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APPENDIX

TABLE A1
Study Characteristics and MPFL Data[a]

First Author (Year)	Study Design (LOE)	DB Score[b]	Sample Size,	Age at Injury,[c] y	Diagnosis Method	Prevalence of MPFL Injuries, n (%)	Location of MPFL Injuries, n (%)
Nomura[27] (1999)	Case series (4)	9	18	19.6 (12-38)	Surgery	7/18 (38.9) avulsions, 10/18 (55.6) ruptures, 17/18 (94.4) total injuries	NR
Ahmad[1] (2000)	Case series (4)	9	8	32 (16-56)	MRI	8/8 (100.0)	8/8 (100.0) at FEM
Sanders[32] (2001)	Case series (4)	9	14	29.6 (12-60)	MRI (mean, 11 d from injury) and arthroscopic surgery (mean, 21 d from imaging)	8/14 (57.1) with complete disruption on MRI, 14/14 (100.0) with some degree of MPFL injury during arthroscopic surgery	On MRI: 4/14 (28.6) with edema isolated to FEM, 1/14 (7.1) with focal edema isolated to PAT, 5/14 (35.7) with diffuse edema beginning at FEM and extending into MID, 4/14 (28.6) with diffuse edema extending entire length of MPFL from FEM to PAT During arthroscopic surgery: 7/14 (50.0) with complete disruption near FEM or avulsion of femur, 7/14 (50.0) with stretching or partial tear of MPFL and adjacent soft tissue edema
Elias[15] (2002)	Case-control (3)	13	179 (82 knees [81 patients] with acute lateral patellar dislocations, 98 controls)	Cases: 20 (9-57) Controls: 29 (13-49)	MRI (mean, 21 d after injury)	NR	62/82 (75.6) at PAT, 25/82 (30.5) at MID, 39/82 (47.6) with COM injuries
Nomura[28] (2002)	Case series (4)	8	27	18 (13-29)	MRI (mean, 6 d after injury) and open exploration	24/27 (88.9) on MRI, 26/27 (96.3) during open exploration	13/27 (48.1) with substantial-type tears on MRI, 10/27 (37.0) with avulsion tears, 16/27 (59.3) with substantial-type tears during open exploration[d]
Trikha[40] (2003)	Case series (4)	9	10	Median = 20.5 (13-37)	US	8/10 (80.0)	8/10 (80.0) at PAT
Sillanpää[37] (2008)	Cohort (2)	12	76 (30 operative, 46 nonoperative)[e]	Median = 20 (19-22)	MRI (mean, 4 d after injury)	44/46 (95.7)	25/46 (54.3) at FEM, 9/46 (19.6) at PAT, 10/46 (21.7) at MID, 10/46 (21.7) with COM injuries (MID and PAT injuries also had signs of partial disruption at femur)
Sillanpää[36] (2008)	Case series (4)	9	73	Median = 20 (18-23)	MRI (mean, 4 d after injury) and open surgery	73/73 (100.0) both on MRI and during open surgery[f]	NR
Camanho[8] (2009)	RCT (2)	21	33 (17 operative, 16 nonoperative)	Operative: 24.6 (15-33) Nonoperative: 26.8 (12-74)	MRI[g]	17/17 (100.0)	10/17 (58.8) at PAT, 7/17 (41.2) at FEM
Guerrero[18] (2009)	Case series (4)	9	195	23 (10-56)	MRI	169/195 (86.7) with ruptures, 26/195 (13.3) with attenuation of MPFL without rupture	93/195 (47.7) at PAT, 50/195 (25.6) at FEM, 26/195 (13.3) with COM injuries at PAT + FEM
Sillanpää[38] (2009)	RCT (1)	23	40 (18 operative, 22 nonoperative)	Median = 20 (19-22)	MRI (median, 3 d after injury)	17/18 (94.4) injuries in operative group, 22/22 (100.0) injuries in nonoperative group, 39/40 (97.5) total injuries	NR

(continued)

TABLE A1 (continued)

First Author (Year)	Study Design (LOE)	DB Score[b]	Sample Size,	Age at Injury,[c] y	Diagnosis Method	Prevalence of MPFL Injuries, n (%)	Location of MPFL Injuries, n (%)
Sillanpää[39] (2009)	Cohort (3)	13	53	20 (19-23)	MRI (mean, 3 d after injury)	53/53 (100.0)	35/53 (66.0) at FEM, 7/53 (13.2) at PAT, 11/53 (20.8) at MID
Balcarek[4] (2010)	Case-control (4)	13	146 (73 patients with acute lateral patellar dislocations, 73 controls)	23.6	MRI (within 7 wk of injury)	35/73 (47.9) partial tears, 37/73 (50.7) complete tears, 72/73 (98.6) total tears	36/73 (49.3) at FEM, 10/73 (13.7) at MID, 10/73 (13.7) at PAT, 16/73 (21.9) with COM injuries (13 at PAT + FEM and 3 at FEM + MID)
Balcarek[6] (2011)	Case-control (3)	13	43 (22 children and adolescents with acute patellar dislocations, 21 adults with acute patellar dislocations)	Children: 14.2 (11-15) Adults: 25.7 (18-38)	MRI (within 13 d of injury)	Children: 12/22 (54.5) partial tears, 8/22 (36.4) complete tears, 20/22 (90.9) total tears Adults: 11/21 (52.4) partial tears, 10/21 (47.6) complete tears, 21/21 (100.0) total tears	Children: 8/22 (36.4) at FEM, 7/22 (31.8) with COM injuries at FEM + PAT, 3/22 (13.6) at MID, 2/22 (9.1) at PAT Adults: 13/21 (61.9) at FEM, 1/21 (4.8) with COM injuries at FEM + PAT, 3/21 (14.3) at MID, 4/21 (19.0) at PAT
Kepler[23] (2011)	Case series (4)	8	44	14.3 (9.8-17.8)	MRI	41/44 (93.2)	27/44 (61.4) at PAT, 5/44 (11.4) at FEM, 9/44 (20.5) with COM injuries (5 at PAT + FEM and 4 at MID + FEM or PAT)
Menon[25] (2011)	Case series (4)	8	150	28 (10-72)	MRI	137/150 (91.3)	60/150 (40.0) at FEM, 31/150 (20.7) at PAT, 46/150 (30.7) with diffuse pattern of injury
Balcarek[5] (2012)	Case series (4)	9	12 patients with acute patellar dislocations[h]	Median = 18 (13-42)	MRI (mean, 3 d after injury) and arthroscopic surgery	On MRI: 7/12 (58.3) partial tears, 5/12 (41.7) complete tears, 12/12 (100.0) total tears During arthroscopic surgery: 11/12 (91.7)	On MRI: 7/12 (58.3) at FEM, 5/12 (41.7) with COM injuries at PAT + FEM, 7/12 (58.3) with osteochondral flake fractures Arthroscopic surgery failed to show direct injuries of femoral MPFL in all patients with MPFL tears at FEM and COM injuries. After transection of synovial membrane, hematoma became obvious during arthroscopic surgery and could be confirmed as injury of MPFL by mini-open exploration in 11/12 patients.
Beran[7] (2012)	Case series (4)	9	21 patients (22 knees) with weightbearing lesions of LFC	13.8	MRI	15/22 (68.2)	13/22 (59.1) at PAT with combined osteochondral fractures or bone bruises of midlateral weightbearing region of LFC, 2/22 (9.1) at FEM
Felus[16] (2012)	Case series (4)	8	50	14.75 (10.5-17.5)	US and surgery	26/50 (52.0) partial ruptures, 21/50 (42.0) complete ruptures, 47/50 (94.0) total ruptures	12/50 (24.0) at PAT, 11/50 (22.0) at MID, 1/50 (2.0) at FEM, 23/50 (46.0) with COM injuries (10 at PAT + MID, 8 at PAT + FEM, 4 at PAT + FEM + MID, and 1 at MID + FEM)
Seeley[33] (2012)	Case series (4)	8	111	14.9 (11-18)	MRI (mean, 17 d after injury)	87/111 (78.4)	16/111 (14.4) at FEM, 34/111 (30.6) at PAT, 37/111 (33.3) with COM injuries at PAT and FEM, 61/111 (55.0) with MID attenuation
Kang[21] (2013)	Case series (4)	9	85 patients (33 in overlap region of MPFL, 52 in nonoverlap region of MPFL)[i]	19.7	MRI	33/85 (38.8)	33/85 (38.8) at PAT

(continued)

TABLE A1 (continued)

First Author (Year)	Study Design (LOE)	DB Score[b]	Sample Size,	Age at Injury,[c] y	Diagnosis Method	Prevalence of MPFL Injuries, n (%)	Location of MPFL Injuries, n (%)
Petri[30] (2013)	Case series (4)	8	40	24.6 (16-40)	MRI (within 3 mo of injury)	17/40 (42.5) partial tears, 23/40 (57.5) complete tears, 40/40 (100.0) total tears	20/40 (50.0) at PAT, 11/40 (27.5) at MID, 18/40 (45.0) at FEM, 9/40 (22.5) with COM injuries
Seeley[34] (2013)	Case series (4)	9	46	14.6 (11-18)	MRI (mean, 12 d after injury)	45/46 (97.8)	4/46 (8.7) at FEM, 18/46 (39.1) at PAT, 23/46 (50.0) with COM injuries at PAT + FEM, 40/46 (87.0) with MID attenuation
Wilson[42] (2013)	Case series (4)	9	36	14.5 (8-17)	MRI (mean, 35 d [range, 5-135 d] after injury)	5/36 (13.9) sprains, 16/36 (44.4) tears, 21/36 (58.3) total injuries	5/36 (13.9) at PAT, 6/36 (16.7) at FEM, 5/36 (13.9) with COM injuries at PAT + FEM
Zhang[47] (2013)	Case series (4)	9	49	Median = 24.5 (16-41)	US (within 14 d of injury) and surgery	21/49 (42.9) partial tears, 28/49 (57.1) complete tears, 49/49 (100.0) total tears	9 partial tears at FEM, 8 at PAT, and 1 at MID were diagnosed on US and confirmed during surgery. 15 complete tears at FEM and 11 at PAT were confirmed during surgery. 1 partial tear at PAT and 2 partial tears at FEM were misinterpreted as complete tears on US, and 1 complete tear at FEM and another at PAT were misinterpreted as partial tears on US.
Zhang[43] (2015)	Case series (4)	8	97	22 (9-44)	MRI, US, and surgery	Partial tears: 69/97 (71.1) on US, 62/97 (63.9) on MRI, 41/97 (42.3) during surgery Complete tears: 44/97 (45.4) on US, 41/97 (42.3) on MRI, 53/97 (54.6) during surgery Total tears: 94/97 (96.9) during surgery	During surgery: 36/97 (37.1) at FEM, 27/97 (27.8) at PAT, 3/97 (3.1) at MID, 28/97 (28.9) with COM injuries (5 at PAT + FEM, 10 at MID + PAT, 8 at FEM + MID, and 5 at MID + PAT + FEM)
Zhang[44] (2015)	Case series (4)	8	121	25 (18-44)	MRI	48/121 (39.7) partial tears, 71/121 (58.7) complete tears, 119/121 (98.3) total tears	48/121 (39.7) at FEM, 36/121 (29.8) at PAT, 5/121 (4.1) at MID, 30/121 (24.8) with COM injuries (16 at FEM + PAT, 8 at FEM + MID, 4 at PAT + MID, and 2 at FEM + MID + PAT)
Zheng[49] (2015)	Case series (4)	8	127	14.1 (9-14)	MRI	54/127 (42.5) partial tears, 69/127 (54.3) complete tears, 123/127 (96.9) total tears	47/127 (37.0) at PAT, 41/127 (32.3) at FEM, 4/127 (3.1) at MID, 31/127 (24.4) with COM injuries (14 at PAT + FEM, 8 at PAT + MID, 5 at FEM + MID, and 4 at MID + PAT + FEM)
Askenberger[3] (2016)	Case series (4)	9	74	13.1 (9-14)	MRI and arthroscopic surgery	73/74 (98.6)	On MRI: 44/74 (59.5) at PAT, 26/74 (35.1) with COM injuries (18 at PAT + FEM, 7 at PAT + MID, and 1 at PAT + FEM + MID), 3/74 (4.1) at FEM During arthroscopic surgery: 60/74 (81.1) at PAT (49/60 were complete tears), 13/74 (17.6) with COM injuries (PAT + blood-tinged synovium toward femoral insertion)

(continued)

TABLE A1 (continued)

First Author (Year)	Study Design (LOE)	DB Score[b]	Sample Size,	Age at Injury,[c] y	Diagnosis Method	Prevalence of MPFL Injuries, n (%)	Location of MPFL Injuries, n (%)
Lawrie[24] (2016)	Case series (4)	8	47 patients (49 MPFL repairs)	NR	MRI	47/49 (95.9)	28/49 (57.1) at PAT, 15/49 (30.6) at FEM, 3/49 (6.1) with COM injuries at PAT + FEM, 1/49 (2.0) at MID
Ji[20] (2017)	RCT (2)	24	56 (30 operative, 26 nonoperative)	NR	MRI (within 3 wk of injury)	56/56 (100.0)	NR
Zhang[45] (2017)	Case series (4)	8	140	14.3 (9-17)	MRI	58/140 (41.4) partial tears, 75/140 (53.6) complete tears, 133/140 (95.0) total tears	52/140 (37.1) at PAT, 42/140 (30.0) at FEM, 5/140 (3.6) at MID, 34/140 (24.3) with COM injuries (17 at FEM + PAT, 8 at PAT + MID, 5 at FEM + MID, and 4 at FEM + MID + PAT)
Zhang[46] (2018)	Case series (4)	8	132	24 (18-44)	MRI	52/132 (39.4) partial tears, 76/132 (57.6) complete tears, 128/132 (97.0) total tears	53/132 (40.2) at FEM, 37/132 (28.0) at PAT, 6/132 (4.5) at MID, 32/132 (24.2) with COM injuries
Zhang[48] (2018)	Case series (4)	8	147	20 (8-42)	MRI	62/147 (42.2) partial tears, 80/147 (54.4) complete tears, 142/147 (96.6) total tears	47/147 (32.0) at PAT, 65/147 (44.2) at FEM, 4/147 (2.7) at MID, 26/147 (17.7) with COM injuries
Cao[9] (2019)	Case series (4)	8	74	21.1 (9-42)	MRI	19/74 (25.7) partial tears, 53/74 (71.6) complete tears, 72/74 (97.3) total tears	16/74 (21.6) at PAT (type 2a: complete tear and osteochondral avulsion fracture without articular cartilage), 5/74 (6.8) at MID (type 2b: complete tear), 27/74 (36.5) at FEM (type 2c: complete tear and osteochondral avulsion fracture without articular cartilage), 5/74 (6.8) with type 3 MPFL injuries (fracture of patella's medial facet affecting articular surface)

[a]COM, combined site involving more than 1 location; DB, Downs and Black; FEM, femoral attachment; LFC, lateral femoral condyle; LOE, level of evidence; MID, midsubstance; MPFL, medial patellofemoral ligament; MRI, magnetic resonance imaging; NR, not reported; PAT, patellar insertion; RCT, randomized controlled trial; US, ultrasound.

[b]The maximum scores (indicating good quality/low risk of bias) were 9 for case series, 15 for observational studies, and 32 for RCTs.

[c]Values are presented as mean or mean (range) unless otherwise indicated.

[d]Nomura et al[28] defined substantial-type tears as ruptures in the substance of the ligament itself, especially near the femoral attachment. An avulsion tear was defined as a detachment-type injury of the femoral attachment of the MPFL. For analysis, we considered both substantial-type and avulsion tears as MPFL injuries at the femur.

[e]Preoperative MRI data were only available for the 46 patients who underwent nonoperative management.

[f]A total of 28 of 73 patients had an MRI scan available, and only 3 patients underwent open surgery.

[g]MRI scans were only available for 17 patients in the operative group.

[h]There were 10 patients excluded with recurrent patellar dislocations.

[i]Kang et al[21] defined the overlap region as an injury from the dividing point to the medial patellar margin and the nonoverlap region as an injury from the dividing point to the femoral origin. We only included data from cases with MPFL injuries in the overlap region in our analysis.

Study name	Event rate	Lower limit	Upper limit
Nomura 1999	0.974	0.690	0.998
Ahmad 2000	0.944	0.495	0.997
Sanders 2001	0.967	0.634	0.998
Nomura 2002	0.963	0.779	0.995
Trikha 2003	0.800	0.459	0.950
Sillanpaa 2008A	0.957	0.842	0.989
Sillanpaa 2008B	0.993	0.901	1.000
Camanho 2009	0.972	0.678	0.998
Guerrero 2009	0.867	0.811	0.908
Sillanpaa 2009A	0.975	0.843	0.996
Sillanpaa 2009B	0.991	0.869	0.999
Balcarek 2010	0.986	0.909	0.998
Balcarek 2011	0.953	0.832	0.988
Kepler 2011	0.932	0.809	0.978
Menon 2011	0.913	0.856	0.949
Balcarek 2012	0.917	0.587	0.988
Beran 2012	0.682	0.466	0.840
Felus 2012	0.940	0.830	0.981
Seeley 2012	0.784	0.698	0.851
Kang 2013	0.388	0.291	0.495
Petri 2013	0.988	0.833	0.999
Seeley 2013	0.978	0.861	0.997
Wilson 2013	0.583	0.419	0.731
Zhang 2013	0.990	0.859	0.999
Zhang 2015A	0.969	0.908	0.990
Zhang 2015B	0.983	0.936	0.996
Zheng 2015	0.969	0.919	0.988
Askenberger 2016	0.986	0.910	0.998
Lawrie 2016	0.959	0.851	0.990
Ji 2017	0.991	0.875	0.999
Zhang 2017	0.950	0.899	0.976
Zhang 2018A	0.970	0.922	0.989
Zhang 2018B	0.966	0.921	0.986
Cao 2019	0.973	0.898	0.993
	0.947	0.912	0.968

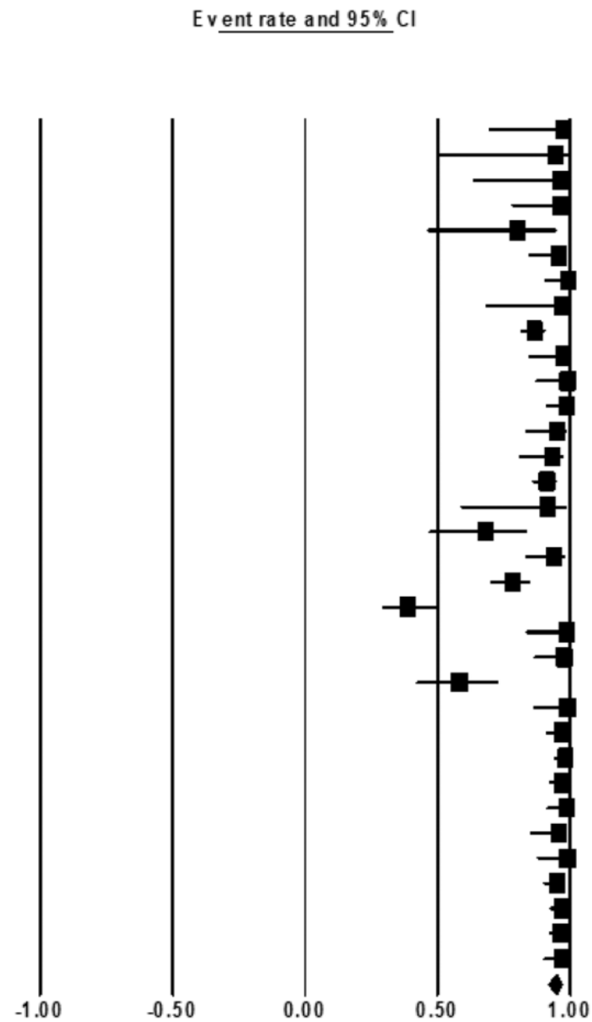


Figure A1. Forest plot illustrating the overall prevalence of medial patellofemoral ligament (MPFL) injuries. All diagnostic methods for MPFL injuries were included. For studies that reported the prevalence of MPFL injuries based on both imaging and surgical findings, surgical findings were included in the analysis. $Q = 261.8$ ($P < .001$); $I^2 = 87\%$.

Study name	Event rate	Lower limit	Upper limit
Ahmad 2000	0.944	0.495	0.997
Sanders 2001	0.571	0.316	0.794
Nomura 2002	0.889	0.707	0.964
Sillanpaa 2008A	0.957	0.842	0.989
Sillanpaa 2008B	0.993	0.901	1.000
Camanho 2009	0.972	0.678	0.998
Guerrero 2009	0.867	0.811	0.908
Sillanpaa 2009A	0.975	0.843	0.996
Sillanpaa 2009B	0.991	0.869	0.999
Balcarek 2010	0.986	0.909	0.998
Balcarek 2011	0.953	0.832	0.988
Kepler 2011	0.932	0.809	0.978
Menon 2011	0.913	0.856	0.949
Balcarek 2012	0.962	0.597	0.998
Beran 2012	0.682	0.466	0.840
Seeley 2012	0.784	0.698	0.851
Kang 2013	0.388	0.291	0.495
Petri 2013	0.988	0.833	0.999
Seeley 2013	0.978	0.861	0.997
Wilson 2013	0.583	0.419	0.731
Zhang 2015	0.983	0.936	0.996
Zheng 2015	0.969	0.919	0.988
Askenberger 2016	0.986	0.910	0.998
Lawrie 2016	0.959	0.851	0.990
Ji 2017	0.991	0.875	0.999
Zhang 2017	0.950	0.899	0.976
Zhang 2018A	0.970	0.922	0.989
Zhang 2018B	0.966	0.921	0.986
Cao 2019	0.973	0.898	0.993
	0.938	0.896	0.964

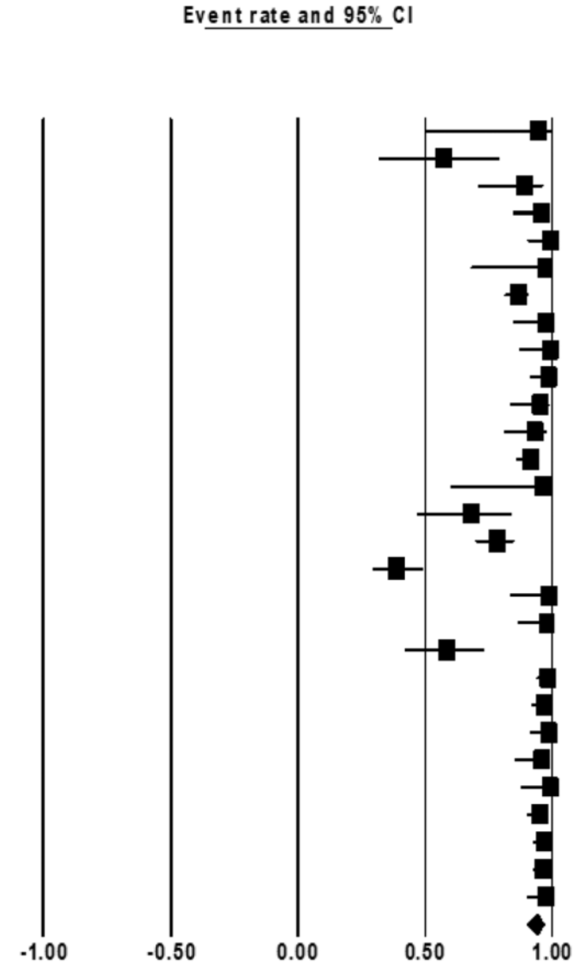


Figure A2. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries confirmed by magnetic resonance imaging. $Q = 251.2$ ($P < .001$); $I^2 = 89\%$.

Study name	Event rate	Lower limit	Upper limit
Balcarek 2011	0.909	0.700	0.977
Kepler 2011	0.932	0.809	0.978
Beran 2012	0.682	0.466	0.840
Felus 2012	0.940	0.830	0.981
Seeley 2012	0.784	0.698	0.851
Seeley 2013	0.978	0.861	0.997
Wilson 2013	0.583	0.419	0.731
Zheng 2015	0.969	0.919	0.988
Askenberger 2016	0.986	0.910	0.998
Zhang 2017	0.950	0.899	0.976
	0.908	0.818	0.956

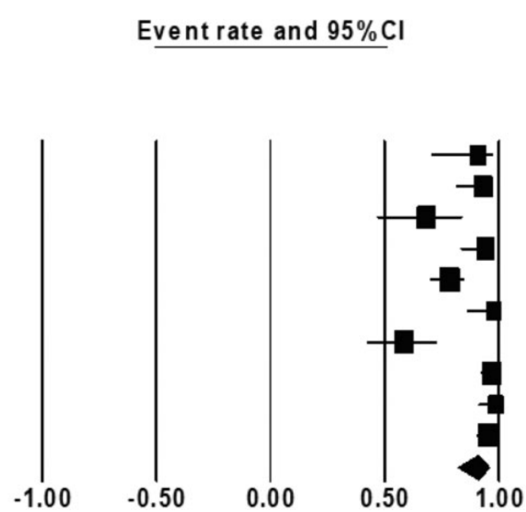
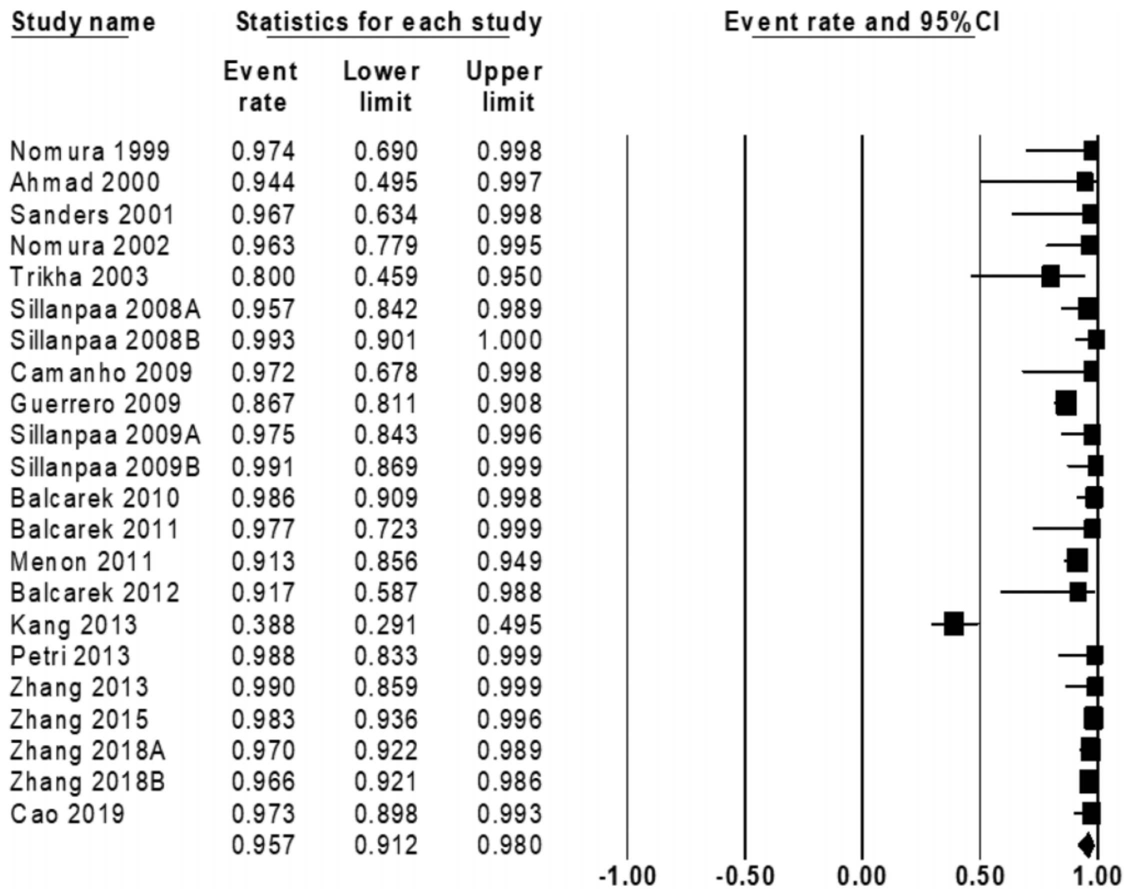
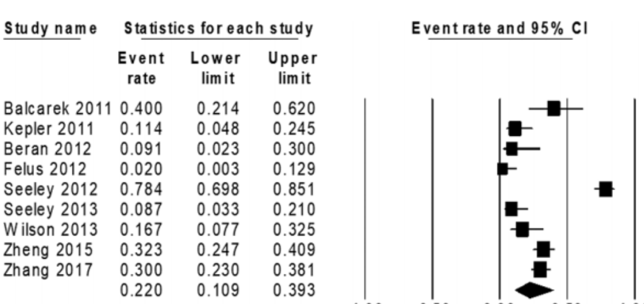


Figure A3. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries in studies with a mean patient age ≤16 years. $Q = 62.5$ ($P < .0001$); $I^2 = 86\%$.



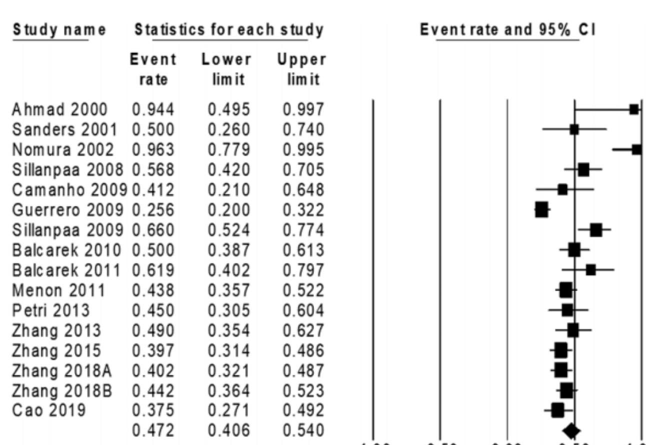
Study name	Event rate	Lower limit	Upper limit
Nomura 1999	0.974	0.690	0.998
Ahmad 2000	0.944	0.495	0.997
Sanders 2001	0.967	0.634	0.998
Nomura 2002	0.963	0.779	0.995
Trikha 2003	0.800	0.459	0.950
Sillanpaa 2008A	0.957	0.842	0.989
Sillanpaa 2008B	0.993	0.901	1.000
Camanho 2009	0.972	0.678	0.998
Guerrero 2009	0.867	0.811	0.908
Sillanpaa 2009A	0.975	0.843	0.996
Sillanpaa 2009B	0.991	0.869	0.999
Balcarek 2010	0.986	0.909	0.998
Balcarek 2011	0.977	0.723	0.999
Menon 2011	0.913	0.856	0.949
Balcarek 2012	0.917	0.587	0.988
Kang 2013	0.388	0.291	0.495
Petri 2013	0.988	0.833	0.999
Zhang 2013	0.990	0.859	0.999
Zhang 2015	0.983	0.936	0.996
Zhang 2018A	0.970	0.922	0.989
Zhang 2018B	0.966	0.921	0.986
Cao 2019	0.973	0.898	0.993
	0.957	0.912	0.980

Figure A4. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries in studies with a mean patient age >16 years. $Q = 183.4$ ($P < .001$); $I^2 = 89\%$.



Study name	Event rate	Lower limit	Upper limit
Balcarek 2011	0.400	0.214	0.620
Kepler 2011	0.114	0.048	0.245
Beran 2012	0.091	0.023	0.300
Felus 2012	0.020	0.003	0.129
Seeley 2012	0.784	0.698	0.851
Seeley 2013	0.087	0.033	0.210
Wilson 2013	0.167	0.077	0.325
Zheng 2015	0.323	0.247	0.409
Zhang 2017	0.300	0.230	0.381
	0.220	0.109	0.393

Figure A5. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries at the femur in studies with a mean patient age ≤16 years. $Q = 111.1$ ($P < .0001$); $I^2 = 93\%$.



Study name	Event rate	Lower limit	Upper limit
Ahmad 2000	0.944	0.495	0.997
Sanders 2001	0.500	0.260	0.740
Nomura 2002	0.963	0.779	0.995
Sillanpaa 2008	0.568	0.420	0.705
Camanho 2009	0.412	0.210	0.648
Guerrero 2009	0.256	0.200	0.322
Sillanpaa 2009	0.660	0.524	0.774
Balcarek 2010	0.500	0.387	0.613
Balcarek 2011	0.619	0.402	0.797
Menon 2011	0.438	0.357	0.522
Petri 2013	0.450	0.305	0.604
Zhang 2013	0.490	0.354	0.627
Zhang 2015	0.397	0.314	0.486
Zhang 2018A	0.402	0.321	0.487
Zhang 2018B	0.442	0.364	0.523
Cao 2019	0.375	0.271	0.492
	0.472	0.406	0.540

Figure A6. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries at the femur in studies with a mean patient age >16 years. $Q = 60.8$ ($P < .001$); $I^2 = 75\%$.

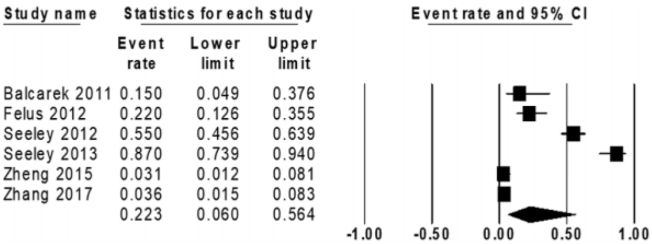


Figure A7. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries at the midsubstance in studies with a mean patient age ≤16 years. $Q = 123.0$ ($P < .0001$); $I^2 = 96\%$.

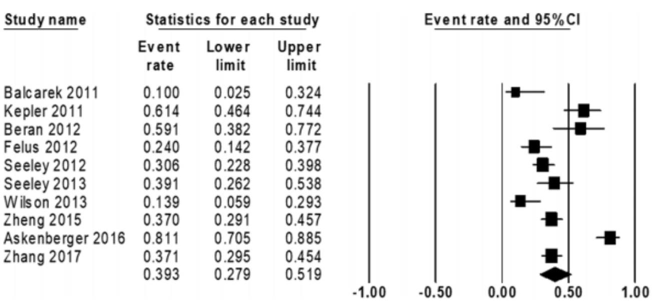


Figure A9. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries at the patella in studies with a mean patient age ≤16 years. $Q = 74.9$ ($P < .0001$); $I^2 = 88\%$.

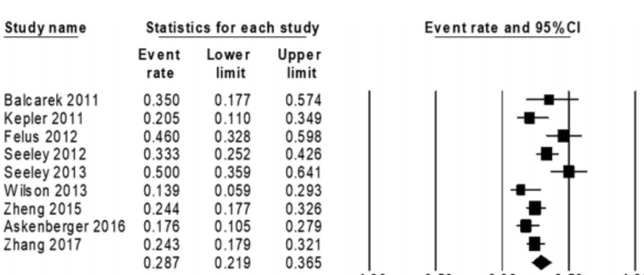


Figure A11. Forest plot illustrating the prevalence of combined sites of medial patellofemoral ligament (MPFL) injuries in studies with a mean patient age ≤16 years. Combined MPFL injuries involved the femur, midsubstance, and/or patella. $Q = 29.9$ ($P < .0001$); $I^2 = 73\%$.

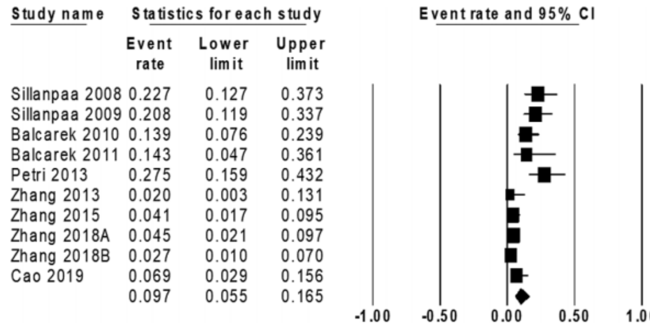


Figure A8. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries at the midsubstance in studies with a mean patient age >16 years. $Q = 44.6$ ($P < .001$); $I^2 = 80\%$.

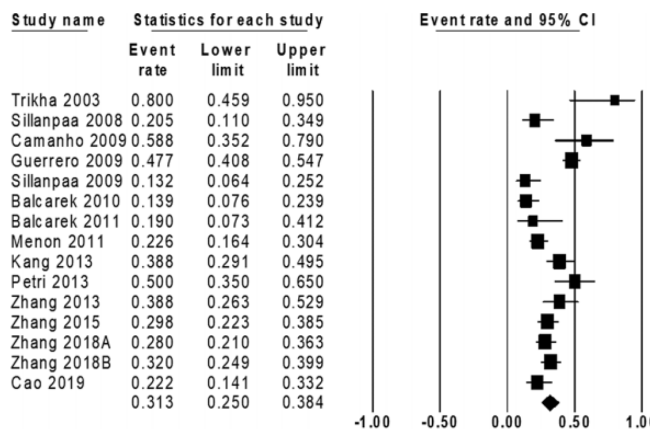


Figure A10. Forest plot illustrating the prevalence of medial patellofemoral ligament injuries at the patella in studies with a mean patient age >16 years. $Q = 73.4$ ($P < .0001$); $I^2 = 81\%$.

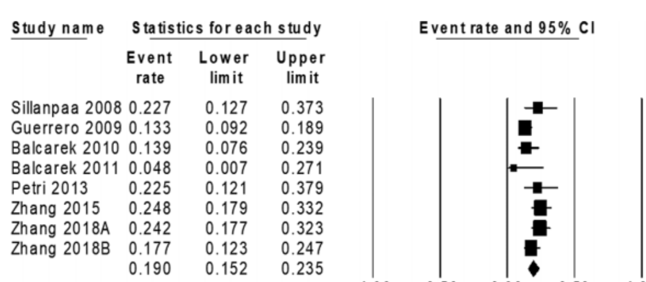


Figure A12. Forest plot illustrating the prevalence of combined sites of medial patellofemoral ligament (MPFL) injuries in studies with a mean patient age >16 years. Combined MPFL injuries involved the femur, midsubstance, and/or patella. $Q = 13.3$ ($P < .0001$); $I^2 = 47\%$.