MENTORS IN ORTHOPEDICS

MULTILIGAMENT KNEE INJURIES AND GAIT ANALYSIS

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SUMMARY

Background: Multiligament knee injuries (MLKI) are complex, potentially limb-threatening conditions involving the disruption of at least two major stabilizing structures. Despite the prevalence of multiligament knee reconstruction (MLKR) to restore mechanical stability, significant heterogeneity in injury patterns and recovery potential persists. Current clinical challenges include determining optimal surgical timing, graft selection, and the balance between postoperative joint stability and arthrofibrosis.

Objective: This study aims to characterize the demographics and clinical outcomes of an MLKI cohort and utilize three-dimensional gait analysis to evaluate functional recovery and spatiotemporal adaptations following reconstructive surgery.

Key Points: Analysis of 165 patients revealed a mean age of 32.4 years, with a 18.9% incidence of peroneal nerve injury. Postoperative functional scores remained below population norms, with a mean subjective IKDC score of 70.5. Gait analysis of 16 MLKR patients compared to matched controls demonstrated significant alterations, including reduced walking velocity, shorter step length, and increased initial double support time. Kinematic data indicated decreased arcs of motion in sagittal, frontal, and transverse planes during the early stance phase. Regression modeling identified that flexion contractures and medial collateral ligament involvement were more strongly associated with pathological gait patterns than residual anterior tibial laxity.

Conclusion: MLKR effectively restores gross stability, yet functional gait abnormalities persist postoperatively. Clinical outcomes are more adversely affected by postoperative joint stiffness and extension deficits than by minor residual laxity. These findings suggest that rehabilitation protocols should prioritize the early restoration of joint mobility to optimize long-term functional gait characteristics.

KEYWORDS

Knee Injuries; Joint Instability; Knee Dislocation; Gait Analysis; Range of Motion, Articular

INTRODUCTION

Multiligament knee injuries (MLKI) involve injuries to a combination of at least 2 of the 4 major ligaments; anterior cruciate ligament (ACL), posterior cruciate ligament (PCL), medial collateral ligament (MCL) and/or postero-lateral corner (PLC) injuries. MLKI are relatively rare with an incidence of 0.01-0.013% per year, but are potentially limb-threatening injuries [1],[2]. There are various mechanisms for injury: high speed injuries, most commonly in motor-cross sports, lower speed sports injuries, and less commonly but well recognised, knee dislocations may be associated with overload in the super obese. Irrespective of the mechanism, patients present with varying patterns of ligamentous disruption and often have significant associated injuries. These complex injuries most often require extensive surgical and rehabilitative intervention. The nature of MLKI is underpinned by substantial heterogeneity with regard to demographics, injury pattern and recovery potential in the typical patient cohort. Consequently, MLKI are difficult to study and their management is still challenging. For each MLKI patient, orthopaedic surgeons have to answer several questions: What is the best timing of surgery? How to decide between repair and reconstruction techniques? Which grafts should we use? How do we manage the postoperative period? What results do patients have to accept? The available literature gives us some direction in making these decisions. In order to obtain good clinical results and to minimize the risk of re-injury, MLKI reconstruction (MLKR) is generally recommended during the acute phase if the patient's condition allows[3],[4].

Although reconstructive surgery is thought to be effective at restoring the clinical stability of the knee joint following MLKR, there are currently no studies that have evaluated such changes in multiple-ligament knee injury patients. The constraints to movement that might encourage gait adaptations in these patients, such as knee pain, flexion contracture, instability or lack of confidence have not been well identified. Furthermore, the question of the balance between joint stability restoration and joint postoperative stiffness after MLKR remains irresolute [5]. No study provides a formal answer to the question of how to adjust the graft tension during the surgical procedure. Similarly, it is unclear whether the rehabilitation protocol should include prolonged immobilization to promote the healing process and reduce the risk of re-injury, or on the contrary, should it promote rapid recovery of joint mobility in order to reduce postoperative stiffness? Consequently, performing a gait analysis in these patients and comparing them to normal subjects should allow us to have clearer answers to these questions.

This article hopes to answer these questions, introduced in stages. The first stage provides an overview of an MLKI population to identify its specificities, particularly in terms of injury pattern, associated lesions and clinical results. The second part explains the principles and variables studied during a gait analysis. Finally, by associating these 2 issues, we will present the results of our study on gait analysis for MLKR patients.

GAIT ANALYSIS

Objective

This purpose of this assessment is to collect valuable information about functional outcomes of surgeries: preoperatively the profile of patients, their injury and details of the surgical procedure can be collected, and postoperatively gait analysis is used as a functional assessment. For example, we have previously validated and use gait analysis in our clinical practice to assess readiness for return to sport after reconstructive surgery assessment (functional tests).

Methods

Retroreflective markers were attached to bony landmarks using double-sided tape in accordance with the Cleveland Clinic marker set (Figure 1).
Specifically, this included the placement of markers onthe trunk and head, as well as the upper and lower limbs, including 3-marker clusters placed bilaterally on the thigh and shank. The kinematic data was collected using a 14 camera 3D motion capture system (Eagles cameras and Cortex 3.1, Motion Analysis Corp., Santa Rosa CA) sampling at 200Hz. Ground reaction forces were recorded from 2 forceplates (Kistler, Winterthur, AG) sampling at 1000Hz embedded in the laboratory floor. Force plates were used to identify the heel strike. The laboratory walkway was 10m long and the calibrated volume was 4m X 2.4m X 2.5m.

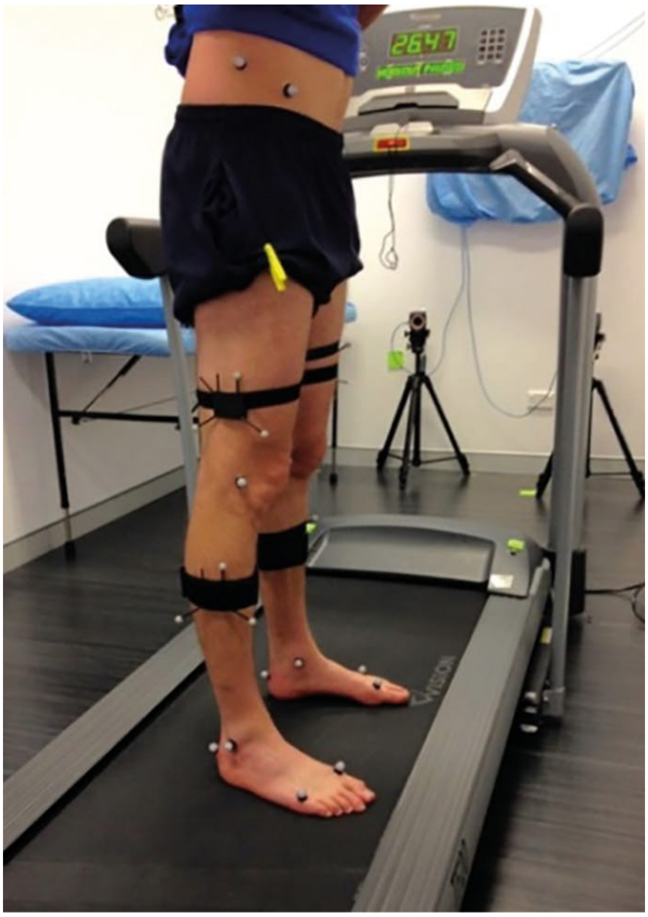


Figure 1: Attachment of retroreflective markers to bony landmarks.

Data analysis

Prior to data collection, a static calibration of the marker set was performed for each participant to align the 3D coordinate systems of the segments with the anatomical landmarks Patients then performed 12 walking trials at a comfortable self-selected pace.

Marker trajectories were identified in specialised software (Cortex v3.1, Motion Analysis Corp, CA), allowing the creation of a 3D model (Visual3D v4.96.11, C-Motion Inc, Germantown, MD) (Figure 2). With this model, we can identify the position of hip, knee and ankle joint centres as well as pelvis, thigh, shank and foot segments at each time. To obtain interpretable kinetic data, a Butterworth filter was used to smooth the data.

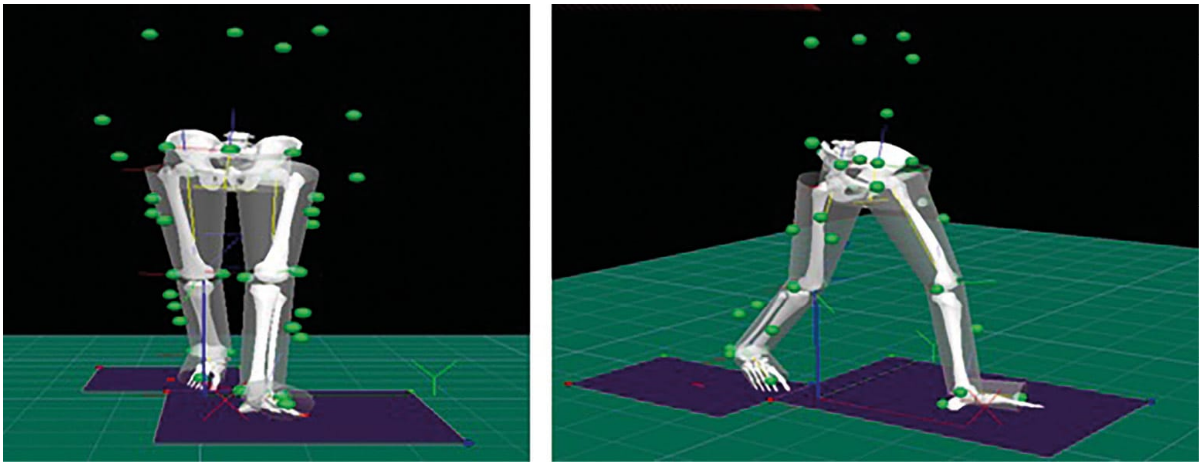
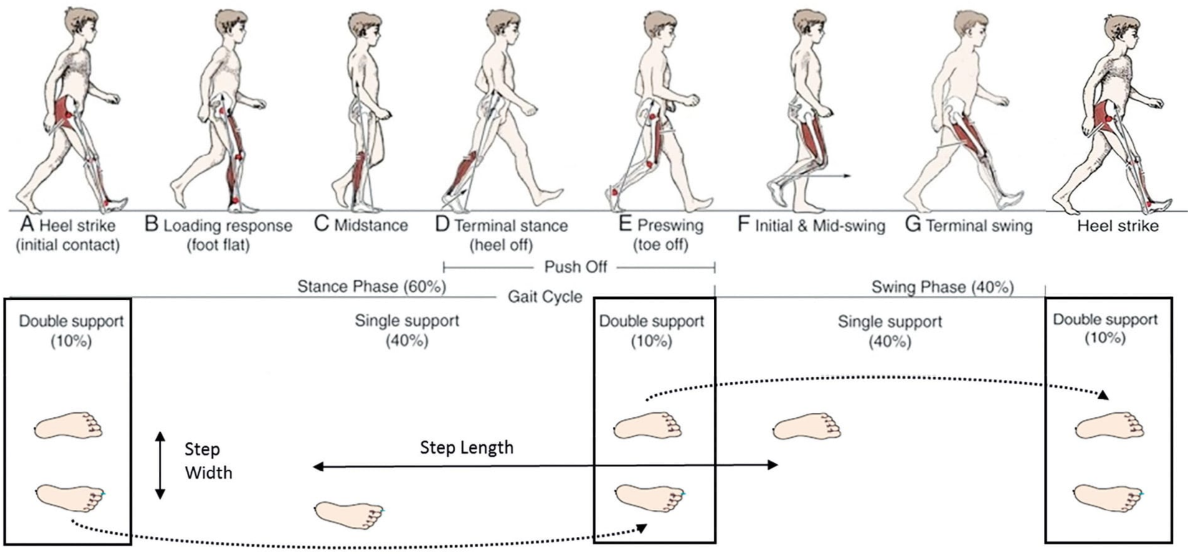


Figure 2: Model created in Visual 3D used to calculate joint centres and segments.



Stance Phase	A: Initial Contact (Heel Strike)	the heel is touching the ground
	B: Loading Response (Foot Flat)	the weight is transferred onto the referenced limb
	C: Mid Stance	alignment and balancing of body weight on the reference foot
	D: Terminal Stance	the heel of reference foot rises while toes are still in contact with the ground
	E: Toe Off (Pre Swing)	the toe of reference foot leave the ground and swings in air
Swing Phase	F: Initial Swing	the hip extends to 10° and then flexes 20° with lateral rotation. The knee flexes to 40-60°. The ankle goes from 20° of plantar flexion to dorsiflexion, to end in a neutral position
	F: Mid Swing	the hip flexes to 30°. The knee flexes 60° but then extends approximately 30°. The ankle becomes dorsiflexed
	G: Terminal Swing	the hip is still flexes to 25-30°. The knee is locked in extension. The ankle is in neutral position

Figure 3: Gait cycle

Gait characteristics evaluation

The gait cycle duration consists of 2 phases (swing and stance) and 2 types of stance (single and double support). The stance phase is the part of a gait cycle during which the foot remains in contact with the ground (60 % of the gait cycle) and consists of 5 parts (Figure 3). The swing phase is the part of the gait cycle during which the reference foot is not in contact with the ground and swings in the air (40% of gait cycle) and is constituted by 3 parts. The single support is when only one foot is in contact with the ground. The double support is when the both feet are in contact with the ground.

Spatiotemporal characteristics were calculated based on segment motion relative to the key gait events (Table 1): Velocity, Cadence, Step Length, Step Width, Single Support Time (SST), Initial Double Support Time (IDST), Double Support Time (DST) and Stance time.

Variables	Definition
Velocity (m/s)	Stride length / Stride time
Cadence (steps/min)	Step count / time in minutes
Step Length (m)	Distance between the proximal end position of the foot at ipsilateral heel strike to the proximal end position of the foot at the consecutive contralateral heel strike
Step Width (m)	Distance between the ipsilateral heel strike to the proximal end position of the foot at the next contralateral heel strike
Single Support time (%)	Time between toe-off and heel strike of the contralateral limb
Initial Double	Time between heel strike of the ipsilateral limb and toe off of the contralateral limb
Double Support time (%)	Sum of initial double support times for the left and right limbs
Stance time (%)	Time between heel strike and toe off of the ipsilateral limb

Table 1: Gait characteristics

MULTI LIGAMENT INJURIES

Injury pattern and demographic characteristics

We prospectively recorded data from 165 MLKI patients. The mean age was 32.4 years. There was a predominance of males (118 males and 45 females), most likely due to the mechanism of injury (high speed injuries, most commonly in motor-cross).

The MLKI were classified according to the Knee Dislocations (KD) Schenck classification (Table 2).

Class	Injuries description
KD I	injury to ACL or PCL with variable collateral involvement **IM** (ACL or PCL, MCL-PMC), **IL** (ACL or PCL, LCL-PLC)
KD II	injury to ACL and PCL only (collaterals intact)
KD III	injury to ACL, PCL, and one collateral injury (3 ligaments)**IIIM** (ACL, PCL, MCL-PMC), **IIIL** (ACL, PCL, LCL-PLC)
KD IV	injury to ACL, PCL, MCL-PMC, and LCL-PLC (4 ligaments)
KD V	MLKI with periarticular fracture-dislocation
Subtypes	C = arterial injury; N = neurologic injury

Table 2: Knee Dislocation Classification according to Schenck et al.

In our cohort, there were 30% of KD IL, 17% of KD IM, 7% of KD II, 20% of KD IIIL, 23% of KD IIIM and 3% of KD IV. Figure 4 shows the breakdown of injury pattern; a single cruciate combined with a lateral injury is the most common (30%).

The incidence of nerve injury was 18.9% overall. Vascular injury occurred in 5.3% of knees overall.

Clinical outcomes

Compared to a normal population, the functional results of MLKR patients remain low regardless of the number of injured ligaments (Figure 4).The mean IKDC subjective score was 70.5 ± 22.6 [36.6, 98.9]. For KOOS, Daily Living (90.6 ± 11.1 [62, 100]) and Pain (85.3 ± 15.2 [56, 100]) subscales improved more than the symptoms (73.7 ±18 [25, 100]), sports (64.7 ± 25.8 [25, 100], 42.5–83.8) and Quality of life (61.8 ± 24.4 [19, 94]) subscales. According to the IKDC objective score, 63% of patients were classified as “nearly normal”, 31 % classified as “abnormal”, one patient did not respond and none of them were considered clinically normal (Figure 5).

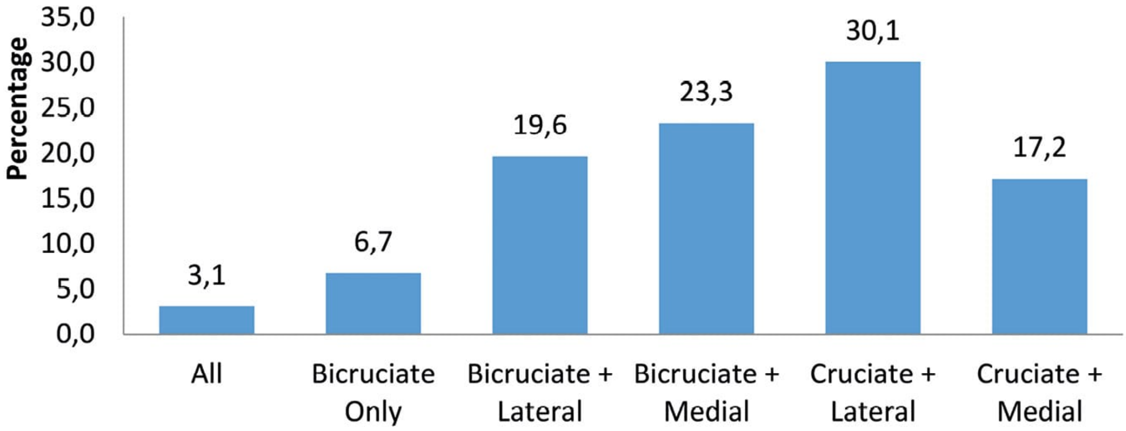


Figure 4: Percentage breakdown of injury classifications for patients who underwent a MLKR

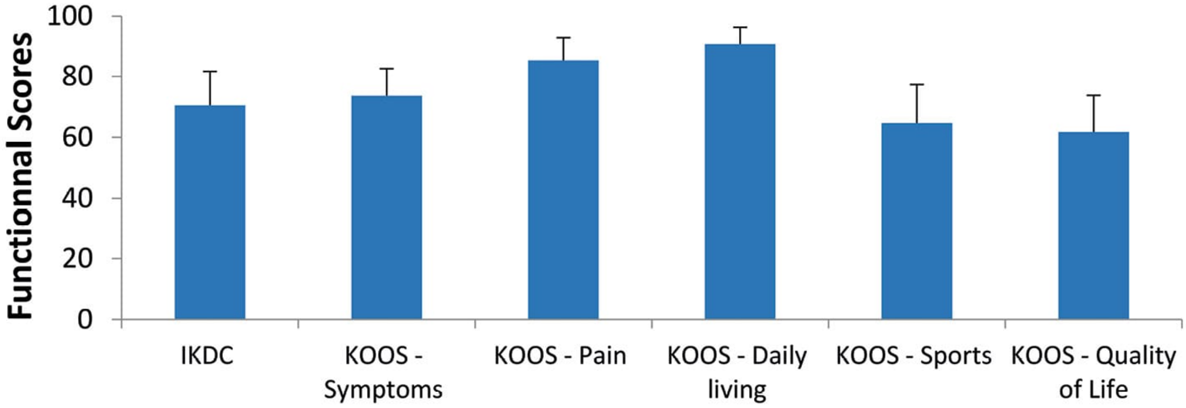


Figure 5: Functional scores outcomes for IKDC subjective and KOOS subscales scores (IKDC: International Knee Documentation Committee, KOOS: Knee Injury and Osteoarthritis Outcome Score).(IKDC: International Knee Documentation Committee, KOOS: Knee Injury and Osteoarthritis Outcome Score)

MULTILIGAMENT INJURIES AND GAIT ANALYSIS

Objectives

We hypothesized that the gait of MLKR patients remains altered post-surgery, and is related to their clinical profile. It was also hypothesised that patients with residual laxity had better functional outcomes than those with joint stiffness. Therefore, we aimed to compare the gait characteristics of MLKR patients with healthy controls, and to test the association between their clinical characteristics and gait variables.

Patient's recruitment

From a database of 165 patients that underwent MLKI surgery, a sample of 16 participants were recruited (Figure 6). MLKR were compared with contralateral knees and matched healthy control knees. Healthy control knees were matched for gender, age, height and weight (within 10%), were free of any lower limb pathology and had no prior history of surgery.

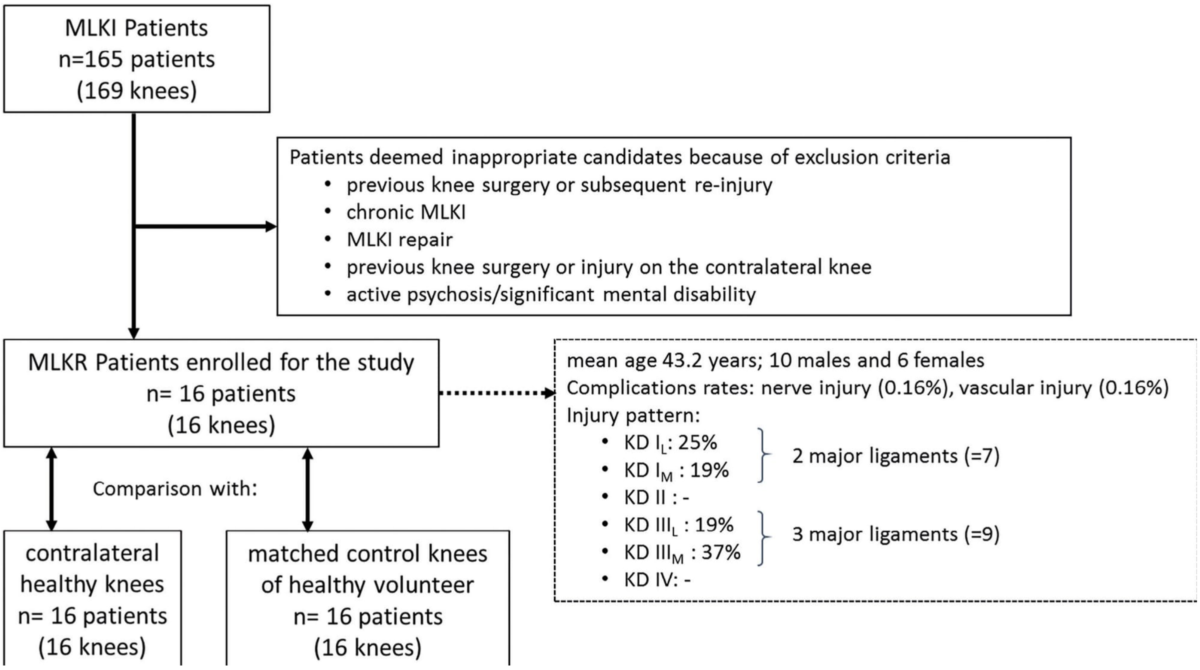


Figure 6: Study flowchart demonstrating recruitment, data characteristic and injury pattern

Gait analysis outcomes

Single subject analysis detected a number of significant inter-limb differences at heel strike and during the first 20% of stance. A proportion (38- 69%) of patients showed significant increases in knee angle at heel strike (Table 3). A proportion (31 - 69%) displayed significantly decreased arc of motion in their reconstructed knee compared to both their contralateral limb and matched healthy control (Table 3) for sagittal, frontal and rotational planes.

		Direction change	of Compared to Contralateral Knee	Compared to Matched Control
Heel Strike	Flexion	Increased	69%	38%
		Decreased	6%	44%
Angle	Rotation	Increased	31%	50%
		Decreased	44%	25%
Arc of Motion	Sagittal	Increased	0%	19%
		Decreased	69%	63%
	Rotation	Increased	31%	13%
		Decreased	50%	31%

Table 3: Percentage of patients with increased or decreased knee angle at heel strike and range of motion during first 20% of stance phase compared to their uninjured knee or matched control. Increased rotation equates to more internal rotation.

The MLKR group walked slower, had a shorter step length and spent more time in the initial double support phase compared to the control group ($P<0.05$) (Table 4). This may be due to more pain, less confidence, less stability and / or neuromuscular disorder in the MLKR group.

	Mean ± 95%CI MLKR group	Control	P-Value
Velocity (m/s)	1.49 ± 0.06	1.59 ± 0.06	0.04
Step Length (m)	0.73 ± 0.02	0.78 ± 0.02	<0.01
Step Width (m)	0.13 ± 0.01	0.13 ± 0.02	0.65
Cadence (steps/min)	118.2 ± 4.6	119.4 ± 4.6	0.33
Stance Time (%)	60.4 ± 0.9	59.7 ± 0.6	<0.01
Single Support duration (%)	40.0 ± 1.1	41.0 ± 0.43	0.09
Double Support duration (%)	20.4 ± 1.9	18.5 ± 1.0	0.095
Initial Double Support duration (%)	10.3 ± 0.9	9.3 ± 0.75	0.03

Table 4: Comparison of gait characteristics between groups (MKLR vs control) and limbs (injured vs contralateral).

Gait analysis relating clinical and laxity testing parameter

Significant relationships were present between the predictors and gait characteristics, measured as the difference (Δ) between MLKR and control knees. We summarized these main relationships in Table 5. It is noted that a patient with a pathologic gait has shorter and wider steps, a decreased single leg stance time (SST) and an increased bipedal support time (IDST).

		Δ gait characteristics			
		Δstep length	Δstep width	Δsingle support time	Δinitial double support time
demographics:	gender: Female	+0.29	-	-	-0.08
	age	-	+0.35	-	-
injuries pattern:	IM	-	-0.16	-	+0.08
	IIIM	-0.51	+0.12	-0.39	+0.38
	IIIL	-0.16	-0.15	-0.01	+0.20
functionnal scores:	IKDC	-	-0.12	-	-
	KOOS Symptoms	+0.17	+0.19	-0.28	+0.16
	KOOS Pain	-	-0.21	-0.18	+0.05
	KOOS QoL	-0.23	-0.26	-0.13	+0.09
	KOOS Sports	-0.06	-	-	-
stiffness/laxity:	extension deficit	-	-0.40	-0.61	+0.46
	KTmax	+0.17	-	-	+0.10
delay between surgery and gait analysis:		+0.07	-	+0.31	-0.24

Table 5: Regression coefficients for partial least squares model between MLKR and control groups for Δstep length, Δstep width, Δsingle support time and Δinitial double support time. Only the significant variables are reported. More the relationship is strong more the absolute value is high. In green, the relationship associated with more normal gait characteristics. In red, the relationship associated with more pathological gait characteristics.Only the significant variables are reported. More the relationship is strong more the absolute value is high.In green, the relationship associated with more normal gait characteristics.In red, the relationship associated with more pathological gait characteristics.

MKLR patients with stiffness have a more pathological gait than patients with laxity. Indeed, a flexion contracture (extension deficit) was strongly associated with pathological gait (shorter SST and longer IDST). Conversely, increased tibial anterior laxity at KT 1000 had a weak effect on the gait (more normal step length and increased IDST).

The injury pattern also influences the gait; patients with more than 2 injured ligaments, especially those involving the MCL, have more pathological gait (shorter and wider step, shorter SST, longer IDST). Generally, there were relationships between functional scores (IKDC, KOOS subscales) and gait characteristics. For example, higher functional scores (KOOS Symptoms and IKDC scores) were correlated with more normal step width and length, and lower subjective scores are reflected in shorter SST. With an increased follow up time (delay between surgery and gait analysis), some gait characteristics such as the IDTS and SST were improved, probably due to proprioceptive or psychological gait adaptation.

Lastly, amongst the demographic predictors, females generally had a more normal gait than males, and older patients walked with wider steps, as expected.

CONCLUSION

Injury patterns and mechanisms were varied, but the majority of cases were single cruciate combined with a lateral injury. The functional outcomes analysis showed that MLKI have a significant impact and patients rarely return to normal after treatment.

Although reconstructive surgery may be effective at restoring the clinical stability of the knee joint following MLKI, gait function remains altered post-surgery and these alterations are related to the clinical profile of patients. Certain injury patterns, such as bicruciate and collateral ligament injuries (especially those involving the MCL), seem to have worse results. Over time, adaptation phenomena appear to be working and allow an improvement of certain gait parameters. Generally, stiffness has a worse effect than residual laxity, supporting the recommendation for good functional rehabilitation compared with restricting mobility postoperatively.

REFERENCES

1. Ridley TJ, McCarthy MA, Bollier MJ, Wolf BR, Amendola A. The incidence and clinical outcomes of peroneal nerve injuries associated with posterolateral corner injuries of the knee. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2017. doi:10.1007/s00167-016-4417-2.

2. Wilson SM, Mehta N, Do HT, Ghomrawi H, Lyman S, Marx RG. Epidemiology of multiligament knee reconstruction. Clin Orthop 2014;472:2603–8. doi:10.1007/s11999-014-3653-3.

3. Cook S, Ridley TJ, McCarthy MA, Gao Y, Wolf BR, Amendola A, et al. Surgical treatment of multiligament knee injuries. Knee Surg Sports Traumatol Arthrosc Off J ESSKA 2015;23:2983–91. doi:10.1007/s00167-014-3451-1.

4. Maslaris A, Brinkmann O, Bungartz M, Krettek C, Jagodzinski M, Liodakis E. Management of knee dislocation prior to ligament reconstruction: What is the current evidence? Update of a universal treatment algorithm. Eur J Orthop Surg Traumatol Orthop Traumatol 2018. doi:10.1007/s00590-018-2148-4.

5. Lynch AD, Chmielewski T, Bailey L, Stuart M, Cooper J, Coady C, et al. Current Concepts and Controversies in Rehabilitation After Surgery for Multiple Ligament. Knee Injury. Curr Rev Musculoskelet Med 2017;10:328–45. doi:10.1007/s12178-017-9425-4.