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Current Concepts and Controversies in Rehabilitation After Surgery for Multiple Ligament Knee Injury

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Abstract
Purpose of Review The purpose of this manuscript is twofold: (1) to review the literature related to rehabilitation after surgery for multiple ligament knee injury (MLKI) and after isolated surgery for the posterior cruciate ligament (PCL), posterolateral corner (PLC), and medial side of the knee and (2) to present a hierarchy of anatomic structures needing the most protection to guide rehabilitation.
Recent Findings MLKIs continue to be a rare but devastating injury. Recent evidence indicates that clinicians may be providing too much protection from early weight bearing and range of motion, but an accelerated approach has not been rigorously tested.
Summary Consideration of the nature and quality of surgical procedures (repair and reconstruction) can help clinicians determine the structures needing the most protection during the rehabilitation period. The biomechanical literature and prior clinical experience can aid clinicians to better structure rehabilitation after surgery for MLKI and improve clinical outcome for patients.

Keywords Multiple ligament knee injury · Post-surgical rehabilitation · Knee dislocation · Early weight bearing · Early range of motion

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Introduction

Multiple ligament knee injuries (MLKIs), including knee dislocations, represent a spectrum of injury ranging from disruption of two ligaments (one cruciate ligament and one collateral ligament) to all four ligaments (both cruciates and both collateral ligaments). These injuries are potentially devastating and are often associated with significant injury to multiple structures of the knee including the ligaments, capsule, tendons, menisci, chondral surfaces, bone, nerves, and blood vessels [1–5]. While multiple studies have reported treatment algorithms and outcomes for MLKIs, many of these studies are retrospective in nature with small sample sizes. Only a few prospective studies have been published, and to date, there are no randomized controlled studies that have investigated optimal treatment methods for these complex knee injuries.

The lack of high-level evidence related to treatment of MLKIs is due to both the heterogeneity of the injury and the relatively low incidence of MLKIs compared to isolated ligament injury. The incidence of ACL injuries ranges from 0.31 to 0.69 per 1000 person-years [6, 7]. The incidence of MLKIs in the general population has

not been precisely reported; however, in civilians with an orthopedic injury, the incidence of a MLKI has recently been estimated to be 0.072 per 100 patient-years [8].

Operative management is superior to non-operative management for MLKIs [9••, 10–12]. Patients treated surgically are significantly more likely to return to work [13, 14] and sports [9••, 14, 15]. Furthermore, patients who underwent operative treatment for MLKI have been shown to develop end-stage arthritis less frequently and have reported superior patient-reported outcome scores than their peers who underwent non-operative management [9••]. However, there is controversy over the optimal time to perform surgery (early versus late) [11, 16, 17••] and, specifically, which surgical procedures should be performed (repair versus reconstruction) [18••, 19–22].

The variability in surgical procedures has resulted in a relative paucity of studies investigating the timing and composition of rehabilitation protocols. As a result, this issue has been poorly understood and remains the subject of intense debate. Early motion and weight bearing after surgery presents a perceived risk to the individual as it is thought to negatively affect healing and long-term joint stability of surgically repaired or reconstructed tissues [23–26]. However, some experts recommend early motion to prevent scar tissue from limiting joint motion and to lessen the impact of muscle atrophy [19, 27, 28], while others propose a hybrid approach. Results from a systematic review of clinical trials indicate that delayed rehabilitation runs the risk of poorer patient-reported and knee-related outcomes [17••].

Surgically repaired tissues need significant protection to prevent disruption. Repair of the medial or posterolateral corner (PLC) structures relies on suture fixation of soft tissues to bone, which must be protected from excessive forces to prevent failure [18••, 19, 29]. Repair or reconstruction of the posterior cruciate ligament (PCL) or PLC may be overly stressed by posterior translation, varus, and/or external rotation of the tibia, which can be caused by gravity or hamstring contraction [30–33]. In contrast, the anterior cruciate ligament (ACL) is typically reconstructed by placement of a graft through bone tunnels with the use of hardware that provides good graft security that should not be disrupted by early weight bearing (WB), early motion, or early exercise [34].

While protection after MLKI surgery is important to allow the surgically repaired or reconstructed tissues to heal, massive injuries and complicated surgeries are more likely to develop knee joint stiffness, loss of motion, and arthrofibrosis [17••]. The balance between protection from disruption and prevention of motion loss often favors over-protection, resulting in potentially more motion loss.

The combination of variable procedures and recommendations with the relative scarcity of these injuries results in many rehabilitation professionals being directed to treat every patient in a different manner. Therefore, the purpose of this manuscript is twofold:

1. To review the literature related to rehabilitation after surgery for MLKI and after isolated surgery for the PCL, PLC, and medial-sided knee injuries.
2. To present a hierarchy of structures needing the most protection to guide rehabilitation.

Rehabilitation Controversies After Surgery for MLKI

There have been no comparative clinical trials to determine the optimal timing of rehabilitation after surgery for MLKI. However, Mook and colleagues [17••] systematically reviewed the available literature through 2008 concerning both the timing of operative intervention and post-operative rehabilitation. Early surgery and immediate motion resulted in fewer instances of posterior instability, varus laxity, valgus laxity, flexion loss greater than 10°, extension loss greater than 5°, and poorer outcome scores compared to early surgery and delayed rehabilitation [17••]. These results are specific to the mobility component of rehabilitation as "early mobility" was defined as allowing for greater than 30° of knee motion prior to 3 weeks after surgery. Therefore, it is not reasonable to compare early motion and WB with a strict immobilization protocol after surgery for MLKI. However, many reports still advocate up to 3 weeks of immobilization in extension, limited in motion [35–40], or motion controlled by a continuous passive motion device [41, 42].

Many reports call for an extended period of non-weight bearing (NWB) after surgery for MLKI ranging from 4 to 6 weeks after surgery [35–38, 41, 43, 44, 45••]. Very few protocols recommend WB as tolerated (WBAT) [39], while others recommend early partial WB (PWB) [5, 9••, 19, 33, 40, 42, 46] or toe-touch WB (TTWB) [47–49].

Recommendations for rehabilitation after surgery for MLKI are variably described and likely differ based on the tissues involved (Table 1). Low-impact activities such as stationary cycling are initiated at various times after surgery ranging from 6 to 12 weeks [39, 40, 44, 59, 61, 62]. Initiation of resisted hamstring exercise has been reported to start at various times, most often from 8 to 16 weeks depending on the involvement of PCL injuries and/or other posterior structures (i.e., PLC, hamstrings, joint capsule) [5, 23, 27, 33, 40, 42, 43, 45••, 57, 59, 60]. Initiation of impact activities, such as running, is also variable, ranging from initiation at 3 to as late as 10 months [5, 27, 33, 40, 44, 46, 47, 59, 62]. Full activity has been typically promoted between 8 and 12 months from surgery [5, 23, 27, 33, 37, 40–43, 54, 45••], but may be

Table 1 Rehabilitation Recommendations from the Literature Concerning Initiation of Rehabilitation and Gait Activities

Author	Population	Initiation of ROM	Initiation of WB	Initiation of HS Ex	Initiation of WB LE TE	Initiation of NWB LE TE	Notes
Edson, 2006 [26]	MCL (combined with ACL)	Weeks 0-3: locked in extension Week 3+: ROM as tolerated Week 6 goal: 90 to 120	Weeks 0-6: NWB Weeks 6-10: Add 25% BW per week Week 10: transition to functional brace	NR	Week 10+	Week 0: quadriceps isometrics and SLR, NMES	
LaPrade, 2012 [50]	Medial Side	Weeks 0-2: PROM extension to max flexion within safe zone Week 2 Goal: 90 Week 2+: as tolerated Week 6 Goal: 130	Weeks 0-6: NWB; braced unless exercising Week 6+: WBAT with crutches, brace unlocked per quadriceps control	Weeks 2 to 6	Week 6: WB TE including 70° knee flexion on leg press	Week 0: quadriceps sets, SLR (flex, abd, ext) Prohibited through week 12; unclear as to when to initiate	"Safe zone" for ROM determined intra-operatively as the allowable tissue tension immediately after surgery; Goal is 0 to 90
Chhabra, 2005 [51]	MLKI	Week 0-4: Locked in extension Week 0: PROM extension Week 2: PROM to 90 with tibial support Week 6+: A/PROM and stretching initiated	Week 0-4: PWB and progress to FWB	Week 6: active flexion Week 12: resisted flexion		Week 0: quadriceps isometrics Week 4: NWB quads from 75 to 60	
Cole, 1999 [52]	MLKI	Week 0: PROM with tibial support 6 months Goal: Full ROM	Weeks 0-4: NWB with knee locked in extension Week 4+: WBAT (unless PLC involved then PWB until 12 weeks)	12 weeks		Week 0: quadriceps isometrics	
Edson, 2011 [38]	MLKI	Weeks 0-5: brace locked in extension 24h/day Week 10 Goal: 100 Week 24 Goal: 120	Weeks 0-5: NWB with brace locked Weeks 6-10: Initiate WB, add 20% BW per week to FWB at 10 weeks			Weeks 0-5: quadriceps isometrics, NMES Weeks 6-10: Isometrics at 60° with NMES Week 16+: full quadriceps strengthening	
Engebretsen, 2009 [42]	MLKI	Weeks 0-4: locked in extension, 2h/day of CPM from 0 to 60 (or PROM in prone) Week 4 goal: 90° Week 8: d/c brace & increase ROM exercise	Weeks 0-4: PWB with crutches Week 8+: FWB	Week 8	Week 8	Week 0: quadriceps isometrics and SLR in brace; otherwise – NR	
Eranki, 2010 [53]	MLKI	Weeks 0 to 4 Goal: achieve maximum possible ROM	NR	NR	NR	NR	Week 4+: strength exercises Month 3: light activity
Fanelli, 2011 [54]	MLKI	Weeks 0-5: Braced in extension Weeks 5-10: Progressive ROM Week 10: d/c post-op brace, transition to PCL brace	Weeks 0-5: NWB locked in extension	NR	Week 11	NR	
Harner, 2004 [40]	MLKI	Week 0: full extension Weeks 2-6: passive flexion with tibial support to 90; If PLC involvement: limit to 0 Week 12 goal: symmetrical flexion; Flexion <90 between 8-12 weeks - MUA	Week 0: PWB with brace locked in ext; Week 4-6: WBAT, brace unlocked Brace d/c when 90° flexion achieved; Crutches d/c @ 6-8 weeks pending swelling, ROM	6 weeks: active knee flexion 12 weeks: resisted knee flexion	Between weeks 4 and 6	Week 0: isometric extension to restore SLR without lag; NMES in extension; Week 4+: LAQ 75°-60°; 6 weeks: AROM/PROM, stretching	Refers to Irrgang, 2000 #689
Hubert, 2011 [28]	MLKI			NR	Weeks 4-6	Months 5-6	

Table 1 (continued)

Author	Population	Initiation of ROM	Initiation of WB	Initiation of HS Ex	Initiation of WB LE TE	Initiation of NWB LE TE	Notes
		Week 0-2: unlocked brace except for ambulation Week 6 Goal: 0 to 90	POD 1: WBAT with crutches in brace Week 6 Goal: Relatively normal gait; d/c brace when achieved				
Irrgang, 2000 [33]	MLKI	Week 1 Goal: full extension, 0° if PCL or PLC involved Week 4 Goal: 90° flexion Week 8 to 12 Goal: Full ROM	Week 0: PWB with crutches and brace locked in extension Week 6: WBAT (generally) D/c crutches when 90° flexion, full extension, no lag, normal gait	Avoid if HS contraction will stress surgery site; 12 weeks otherwise	Weeks 4 to 6	Week 0: quadriceps isometrics, SLR, NMES	
Jenkins, 2011 [45••]	MLKI	Weeks 0 – 6: hinged knee brace from full extension to 90°	Weeks 0-4: NWB Weeks 4-6: PWB Week 6+: progress to FWB	Weeks 0-6: If PCL involved, no active flexion 8 weeks: WB and isometric 12 weeks: isotonic	Week 6+: leg press, calf raise, mini squat	Week 0-2: quadriceps isometrics, prone SLR; Week 2-6: AAROM flexion, hip, calf, quadriceps isometrics Week 6+: NWB PREs for quad	
Lachman, 2015 [55]	MLKI	Week 0-6: 0 to 90	NR	NR	NR	NR	
Noyes, 1997 [27]	MLKI	Week 0-4: 10-90; split cylinder cast when not exercising Week 5-8: 0 – 110; hinged brace used Week 9-12: 135 No hyperextension for 6 months	Weeks 0-4: TTWB Weeks 4-6: 25# WB, slow advancement to FWB by week 12 with weaning of crutches	Week 12	Week 4: mini-squats	Weeks 0-4: quadriceps isometrics, SLR, NMES Week 8: PREs initiated	
Owens, 2007 [41]	MLKI	POD1: CPM 0 to 30, progress to 90 by POD10 8 Week Goal: 120 Week 12: MUA if not 0-120	Weeks 0-8: NWB Weeks 8-12: PWB with crutches Week 12+ Goal: WBAT without crutches	Avoid weeks 0-4; Week 4: begin HS co-contraction	Week 12	Week 16-24	
Rinh 2004 [25]	MLKI	Week 0-4: Locked in extension Week 2-6: PROM with PT, limited to 90 12 weeks: Goal is full PLC involvement: 0° stop in place Weeks 8-12: MUA if flexion is less than 90°	Week 0-4: PWB with brace locked in extension & progress to WBAT; Week 4-6: WBAT, brace unlocked If lateral repair or reconstruction: PWB and locked in extension for 8 weeks Brace d/c when 90° flexion achieved; Crutches d/c @ 6-8 weeks (pending strength, ROM, ambulatory ability)	6 weeks: Avoid active flexion (hamstring contraction) & WB HS TE 12 Weeks: No OKC flexion for 12 weeks		Week 0: isometric extension to restore SLR without lag; NMES in extension; Week 4+: LAQ 75°-60°; 6 weeks: AROM/PROM, stretching	Refers to Irrgang, 2000 #689
Skendzel, 2012 [23]	MLKI	Week 0: patellar mobilization Week 6 goal: 90° flexion Week 12 goal: 120° flexion	Weeks 0-6: NWB Weeks 0-3: brace locked in extension Initiation of PWB depends on muscle control, increase by 25% BW	12 weeks	Used until (70% quad symmetry)	Week 0: isometrics & NMES to enhance quad recruitment	Activities gradually increased from 4 to 6 months

Table 1 (continued)

Author	Population	Initiation of ROM	Initiation of WB	Initiation of HS Ex	Initiation of WB LE TE	Initiation of NWB LE TE	Notes
			per week to WBAT				
Talbot, 2004 [49]	MLKI	Week 0	Week 0: TTWB Week 6: Progress to WBAT (pending muscle strength)	NR	Week 6	NR	
Tzurbakis, 2006 [5]	MLKI	Week 1-2: Full extension Week 4: Goal of 90 Week 8: Full flexion PLC/PCL involvement: protect posterior sag Extensor mechanism repair - 30 flexion for 3 to 4 weeks	Week 0 -4/6: PWB with brace in extension Week 12 (approx): FWB pending quadriceps strength recovery)	If PLC involved: 16 weeks	6 weeks	Immediate quadriceps isometrics	
Yasuda, 2009 [56] KSSTA	MLKI	Week 1: locked in extension Week 3-4: PROM 0 to 90 Week 5-8: AROM 0 to 120 Week 9-12: AROM 0 to 140 Month 4-6: Full range	Week 1: NWB Week 2: PWB, locked in extension Week 3-4: WBAT, locked in extension Week 5: unlock brace	Week 3-4: quadriceps and hamstrings co-contraction Month 7: PREs	Week 9-12: 45° static squat Month 4-6: Squats to 30, progress to 60, stairs exercise Month 7: full squat	Week 1: SLR (flex, abd, ext) Week 2: quadriceps isometrics Week 5-8: add 45° isometrics Month 7: PREs	
Richter, 2002 [9••]	MLKI – Functional Rehab	POD0-2: immobilization in bed POD2-Week 6: 0 to 60 (with PT and in CPM) Week 6+: unrestricted	POD2-Week 6: PWB in brace from 0 to 60 Week 6+: WBAT with full motion	NR	NR	NR	
Richter, 2002 [9••]	MLKI – Immobilization Protocol	POD0-2: immobilization in bed POD2-Week 6: immobilization in cast or external fixator Week 6+: unrestricted	POD2-Week 6: PWB in locked brace Week 6+: WBAT with full motion	NR	NR	NR	
Hua, 2016 [57]	MLKI (repair)	Week 1: Full ROM as tolerated in brace Week 4+ Goal: 0-120	Month 4: PWB with crutches Month 7: WBAT without crutches	12 weeks: co-contraction and WB exercise 16 weeks	NR	POD1: quadriceps isometrics and SLR Month 4+: exercise initiated Month 6: Begin PREs	Brace locked at 30
Shelbourne, 2007 [58]	MLKI with lateral repair	POD 0: bed rest and CPM 0 to 30, progress to 90 by POD 7 with maximum flexion 4x/day for 10 minutes Week 0 to 2: prevent hyperextension	POD 0-7: bed rest with ambulation to the bathroom only Week 1+: WBAT with or without crutches	NR	Week 2: gentle quadriceps exercises	NS	
Edson, 2006 [26]	MLKI with MCL	Weeks 0-3: locked in extension Week 3+: ROM as tolerated Week 6 goal: 90 to 120	Weeks 0-6: NWB Weeks 6-10: Add 25% BW per week Week 10: transition to functional brace	Week 16: active TE Week 20: Resistive TE		Week 0: quadriceps isometrics and SLR, NMES	Brace recommended for 18 months
Werner, 2014 [48]	MLKI with medial injury	Week 1: unspecified therapy in a knee brace	Week 0: TTWB	NR	NR	NR	
Quelard, 2010 [59]	PCL	POD1-45 Goal: 0 – 60; flexion ROM with tibial support; locked in extension except for exercise POD45:Goal 90 POD 45-90 Goal: 120 POD 90+: unlimited	POD10-45: FWB POD21: remove brace POD45-90: Removal of brace, then crutches	24 weeks	POD 45: ROM 0-60	POD15: eccentric knee flexion initiated	
Lee 2011 [60]	PCL (Chronic) and PLC	POD 3-5: PROM with tibial support Week 0-6: 0 to 90	Week 0-6: PWB	16 weeks	NR	NR	

Table 1 (continued)

Author	Population	Initiation of ROM	Initiation of WB	Initiation of HS Ex	Initiation of WB LE TE	Initiation of NWB LE TE	Notes
		Week 12 to 24 goal: full ROM	Week 0-3: brace locked in extension Week 3-6: PCL brace Week 6+: WBAT (pending pain)				
Fanelli, 2015 #3750	PCL and Medial Sided Injury	Weeks 0-3: Braced in extension Weeks 3-10: Progressive ROM Week 10: d/c post-op brace	Week 0-3: NWB locked in extension Weeks 3-5: Progressive WB	NR	Week 12	NR	
Fanelli, 2007 [35]	PCL and PLC	Weeks 0-3: Braced in extension Weeks 3-6: Progressive ROM	Week 0-3: NWB locked in extension Weeks 4-6: NWB with unlocked brace Weeks 7-10: Add 25% BW per week	NR	NR	NR	
Kim, 2013 [61]	PCL and PLC	Week 0 to 6: immobilization in extension Week 2: prone passive flexion initiated Week 6+: brace unlocked	Week 0 to 6: TTWB Week 6: WBAT	NR	Week 6: initiated loaded flexion, progress to 90 Week 8: WB TE initiated Week 12+: full squatting allowed	Week 0: quadriceps isometrics	Week 12: stair stepper, single leg stance
Chahla, 2016 [62]	PLC	Week 0-2: 0-90 Week 2+: Full ROM as tolerated	Weeks 0-6: NWB with immobilizer Week 6+: d/c crutches	16 weeks	After d/c of crutches	NR	
Murphy, 2006 [47]	PLC & LCL	Week 0-2: 0-90 Week 5-6 goal: 0-110	Week 0-2: TTWB, locked in ext Week 3-4: PWB, locked in ext with crutches Week 5-6: WBAT, unlocked; Crutches d/c when gait is normalized Brace d/c at weeks 9-12	NR	NR	Week 0-2: SLR	
Geeslin, 2011 [44]	PLC (Isolated & Combined)	Weeks 0-2: locked in extension except when exercising in "safe zone" 4x/day Week 2+: "safe zone" flexion increased Weeks 12-16 Goal: Full ROM	Weeks 0-6: NWB Week 6: PWB, progresses as tolerated Weeks 12-16 Goal: Normal gait	NR	Week 6: Leg press to max 70° flexion with 25% BW	NR	"Safe zone" for ROM determined intra-operatively as the allowable tissue tension; goal was 0-90, but further motion that would not cause damage was allowable
Gormeli, 2015 [32]	PLC (isolated and combined)	Weeks 0-4: immobilization in a brace Week 4+: flexion as tolerated	Week 0: WBAT	NR	Week 6-8 Week 10-12: stair stepping, single leg stance Week 12: full squatting allowed	Week 0: isometric quadriceps exercises	
LaPrade, 2010 [39]	PLC (isolated and combined)	Weeks 0-2: ROM TE 4x/day, increase as tolerated Weeks 0-2: Goal 90° Week 6: Goal Full ROM Weeks 13-16 Goal: Full ROM	Weeks 0-6: NWB Week 6+: progressive WB; crutches d/c when limp resolved Weeks 13-16 Goal: Normal gait	16 weeks	16 weeks: 25% to 50% body weight to 70° knee flexion on leg press or mini squat	Week 0-6: quadriceps sets and SLR (using an immobilizer pending lag); Week 0-6: NWB lower extremity and core exercise avoiding varus, tibial ER, or hyperextension	No loaded weight bearing beyond 70 degrees (unspecified time frame); Months 4-6: Focus on endurance without impact

Table 1 (continued)

Author	Population	Initiation of ROM	Initiation of WB	Initiation of HS Ex	Initiation of WB LE TE	Initiation of NWB LE TE	Notes
Camarda, 2010 [43]	PLC (Isolated)	Week 0-3: Locked in extension Week 3: PROM begins Week 4: 0-110	Week 4+: "Partial" WBAT with crutches Week 7: WBAT Week 12: d/c brace	NR	NR	NR	
Stannard, 2005 [46]	PLC (Isolated)	POD 0-10: knee immobilizer POD 10-14: "aggressive" ROM with CPM (0 to 3), progressing to 0 to 90	Week 0-1: PWB with crutches; Week 1+: Progress to FWB (pending other injuries)	NR	NR	NR	
Stannard, 2005 [19]	PLC combined with cruciate recon	POD1: Early "aggressive" ROM with CPM (0 to 3), progressing to 0 to 90	Week 0-1: PWB with crutches; Week 1+: Progress to FWB (pending other injuries)	NR	"Dictated by cruciate ligament injuries" with early closed chain exercise	NR	

allowed as early as 4 to 6 months post-operatively [39, 47, 58, 65].

Rehabilitation Outcomes After Repair and Reconstruction for MLKIs

Multiple ligament knee injuries result in significant time away from military duty, work, and sports [63–66]. In fact, the return to duty rate after combat-related MLKIs has been reported as low as 41% [64] to 50% [63] and is substantially lower than the average reported civilian return to work rate of 81% [9••, 12, 67]. Return-to-sport rates after MLKI are generally lower than return-to-work rates, ranging from 17 to 81%, with a mean of 50% [12]. Strength outcomes are poor in individuals after surgery for MLKI, with considerable deficits reported at 2 years after surgery in both the quadriceps and hamstrings [45••].

Criterion-Based Rehabilitation Progression

To improve motion, strength, and return to activity, it is prudent to follow a criterion-based rehabilitation progression that allows symptom-free activity and can be modified on an individual basis. The goals of our criterion-based rehabilitation progression are to return individuals to (1) normal activities of daily living and (2) work, military duty, and sports activities at the same level of participation as before injury. We have outlined three phases of rehabilitation after surgery: (1) tissue protection, (2) restoration of motor control, and (3) optimization of function. As a general rule, patients should be encouraged to exercise and ambulate without causing pain or discomfort greater than 3/10.

Knee joint inflammation should be measured via the amount of swelling, pain, range of motion (ROM) restriction, and joint warmth (see Table 2). As the signs of inflammation subside, activity should progress. Soft tissue swelling and/or an effusion should not occur in response to increasing loads. Pain should steadily decrease, and pain exceeding 5/10 should result in activity reduction or modification. Any increased joint pain or pain in the surgical tissues from exercise should subside within a few hours. Pain increases lasting greater than 12 to 24 h indicate that exercise was too aggressive and should be modified appropriately. Range of motion (ROM) limitations are often accompanied with pain at the end ROM without over-pressure, and when this occurs, exercises or over-pressure near end range should be avoided. Pain at rest should result in activity modification or reduction. Lastly, any palpable joint warmth should result in avoidance of further joint loads and tissue stress. The knee should be continually monitored for signs of inflammation that may indicate that the repaired/reconstructed structures were exposed to excessive

Table 2 Knee Joint Inflammation Scale

Level	Effusion	Pain Status	ROM Status	Other
High	at least 2+ on sweep test*	moderate to severe pain (> 6/10)	limited with pain before end range	increased skin temperature
Moderate	stable 1+ or lower on sweep test	mild and stable pain levels (3 to 5/10)	pain around the end of ROM	
Low	trace or zero with sweep test	no pain at rest or with ADLs	may have some pain with overpressure at end of ROM	

load. Though rare, increasing joint warmth or erythema should prompt the clinician to rule out the presence of a post-operative infection. Rehabilitation activities progress based on a combination of time from surgery, performance of basic tasks, and tissue response to increased loading. The progression is best described as an "as-tolerated" approach to restoring motion, WB, and activity.

Rehabilitation and Activity Progression in the Tissue Protection Phase

The goals of the tissue protection phase focus on restoration of knee motion without over-stressing the repaired/reconstructed tissues, prevention of muscle atrophy, and reestablishment of appropriate gait patterns with assistive devices that improve function.

Range of Motion

During the first tissue protection phase, pain during ROM interventions should not exceed 3/10. For flexion, end-range over-pressure, muscle stretching, and aggressive mobilization should be avoided during the first 4 weeks post-operatively. For extension, MLKI can be limited to neutral extension (avoiding hyperextension) for 6 weeks. Patient-specific factors, such as generalized joint hyperlaxity, should also be considered during the progression of knee ROM. Specifically, rehabilitation professionals should exercise caution and avoid early aggressive hyperextension as additional ROM will be gained throughout the later phases of rehabilitation. Patellofemoral mobilizations in the non-restricted range can begin immediately after surgery.

Range of motion may need to be limited due to specific surgical procedures (see "Tissue-Specific Restrictions" section). Aggressive patellofemoral mobilization and stretching at end-range should begin around 4 weeks post-operatively if the patient has not achieved neutral knee joint extension (anatomic 0°) or 60° of knee flexion. In the case of posterolateral or posteromedial reconstruction or repair, the physical therapist should avoid hyperextension and exercise care in stretching the hamstrings, gastrocnemius, and posterior capsule so as not to disrupt the surgical repairs.

If a knee joint contracture of 10° or greater (compared to anatomic 0°) exists at 6 weeks, the patient should be referred to their treating surgeon for further assessment. If the patient has not achieved 90° of flexion by 12 weeks post-surgery, the surgeon should also be notified. Additionally, if the patient loses ROM consistently at any point after surgery, referral back to the surgeon is warranted.

Restoring knee flexion can present issues for individuals with PLC or PCL surgery. Active contraction of the hamstrings to flex the knee can cause a posterior drawer effect, which could stress the repaired/reconstruction tissues. Therefore, initial flexion exercises should be performed passively, either prone to eliminate gravity causing a posterior sag or supine with support provided to the posterior tibia, for at least 6 weeks.

Stationary Cycling for ROM Cycling can begin when the individual has achieved neutral extension and 90° of flexion but no earlier than post-operative week 3. Other protocols have recommended waiting 6 to 7 weeks [44, 59, 62] to 10 [39]or 12 weeks [65]. However, stationary cycling has been shown to produce minimal strain on the ACL [68] and should be completed without resistance.

The goal of this exercise is promote ROM until 10 weeks post-surgery. Resistance should be kept to a minimum, and the individual should move in a smooth and controlled motion. Individuals who cannot complete a full revolution due to limited knee flexion should not force motion and only move in a comfortable arc. Seat height may be adjusted to limit the flexion necessary to complete a full revolution and may be lowered as ROM improves. After 10 weeks, cycling for cardiovascular endurance may begin pending the recovery of motion. Prior to 10 weeks, cycling for endurance may promote unwanted, excessive hamstring contractions. Additionally, the use of toe clips has been shown to increase hamstring co-contraction.

Weight Bearing and Gait Progression in the Tissue Protection Phase

Weight bearing recommendations are highly variable after surgery for MLKI. However, laboratory studies indicate that individuals do not use a consistent amount of WB when given recommendations for PWB and TTWB [69] [70] [71].

Clinical training paradigms to standardize the forces through the limb have been suggested but not validated [72, 73]. Considering the lack of outcome measurement after MLKI surgery, there is little evidence to support the need for NWB status. Conversely, controlled WB benefits cartilage and meniscal nutrition [74], can provide beneficial proprioceptive input to the knee, and promotes muscle activity. Therefore, we have operationally defined a method to dose WB to tolerance based on the presence or absence of the cardinal signs of inflammation in the surgical knee.

Patients are instructed to bear weight on their surgical limb to tolerance based on the response of the knee as measured by the presence of pain and effusion. Initially, WB should be performed in a locked, double upright knee brace to prevent excessive sagittal or frontal plane motion. The brace and axillary crutches are used for at least 6 weeks for safety, but the patient may bear as little weight through the crutches as tolerable. Gait activities are progressed based on knee inflammation and ROM, quadriceps strength, neuromuscular control, and general improvements in gait patterns. Criteria to progress gait activities are in Table 3.

Patients must be able to perform a straight leg raise with less than a 5° lag in order to begin weight bearing with an unlocked brace. A lag is present when the range of maximum knee extension during the straight leg raise is more flexed than the maximum knee joint extension measured in a resting position.

Unlocking the Post-Operative Brace When the criteria are met, the brace may be unlocked to 45° or 60° for ambulation, depending on the settings available on the brace. The individual should also be performing basic bilateral WB exercises (see below), which should include gait training. The physical therapist should focus on the patient using the available ROM in swing and weight acceptance and proper sequencing with the crutches to prevent over-loading.

Discontinuation of Crutches The primary concern with discontinuing use of crutches is adequate quadriceps strength and neuromuscular control required for safely negotiating stairs. Therefore, the individual should be able to complete five repetitions of step-up and step-down exercises to a 7-in step with general safety and control. Patients should be instructed to use a non-reciprocal stair negotiation pattern until safety is assured.

Discontinuation of Post-Operative Brace and Crutches Criteria are presented in Table 3. To screen for compensations and poor control in stair negotiation, a step-down test and step-up task to a 7-in step may be used, considering the criteria provided by Piva et al. [75]. Generally, the gait cycle must also be symmetrical and without the presence of a limp.

Once the orthosis and crutches have been discontinued, treadmill or over-ground walking may be initiated to improve cardiovascular conditioning, but careful attention should be paid to joint inflammation. Time and distance walked should not progress faster than 10 to 20% increments per week.

Initiation and Progression of Rehabilitation Exercises for Strengthening in the Tissue Protection Phase

Immediate Exercise Prescription

Patients should begin motor control exercises immediately after surgery while still in the tissue protection phase. Patients may perform exercises to restore quadriceps activation including isometric quadriceps setting with the knee in neutral and within safe ranges of flexion. All patients should receive high-intensity neuromuscular electrical stimulation [76, 77]. Other therapeutic exercises should include gluteal sets, ankle pumps, and four-way straight leg raises (i.e., hip flexion, abduction, extension, adduction modified per the "Tissue-Specific Restrictions" section).

Home exercise programs to promote knee extension to neutral; improve quadriceps muscle activation; prevent atrophy of the hamstring, calf, and gluteal muscles; and prevent fibrosis of the patellofemoral joint are essential additions to formal physical therapy.

Progressive Resistive Exercises and Body Weight Exercises

Patients may begin NWB knee extension exercises, bilateral WB exercises, unilateral WB exercises, and stationary cycling prior to 4 weeks post-surgery, provided the individual meets the knee inflammation guidelines outlined (see Table 3) assuming that there are no peri-articular or extra-articular fractures. The gradual introduction of activities prior to 4 weeks provides the patient and physical therapist an opportunity to slowly increase the load on the surgical tissues while monitoring tissue response.

Progressive resistive exercises (PREs) to recover muscle strength and endurance may begin as early as 1 week after surgery. A combination of both WB and NWB exercises should be used depending on tissue tolerance. To avoid excessive posterior tibial translation, resisted hamstring strengthening should be avoided for 12 weeks in all patients who underwent repair or reconstruction of the PCL, PLC, or menisci.

After ACL reconstruction, WB and NWB exercises are initiated early on to restore quadriceps muscle function [34], reduce disuse atrophy, and restore ROM and gait to pre-injury conditions without adverse effects [78, 79]. Non-weight bearing knee extension exercises should be completed in a safe

Table 3 Criterion Based Rehabilitation Progression – Tissue Protection and Restoration of Motor Control Phases

Activity	Time to Begin in		Knee Joint Inflammation	Range of Motion	Strength	Neuromuscular Control & Task Mastery
	Early Group	Delayed Group				
Gait – WBAT using bilateral crutches with locked brace	Week 0	Week 4	High	Able to wear brace locked in extension comfortably	--	Able to sequence gait with bilateral crutches safely
Exercise – NWB Quadriceps	Week 1			90^o flexion		Active quadriceps contraction
Exercise – Basic Bilateral WB for LE			Moderate	Neutral extension (anatomic 0^o) to 45^o		
Gait – WBAT using bilateral crutches with unlocked brace				Neutral extension to 60^o	Lag < 5^o with SLR	Able to demonstrate single leg balance for 5-10 seconds and semi-normal gait pattern
Exercise – Basic Unilateral WB for LE	Week 3					Able to demonstrate single leg balance for 5-10 seconds
Gait – WBAT with unlocked brace and no crutches				Neutral extension to 90^o	Lag < 3^o with SLR	Semi-normal gait pattern 5 reps each limb of 7" step up without obvious compensation
Exercise – Stationary Cycling for ROM						Able to weight shift to 75% WB on surgical limb
Exercise – Advanced WB LE Strengthening	Week 6		Low			5 reps each limb of 7" step up without obvious compensation
Gait – without brace or crutches				Neutral extension to 120^o		Generally normal gait pattern Reciprocal stair negotiation 10 repetitions each of step ups AND step downs to a 7" step without pain or aberrant movements
Exercise – Active HS Strengthening without Resistance	Week 8		Moderate	Neutral extension to 90^o	Pain free contraction of the HS	Absence of posterior drawer with hamstring activation
Exercise – Active Resistive HS Strengthening	Week 12		Low			

Abbreviations: WBAT – weight bearing as tolerated; NWB – non-weight bearing; LE – lower extremity; reps – repetitions; ROM – range of motion; HS - hamstrings

range from 90° to 60° of flexion including isotonic and isometric exercise [80]. Range of motion for WB exercise is limited to 45° of flexion early in rehabilitation. Even though hamstring co-contraction occurs with WB [80], the moment arm of the hamstrings to produce a posterior translation near extension is extremely small [31] and can be minimized by keeping a more neutral trunk as in the low-range squat and wall sit exercises [81]. This is well controlled with the leg press exercise [82]. A 45° range also balances stress applied to a reconstructed PCL (and likely PLC) with the added benefit of quadriceps strengthening [83]. Cruciate ligament stress in unilateral stance and unilateral squatting exercises at less than 45° is similar when compared to bilateral squatting exercises [84].

Resisted exercises should follow a timeline to gradually introduce forces to the knee and to not provide excessive stress. The first exercises to be implemented should be unilateral NWB and bilateral WB exercises as early as 1 week after surgery. Unilateral WB strength exercises may begin 3 weeks after surgery. Advanced WB lower extremity strengthening should not begin until at least 6 weeks after surgery.

Non-weight Bearing Quadriceps Strengthening Exercises In the first 6 weeks after surgery, fewer than 10 lb of external resistance should be used [80]. Early external resistance should be performed with cuff weights to prevent overloading the patellofemoral joint. Isometric exercises at 90°, 75°, and 60° of flexion may be used with proximal resistance and an intensity that does not cause pain. From 6 to 8 weeks, resistance may be increased beyond 10 lb and may transition to resistance equipment for training, as tolerated. Range of motion may be increased to 45° at 8 weeks, and ROM restrictions may be lifted at 12 weeks. Progression should initially focus on quadriceps endurance (12 to 20 repetitions) and progress to quadriceps strengthening (8 to 12 repetitions).

Weight Bearing Strengthening Exercises Initiation of WB may cause some knee discomfort. Exercises should be performed in a safe environment where the individual has external support for balance if needed (e.g., therapist support, parallel bars, etc.) and should be performed in the post-operative brace (Table 4). These exercises target the general strengthening of the lower extremity musculature while preparing the individual to resume a normal gait pattern.

When basic unilateral WB strengthening begins, gait training is the first unilateral strengthening exercise in an unlocked brace using one or two crutches, as necessary. The focus of gait training should be on reciprocal motions for each leg and normal knee excursion through swing and stance. Step-up exercises and step-and-hold exercises may begin at this time, as well (see Table 5).

Advanced weight bearing strengthening exercises are operationally defined as requiring significant eccentric control of the lower extremity or ROM greater than 45° of knee flexion. Initially, exercises should be performed in the post-operative brace and can begin when the individual is 6 weeks out from surgery and has met all criteria for discontinuation of crutches. Weight bearing flexion beyond 45° loads the PCL, while not excessively loading the ACL [83] [84]. Lunging exercises should be implemented cautiously in PCL-injured and PLC-injured subjects, with careful attention paid to the ROM due to the loads placed on the posterior stabilizers beyond 45° [85]. These exercises do not appreciably load the ACL.

When advanced WB strengthening begins, gait training without the post-operative brace may begin during rehabilitation (Table 6).

Tissue-Specific Restrictions

Progression of rehabilitation should be altered to respect the structure addressed during surgery that has the slowest time course for healing or that has the greatest probability of failure (typically soft tissue repairs). Biomechanical studies have indicated that some muscle activities need to be restricted to protect surgically repaired tissues [30–33]. The authors have agreed on a set of specific guidelines to protect vulnerable healing structures (Table 7). Reconstruction or fixation with hardware and bone tunnels is regarded as strong and able to withstand early stress, whereas soft tissue repairs performed with sutures are more likely to fail with early stress. As a reference, the ACL reconstruction rehabilitation is the standard and includes early unlimited ROM and unrestricted WB. Each additional procedure provides additional considerations.

Posterolateral Corner Repair and Reconstruction/ Posterior Cruciate Ligament Repair and Reconstruction Repair or reconstruction of the PLC requires protection of

Table 4 Bilateral Weight Bearing Exercises

Exercise	Limitations and Considerations
Squats to no more than 45° knee flexion	Place a chair, table, or box behind the individual to block excessive motion
Leg Press from 45° to 0°	Loads no greater than body weight
Isometric wall sits to 45°	Begin with short duration (~10 seconds)
Terminal Knee Extension	Avoid hyperextension in PCL/PLC surgery
Weight Shifting	Can perform laterally, anteriorly, and in a 45° stagger

Table 5 Unilateral Weight Bearing Exercises

Exercise	Limitations and Considerations
Gait Training (Braced)	• Avoid compensations at the hip/trunk • Ensure reciprocal gait with decreasing dependence on crutches • Emphasize knee flexion through loading response • Emphasize knee extension at initial contact and in midstance
Step Up Exercises	• Up to 5 weeks - no higher than 4 inches • Up to 6 weeks - no higher than 7 inches (ADA maximum height)
Step and Hold Exercise	• Patient steps from the uninjured onto the injured limb, at least the distance of the normal stride • The individual is cued to imagine they are stepping over a puddle of water and to land with a heel-toe gait pattern to simulate walking • Avoid excessive stiffening, knee flexion, or medial collapse

ROM from excessive hyperextension and varus forces, posterior tibial sag, and forceful contractions of the biceps femoris and gastrocnemius. Soft tissue repairs of the PLC, including the posterior capsule, mid-substance tears of the biceps femoris, and iliotibial band, require protection. For reconstruction of the popliteofibular ligament or lateral collateral ligament, similar restrictions are in place with heightened awareness for varus loading of the knee.

Repair or reconstruction of the PCL is also at risk for failure with excessive posterior translation of the tibia. When the hamstrings contract without an opposing contraction from the quadriceps in ranges beyond 20° to 30° of flexion, there is a significant posterior drawer force [31, 32] [86]. Therefore, after PCL repair or reconstruction, the therapist should prevent posterior tibial translation as knee flexion is performed for 6 weeks after surgery. In the presence of pain or discomfort with flexion, the physical therapist may apply manual tibial external rotation or anterior tibial glide to remove tension from the surgical sites.

Isolated hamstring strengthening has been recommended to begin from 8 to 24 weeks after surgery [5, 23, 27, 40, 42, 43, 45••, 57, 59, 60, 87]. For both PLC and PCL procedures, patients may initiate active hamstring contraction without resistance and gentle stretching after 8 weeks. The patient should be monitored for posterior knee pain and an active posterior drawer, in which the tibia visually glides posteriorly when performed isometrically at 90° of flexion at 50% effort. Exercises may include active heel slides on a smooth surface as well as prone and standing hamstring curls.

Resisted hamstring strengthening can begin 12 weeks after surgery if hamstring contraction does not cause posterior pain or an active posterior drawer effect when performed isometrically at 90° of flexion at 75% effort. Exercises may include resisted hamstring curls, both prone and standing, and multiple-angle isometrics. As performance improves, eccentric training may occur to include Romanian dead lifts, Nordic hamstring curls, and other exercises. The emphasis for individuals returning to activity should focus on eccentric control of the hamstrings that occurs with sprinting, landing from a jump, and pivoting.

Meniscus Repair Meniscus repairs require protection from excessive shear forces and translation for 4 weeks, but can tolerate early weight bearing in a brace [88–91]. Non-weight bearing flexion should be limited to 90°. Additionally, WB flexion should be limited to no more than 30° and with no more than one-half body weight (i.e., bilateral WB). Unilateral WB should be permitted with the knee braced in extension to allow ambulation. After 4 weeks, activity progression can resume as tolerated. Meniscal root repairs (especially medial) require protection from hamstring contraction; therefore,

Table 6 Advanced Strengthening Exercises

Exercise	Limitations and Considerations
Gait Training (Unbraced)	• Avoid compensations at the hip/trunk • Ensure reciprocal gait with decreasing dependence on crutches • Emphasize knee flexion through loading response • Emphasize knee extension at initial contact and in midstance
Step Down Exercises	• Can be performed posterior, lateral, and anterior
Squats to no more than 90°	• Careful progression should be used to increase range from 45°
Wall sits to no more than 90°	• Careful progression should be used to increase range from 45°
Forced-use/Preferential squats	• A staggered stance is assumed with the surgical limb positioned under the body and the non-surgical limb positioned in front of the body. This forces the individual to use the surgical limb and prevents off-loading to the non-surgical limb.

Table 7 Tissue Specific Considerations

Tissue Involved	Rehabilitation Modifications
ACL	No modifications to rehabilitation
PCL	Protect posterior translation of the femur for 6 weeks
	- Anterior tibial glide with knee flexion
	- Avoid gravity causing posterior glide
	Protected Hamstrings Contractions:
	- Weeks 0 to 8 – No active hamstring contractions
	Passive flexion ROM with support to the posterior tibia x 6 wks
	- Weeks 8 to 12 – Active hamstrings contractions without external resistance
	Based on absence of active posterior drawer with hamstring activation
	Active hamstring exercises (heel slides, prone knee flexion, WB flexion)
	Gentle hamstring stretching
	- Weeks 12+ - Resisted hamstring contractions allowed
	Based on absence of active posterior drawer with hamstring activation
PLC	Extension ROM limited to 0^{o} (no hyperextension)
	Protect posterior translation of the femur for 6 weeks
	- Anterior tibial glide with knee flexion
	- Avoid gravity causing posterior glide
	Avoid excessive varus forces on knee joint
	Hamstring restrictions same as PCL
MCL	ROM exercises with foot internally rotated
	Avoid excessive valgus forces on knee joint
Meniscus Body Repair	Brace locked in extension for 4 weeks for ambulation, WBAT
	Avoid unilateral WB flexion (any range) & bilateral WB flexion beyond 30^{o} for 4 wks
	NWB flexion ROM to 90^{o} for 4 weeks
Meniscus Root Repair	NWB x 4 weeks
	Protected Hamstrings Contractions:
	- Weeks 0 to 6 – No active hamstring contractions
	Passive flexion ROM with support to the posterior tibia x 6 wks
	- Weeks 6 to 12 – Active hamstrings contractions without external resistance
	Based on absence of posterior pain at the repair site with hamstring activation
	Active hamstring exercises (heel slides, prone knee flexion, WB flexion)
	- Weeks 12+ - Resisted hamstring contractions allowed
	Based on absence of posterior pain at the repair site with hamstring activation

hamstring protection similar to a PCL or PLC should be implemented [92, 93].

Medial Collateral Ligament Repairs and Reconstructions Medial sided repairs (MCL, medial capsule) should be protected from excessive valgus force or lateral rotation [94]. In the presence of pain or discomfort with flexion, the physical therapist may apply manual tibial internal rotation or slight varus to reduce tension from the repair sites.

Rehabilitation and Activity Progression in the Restoration of Motor Control Phase

In the restoration of motor control phase, surgical tissues can be loaded in a graduated fashion. Full ROM compared to the opposite limb, nearly symmetrical muscle strength, normal gait, and return to activities of daily living are the goals of this phase. The general progression of rehabilitation activities is continued in Table 3, along with the criteria necessary to begin those activities.

Return to Loaded Weight Bearing Strengthening Exercise Initial rehabilitation activities use body weight as the primary resistance to increase strength. As strength returns, body weight exercises reach a point of diminishing returns, and external resistance is needed, which increases the challenge but also may overload the surgical knee. Therefore, external resistance should not be added to exercises until the individual can perform a bilateral squat to 90° without pain and a step down from a 7-in

Table 8 Criterion Based Rehabilitation Progression – Optimization of Function

Activity	Time to Begin	Knee Joint Irritability	Range of Motion	Strength	Neuromuscular Control & Task Mastery
Cycling for Conditioning	10 weeks	Moderate	Neutral extension to 120°		Able to control rotation of cycling revolutions
Elliptical Trainer for Conditioning	12 weeks			70% QI	Normal walking gait without antalgia or deviations
Bilateral LE Weight Training with free weights		Low			Able to complete body weight squat to 90° without aberrant movements Active terminal knee extension in standing
Walk-Jog-Run Progression	16 weeks		Full (within 5° of contralateral)	80% QI 50% H:Q Ratio	30 Step & Holds without deviations 10 single leg squats to 45° without deviations
Basic Agility Drills, Jumping Drills	18 weeks				Able to run 1 mile without deviations 10 single leg squats to 60° without deviations
Hopping, Cutting/Pivoting, & Sport-Specific Drills	20 weeks			85% QI 60% H:Q Ratio	Perform full effort sagittal and frontal plane direction changes without compensations Perform full effort sagittal and frontal plane jumping without compensations
Return to Unrestricted Training	24 weeks			90% QI 70% H:Q Ratio	Complete Return to Training Testing

Abbreviations: QI – Quadriceps Index; H:Q Ratio – Hamstrings to Quadriceps Ratio

step without pain or compensation (score <2 per Piva criteria) [95]. Inflammation should be kept to a minimum. This should occur no earlier than 12 weeks after surgery and only when inflammation is low and quadriceps strength symmetry has achieved 70%.

Conditioning Exercises Because of the relatively long period of relative immobilization that allows the tissues to recover, conditioning exercises are important to initiate when safe. Cycling for aerobic conditioning can be initiated 10 weeks after surgery when the individual has the necessary ROM and control of the lower extremity to initiate and safely stop cycling (i.e., they can control the momentum of the pedals adequately). This is a direct progression from cycling for ROM.

When the individual can walk independently without a post-operative brace or crutches, and there is sufficient quadriceps strength, the individual may begin training on an elliptical machine. For treadmill walking, stationary cycling, and the elliptical machine, training should start with constant load and constant speed exercises to provide an initial conditioning stimulus. Individuals may progress to an interval training program with variable speed and resistance as tolerated. Training loads should be progressed slowly (approximately 10 to 20% per week).

Rehabilitation and Activity Progression in the Optimization of Function Phase

The ultimate goal of surgery for MLKI is to restore the function of the individual to their pre-morbid level. Rehabilitation plays an important role in this process. At the point of functional optimization, most tissue-specific considerations are not relevant, and the rehabilitation specialist is able to advance function without the restrictions of tissue protection. The reader is referred to available clinical commentaries that address return to sport and injury prevention for the knee joint (e.g., [96, 97]). Sample criteria and timelines are provided in Table 8.

Conclusion

Rehabilitation after surgery for MLKI depends on the condition of the host, including comorbidities, the anatomic structures that were injured, the quality of the repaired/reconstructed tissues, the strength of the fixation method, and any associated injuries. In addition, guiding rehabilitation with an as-tolerated approach that considers inflammation, ROM, and muscle strength will lead to gradual and safe increases in activity. Careful progression should reduce the risk for post-operative complications and maximize clinical outcomes for patients.

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