Surgical Technique

Articulated External Fixator for Treatment of Complex Knee Dislocation

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Abstract

Background Knee dislocation is a severe but relatively uncommon injury caused by violent trauma that can result in long-term complications, such as arthrofibrosis, stiffness, instability, and pain. Perhaps owing in part to its rarity, treatment of this injury is controversial. We therefore

One of the authors certifies that he (MM) has designed a device used in this study and a member of his immediate family has or may receive payments or benefits, in any 1 year, of less than \$10,000 from a commercial entity (Citieffe, Calderara di Reno, BO, Italy) related to this work.

Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

This work was performed at the Rizzoli Orthopaedic Institute, Bologna, Italy.

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describe a treatment approach for these complex cases involving a novel dynamic knee external fixator.

Description of Technique We performed open PCL reconstruction when possible and/or repair of other associated lesions. At the end of the surgical procedure, the surgeon applied an external fixator that reproduced normal knee kinematics, allowing early motion exercises and reducing the risk of joint stiffness while protecting the bony and soft tissue structures involved in the repair during the first healing phase.

Patients and Methods We retrospectively reviewed eight patients treated with this approach, four of whom had the PCL reconstructed and four of whom had only associated injuries reconstructed. We evaluated all patients with clinical scores (subjective International Knee Documentation Committee form, Lysholm score, and Tegner level), physical examination (objective International Knee Documentation Committee form), and KT-1000™ arthrometer for AP laxity. Minimum followup was 10 months (mean, 26 months; range, 10–45 months).

Results One patient had manipulation under anesthesia. The median Lysholm score was 76, Tegner level was 4, and subjective International Knee Documentation Committee was 73. All patients recovered to their preinjury work activity, except one unemployed patient. Stability was normal or nearly normal in five patients; the mean side-to-side difference in AP displacement with manual maximum force was 2.9 mm.

Conclusions This approach with an external fixator allowed staged reconstruction and early motion and provided reasonable stability, ROM, and activity level at followup in patients with complex injuries.

Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

A knee dislocation is a severe injury caused by violent trauma and can result in long-term adverse effects that impair the patient's ability to return to physical work or recreational activities. The incidence of this injury is quite low, comprising less than 0.2% of orthopaedic injuries [27]. Recently, the Knee Dislocation Study Group defined this type of injury as a traumatic lesion resulting in the rupture of at least three of the four major ligaments of the knee and leading to a substantial degree of functional instability [16]. However, associated injuries, such as knee fractures and vascular and neurologic injuries, make it challenging to define the wide spectrum of knee dislocations.

Strategies for the management of knee dislocation are varied and controversial [18, 19, 40]. Nonoperative treatment generally results in stiff knees with limited ROM and low functional scores [1, 16, 27, 37]. Many surgeons therefore recommend surgery to repair or reconstruct all of the involved stabilizing structures [2, 8, 9, 13, 14, 16, 20–22, 25, 31, 32]. However, even after surgery, some residual impairment of function is still expected, with an incidence of complications, such as stiffness or failure of some reconstructed structures, between 21% and 61% [27].

Many authors advocate the use of aggressive rehabilitation to avoid postoperative stiffness despite the risk of placing excessive force on the graft tissue [5, 12, 13, 24, 36]. In recent papers, high subjective scores, reasonable stability, and a return to activities were achieved by performing simultaneous reconstruction of the ACL and PCL, as well as medial or lateral structures, followed by an aggressive rehabilitation protocol [5, 12, 13].

However, in complex cases with associated lesions, such as neurovascular injuries or fractures, there is no agreement on

treatment, and given the infrequent and varied nature of these injuries, it is difficult to standardize a treatment algorithm. In these complex cases, reconstruction of all of the ligaments combined with other additional surgery may be performed, but sometimes a staged procedure is recommended.

We describe a treatment approach for these complex cases that involves combining open surgery with a novel dynamic knee external fixator (EF) (Fig. 1A) that reproduces the normal kinematics of the knee. This device allowed for staged reconstruction and early motion exercise. It also reduced the risk of joint stiffness while protecting the graft and other bony and soft tissue structures during the first healing phase. We report eight patients with complex, high-energy dislocations treated with our protocol.

Surgical Technique

This approach was for complex knee dislocation where all of the four major ligaments of the knee were injured or where associated lesions, such as knee fractures or neurovascular injuries, coexisted. At the time of admission, all patients had a history, physical examination, standard radiographic evaluation, and MRI performed. The status of the ligaments was documented and graded according to the classification made by Schenck [28] and modified by others [35, 39], which assessed the injury pattern and presence or absence of associated knee fractures. Knee dislocations without both cruciates involved are considered KD-I, with both cruciates only KD-II, with both cruciates and medial or lateral structures KD-III, with both cruciates and both lateral and medial structures KD-IV, and if associated fractures occur KD-V. Four knees were KD-V and four were KD-IV. A complete examination of the neurovascular status of the involved leg was also performed.

Fig. 1A–C (A) A photograph shows the novel dynamic EF. Diagrams show (B) how the EF reproduces the four-bar linkage model of the cruciate ligaments and (C) the four-bar linkage model of the cruciate ligaments in a normal knee.

Patients underwent an open reduction surgery with the standard medial parapatellar arthrotomy and, when possible, a single-bundle PCL reconstruction using hamstrings tendons. Concurrently, we reconstructed or repaired the lateral and the medial structures if they were severely damaged and internally fixed any associated fractures. After PCL reconstruction and/or caring of the other associated lesions, a dynamic EF (Citieffe, Calderara di Reno, BO, Italy) designed by one of the authors (MM) was applied using the following procedure (Fig. 2).

In certain patients, we modified this protocol because associated lesions contraindicated the PCL reconstruction and medial or lateral reconstruction/repair. These injuries included associated tibial or femoral fractures compromising

the ability to perform the tunnels, wide knee exposure increasing the risk of infection, and severe vascular injury. In these patients, we surgically treated the associated lesions but not the PCL or medial or lateral structures and delayed the reconstruction of the injured ligaments.

The EF was designed to replicate motion based on a four-bar linkage model of the knee [21]. The hinge was designed with a central body made of radiotransparent material and a shaft and distraction ring nuts made of a light titanium alloy. As per the four-bar linkage model, the crossed position of the cruciate ligaments provided posterior rollback of femoral condyle during knee flexion. The device allowed knee flexion-extension motion and posterior rollback, as in a normal knee with a rotational axis that changes during flexion (Fig. 1B–C). Internal-external rotations that normally occur along the longitudinal axis were fixed. The knee was allowed to move only in the sagittal plane with a reduced ROM (0° – 100°). The normal flexion-extension axis of the knee is nearly parallel to the transepicondylar axis [4, 34]. In a preliminary in vitro study of a cadaveric knee, we performed a kinematic evaluation of the same knee without and with the EF applied and aligned with the epicondylar axis. The data suggested, through the ROM, the EF did not affect the tibial movement with respect to the femur when compared with a normal knee (Fig. 3). We did not, however, perform any studies with incorrect EF placement. Therefore, we believed it important to align the fixator axis with the knee flexion-extension axis to reproduce the natural knee motion and avoid placing aberrant forces on the joint. This step was demanding

Fig. 2A–D (A) AP and (B) lateral radiographs show the knee dislocation in Patient 3. (C) AP and (D) lateral radiographs show the same knee after PCL reconstruction and the EF implant.

Fig. 3 A graph shows the movement of the tibia with respect to the femur of a normal knee (NK) and of the same knee with our external fixator (EF). This movement was evaluated by means of a navigation system considering the anteroposterior (AP) and the proximodistal (PD) displacement between the two bones during the ROM.

because identifying the epicondyles was difficult [33]. Once we identified the lateral epicondyle by palpating the lateral aspect of the knee, we marked it with a sterile surgical marker. Then, we implanted a Kirschner guidewire through the marked point under fluoroscopic control to reproduce the transepicondylar axis. This Kirschner wire was used as a reference for positioning the hinge. A hole in the center of the EF allowed us to position the system according to the transepicondylar axis as confirmed by the implanted guidewire. We then inserted the first pin in the lateral aspect of the femoral diaphysis with the knee flexed at 90°. Flexion-extension movements of the knee were performed to check whether the EF alignment allowed unconstrained joint motion. Once the position was checked, and depending on any possible associated lesion of the tibia, we inserted a tibial pin on the medial side by means of a half ring or directly on the lateral side to avoid further damage to the involved leg. We then inserted two more pins parallel to the previous one to gain additional stability. The system also allowed joint distraction to protect from coexisting internally fixed or nondisplaced articular fractures.

Postoperative rehabilitation was started the day after surgery with continuous passive motion from 0° to 100° for the first week (Fig. 4). For the next 3 weeks, we allowed patients active ROM with no motion restriction. Patients immediately began walking and performing partial weightbearing and isometric exercises the day after surgery. This was true even for patients with fractures, as the EF provided some distraction force to the joint. For patients with associated fractures, we allowed partial weightbearing at 30% of total body weight.

We removed the EF under epidural anesthesia 1 month after surgery and tested the ROM and stability of the knee. All patient presented knee flexion of at least 100° without

any extension deficit. In one patient, we performed further ligament reconstruction not performed at the initial surgery.

The rehabilitation program was continued to achieve full ROM and allow complete healing of the soft tissues involved in the injury and open surgery. The program included active knee mobilization, cycling, swimming, and concentric exercises. Duration and intensity of the program were customized according to the specific needs of the patients. Full weightbearing was allowed 15 or 30 days after EF removal depending on the associated fracture status.

Patients and Materials

We retrospectively reviewed the records of eight patients with complex, high-energy dislocation treated with our protocol (Table 1). Every patient sustained a dislocation as a result of high-energy trauma and no patients sustained bilateral knee dislocations. The mechanism of injury involved a motorcycle crash, pedestrian struck by a vehicle, pedestrian struck by a motorcycle, or an automobile crash. No sports-related knee dislocations were included in this study group. Minimum followup was 10 months (mean, 26 months; range, 10–45 months).

In three patients, we observed and treated a unicondylar tibial plateau fracture. These patients underwent internal fixation with a gentle distraction obtained by the EF to allow partial weightbearing. A patient who presented with a combined patella fracture underwent the tension band wiring technique, and in another, we treated a popliteal artery lesion with bypass (Table 1).

We did not reconstruct the PCL in four patients. This treatment strategy was necessary because fractures made the PCL reconstruction impracticable due to structural impairments (one), open injury with high risk of infection

Fig. 4A–B Photographs show postoperative rehabilitation with continuous passive motion starting from (A) extension to (B) about 100° of knee flexion.

Table 1. Patient characteristics

Patient	Sex	Age at injury (years)	Followup (months)	Body mass index (kg/m ²)	Open dislocation	Injured ligaments	Associated fractures	Neurovascular status	Surgery associated with EF implant
1	Male	47	45	32.2	No	ACL + PCL + MCL + LCL	No	No	PCL + MCL repair
2	Male	42	33	41.9	No	ACL + PCL + MCL + LCL	Tibial plateau	No	PCL + PLC repair + internal fixation
3	Male	20	10	22.4	Yes	ACL + PCL + MCL + LCL	No	No	PCL + MCL repair
4	Male	18	18	20.9	No	ACL + PCL + MCL + LCL	No	Popliteal artery	Popliteal artery bypass
5	Male	18	26	21.3	No	ACL + PCL	Tibial plateau	No	PCL + internal fixation
6	Male	27	22	28.8	Yes	ACL + PCL + MCL + LCL	No	No	Wound suture
7	Female	45	20	27.5	No	ACL + PCL + MCL + LCL	Tibial plateau	No	Internal fixation
8	Male	20	34	21.5	Yes	ACL + PCL + MCL	Patella	No	Patella TBW

EF = external fixator; MCL = medial collateral ligament; LCL = lateral collateral ligament; PLC = posterolateral corner; TBW = tension band wiring.

(two), or severe injury of the popliteal artery (one). In these patients, we treated the severe associated lesions during the first stage of surgery and before any ligament reconstruction. None of these four patients underwent further ligament reconstruction before the followup evaluation as they had reasonable knee stability. Of the four patients who underwent PCL reconstruction at the time of EF application, one underwent manipulation under anesthesia 2 months before followup because of flexion limitation at 65°, and one patient underwent an ACL reconstruction 5 months after EF removal.

The patients underwent postoperative controls (1 and 3 months after EF removal) to check whether supplementary surgery was necessary. The final followup consisted of clinical evaluation and a series of self-administered questionnaires, including the subjective International Knee Documentation Committee (IKDC) form [11], Lysholm score, and Tegner level [38]. The patients were also asked whether they had recovered their preinjury work activity. Each patient underwent a physical examination by one of the authors, who graded the results according to the guidelines of the objective IKDC knee ligament standard evaluation form [10]. ROM of both knees was determined with a goniometer and loss of flexion and extension was determined relative to the uninvolved side. AP laxity was determined with the KT-1000TM arthrometer (MEDmetric Corp, San Diego, CA, USA) using the manual maximum test, a reportedly discriminating and reliable test to evaluate the side-to-side differences in AP laxity between the knees [3, 15, 26].

Results

At last followup, the median Lysholm score was 77, Tegner level was 4, and subjective IKDC was 73. All patients recovered their preinjury work activity except Patient 3, who was unemployed before the trauma. Of these seven patients, two were heavy workers while five were involved in sedentary work activity (Table 2).

Based on the objective IKDC assessment, stability was normal in one patient (Patient 5 who underwent a delayed ACL reconstruction), nearly normal in four patients, and abnormal in three patients. Of these three patients, Patients 2 and 4 had abnormal AP laxity but had not undergone ACL reconstruction. Patient 2 had a high body mass index (41.9), and Patient 4 decided not to undergo surgery because of his high level of activity. Patient 3 also had abnormal laxity. We observed no loss of extension in these patients, while the mean loss of flexion was 11.9° compared to the contralateral knee. The instrumented evaluation of the mean side-to-side difference in AP displacement with manual maximum force was 2.9 mm. The ACL reconstruction in Patient 5 resulted in normal stability with respect to the IKDC evaluation and KT-1000TM and a 5° loss of knee motion (Table 2).

We observed no infections related to the pins or to the reconstruction procedure.

Discussion

Strategies for treating knee dislocations have been varied and controversial [18, 19, 40]. Several authors have reported

Table 2. Clinical results

Patient	Lysholm score	IKDC (subjective) score	Tegner level	IKDC (objective) score	ROM	Loss of flexion	KT-1000™ at MMT (mm)
1	68	67	3	B	0°–100°	20°	2
2	71	68	3	C	0°–110°	15°	4
3	62	61	3	C	0°–120°	15°	2
4	96	92	7	C	0°–140°	0°	6
5	82	78	4	A	0°–120°	5°	1
6	76	69	4	B	0°–115°	20°	2
7	75	73	4	B	0°–120°	10°	3
8	82	78	5	B	0°–130°	10°	3

IKDC = International Knee Documentation Committee; MMT = manual maximum test (side-to-side difference).

Table 3. Literature comparison

Study	Number of patients	Patient injury type	Followup (months)*	Lysholm score*	Tegner level*	IKDC (objective) score	ROM*	KT-1000™ (mm)*
Ohkoshi et al. [23]	8 (9 knees)	KD-III: 100%	40.1 ± 16			B: 77.8% C: 22.2%	Active: 0°–127° Passive: 0°–139.5°	2.3 ± 1.9
Fanelli and Edson [6]	35	KD-II: 3% KD-III: 80% KD-IV: 17%	24–120	91 (70–100)	5.3 (3–7)			2.6 (0.0–9.0)
Engebretsen et al. [5]	85	KD-II: 6% KD-III: 82% KD-IV: 12%	64 (24–108)	83 (15–100)	5 (0–9)			2.7 ± 3.7
Stannard et al. [36]	37	Group A: 12 Control Group B: 25	24 (14–41)				A: 3°–118° B: 2°–120°	
Marcacci et al.	8	KD-IV: 50% KD-V: 50%	26 (10–45)	77 (62–96)	4 (3–7)	A: 12.5% B: 50.0% C: 37.5%	0°–119°	2.9 (1.0–6.0)

* Values are expressed as mean or mean ± SD, with range in parentheses; IKDC = International Knee Documentation Committee.

[9, 13, 41] a loss of flexion of less than 12°, improved stability, and high subjective scores with single-stage surgery of all involved stabilizing structures. However, these studies included predominantly low-energy or lower-grade (< KD-IV) knee dislocations and excluded open dislocations and patients with vascular lesions and associated fractures. To our knowledge, there is a lack of papers focused on complex high-energy knee dislocations [16, 27]. We therefore developed a treatment approach for these complex cases involving a novel dynamic knee external fixator that reproduced closely the features of normal knee kinematics; the device allowed staged reconstruction and early motion exercise, reducing the risk of joint stiffness while protecting the graft and other bony and soft tissue structures during the first healing phase. We described the followup observations of eight patients with complex, high-energy dislocations treated with our approach.

This study had some limitations. First, we had a small number of patients; however, knee dislocations are relatively uncommon, and out of this wide spectrum of injuries, we included only patients with complex knee dislocations caused by high-energy traumas, which are even rarer. However, our primary purpose was to describe the approach. Second, because ours was a retrospective review, we had no standard protocol for evaluation and treatment before this study. Third, since we had no control group of patients treated in another way, we compared our results to the available literature, and owing to variability in patient selection and methods, such a comparison was only an approximation. Fourth, this system presented a risk of infection related to the use of pins implanted close to the reconstructed structures. However, we did not observe, in our small series, any infection either related to the pin itself or to the reconstruction procedure.

Comparing our findings with those of other studies was difficult since the study populations often differed due to the heterogeneity of this type injury (Table 3). Ohkoshi et al. [23] reported on a series of eight patients (KD-III) who underwent staged reconstruction: early PCL followed by delayed ACL reconstruction. They gained full passive ROM (0° – 139.5°) in all knees. Those authors concluded staged reconstruction minimized postoperative stiffness. Their results confirmed the risk of arthrofibrosis and stiffness was higher when both cruciate ligaments were reconstructed at the same time [6, 7, 16, 17, 29, 30]. This aspect was even more important when associated lesions, such as neurovascular injuries, or fractures occurred. Fanelli and Edson [6] reviewed a series of 35 patients, including six with KD-IV dislocations. They reported variable results: the Tegner score ranged from 3 to 7 and the Lysholm score ranged from 70 to 100. They concluded multiligament reconstruction did not require staged surgery but suggested their procedure was less reliable for PCL reconstruction, possibly owing to the placement of too much stress on the graft during the rehabilitation phase. Engebretsen et al. [5] evaluated 85 consecutive patients treated with simultaneous reconstruction of the ACL and PCL, repair of medial or lateral structures, and early aggressive rehabilitation protocol. They also performed a subanalysis based on high- (51%) and low-energy (49%) trauma, acute and chronic surgery, and KD-IV (12%) versus KD-II–III (88%). They concluded their procedure provided worse outcomes, especially concerning subjective scores and one-leg hop tests, in patients with high-energy or KD-IV knee dislocations compared to those with low-energy or lower-grade knee dislocations. Stannard et al. [36] presented the Compass knee hinge (CKH) external fixator (Smith and Nephew, Memphis, TN, USA) in caring for knee dislocations. This device was designed to allow early ROM without overstressing the graft tissues. In their series, they performed staged surgery in 12 patients using the CKH in the initial surgery, followed by aggressive rehabilitation. Twenty-seven patients treated without the CKH formed the control group. They found a higher rate of PCL failures in the control group and concluded their device allowed for the healing of reconstructed structures and other secondary restraints during rehabilitation, leading to good joint mobility without a sacrifice in stability. However, the CKH does not allow for femoral posterior rollback during knee flexion, which is a distinctive feature of knee ROM; our device more closely reproduces the kinematics of the normal knee, allowing not just flexion-extension movement but also reproducing the posterior rollback. This feature reduces the stress on repaired soft tissue structures, such as the reconstructed grafts and the capsule, and presumably would allow them to heal under more physiologic stress.

All seven of the employed patients in our study returned to their preinjury work activity. Stability was normal in the one patient who underwent the delayed ACL reconstruction, nearly normal in four patients, and not normal in three patients (Table 2). Of these latter three patients, two had abnormal AP laxity but did not undergo ACL reconstruction: one was precluded because of his high body mass index (41.9) and the other decided not to undergo further surgery because of his high level of activity. The third patient (Patient 3) had abnormal varus laxity. This patient was the only one who failed because of stiffness, for which we performed manipulation under anesthesia.

Our observations show this surgical approach to complex high-energy knee dislocations resulted in more than 60% of normal or nearly normal knees. These data are similar to those reported in the literature [16, 27]. Moreover, the opportunity to stage surgery while protecting soft tissues and limiting the risk of knee stiffness allowed for later ligament reconstruction to be performed, similar to that performed for isolated ligament injuries.

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