Arthroscopic Suture Fixation of Tibial Eminence Avulsion Fractures

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Purpose: This study presents the clinical results of a procedure for treating tibial eminence fractures of the anterior cruciate ligament (ACL) using arthroscopic reduction and No. 5 Ethibond sutures (Ethicon, Somerville, NJ). **Methods:** This prospective study analyzed 36 patients who underwent arthroscopic reduction and suture fixation for image-proven ACL avulsion fractures of the tibial eminence. The classification of Meyers and McKeever identified 6 type II, 16 type III, and 14 type IV fractures. The mean follow-up period was 34.4 months (range, 24 to 91 months). Follow-up assessment included Lysholm knee score, Tegner activity score, International Knee Documentation Committee (IKDC) score, and KT-1000 arthrometer (MEDmetric, San Diego, CA) and radiographic evaluation. **Results:** The mean preoperative Lysholm score in the 36 knees was 38 (range, 28 to 54); the mean postoperative Lysholm score was 98 (range, 83 to 100). The mean preinjury and preoperative Tegner scores in the 36 knees were 7.5 ± 1.5 (range, 5 to 9) and 3 ± 1.7 (range, 2 to 5), respectively. The mean postoperative Tegner score was 7.3 ± 1.7 (range, 5 to 9). At final follow-up, 34 patients (94.5%) were classified by IKDC score as normal or nearly normal (grade A or B). The IKDC classification was abnormal (grade C) in 2 patients (5.5%). All 36 fractures achieved union within 3 months. No significant complications, such as arthrofibrosis, loss of initial fixation, or wound infection, were noted. **Conclusions:** Treating ACL avulsion fracture by arthroscopic suture fixation by use of 4 No. 5 Ethibond sutures can restore ACL length, stabilize fragments, promote early motion, and minimize morbidity. **Level of Evidence:** Level IV, therapeutic case series. **Key Words:** Anterior cruciate ligament—Avulsion fracture—Suture fixation—Arthroscopy.

Avulsion fracture of the tibial attachment of the anterior cruciate ligament (ACL) is more common in children and adolescents than in adults[1]; these avulsion fractures account for only 1% to 5% of ACL injuries in adults.[2] Meyers and McKeever[3,4] developed a system for classifying these fractures. Type I fractures produced minimal fragment displacement, type II fractures exhibited elevation of the anterior half of the fragment with the posterior half remaining well seated on the tibia, and type III fractures were those with complete displacement. This system was modified by Zaricznyj,[5] who suggested that comminution of a displaced avulsion fracture should be classified as a type IV fracture. Surgical intervention is indicated for Meyers and McKeever types II, III, and IV because displaced fractures may cause nonunion or malunion as well as loss of knee extension or instability.[5-8]

Treatment techniques include surgical open reduction or arthroscopic approaches and internal fixation with pins, wires, or suture fixation.[2-4,8,9] Open modes of reduction and fixation have particular disadvan-

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tages and morbidities, including arthrotomy with soft-tissue dissection, postoperative pain, delayed rehabilitation, prolonged hospitalization, and the need for subsequent implant removal. However, arthroscopic techniques have recently become the preferred treatment. The various arthroscopic intervention techniques include fixation with Kirschner wires,[10] staples,[11] metal screws,[12,13] or sutures.[14-20] This study prospectively evaluated 36 patients treated consecutively to determine patient outcome efficacy and complication potential of arthroscopic reduction and fixation by use of 4 No. 5 Ethibond sutures (Ethicon, Somerville, NJ) to treat tibial eminence fractures of the ACL at 2 to 8 years' follow-up. The hypothesis of the study is that arthroscopic suture fixation by use of 4 No. 5 Ethibond sutures to treat ACL avulsion fracture can restore ACL length, stabilize fragments, promote early motion, and minimize morbidity.

METHODS

Between December 1999 and August 2005, this prospective study enrolled 36 patients with imaging evidence of ACL avulsion fractures of the tibial eminence who underwent arthroscopy-assisted surgery. The inclusion criteria for the study were a displaced ACL avulsion fracture and anterior knee instability of grade II or higher (Fig 1). We determined anterior instability by performing the anterior drawer test and the Lachman test and by measuring knee laxity with a knee ligament arthrometer (KT-1000; MEDmetric, San Diego, CA). All patients were given a consent form to sign before surgery and underwent the same treatment protocol for arthroscopic suture fixation by use of 4 No. 5 Ethibond sutures (Ethicon) to treat tibial eminence fractures of the ACL. Avulsion fracture of the ACL is diagnosed by anterior instability on physical examination and radiographic evidence of bone fragmentation. The anterior drawer test was performed at 90° of knee flexion and was graded according to the extent of anterior translation (grade I indicated by translation <5 mm, grade II indicated by translation of 5 to 10 mm, and grade III indicated by translation >10 mm). Bone fragments shown by preoperative radiographs were measured with a ruler. The sizes of small or comminuted fragments were estimated during arthroscopy by use of a 5-mm vertical probe tip. All fragments were fixed with 4 No. 5 Ethibond polyester sutures through 2 tibial tunnels.

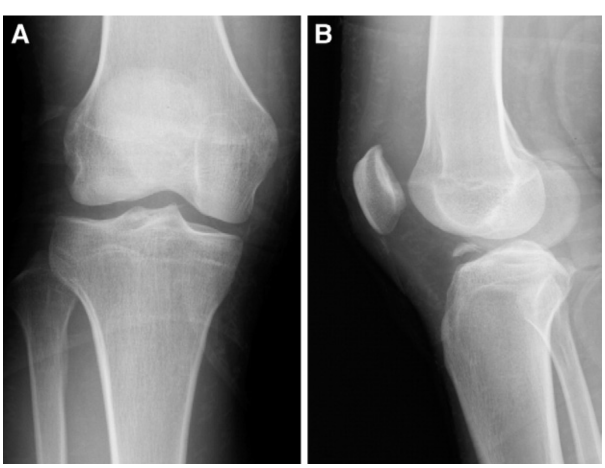

FIGURE 1. Anteroposterior (A) and lateral (B) radiographs in a 30-year-old male motorcycle accident victim with displaced type III tibial eminence fracture of right knee.

Operative Procedure

Patients were positioned supine on the operating table. Three anterior knee portals were used: anteromedial, anterolateral, and lateral midpatellar. Fracture debris and blood clots were debrided for visual access to the avulsed bone fragment and fracture site. An ACL tibial angle guide (Smith & Nephew Endoscopy, Andover, MA) was used to manipulate and anatomically reduce the displaced fracture fragment (Fig 2A). A 2-inch longitudinal incision was made just medial and inferior to the tibial tuberosity, then deepened until the tibial metaphysic was exposed subperiosteally. An ACL tibial drill guide was introduced in the anteromedial portal with the arthroscope placed in the anterolateral portal. Two 2.4-mm Kirschner wires were inserted through the guide from the proximal tibia into the knee joint (Fig 2B). Holes were considered correctly drilled upon observation of a 1-cm bridge of metaphyseal cortex. A 26-gauge wire loop was inserted into the knee joint via the medial and lateral tibial bone tunnels, and the diameter of the loop was dilated with a probe or suture grasp (Fig 2C). The suture hook (Linvatec, Largo, FL), loaded with No. 2 polydioxanone (PDS) (Ethicon), was used as a guide suture by passing it through the knee joint via the anteromedial portal and then through the medial wire loop, the posterior part of the ACL, and the lateral wire loop. The second guide suture was then passed through the medial wire loop, the anterior part of the ACL, and the lateral wire loop (Fig 2D). The medial and lateral wire loops were used to shuttle the No. 2 PDS through the medial and lateral bone tunnels, respectively (Fig 2E). After removal of the Kirschner

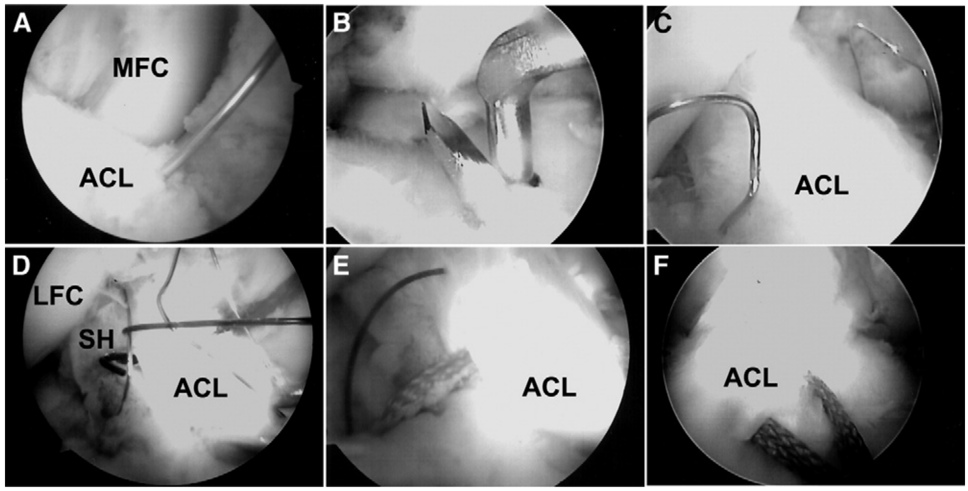

FIGURE 2. Intraoperative arthroscopic views. (A) The fragment was reduced by an ACL tibial guide and temporarily fixed with a 1.5-mm-diameter Kirschner wire. (B) Medial and lateral tunnels were drilled by two 2.4-mm Kirschner wires, and the wire loops were passed as depicted in C. (C) A 26-gauge wire loop was inserted into the knee joint via medial and lateral tibial bone tunnels. (D) The suture hook was loaded with No. 2 PDS as a guide suture was passed twice—one loop went through the posterior aspect of the ACL, and the second went through the anterior aspect. (E) The medial and lateral wire loops were used to shuttle the No. 2 PDS through the medial and lateral bone tunnels, respectively. The actual shuttling of the Ethibond was done by use of the PDS. The medial ends of each No. 2 PDS suture were tied with No. 5 Ethibond loops and retrieved through the medial tibial bone tunnel, passed through the anterior and posterior part of the ACL, and then shuttled into the lateral tibial bone tunnel. (F) The 4 No. 5 Ethibond sutures were individually identified and tied over bone tunnels on the anterior tibial cortex. (LFC, lateral femoral condyle; MFC, medial femoral condyle; SH, suture hook.)

wire, the knee was extended, and the tibial eminence avulsion fracture was reduced to the fracture bed. Next, tension was applied to all sutures (by use of a probe if necessary) to achieve anatomic reduction and restore normal position and tension to the ACL. The 4 No. 5 Ethibond sutures were individually identified and tied over bone tunnels on the anterior tibial cortex (Fig 2F). All procedures were performed by a single surgeon (Y-S.C.).

Rehabilitation Protocol

During the first postoperative week, each patient was immobilized with a full-extension knee brace. Full weight-bearing, quadriceps-strengthening, and isometric exercises were encouraged along with straight-leg raises. During weeks 2 to 4, the range of motion (ROM) for the 36 knees was 0° to 60° in flexion. At week 8, ROM was 0° to 120° in flexion, and closed-chain kinetic exercise was encouraged. During weeks 10 to 12, stationary bicycling and straight-leg stance were encouraged. At 6 months, all patients could fully resume sports activity.

Follow-up Evaluation

All subjects underwent clinical and radiographic assessments at follow-up (Fig 3). A fracture was considered to be united if no fracture line was visible radiographically. All patients were evaluated preoperatively; at 3 months, 6 months, 9 months, and 1 year postoperatively; and then annually thereafter. All patients were examined by an independent observer (T-W.H.) who was not involved in the surgeries. The

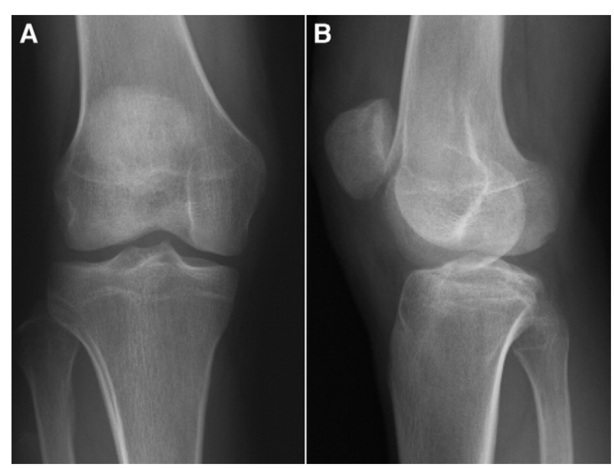

FIGURE 3. The anteroposterior (A) and lateral (B) radiographs of the knee 3 years after surgery showed that the tibial eminence was anatomically united. Clinically, the patient had excellent results according to knee functional scoring evaluation and was able to resume participation in competitive sports activity.

Lysholm scoring system[21] was used for follow-up assessment to document subjective symptoms; in addition, the Tegner activity score[22] and standard knee ligament evaluation of the Internal Knee Documentation Committee (IKDC) were used.[23] The IKDC score combines assessment of both symptoms and signs. Each category is assigned an overall grade of A (normal), B (nearly normal), C (abnormal), or D (severely abnormal). The final grade of A, B, C, or D is determined by the lowest score in each category. A manual anterior drawer test and a KT-1000 arthrometer (MEDmetric, San Diego, CA) were used to assess knee stability. Side-to-side differences in maximal manual test scores were determined to evaluate anteroposterior translation of ligament laxity. Knee radiographs in standing anteroposterior, standing lateral, and Merchant views were examined for alignment, joint space narrowing, and degenerative knee changes. The severity of degenerative knee changes was graded according to the classification of Ahlback.[24]

Statistics

Each radiograph was evaluated by 3 observers (visiting orthopaedic staff) in a blinded fashion to assess interobserver variance. The 3 observers also classified fracture type and union time in the 36 patients. Statistical analysis determined the interobserver variance in diagnosis for secondary osteoarthritis, fracture type, and union time. The interobserver variability by use of the κ method in diagnosis of secondary osteoarthritis, fracture type, and time for fracture union was in all cases insignificant ($P > .05$). The χ^2 test was used to compare categorical data by comparing IKDC changes in groups A and B with that in groups C and D (normal or nearly normal *v* abnormal or severely abnormal) between preoperative and final follow-up assessments. The Mann-Whitney *U* test was applied for ranking continuous data (Lysholm scores), and the unpaired Student *t* test was used to analyze continuous data (KT-1000 arthrometer comparison). Statistical analysis was conducted by an independent statistician blinded to surgical outcomes. $P < .05$ was considered statistically significant. Statistical analysis was performed by use of SigmaStat software, version 2.0 (Systat Software, San Jose, CA).

RESULTS

The subjects were 14 male and 22 female patients, and the mean age at the time of surgery was 37 years (range, 17 to 73 years). The injury mechanism was related to a traffic accident in 30 patients, related to sports in 5, and caused by a fall in 1. The Meyers and McKeever classification identified 6 type II, 16 type III, and 14 type IV fractures. The mean time from injury to surgery was 4.6 days (mean, 1 to 9 days). The mean follow-up period was 34.4 months (range, 24 to 91 months). Examination with the patient under anesthesia before surgery showed grade II anterior instability in 10 knees and grade III in 26.

Lysholm Knee Scores

The Lysholm knee scoring system was used to analyze subjective symptoms. The mean preoperative Lysholm score in the 36 knees was 38 (range, 28 to 54); the mean postoperative Lysholm score was 98 (range, 83 to 100). After a minimum of 2 years' follow-up, 32 of 36 patients (89%) had achieved excellent outcomes and 2 patients (5.5%) had achieved good outcomes. The 2 remaining patients achieved fair outcomes. No patient had a poor outcome. Lysholm scores significantly differed between preoperative evaluation and final follow-up ($P < .001$) (Table 1).

Tegner Activity Level

The mean preinjury and preoperative Tegner scores for the 36 knees were 7.5 ± 1.5 (range, 5 to 9) and 3 ± 1.7 (range, 2 to 5), respectively. The mean postoperative Tegner score was 7.3 ± 1.7 (range, 5 to 9). Improvement from preoperative to postoperative values was statistically significant ($P < .001$) (Table 2).

IKDC Evaluation

Activity: Preinjury activity levels for all patients ranged from strenuous to moderate. At the time of surgery, only 6 of 36 patients (17%) had light activity levels, and 30 (83%) had sedentary activity levels. Of the 36 patients, 34 (94.5%) achieved strenuous to

TABLE 1. *Comparison of Lysholm Knee Scores Preoperatively and at Final Follow-up*

Lysholm Knee Score	Preoperatively		Final Follow-up	
	No.	%	No.	%
Excellent (95-100)	0	0	32	89
Good (84-94)	0	0	2	5.5
Fair (65-83)	0	0	2	5.5
Poor (<65)	36	100	0	0
Mean ± SD	38 ± 10		98 ± 9*	
Range	28-54		83-100	

*$P < .05$ (Mann-Whitney *U* test).

TABLE 2. *Comparison of Tegner Activity Level Preoperatively and at Final Follow-up*

Tegner Activity Level	Preoperatively		Final Follow-up	
	No.	%	No.	%
0-3	25	69	0	0
4-6	11	31	8	22
7-10	0	0	28	78
Mean ± SD	3 ± 1.7		7.3 ± 1.7*	
Range	2-5		5-9	

*$P < .05$ (Mann-Whitney *U* test).

moderate activity levels at final follow-up whereas 2 (5.5%) could perform light activity. Thus activity levels significantly improved after surgery ($P < .001$) (Table 3).

Knee Function by Subjective Patient Assessment: Of the 36 patients, 34 (94.5%) subjectively rated their knee function as normal or near normal whereas 2 (5.5%) subjectively rated their knee function as abnormal.

Symptoms

Of the 36 patients, 97% (n = 35) reported no pain during moderate or strenuous activities; 1 patient (3%) reported inconstant and slight pain with moderate or strenuous activities.

Range of Motion

Before surgery, 7 patients (19.4%) had a 15° difference in flexion defect between the 2 sides. Of the patients, 13 (36.1%) had an extension defect exceeding 10°. At review, 16 patients (44.4%) whose normal and reconstructed limbs had a 3° or smaller difference in full extension or a 5° or smaller difference in full flexion were given a normal rating. A rating of abnormal was found in 2 patients (5.5%) (1 type III and 1 type IV) with 16° and 25° deficits in flexion. No patient had a severely abnormal rating (i.e., extension deficit >10° or flexion deficit >25°).

Ligament Examination

KT-1000 arthrometer data at 89 N were available for all 36 patients. Postoperatively, all patients had negative Lachman tests, and none exhibited pivot-shift phenomena. All patients had side-to-side differences of less than 3 mm at final follow-up. The mean difference at final follow-up was 1.0 mm (range, 0 to 2 mm). There was no statistically significant difference in postoperative KT-1000 scores compared with the contralateral uninjured limb data ($P > .05$).

Radiographic Assessment

By 3 months after surgery, radiologic assessments showed solid union in all 36 fractures. At final follow-up, 2 patients (10%) showed stage I degeneration according to the Ahlback classification.[24] These 2 patients had associated meniscal injuries (lateral meniscus in both cases) treated by partial meniscectomy.

Functional Testing

On the functional 1-leg hop test at final follow-up, 28 patients (78%) were able to hop 90% of the distance or greater using their healthy limbs, 6 (16.5%) were able to hop 76% to 89% of the distance using their healthy limbs, and 2 (5.5%) were able to hop 50% to 75% of the distance using their healthy limbs.

Associated Injuries

The associated injuries included meniscal injury in 9 patients (25%) (lateral meniscus in 7 and medial meniscus in 2) treated by partial meniscectomy. None of the 36 consecutive patients had collateral ligament, popliteal artery, or peroneal nerve injuries.

Complications

No complications were directly associated with arthroscopy. No deep infection, thrombophlebitis, or vascular injury was noted in this series.

DISCUSSION

The development of effective arthroscopic techniques for treating ACL avulsion has been reported recently. Techniques using Kirschner wire,[10] staples,[11]

TABLE 3. *IKDC Rating Preoperatively and at Final Follow-up*

Rating	Preoperatively		Final Follow-up*	
	No.	%	No.	%
A (normal)	0	0	28	78
B (nearly normal)	0	0	6	16.5
C (abnormal)	6	17	2	5.5
D (severely abnormal)	30	83	0	0

*$P < .05$ (χ^2 test) for final rating in those with a normal or nearly normal rating versus those with an abnormal or severely abnormal rating.

and metal screws[11,12] have proved effective. In 1982 McLennan[10] first described arthroscopy-assisted reduction of ACL avulsion fracture with percutaneous K-wire fixation in 11 children and adults. Anterior knee pain, instability, and loss of motion were commonly noted, and each patient required further surgery for pin removal. The surgical results of an arthroscopic technique developed by Veselko and Senekovic[13] using cannulated screws were evaluated over a 5-year period. Thirty-two fractures (types II, III, and IV) were treated successfully by anterograde fixation with cannulated screws and washers. Unfortunately, when type IV (comminuted) fractures were treated, stabilizing the fracture site by screw fixation was technically impossible. Moreover, patients treated with implants in the study of Veselko and Senekovic required further surgery for implant removal.

In contrast to arthroscopic reduction and fixation with implants, the suture method requires no further surgery for implant removal. Suture fixation techniques can be classified as those for treating the ACL itself (ligament suture methods)[14,17,18,20,25] and those for treating the avulsed bone fragment (avulsed bone fragment suture methods).[26] When an ACL avulsion fracture fragment is comminuted or small, sutures inserted through the ACL base provide secure fixation.[14,17,18,20,25] Matthews and Geissler[14] developed a technique for arthroscopic reduction and fixation by use of multiple No. 2 PDS sutures in 6 patients with tibial eminence fractures. No patients had subjective complaints of instability at 1 year, and only 1 patient lost 2° of terminal extension at latest follow-up. Kogan et al.[25] showed a modified technique for arthroscopic reduction and fixation by use of No. 1 PDS sutures in 6 patients with displaced fractures of the intercondylar eminence of the tibia. After a mean of 22 months' follow-up, all patients reported satisfaction with surgical outcome, and all had regained preinjury functional activity. Jung et al.[26] reported on 16 patients with tibial eminence fractures treated arthroscopically. All patients had good results and good stability. In a cadaveric biomechanical study Bong et al.[27] compared surgical outcomes of 2 techniques in 7 matched pairs of fresh-frozen human cadaveric knees with type III tibial eminence fractures. A fixation technique was performed using a single 4-mm cannulated cancellous screw with a washer, and an arthroscopic suture technique was performed using 3 No. 2 FiberWire sutures (Arthrex, Naples, FL) passed through the tibial base of the ACL and tied over bone tunnels on the anterior tibial cortex. The FiberWire fixation of eminence fractures provides biomechanical advantages over cannulated screw fixation. Tsukada et al.[28] and Mahar et al.[29] reported on biomechanical comparisons of pullout suture and screw fixation for ACL tibial avulsion fractures under cyclic loading. They also concluded that both methods were effective in obtaining initial rigid fixation for ACL avulsion fractures.[28,29] Our study used arthroscopic reduction and 4 No. 5 Ethibond suture fixation procedures to treat ACL avulsion fractures. The fixation method in this study was similar to that described by Bong et al. Postoperatively, all 36 patients had a negative Lachman test and no pivot-shift phenomenon. The KT-1000 arthrometer data showed side-to-side differences of less than 3 mm in all patients at final follow-up. The clinical results showed that this fixation technique can restore ACL length, stabilize all fragments, and achieve effective fracture unions. Of the 36 subjects in this study, 34 (94.5%) had excellent or good Lysholm knee scores as well as normal or nearly normal IKDC scores after more than 2 years of follow-up. Patient activity levels improved markedly after arthroscopic surgery.

The operative technique presented here has several advantages. First, the suture fixation technique requires no further surgery for implant removal. Second, the 4 No. 5 Ethibond intraligamentous sutures are sewn into the ACL base rather than into the avulsed bone; thus even reduction and fixation of type III or IV fractures are easily performed. Suture fixation is superior to screw fixation for treating avulsion fracture of the ACL because screw fixation may potentially break the bone fragment. Moreover, multiple sutures can be used for precise repair of bone fragments. Finally, special instruments such as suture punches are unnecessary.[14,25]

Berg[30] reported on 2 cases of arthroscopic reduction and fixation of eminence fractures in which postoperative arthrofibrosis developed. In a study by Montgomery et al.[31] 9 (53%) of 19 patients had severe difficulties regaining postoperative ROM. This limited ROM may be related to loose intra-articular bodies, anterior scar impingement, or hardware effects. The most common complications after arthroscopic reduction and fixation of ACL avulsion fracture are nonunion, arthrofibrosis, infection, and motion limitation.[30,31] Nonunion may be related to inadequate debridement of the fragment and fracture site. Limited ROM is another common postoperative problem. In this study no significant complications were noted. The lack of complications may have been because of the use of 4 No. 5 Ethibond intraligamentous sutures for stable fixation combined with the effects of an aggressive early postoperative motion treatment and rehabilitation program. Multiple sutures composed of PDS provide precise repair of bony fragments, consistent fixation strength throughout the fixation site, and early recovery of full ROM.[14,25,26] However, 2 patients (5.5%) (1 type III and 1 type IV) with 16° and 25° deficits in flexion were given a rating of abnormal. Patients with ACL avulsion fractures who undergo this procedure should be counseled regarding the increased risk of motion complications. More aggressive training for knee flexion and squatting ability should be strongly emphasized to avoid this problem.

The unique features of this prospective study are as follows: (1) All arthroscopic surgical techniques were performed by a single surgeon using only 1 fracture fixation method and suture material, and all patients underwent the same rehabilitation program. (2) All 36 patients received complete follow-up and outcome assessment. However, acknowledged limitations of this study are the lack of a control group, the small case number, and the short observation period.

CONCLUSIONS

Treating ACL avulsion fracture by arthroscopic suture fixation by use of 4 No. 5 Ethibond sutures can restore ACL length, stabilize fragments, promote early motion, and minimize morbidity.

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