Systematic Review

Medial Patellofemoral Ligament Reconstruction for Recurrent Patellar Dislocation: A Systematic Review Including Rehabilitation and Return-to-Sports Efficacy

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Purpose: We systematically reviewed the evaluated efficacy of medial patellofemoral ligament (MPFL) reconstruction, rehabilitation, and patient outcomes for safely returning patients to sports. **Methods:** We performed a literature search using the Ovid Medline database from 1950 to present, as well as the SportDiscus and CINAHL (Cumulative Index to Nursing and Allied Health Literature) databases. Only English-language studies that described MPFL reconstruction or repair, rehabilitation, and patient outcome information were included. Search terms were combinations of "MPFL repair," "MPFL reconstruction," "patellofemoral ligament," "patellar dislocation," "patient outcome," and "rehabilitation." Coleman Methodology Scores were used to evaluate research quality. **Results:** A total of 21 studies (11 prospective and 10 retrospective) met our inclusion criteria, with a total of 488 patients (184 male and 304 female patients) and 510 knees contributing to this review. Most patients were female (62.3%), and the mean age at surgery was 23.4 years (range, 6 to 52 years). Semitendinosus autografts were most commonly used (n = 145 [28.4%]). Of all reported complications at follow-up (n = 155), quadriceps dysfunction (n = 48 [31.0%]), positive apprehension (n = 32 [20.6%]), and decreased knee range of motion (n = 28 [18.1%]) were most common. Although inclusion criteria required rehabilitation information, the level of description was generally limited to acute care rehabilitation, with insufficient progressive exercise descriptions. Coleman Methodology Scores (58.76 ± 8.6) indicated generally poor study methodologies. **Conclusions:** MPFL reconstruction and rehabilitation are likely to improve a patient's ability to perform activities of daily living. Poor study methodology including outcome surveys that lack either sensitivity or validity to measure the influence of patellofemoral joint dysfunction on sports participation, as well as limited exercise rehabilitation information, make it difficult to determine efficacy. Recommendations for improved outcome measurements and more comprehensive functional rehabilitation are provided. **Level of Evidence:** Level IV, systematic review.

The patella is positioned within a soft-tissue sleeve that extends from the anterior iliac spines of the pelvis and proximal femur to the tibial tubercle.[1] Over the last 30° of knee extension, the patella lies outside the bony limits of the femoral trochlea, becoming more dependent on soft-tissue constraints.[2] Acute patellar dislocation is primarily an injury of active young patients of both sexes, with a higher recurrence rate in female patients.[3-6] The overall recurrence rate after primary patellar dislocation approaches 40%.[7] Patients who have a primary patellar dislocation have a 17% recurrence rate, and patients who sustain repeat patellofemoral joint dislocation have a 49% recurrence rate. Surgical treatment is generally recommended after a second dislocation.[3]

There is growing interest in the soft-tissue structures that help stabilize the patella.[8-11] The medial

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patellofemoral ligament (MPFL) provides approximately 60% of the total medial restraining force against lateral patellar displacement, whereas the medial patellomeniscal ligament, medial retinaculum, and medial patellotibial ligament contribute 13%, 3%, and 3%, respectively, at 20° of knee flexion.[9] The MPFL experiences maximal loads at full knee extension or early flexion as quadriceps femoris neuromuscular activation pulls the patella toward the femoral trochlea.[8,12,13] After 30° of knee flexion, patellar stability is provided more by the femoral trochlea.

In studying 20 athletes who had experienced traumatic patellar dislocation, Garth et al.[14] reported surgical evidence of MPFL deficiency in 50% of the cases. In studying 26 patients who had an acute patellar dislocation at a mean age of 18 years, Nomura et al.[15] reported evidence of MPFL damage in 96% of the knees examined during open surgical exploration (26 of 27). The MPFL is often damaged during patellar subluxation or dislocation, and many different MPFL surgical reconstruction or repair techniques have been described in the literature.[16,17] Previous reviews have identified study methodologic flaws[16,17] and poorly described rehabilitation;[16] however, with consideration for these limitations, functional outcome findings have been reported to be encouraging.[17] The purpose of this review was to evaluate the efficacy of MPFL reconstruction or reconstruction-repair, and rehabilitation, across the entire treatment period before patients return to sports, and patient outcomes, particularly as they apply to return to sports participation.

METHODS

We performed a systematic review using a literature search of the Ovid Medline database from 1950 to present, as well as the SportDiscus and CINAHL (Cumulative Index to Nursing and Allied Health Literature) databases, to identify any published studies of MPFL reconstruction or repair. Only English-language studies that described MPFL reconstruction or repair with inclusion of rehabilitation and patient outcome information were included in this study. Databases were searched by use of the terms "medial patellofemoral ligament repair," "medial patellofemoral ligament reconstruction," "patellofemoral ligament," "patellar dislocation," "rehabilitation," and "patient outcome." In addition, the reference sections of selected studies were evaluated for their relevance to our primary review. Non–English-language studies, previous reviews, animal studies, cadaveric studies, technical notes, case reports, editorials, and letters or comments to journals were excluded from this study. Focus was placed on identifying studies that described surgical intervention for recurrent lateral patellar dislocation or subluxation with primary MPFL reconstruction or repair that also described rehabilitation and patient outcome assessment.

After identifying studies that met our inclusion criteria, we used the Coleman Methodology Score to evaluate studies for research methodology.[18,19] The Coleman Methodology Score was developed to assess study design and determine the influence of chance, different biases, and confounding factors on the reported patient outcome. In assigning scores based on the Coleman Methodology Score criteria, we relied on the following guidelines.

Study Size

If multiple surgical procedures were compared, the study size item was scored based on only those patients who underwent isolated MPFL reconstruction or repair as part of their treatment.

Number of Treatment Procedures

Only those reports that described MPFL reconstruction or repair as the lone surgical procedure received 10 points. Several studies reported using a lateral release, tibial tubercle transfer, or chondroplasty surgical procedure in addition to MPFL reconstruction or repair. If fewer than 90% of the patient group in any study received MPFL reconstruction or repair alone, the study received 0 points.

Description of Postoperative Rehabilitation

Inclusion criteria required at least a minimal description of rehabilitation; therefore, each study received at least 5 points. To receive 10 points, a study had to either include additional information regarding rehabilitation compliance or provide more comprehensive descriptions of postoperative rehabilitation.

Outcome Criteria

Inclusion of the Kujala, Lysholm, Tegner or another standardized knee score was interpreted as providing a clearly defined outcome measurement (2 points). If timing of the assessment was explicitly mentioned in the study, 2 additional points were given. Studies that used knee scoring systems that have shown adequate test-retest reliability[20] received an additional 3 points. Surveys such as the Kujala score, which was devel-

oped specifically for patients with anterior knee dysfunction, and the higher measurement levels of the International Knee Documentation Committee (IKDC) Patient Self-Reported Perceived Function Survey, the Cincinnati Knee Rating Scale, and visual analog scale (VAS) measurements of specific sports-related knee function, rather than subjective categorical inventories, were given an additional 3 points for displaying sufficient measurement sensitivity.

Procedure for Assessing Outcomes

Subjects were deemed to be properly recruited, receiving 5 points if they were selected from consecutive cases, with the omission of only those individuals who did not meet the study inclusion criteria. The investigator was assumed to be the same as the surgeon unless otherwise noted in the study. If an independent investigator other than the surgeon performed measurements, 4 additional points were given. If evidence of a written assessment was provided, such as inclusion of the Kujala score or a similar self-administered survey, 3 additional points were given.

Description of Subject Selection Process

Most studies clearly reported their subject selection criteria, receiving 5 points. Several studies, however, did not reveal the pool of patients from which study participants were selected and therefore did not account for or did not make clear why certain potential study subjects were omitted. If potential study subjects appeared to be unaccounted for or if the omission of potential subjects was unexplained, 5 points were deducted from the score. Studies also received 3 or 5 points based on the percentage of subjects who completed all study phases. If it appeared that all eligible subjects were accounted for but we could not determine the recruitment rate, 3 points were given. If all eligible subjects could not be accounted for, 0 points were given.

RESULTS

A total of 53 studies were initially identified. After further evaluation by 2 independent reviewers, 21 studies were identified that met all study inclusion criteria. A total of 488 patients (184 male and 304 female patients) and 510 knees contributed to this review (Table 1).[21-41] A majority of patients treated with MPFL reconstruction were female (62.3%). The mean number of male patients per study was 8.8 ± 4.9, whereas the mean number of female patients per study was 14.5 ± 9.1. The mean number of knees per study was 24.8 ± 10.5. The mean age at the time of surgery was 23.4 years (range, 6 to 52 years).

Surgical procedures to reconstruct or repair the MPFL used the following graft types: adductor magnus tendon autograft with retinacular overlap,[22,38] pedicled adductor magnus tendon autograft with lateral release,[27] adductor magnus tendon autograft,[39] gracilis tendon autograft,[23,31,36,40,41] semitendinosus tenodesis with lateral release and distal vastus medialis advancement,[24] semitendinosus tendon autograft,[21,26,29,30,32,36,37,41] semitendinosus-gracilis tendon autograft,[26] iliotibial band graft,[26] direct MPFL repair,[26] semitendinosus or gracilis autograft with tibial tubercle transfer,[41] split one-half semitendinosus tendon autograft,[27] semitendinosus tendon autograft with remnant of torn MPFL and periosteum,[34] polyester "ligament" or tape,[28,35] quadriceps tendon autograft,[25,39] and bone–patellar tendon–bone allograft.[39] Semitendinosus tendon autografts were the most commonly used reconstruction construct (n = 145 [28.4%]) (Fig 1).

The mean follow-up time after surgery was 4.7 ± 2.8 years. Among the 12 studies that reported Kujala scores, subjects improved from 49.7 ± 9.7 to 90.8 ± 3.7.[21,23-26,32,34,35,37-40] Among the 5 studies that reported Lysholm scores, subjects improved from 57.7 ± 9.7 to 89.0 ± 3.1.[21,22,31,39,41] Among the 6 studies that reported Tegner scores, subjects improved from 3.9 ± 1.0 to 5.4 ± 1.2.[21,23,26,31,38,39] Among studies that reported other categorical and/or subjective scale scores, such as the Aglietti, Crosby-Insall, Insall, Larsen-Lauridsen, Fulkerson criteria, or surgeon opinions (number of knees, 182), the following overall approximate outcome distribution was observed: excellent, 108 (59.3%); good, 57 (31.3%); fair, 12 (6.6%); and poor, 4 (2.7%).[22,25,26,28-30,33-35] In the 2 studies that used the IKDC Patient Self-Report Survey, the study mean improved from 50.6 ± 12 to 88 ± 8.1.[21,31] In the study that used the Knee Outcome Survey Activities of Daily Living Scale, patients improved from 50.4 ± 0.4 to 72.8 ± 0.07.[27] In the 2 studies that reported the frequency of subjects who returned to sports at a preinjury performance level, a successful percentage of 77.3% ± 1% was reported.[25,32] Ronga et al.[36] used the modified Cincinnati Knee Rating score, reporting that patients improved from 52 ± 19 to 89 ± 21. Watanabe et al.[41] reported comprehensive VAS findings for 21 items related to patellofemoral joint function, reporting composite total postoperative scores of 91 ± 17 for the group that underwent only primary MPFL reconstruction with a

TABLE 1. *Patient Demographics, Surgical Method, Follow-up, and Outcome Assessment in MPFL Reconstruction Studies*

Study	No. of Male Patients/Female Patients/Knees	Mean Age (range) (yr)	Method	Follow-up (range) (yr)	Kujala*	Lysholm*	Tegner*	Other*
Ahmad et al.[21]	6/15/21	23 (11-43)	ST 17, ST Allo 2, and TA Allo 2 (12 LR)	2.58 (2-3.3)	49.9/88.2	49.5/88.7	3.6/5.6	IKDC: 42.1/82.3
Avikainen et al.[22]	4/10/14	20 (15-27)	AM–ret dupl	6.9 ± 0.5		Post: 84 ± 15		Subjective opinion (Post): 12/14 G and 2/14 F
Christiansen et al.[23]	15/29/44	22 (12-47)	GT	1.83 (1-2.7)	46 (12-67)/84 (62-100)		Post: 4 (1-9)	
Deie et al.[24]	9/34/46	19.2 (6-43)	ST tenodesis–VMA (46) and LR (42)	9.5 (5-12)	45/90 (estimated from figure)			
Dopirak et al.[25]	4/5/14	26.1 (15-46)	QT—1 TTT, 3 LR, 4 MCI, and 3 PC	3.5 (2.3-5.4)	Post: 91.9 (77-100)			Crosby-Insall (Post): 44% E and 56% G; 78% improved sports level
Drez et al.[26]	4/2/6	22 (14-52)	ST	2.62 (2-3.6)	Post: 90.7 (69-100)		6.8 (before injury)/6.7	Overall subjective opinion (Post): 10 E, 3 G, 1 F, and 1 P; Fulkerson (Post): 10 E, 4 G, and 1 F
	2/3/5		ST-GT		Post: 81 (57-100)			
	3/0/3		ITB		Post: 93.3 (82-100)			
	1/0/1		Direct repair		Post: 100			
Gomes[27]	4/8/12	19.3 (16-24)	Pedicled AM-LR	4.42 (2.5-5.9)				KOS-ADL: 50.6 ± 3.8/72.7 ± 1.3
	4/8/12		Split one-half free ST					KOS-ADL: 50.1 ± 3.7/72.8 ± 1.7
Ellera Gomes[28]	12/18/30	29 (17-50)	Polyester ligament	3.25 (2-4.5)				Crosby-Insall (Post): 20 E, 5 G, 4 F, and 1 P
Ellera Gomes et al.[29]	4/11/16	26.7 (21-37)	ST	All >5				Crosby-Insall (Post): 11 E, 4 G, and 1 P Aglietti protocol (Post): 11 E, 3 G, 1 F, and 1 P
Fernandez et al.[30]	8/20/30	23 (17-28)	ST	3.17 (1-4)				Larsen-Lauridsen (Post): 27 E, 2 G, and 1 F
Lim et al.[31]	6/3/9	20.2 (14-23)	GT	0.93 (0.5-1.6)		57.4 (95% CI, 25.6-89.2)/89.4 (95% CI, 80.2-98.5)	5 (95% CI, 3.2-6.8)/6.8 (95% CI, 6.2-7.4)	IKDC: 59.1 (95% CI, 25.2-92.9)/93.6 (95% CI, 88.3-98.7)
Mikashima et al.[32]	10/14/24	21.8 (13-24)	ST	3.42 (2.3-4.3)	30.5 ± 6.7/95.2 ± 12.9			70.8% preinjury sports; 76.5% same sports
Nomura et al.[33]	5/19/27	21 (13-40)	Polyester tape	5.9 (4.1-9.5)				Crosby-Insall (Post): 15 E, 11 G, and 1 F-P
Nomura and Inoue[34]	4/8/12	24.8 (13-24)	ST + MPFL remnant–periosteum	4.2 (3.1-5.6)	56.3 ± 15.6/96 ± 5.2			Insall (Post): 8 E, 2 G, and 2 F
Nomura et al.[35]	4/18/24	22.5 (13-48)	Polyester tape (50% with LR)	11.9 (8.5-17.2)	63.2 ± 12.7/94.2 ± 7			Crosby-Insall (Post): 11 E, 10 G, and 3 F-P
Ronga et al.[36]	21/7/28	32.5 (19-40)	GT, 23; ST, 5	3.1 (2.5-4)				Cincinnati: 52/89
Schöttle et al.[37]	4/8/15	30.1 (19-36)	ST	3.96 (2-5.8)	53.5 (31-76)/85.7 (85-100)			
Sillanpaa et al.[38]	18/0/18	20.2 (19-22)	AM–ret dupl	10.1 (8-13)	Post: 88.0 (57-100)		Post: 4 (2-8)	
Steiner et al.[39]	8/15/23	27	AM	5.54 (2-10.8)	53.3 ± 10.2/89.3 ± 10.4	52.4 ± 12.6/92.2 ± 7.2	3.1 ± 1.6/5.3 ± 1.7	
	2/4/6		QT		53.3 ± 10.2/94.5 ± 4.3	52.4 ± 12.6/91.7 ± 11.4	3.1 ± 1.6/5.3 ± 1.5	
	2/3/5		PT allo		53.3 ± 10.2/92.8 ± 3.9	52.4 ± 12.6/92 ± 11.8	3.1 ± 1.6/4.4 ± 1.1	
Thaunat and Erasmus[40]	8/12/23	22 (21.5-22.5)	GT	2.3 (0.75-4.5)	Post: 93 ± 6			
Watanabe et al.[41]	9/20/29	19 (11-36)	ST or GT	4.3 (1.5-8.1)		70.2 ± 16.7/92.4 ± 7.6		VAS (Post): 91 ± 17
	3/10/13	20 (14-32)	ST or GT with TTT			72.4 ± 15.4/89.8 ± 11.1		VAS (Post): 81 ± 28

Abbreviations: ST, semitendinosus autograft; Allo, allograft; TA, tibialis anterior; LR, lateral release; IKDC, International Knee Documentation Committee Patient Self-Report Survey; AM, adductor magnus; ret dupl, retinacular duplication or imbrication; Post, postoperatively; G, good; F, fair; GT, gracilis tendon autograft; VMA, vastus medialis advancement; QT, quadriceps tendon autograft; TTT, tibial tubercle transfer; MCI, medial capsular imbrication; PC, patellar chondroplasty; Crosby-Insall, Crosby-Insall Rating System; Larsen-Lauridsen, Larsen-Lauridsen Score Criteria; E, excellent; ITB, iliotibial band; Fulkerson, Fulkerson Knee Instability Scale; P, poor; KOS-ADL, Knee Outcome Survey Activities of Daily Living Scale; CI, confidence interval; Cincinnati, Cincinnati Knee Rating Score; PT, patellar tendon; VAS, visual analog scale.

*Data are presented as preoperative/postoperative data unless otherwise indicated.

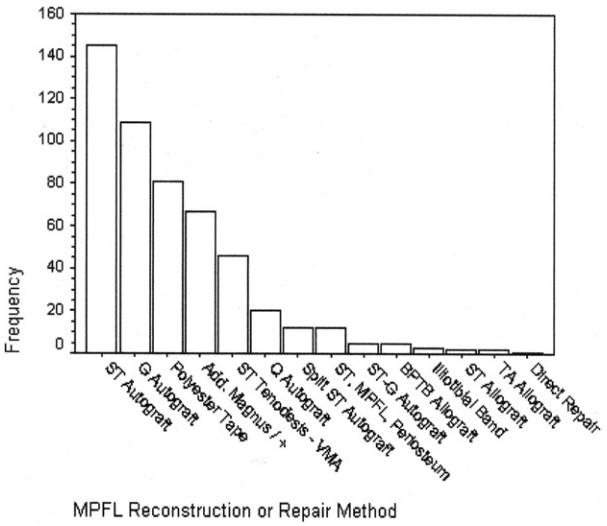

Figure 1. Frequency of construct use for MPFL reconstruction. (ST, semitendinosus; G, gracilis; Add, adductor; plus sign, possibly with concomitant procedure; VMA, vastus medialis advancement; BPTB, bone–patellar tendon–bone; Q, quadriceps; TA, tibialis anterior.)

semitendinosus or gracilis autograft versus 81 ± 28 for the group that underwent both primary MPFL reconstruction and tibial tubercle transfer. However, preoperative measurements were not performed. The incidence of reported complications at patient follow-up is shown in Fig 2. Of all complications (n = 155), quadriceps dysfunction (n = 48 [31.0%]), positive apprehension (n = 32 [20.6%]), and decreased knee range of motion (n = 28 [18.1%]) were most common.

All 21 studies (100%) included in this review provided a basic description of early, acute care postoperative rehabilitation (Table 2). The timing for return to sports participation was described in 14 studies (66.7%).[21,23,26,28-30,32-37,40,41] Of these studies, 13 provided a specific timetable of 6 months (53.8% [n = 7]),[23,28,29,32,36,37,41] 3 months (38.5% [n = 5]),[26,30,33-35] or 4 months (7.7% [n = 1]).[21] One study mentioned that full sports participation was only allowed when the quadriceps was completely rehabilitated; however, it did not describe exactly how this was determined.[40] Of the 14 studies that described return to sports participation timing, 6 (42.9%) mentioned more advanced quadriceps exercise training,[21,22,26,37,40,41] 6 (42.9%) mentioned some form of jogging and/or agility training,[21,32-34,36,41] and 3 (21.4%) mentioned the need for hamstring exercise.[21,36,41] Only 1 of 14 studies (7.1%) mentioned proprioceptive[36] or hip-strengthening exercises.[21] The need for controlled,[5] mild,[32-34] or gradual[36] return to sports participation was mentioned in 5 of 14 studies (35.7%). Of 14 studies, 1 (7.1%) mentioned the need for sports-specific rehabilitation[36] or progressive activities of daily living.[36]

Coleman Methodology Scores are reported in Table 3. Three independent reviewers performed this evaluation, first reviewing all studies independently and then meeting as a group to reach consensus. Although most studies (19 of 21 [90.5%]) had an adequate mean follow-up time for patient outcome assessment, none received maximum points for having adequate subject group size. In addition, only one-third of the studies included in our review received maximum points for reporting outcomes for only 1 surgical treatment intervention (isolated MPFL reconstruction or repair).[22,27,31,38-40] In most studies, though focusing on MPFL reconstruction, concomitant lateral release,[21,24-30,33-35] tibial tubercle transfer,[23,25,30,37,41] or chondroplasty[21,25,28,36] was also performed. One study was unclear in describing the total number of concomitant surgical procedures that was performed while reporting an outcome as if only 1 surgical treatment was performed.[32] No randomized controlled studies were identified. Of the 21 studies that were evaluated, 11 (52.4%) were deemed to be prospective studies whereas the remainder (n = 10 [47.6%]) were retrospective studies. Maximum points for diagnostic certainty was given to all studies, with several specifically reporting arthroscopic,[22,24,26,30,36,40] magnetic resonance imaging,[21,27,31,36] and computed tomogra-

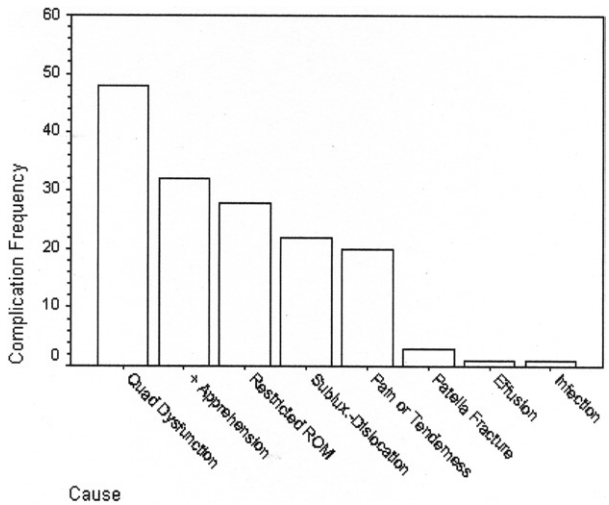

Figure 2. Complications reported at time of follow-up after MPFL reconstruction. (Quad, quadriceps; ROM, range of motion; Sublux, subluxation.)

TABLE 2. *Acute Care Rehabilitation, Advanced Exercise Rehabilitation, and Patient Complications in MPFL Reconstruction Studies*

Study	Acute Care Rehabilitation	Exercise Rehabilitation	Patient Complications
Ahmad et al.[21]	WBT with brace at 0° extension for 6 wk; immediate isometric quadriceps and SLR exercises; AROM and PROM at 2 wk	Quadriceps, hamstring, and hip strengthening at 6 wk; running-agility after 3 mo; full sports at 4 mo postoperatively	None reported
Avikainen et al.[22]	Patient allowed 45°-60° of knee flexion at 5-6 wk; PWB at 2 wk	Quadriceps training	1 patient had 3 recurrences; 1 was dissatisfied but no recurrence
Christiansen et al.[23]	Brace at 0°-90° for 2 wk; FWB with brace locked at 0°; 0°-90° AROM without brace at 2-6 wk; FWB gait	Free ADLs at 6 wk; controlled sports at 12 wk; contact sports at 6 mo	1 patient had redislocation at 6 mo; 3 with subluxation sensation; 1 with patellar fracture at 6 wk
Deie et al.[24]	Knee immobilized for 2 wk in soft brace; PROM and PWB gait at 3 wk postoperatively; FWB at 6 wk	Not described	3 patients (4 knees) with continued subluxation sensation and positive apprehension sign
Dopirak et al.[25]	WBT with immobilizer; seated AROM; quadriceps sets and SLR; immobilizer discontinued with improved quadriceps function	Not described	22% patients did not improve athletic level (1 pain and 1 swelling); 1 had quadriceps atrophy
Drez et al.[26]	Immobilizer for 2 wk; SLR and quadriceps sets at 2 wk; AROM and WBT gait at 3 wk	Full AROM, normal quadriceps strength, and full activity at 12 wk	1 patient had redislocation; 5 of 15 patients had a 5°-10° flexion loss; 9 had quadriceps atrophy
Gomes[27]	FWB with crutches at 1 wk	Not described	1 patient with subluxation
Ellera Gomes[28]	PROM-AROM and PWB on 5th day; FWB on 10th day	Return to sports at 6 mo; some motivated patients return by 4 mo	1 patient had habitual subluxation at full extension; 9 had slightly decreased knee flexion or apprehension; 4 had pain or recurrent subluxation; worse with severe chondral injury
Ellera Gomes et al.[29]	PWB at 2nd day; FWB after 12 days; AROM at 5 days (≤90° for 3 wk)	Sports at 6 mo	1 patient with positive apprehension, patellofemoral pain, and abnormal tracking
Fernandez et al.[30]	Immobilizer in full extension for 1 wk with WBT; progressive AROM after 1 wk; immobilizer with gait for 6 wk	Full activity at 12 wk	1 patient had wound infection and only 120° of flexion
Lim et al.[31]	Brace used for initial 6 wk	Not described	None reported
Mikashima et al.[32]	Immobilizer; quadriceps exercises with extended knee; CPM on 2nd day; patellar brace at 3 wk; FWB at 5 wk	Jogging and "mild" sports at 4 mo; full sports at 6 mo	Two patients had patella fracture; 1 had positive apprehension
Nomura et al.[33]	Immobilizer; quadriceps exercise with full knee extension; CPM on 2nd to 3rd day; patellar brace and WBT gait on day 5; FWB on day 10	Jogging and "mild" sports at 8 wk; full sports at 12 wk	2 knees had positive apprehension; 11 knees had tenderness at staple; 1 knee had subluxation-dislocation
Nomura and Inoue[34]	Brace; SLR and quadriceps sets; WBT and CPM at 0°-40° at 4th day (goal of 90° by 14th day); patellar brace at 4-6 days; FWB by 13th day	Jogging and "mild" sports at 8 wk; full sports at 12 wk	1 patient had 10° decreased flexion
Nomura et al.[35]	Immobilizer; quadriceps exercises; PROM-AROM at 2-5 days; WBT at 5-10 days with patellar brace; FWB at 10-17 days	Sports at 3 mo	Lateral subluxation or dislocation in 2 knees; 1 patient had patellofemoral pain; 5 knees with positive apprehension
Ronga et al.[36]	PWB in splint and PWB-FWB at 2 wk; splint removed and ROM at 6 wk; stationary cycling in first 3 wk to achieve 90° flexion by 7th to 8th week	Concentric, proprioceptive exercise at 7th to 8th week; mini-trampoline jogging at 8th week; sport-specific rehabilitation at 12th wk; gradual ADLs at 3-6 mo; sports at 6 mo	3 patients had recurrent dislocation; all had decreased involved lower extremity isokinetic knee extensor torque and thigh volume

TABLE 2. *Continued*

Study	Acute Care Rehabilitation	Exercise Rehabilitation	Patient Complications
Schöttle et al.[37]	Immobilizer; PWB (50%) BW at 6 wk; PROM to 60° in first 2 wk; after 2 wk, SLR, quadriceps sets, and ROM increased to 90°; no ROM restrictions at 4 wk	Full activity at 6 mo if ROM and quadriceps strength restored	2 patients with recurrent instability
Sillanpaa et al.[38]	Immobilization in patellar orthosis with flexion limited to 60° for 3 wk; no WB restrictions	Not described	1 patient with redislocation, 2 painful subluxations, 2 reoperations, 10 of 13 had OA at follow-up
Steiner et al.[39]	CPM at 0°-60°; active exercise; FWB with immobilizer for 4 wk (until normal quadriceps function and knee ROM)	Not described	1 motor vehicle accident
Thaunat and Erasmus[40]	Immediate full PROM; active flexion and isometric quadriceps exercise; PWB for 4 wk, then FWB	Intense quadriceps exercise at >3 mo; full sports when quadriceps rehabilitation achieved	10 knees had extensor lag/quadriceps weakness
Watanabe et al.[41]	Quadriceps sets and SLR from day 1; PWB in full extension with brace and ROM at 3 days; FWB at 2-4 wk	85% had equal isokinetic knee strength; jogging at 12 wk with good strength, ROM, stability; return to sports at 6 mo	2 patients with 10° knee flexion ROM deficit; 8 with positive apprehension

Abbreviations: WBT, weight bearing as tolerated; SLR, straight leg raise; AROM, active range of motion; PROM, passive range of motion; PWB, partial weight bearing; FWB, full weight bearing; ADLs, activities of daily living; CPM, continuous passive motion device; ROM, range of motion; BW, body weight; WB, weight bearing; OA, osteoarthritis.

phy scan[30,31,37] evaluations in addition to clinical preoperative physical examination. Most studies were given maximum points for surgical treatment descriptions (n = 18 [85.7%]), with only 3 providing descriptions that were deemed to be fair but lacking necessary detail.[22,24,31] Because our inclusion criteria required all studies to include some mention of postoperative rehabilitation, all received at least minimum points for this item. However, only one of the studies received maximum points for providing a sufficiently detailed description of postoperative rehabilitation or rehabilitation compliance information.[36] The Coleman Methodology Score for outcome criteria represents a summative score based on having clearly defined measures, having clearly stated outcome assessment timing, and using an outcome criterion that has good reliability and sensitivity.[18,19] We gave 15 studies (71.4%) maximum points.[21,23-26,31,32,34-41] Studies that were given less than maximum points tended to rely on an outcome measurement that did not include sports activities or that was exclusively dependent on surgeon- or examiner-completed categorical measurement criteria without obvious patient participation.[22,27-30,33] Only 2 of 21 studies (9.5%) were given maximum points for the procedures used to assess patient outcomes.[27,36] Point reductions for this item occurred if it was not clear how subjects were recruited (or if information appeared to have been taken from surgeon files),[24,32,37,39,40] if an investigator independent of the surgeon was not identified,[21-26,28,30-35,37,38,40,41] if a written assessment could not be determined,[22,28-30,33,39] or if outcome assessment completion was not performed by the subjects themselves with minimal investigator assistance.[22,28-30,33,39] One-third of the studies included in this review provided an adequate subject selection process description.[22,23,29-31,39,41] Our reviewers gave less than maximum points to a study if they deemed it to have less than adequately described selection criteria,[28,35,40] if it had a reported recruitment rate of less than 80% of the available study population,[24-28,33-37,40] or if it did not appear to adequately account for eligible subjects who could have been included or who did not complete the study.[21,27,28,33-38,40]

DISCUSSION

Although many surgical procedures and ligament construct options have been identified for MPFL reconstruction or repair, strong evidence obtained from methodologically sound studies that verify its efficacy for allowing a patient to safely return to sports participation does not exist. Although the Lysholm score is a useful tool for determining important activities of daily living capability, it primarily addresses impairment-level knee information such as the presence of a

TABLE 3. *Coleman Methodology Scores for MPFL Reconstruction Studies That Included Patient Rehabilitation and Outcome Information*

	Part A							Part B			
Study	Study Size (10)	Mean Follow-up (5)	No. of Treatment Procedures Included in Each Reported Outcome (10)	Type of Study (15)	Diagnostic Certainty (5)	Description of Treatment Given (5)	Description of Rehabilitation (10)	Outcome Criteria (10)	Procedure for Assessing Outcomes (15)	Description of Subject Selection Process (15)	Total Score
Ronga et al.[36]	4	5	0	10	5	5	10	10	15	8	72
Christiansen et al.[23]	7	2	0	10	5	5	5	10	11	15	70
Watanabe et al.[41]	4	5	0	10	5	5	5	10	11	15	70
Lim et al.[31]	0	0	10	10	5	3	5	10	11	15	69
Steiner et al.[39]	4	5	10	0	5	5	5	10	9	15	68
Deie et al.[24]	7	5	0	10	5	3	5	10	6	13	64
Gomes[27]	4	5	0	10	5	5	5	7	15	8	64
Fernandez et al.[30]	4	5	0	10	5	5	5	7	5	15	61
Sillanpaa et al.[38]	0	5	10	0	5	5	5	10	11	10	61
Ellera Gomes et al.[29]	0	5	0	10	5	5	5	5	9	15	59
Nomura and Inoue[34]	0	5	0	10	5	5	5	10	11	8	59
Nomura et al.[35]	4	5	0	10	5	5	5	10	11	3	58
Ahmad et al.[21]	4	5	0	0	5	5	5	10	11	10	55
Avikainen et al.[22]	0	5	10	0	5	3	5	7	5	15	55
Dopirak et al.[25]	0	5	0	0	5	5	5	10	11	13	54
Drez et al.[26]	0	5	0	0	5	5	5	10	11	13	54
Nomura et al.[33]	4	5	0	10	5	5	5	7	5	8	54
Mikashima et al.[32]	4	5	0	0	5	5	5	10	6	13	53
Thaunat and Erasmus[40]	4	5	10	0	5	5	5	10	6	3	53
Schöttle et al.[37]	0	5	0	0	5	5	5	10	6	8	44
Ellera Gomes[28]	4	5	0	0	5	5	5	5	5	3	37
Mean (SD)	2.76 (2.4)	4.62 (1.2)	3.33 (4.8)	5.24 (5.12)	5.00 (0.0)	4.71 (0.7)	5.24 (1.1)	8.95 (1.8)	9.10 (3.2)	10.76 (4.0)	58.76 (8.60)

limp, the need for ambulatory support, and the presence of joint locking, instability, pain, and swelling.[42,43] Only limited functional limitation information relating to stair climbing and squatting is included.[43] The Kujala Scoring Questionnaire was designed to assess the function of patients who have anterior knee pain from patellofemoral joint conditions, evaluating both impairments such as the presence of a limp and the need for ambulatory support and functional limitations related to walking, stair ascending/descending, squatting, and running.[44] Neither the Lysholm score nor the Kujala Scoring Questionnaire includes information related specifically to sports participation capability. Although the Tegner Activity Score considers both activities of daily living and recreational or competitive sports, it provides little insight as to a patient's proficiency in playing his or her sport, whether he or she had to use any technique modifications, or the relation between disability, functional limitation, and knee joint impairment. In addition, in the studies that were included in this review, it was often difficult to ascertain whether the examiner or the patient completed the surveys.

Scores obtained from the Lysholm, Tegner, Kujala, and Fulkerson[26] surveys have item weights that were determined by their surgeon creators. Therefore we really do not know the impact that knee locking or limping during walking, for example, may truly have on the disability level of the individual patient, even during the performance of routine activities of daily living, let alone during sports participation. Similar issues exist with more subjective categorical inventories such as the Aglietti,[29] Crosby-Insall,[25,29,33-35] and Larsen-Lauridsen[30] criteria, where the surgeon essentially ranks patient function based on his or her measurements, observations, or opinions. Although more comprehensive patient self-administered surveys, such as the VAS used by Watanabe et al.,[41] the IKDC Subjective Patient Self-Report survey used by Ahmad et al.[21] and Lim et al.,[31] the Knee Outcome Survey Activities of Daily Living Scale used by Gomes et al.,[27] and the Cincinnati Knee Rating Score used by Ronga et al.,[36] provided more sensitive measures of knee function, further evaluation may be needed to determine their validity and applicability for measuring patient function after patellofemoral joint injury and MPFL reconstruction particularly as it influences sports participation. Because of deficiencies in existing knee surveys, Paxton et al.[20] recommended using a knee-specific survey such as those reported by Kujala, Lysholm, or Fulkerson[26] in addition to the Tegner Activity Score and a general health questionnaire such as Medical Outcomes Survey Short Form 36. Although this combination would certainly provide a more comprehensive profile of the true impact of knee function on patient disability, important information regarding patient sports participation capability would still be lacking. These surveys have been helpful in organizing and assessing treatment efficacy for various knee procedures, but as surgical methods, rehabilitation science, and patient expectations change, we need to reassess the manner in which we measure postoperative patient outcomes.[42] Though both useful and widely used, the Kujala Scoring Questionnaire,[44] for example, provides only one item each related to jumping and running, and does not specifically address jump landings, or running directional changes. To more effectively evaluate the functional limitations and disability of athletically active patients who have patellofemoral joint dysfunction, surveys need to include items related to cutting/directional-change movements, performing sudden stops/starts, and more sports task–specific impairment scoring for pain and knee giving way. In addition, because patient self-efficacy and confidence levels[45] are known to be related to return–to–sports participation effectiveness after other knee injuries and surgical interventions,

Figure 3. Improving dynamic patellofemoral joint stability by facilitating coordinated 3-dimensional trunk, hip, knee, and ankle interaction (global function) during Matrix (Gray, G. Team Reaction, Adrian, MI) exercise with 1.8-kg medicine ball resistance.

they should also be integrated into surveys that measure the function of patients with patellofemoral joint conditions, injury, or surgery.

In agreement with Smith et al.,[16] initial acute care rehabilitation including early postoperative exercises and wound and effusion management were generally well described; however, very limited information was provided that described the more intense progressive exercise rehabilitation interventions that preceded sport-specific training or criteria-based evaluation methods that contributed to eventual return–to–sports participation readiness decision making. Patients with patellofemoral dysfunction often have weaker external hip rotator and abductor muscle strength at their involved lower extremity compared with their uninvolved lower extremity.[46] During sports movements such as single-leg jump landings, a 3-dimensional loading response occurs including contralateral pelvic drop, femoral internal rotation, knee valgus, tibial internal rotation, and foot pronation.[47] A blend of open and closed kinetic chain exercises are essential components of exercise rehabilitation because open chain exercises more easily enable the training of isolated muscle groups whereas closed kinetic chain exercises more easily enable functional integration of multiple lower extremity segments.[48] Vastus medialis obliquus and MPFL integrity are essential to aggregate quadriceps femoris function. Aggregate quadriceps femoris function however is only optimal when coordinated with synergistic hip muscle activation. In contrast to non–weight-bearing function, where the patella moves over a relatively fixed femur, during weight-bearing function, the femur actually moves beneath a relatively fixed patella.[47] Long-axis femoral internal rotation and hip adduction are largely controlled by the pelvic deltoid musculature, particularly the gluteus maximus and gluteus medius. Although traditional patellofemoral instability and dysfunction rehabilitation have, for obvious reasons, centered on the knee joint through vastus medialis obliquus strengthening and stretching to alleviate patella alta, lateral tracking, and hamstring tightness,[49] the importance of restoring or developing appropriate strength, range of motion, and neuromuscular activation throughout the entire lower extremity to reduce MPFL strain is now more greatly appreciated.[8] In addition to re-establishing unimpaired quadriceps function, progressive rehabilitation should consider local (knee), regional (hip to ankle and core), and global (entire body during simulated sports movements) functional relations. The re-establishment of effective dynamic knee stability,[50] particularly during eccentric lower extremity neuromuscular activation, is essential to having a successful patient outcome and preventing knee reinjury (Fig 3).[51] Earlier implementation of sports-specific exercises during rehabilitation can improve patient confidence and self-efficacy and facilitate an earlier, safe return to sports participation.[45]

On the basis of the current evidence, MPFL reconstruction and rehabilitation are very likely to improve a patient's ability to perform routine activities of daily living regardless of the particular reconstruction method or graft construct that is used. This finding is in agreement with the finding of Buckens and Saris[17] of excellent functional outcomes. Unfortunately, it is equally accurate to suggest that we have a very limited understanding about the true capacity of any of these surgical interventions and their associated rehabilitation to enable patients to safely return to full sports participation.

REFERENCES

1. Eckhoff DG, Brown AW, Kilcoyne RF, Stamm ER. Knee version associated with anterior knee pain. *Clin Orthop Relat Res* 1997:152-155.
2. Heegaard J, Leyvraz PF, Van Kampen A, Rakotomanana L, Rubin PJ, Blankevoort L. Influence of soft tissue structures on patellar three-dimensional tracking. *Clin Orthop Relat Res* 1994:235-243.
3. Fithian DC, Paxton EW, Stone ML, et al. Epidemiology and natural history of acute patellar dislocation. *Am J Sports Med* 2004;32:1114-1121.
4. Hinton RY, Sharma KM. Acute and recurrent patellar instability in the young athlete. *Orthop Clin North Am* 2003;34: 385-396.
5. Nikku R, Nietosvaara Y, Aalto K, Kallio PE. Operative treatment of primary patellar dislocation does not improve medium-term outcome: A 7-year follow-up report and risk analysis of 127 randomized patients. *Acta Orthop* 2005;76:699-704.
6. Sillanpaa P, Mattila VM, Iivonen T, Visuri T, Pihlajamaki H. Incidence and risk factors of acute traumatic primary patellar dislocation. *Med Sci Sports Exerc* 2008;40:606-611.
7. Maenpaa H, Huhtala H, Lehto MU. Recurrence after patellar dislocation. Redislocation in 37/75 patients followed for 6-24 years. *Acta Orthop Scand* 1997;68:424-426.
8. Bicos J, Fulkerson JP, Amis A. Current concepts review: The medial patellofemoral ligament. *Am J Sports Med* 2007;35: 484-492.
9. Desio SM, Burks RT, Bachus KN. Soft tissue restraints to lateral patellar translation in the human knee. *Am J Sports Med* 1998;26:59-65.
10. LaPrade RF, Engebretsen AH, Ly TV, Johansen S, Wentorf FA, Engebretsen L. The anatomy of the medial part of the knee. *J Bone Joint Surg Am* 2007;89:2000-2010.
11. Tuxøe JI, Teir M, Winge S, Nielsen PL. The medial patellofemoral ligament: A dissection study. *Knee Surg Sports Traumatol Arthrosc* 2002;10:138-140.
12. Feller JA, Amis AA, Andrish JT, Arendt EA, Erasmus PJ, Powers CM. Surgical biomechanics of the patellofemoral joint. *Arthroscopy* 2007;23:542-553.
13. Senavongse W, Amis AA. The effects of articular, retinacular, or muscular deficiencies on patellofemoral joint stability: A

biomechanical study in vitro. *J Bone Joint Surg Br* 2005; 87:577-582.
14. Garth WP, DiChristina DG, Holt G. Delayed proximal repair and distal realignment after patellar dislocation. *Clin Orthop Relat Res* 2000:132-144.
15. Nomura E, Horiuchi Y, Inoue M. Correlation of MR imaging findings and open exploration of medial patellofemoral ligament injuries in acute patellar dislocations. *Knee* 2002;9:139-143.
16. Smith TO, Davies L, O'Driscoll M, Donell ST. An evaluation of the clinical test and outcome measures used to assess patellar instability. *Knee* 2008;15:255-262.
17. Buckens CFM, Saris DBF. Reconstruction of the medial patellofemoral ligament for treatment of patellofemoral instability: A systematic review. *Am J Sports Med* 2010;38:181-188.
18. Coleman BD, Khan KM, Maffulli N, Cook JL, Wark JD. Studies of surgical outcome after patellar tendinopathy: Clinical significance of methodological deficiencies and guidelines for future studies. *Scand J Med Sci Sports* 2000;10:2-11.
19. Jakobsen RB, Engebretsen L, Slauterbeck JR. An analysis of the quality of cartilage repair studies. *J Bone Joint Surg Am* 2005;87:2232-2239.
20. Paxton EW, Fithian DC, Stone ML, Silva P. The reliability and validity of knee-specific and general health instruments in assessing acute patellar dislocation outcomes. *Am J Sports Med* 2003;31:487-492.
21. Ahmad CS, Brown GD, Shubin Stein B. The docking technique for medial patellofemoral ligament reconstruction: Surgical technique and clinical outcome. *Am J Sports Med* 2009; 37:2021-2027.
22. Avikainen VJ, Nikku RK, Seppänen-Lehmonen TK. Adductor magnus tenodesis for patellar dislocation: Technique and preliminary results. *Clin Orthop Relat Res* 1993:12-16.
23. Christiansen SE, Jacobsen BW, Lund B, Lind M. Reconstruction of the medial patellofemoral ligament with gracilis tendon autograft in transverse patellar drill holes. *Arthroscopy* 2008; 24:82-87.
24. Deie M, Ochi M, Sumen Y, Adachi N, Kobayashi K, Yasumoto M. A long-term follow-up study after medial patellofemoral ligament reconstruction using the transferred semitendinosus tendon for patellar dislocation. *Knee Surg Sports Traumatol Arthrosc* 2005;13:522-528.
25. Dopirak R, Adamany D, Bickel B, Steensen R. Reconstruction of the medial patellofemoral ligament using quadriceps tendon graft: A case series. *Orthop* 2008;31:1-8.
26. Drez DJ, Edwards TB, Williams CS. Results of medial patellofemoral ligament reconstruction in the treatment of patellar dislocation. *Arthroscopy* 2001;17:298-306.
27. Gomes JE. Comparison between a static and dynamic technique for medial patellofemoral ligament reconstruction. *Arthroscopy* 2008;24:430-435.
28. Ellera Gomes JL. Medial patellofemoral reconstruction for recurrent dislocation of the patella: A preliminary report. *Arthroscopy* 1992;8:335-340.
29. Ellera Gomes JL, Stigler Marczyk LR, Cesar de Cesar P, Jungblut CF. Medial patellofemoral ligament reconstruction with semitendinosus autograft for chronic patellar instability: A follow-up study. *Arthroscopy* 2004;20:147-151.
30. Fernandez E, Sala D, Castejon M. Reconstruction of the medial patellofemoral ligament for patellar instability using a semitendinosus autograft. *Acta Orthop Belg* 2005;71:303-308.
31. Lim AKS, Chang HC, Hui JHP. Recurrent patellar dislocation: Reappraising our approach to surgery. *Ann Acad Med Singapore* 2008;37:320-323.
32. Mikashima Y, Kimura M, Kobayashi Y, Miyawaki M, Tomatsu T. Clinical results of isolated reconstruction of the medial patellofemoral ligament for recurrent dislocation and subluxation of the patella. *Acta Orthop Belg* 2006;72:65-71.
33. Nomura E, Horiuchi Y, Kihara M. A mid-term follow-up of medial patellofemoral ligament reconstruction using an artificial ligament for recurrent patellar dislocation. *Knee* 2000;7:211-215.
34. Nomura E, Inoue M. Hybrid medial patellofemoral ligament reconstruction using the semitendinosus tendon for recurrent patellar dislocation: Minimum 3 years' follow-up. *Arthroscopy* 2006;22:787-793.
35. Nomura E, Inoue M, Kobayashi S. Long-term follow-up and knee osteoarthritis change after medial patellofemoral ligament reconstruction for recurrent patellar dislocation. *Am J Sports Med* 2007;35:1851-1858.
36. Ronga M, Oliva F, Longo UG, Testa V, Capasso G, Maffulli N. Isolated medial patellofemoral ligament reconstruction for recurrent patellar dislocation. *Am J Sports Med* 2009;37:1735-1742.
37. Schöttle PB, Fucentese SF, Romero J. Clinical and radiological outcome of medial patellofemoral ligament reconstruction with a semitendinosus autograft for patellar instability. *Knee Surg Sports Traumatol Arthrosc* 2005;13:516-521.
38. Sillanpaa P, Mattila VM, Visuri T, Maenpaa H, Pihlajamaki H. Ligament reconstruction versus distal realignment for patellar dislocation. *Clin Orthop Relat Res* 2008;466:1475-1484.
39. Steiner TM, Torga-Spak R, Teitge RA. Medial patellofemoral ligament reconstruction in patients with lateral patellar instability and trochlear dysplasia. *Am J Sports Med* 2006;34:1254-1261.
40. Thaunat M, Erasmus PJ. The favourable anisometry: An original concept for medial patellofemoral ligament reconstruction. *Knee* 2007;14:424-428.
41. Watanabe T, Muneta T, Ikeda H, Tateishi T, Sekiya I. Visual analog scale assessment after medial patellofemoral ligament reconstruction: With or without tibial tubercle transfer. *J Orthop Sci* 2008;13:323-338.
42. Jenkins W, Bronner S, Mangine R. Functional evaluation and treatment of the lower extremity. In: Brownstein B, Bronner S, eds. *Functional movement in orthopaedic and sports physical therapy*. New York: Churchill Livingstone, 1997;191-229.
43. Tegner Y, Lysholm J. Rating systems in evaluation of knee ligament injuries. *Clin Orthop Relat Res* 1985:43-49.
44. Kujala UM, Jaakkola LH, Koskinen SK, Taimela S, Hurme M, Nelimarkka O. Scoring of patellofemoral disorders. *Arthroscopy* 1993;9:159-163.
45. Thomee P, Wahrborg P, Borjesson M, Thomee R, Eriksson BI, Karlsson J. A new instrument for measuring self-efficacy in patients with an anterior cruciate ligament injury. *Scand J Med Sci Sports* 2006;16:181-187.
46. Cichanowski HR, Schmitt JS, Johnson RJ, Niemuth PE. Hip strength in collegiate female athletes with patellofemoral pain. *Med Sci Sport Exerc* 2007;39:1227-1232.
47. Powers CM, Ward SR, Fredericson M, Guillet M, Shellock FG. Patellofemoral kinematics during weight-bearing knee extension in persons with lateral subluxation of the patella: A preliminary study. *J Orthop Sports Phys Ther* 2003;33:677-685.
48. Escamilla RF, Fleisig GS, Zheng N, Barrentine SW, Wilk KE, Andrews JR. Biomechanics of the knee during closed kinetic chain and open kinetic chain exercises. *Med Sci Sports Exerc* 1998;30:556-569.
49. Schepsis AA, Farr II J, Fulkerson JP. Patellofemoral instability. Instructional course lecture 204. In: *AOSSM 2005 Annual Meeting Preliminary Program*. Keystone, CO: American Orthopaedic Society for Sports Medicine, 2005:17.
50. Chaudhari AM, Hearn BK, Andriacchi TP. Sport-dependent variations in arm position during single-limb landing influence knee loading: Implications for anterior cruciate ligament injury. *Am J Sports Med* 2005;33:824-839.
51. LaStayo PC, Woolf JM, Lewek MD, Snyder-Mackler L, Reich T, Lindstedt SL. Eccentric muscle contractions: Their contributions to injury, prevention, rehabilitation, and sport. *J Orthop Sports Phys Ther* 2003;33:557-571.