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Original Article

Arthroscopic Pull-Out Suture Fixation versus Double-Loop Cortical Button Fixation for ACL Tibial Eminence Avulsion Fractures: A Retrospective Comparative Study

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ABSTRACT

Objective: This study aimed to compare the perioperative, radiological, and clinical outcomes of arthroscopic pull-out suture fixation and double-loop cortical button fixation for anterior cruciate ligament (ACL) tibial eminence avulsion fractures.

Materials and Methods: This retrospective, two-center comparative study included patients who underwent arthroscopic fixation for ACL tibial eminence avulsion fractures between August 2022 and November 2024. Patients with modified Meyers and McKeever type IIIA or IIIB fractures and a minimum follow-up of 12 months were included. Patients were divided into two groups according to fixation technique: pull-out suture fixation and double-loop cortical button fixation. Demographic and perioperative variables, radiological union, Lysholm Knee Score, range-of-motion deficits, Lachman test results, and revision surgery were evaluated. Patients who underwent revision surgery were retained in the revision analysis, but post-revision clinical findings were excluded from the final comparison of clinical outcomes.

Results: A total of 37 patients were included: 19 in the pull-out suture fixation group and 18 in the double-loop cortical button fixation group. There were no significant differences between the groups in baseline characteristics, fracture type, time from injury to surgery, operation time, length of hospital stay, or follow-up duration. Radiological union was observed in all patients except the patient who underwent revision surgery, and no nonunion or secondary displacement was detected among patients who completed follow-up without revision. Final clinical outcomes were compared between 19 patients in the pull-out suture fixation group and 17 patients in the double-loop cortical button fixation group. The Lysholm Knee Score did not differ significantly between the groups (84.7±8.6 vs. 87.1±8.9, p=0.231). Extension deficit, flexion deficit, and Lachman grade distribution were also similar between the groups. One patient in the double-loop cortical button fixation group required revision ACL reconstruction, whereas no patient in the pull-out suture fixation group required revision (p=0.486).

Conclusion: No statistically significant differences were detected between arthroscopic pull-out suture fixation and double-loop cortical button fixation in the perioperative, radiological, and clinical outcomes evaluated in this cohort. Given the small sample size, these findings should not be interpreted as demonstrating equivalence between the two techniques. Double-loop cortical button fixation may represent an alternative fixation option for selected type IIIA and IIIB fractures.

Keywords: ACL avulsion fracture, arthroscopy, cortical button fixation, Endobutton, pull-out suture fixation, tibial eminence fracture, tibial spine fracture.

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INTRODUCTION

Tibial eminence avulsion fractures are intra-articular injuries in which the anterior cruciate ligament (ACL) is avulsed from its tibial insertion with an attached bony fragment.[1,2] Although these injuries are classically regarded as the pediatric equivalent of midsubstance ACL rupture, they may also occur in skeletally mature patients, particularly after sports trauma or high-energy mechanisms.[1–3] Because displaced fragments may alter ACL tension and knee kinematics, inadequate reduction or fixation may result in residual anterior instability, restricted range of motion, nonunion, or secondary degenerative changes.[2,4]

The Meyers and McKeever classification, with later modifications by Zaricznyj, remains the most widely used system for describing these fractures.[5,6] While nondisplaced type I fractures are generally treated nonoperatively, displaced type III fractures and comminuted type IV fractures usually require surgical reduction and fixation.[1,2,6] The management of type II fractures remains more controversial, particularly when residual displacement or soft-tissue interposition prevents anatomic reduction.[2] In recent years, arthroscopic treatment has become the preferred approach because it allows direct visualization of the fracture bed, assessment and treatment of concomitant intra-articular lesions, less soft-tissue morbidity, and accurate reduction.[1,4,7]

Several arthroscopic fixation methods have been described, including screw fixation, Kirschner wires, suture anchors, pull-out sutures, suture bridge constructs, and cortical button-based techniques.[1,4,8–12] Pull-out suture fixation is one of the most commonly used arthroscopic techniques and is particularly useful for small or comminuted fragments where screw fixation may not be feasible.[2,8,11] However, concerns remain regarding fixation strength, suture cut-through, fragment control, and the ability to allow early rehabilitation.[9–11] Double-loop cortical button fixation has been proposed as an alternative method that may provide stable fixation with a broader implant–bone interface and may reduce the risk of fragment fragmentation or fixation failure.[4,9,10] Nevertheless, the available evidence for this technique remains limited, and comparative clinical data against conventional pull-out suture fixation are scarce.[4,8,9]

The aim of the present study was to compare the perioperative, radiological, and clinical outcomes of arthroscopic pull-out suture fixation and double-loop cortical button fixation in patients with ACL tibial eminence avulsion fractures. We hypothesized that double-loop cortical button fixation would provide clinical outcomes comparable to or better than pull-out suture fixation without increasing operative time, postoperative motion limitation, residual laxity, or the revision surgery rate.

MATERIALS AND METHODS

Study Design and Patient Selection

This retrospective, two-center comparative study was conducted at the Department of Orthopedics and Traumatology, Selçuk University Faculty of Medicine, Konya, Türkiye, and the Department of Orthopedics and Traumatology, University of Health Sciences, Antalya Training and Research Hospital, Antalya, Türkiye. Patients who underwent arthroscopic fixation for anterior cruciate ligament tibial eminence avulsion fractures between August 2022 and November 2024 were evaluated. The study protocol was approved by the institutional ethics committee, and informed consent was obtained from all patients (Ethics Committee Approval No.: 3/7; Approval Date: 05 February 2026). Patients were divided into two groups according to the fixation technique used: arthroscopic pull-out suture fixation and arthroscopic double-loop cortical button fixation. Because this was a retrospective study, treatment allocation was not randomized, and no predefined allocation protocol was used. The choice between pull-out suture fixation and double-loop cortical button fixation was made according to the preference of the operating surgeon. Both fixation techniques were used across the two participating centers.

Patients with ACL tibial eminence avulsion fractures who were treated arthroscopically with either of these two fixation techniques and had a minimum follow-up duration of 12 months were included in the study. The inclusion criteria were Meyers and McKeever type IIIA or IIIB tibial eminence avulsion fractures, complete perioperative records, and available final clinical and radiological follow-up data. Patients were excluded if they had associated tibial plateau fractures or other periarticular fractures requiring additional fixation, multiligament knee injuries requiring ligament reconstruction at the index surgery, previous surgery on the affected knee, chronic neglected fractures or nonunion, open fractures, neurovascular injuries, incomplete medical records, or a follow-up duration shorter than 12 months. Demographic and perioperative data, including age, sex, affected side, body mass index, fracture type, time from injury to surgery, operation time, length of hospital stay, and follow-up duration, were collected from hospital records. Clinical and radiological outcomes were assessed at the final follow-up.

Preoperative Assessment

All patients were evaluated clinically and radiologically before surgery. Standard anteroposterior and lateral knee radiographs were obtained in all cases. Computed tomography was used to define fracture morphology, displacement, rotation, and comminution (Fig. 1). Magnetic resonance imaging was obtained when needed to evaluate ACL continuity and

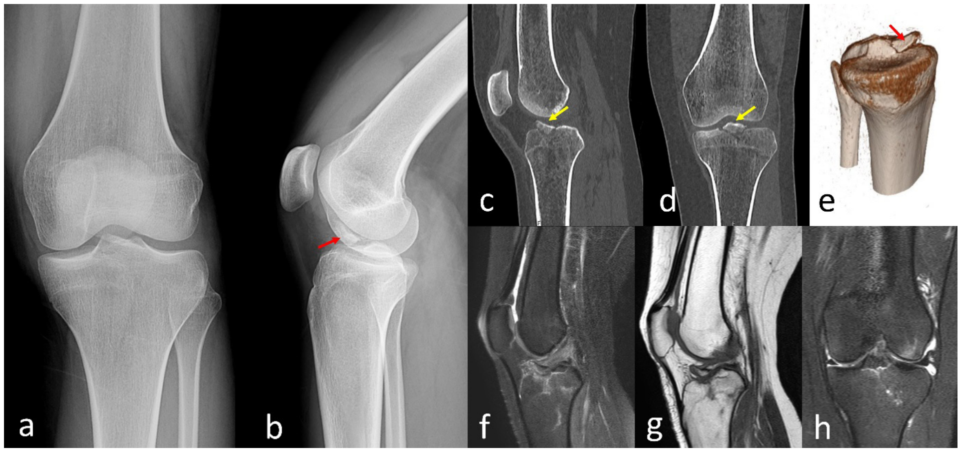

Figure 1. Preoperative radiological evaluation of a 20-year-old female patient with tibial eminence avulsion fracture. Anteroposterior **(a)** and lateral **(b)** knee radiographs show an avulsion fracture of the tibial eminence; the red arrow on the lateral radiograph indicates the displaced avulsed fragment. Sagittal **(c)** and coronal **(d)** computed tomography images demonstrate the fracture morphology, displacement, and involvement of the intercondylar eminence; yellow arrows indicate the displaced fragment of the tibial eminence. Three-dimensional reconstruction **(e)** further illustrates the displaced avulsed fragment, marked by the red arrow. Sagittal and coronal magnetic resonance images **(f–h)** demonstrate the relationship of the avulsed fragment with the anterior cruciate ligament and allow assessment of associated intra-articular injuries.

possible associated meniscal, chondral, or ligamentous injuries. Fractures were classified according to the modified Meyers and McKeever classification (Fig. 2).[5,6] In our treatment algorithm, type I and type II fractures were managed conservatively when acceptable reduction and knee stability could be achieved. Type IV fractures, which are characterized by comminution of the avulsed fragment, were not included because double-loop cortical button fixation was considered unsuitable for these fracture patterns; instead, pull-out suture fixation was preferred for comminuted fragments to allow secure capture of multiple small fragments and the ACL substance. Therefore, to provide a more homogeneous comparison between the two fixation techniques, only type IIIA and type IIIB fractures with a single large displaced fragment were included in the present study. Surgical treatment was indicated for completely displaced or rotated fragments requiring anatomic reduction and stable fixation to restore ACL tension and knee stability.

Surgical Technique

All procedures were performed under spinal or general anesthesia with the patient in the supine position. A pneumatic tourniquet was applied over the thigh. Standard anterolateral and anteromedial arthroscopic portals were used. After evacuation of the hemarthrosis, diagnostic arthroscopy was performed to evaluate the ACL, fracture fragment, menisci, cartilage, and other intra-articular structures. Interposed hematoma, fibrous tissue, and soft-tissue structures preventing reduction were removed. The fracture bed was carefully debrided, and the avulsed fragment was anatomically reduced under direct arthroscopic visualization.

In the pull-out suture fixation group, the avulsed fragment and the ACL substance near its tibial insertion were secured using high-strength sutures. Sutures were passed through the ACL base and/or around the bony fragment using an arthroscopic suture passer, similar to previously described pull-out suture techniques.[3,13–15] A single tibial tunnel was created from the anteromedial proximal tibial cortex toward the fracture bed using an ACL tibial guide. The suture limbs were retrieved through the tibial tunnel and tensioned under arthroscopic visualization to achieve anatomic reduction of the fragment.[3,13–15] After arthroscopic confirmation of anatomic reduction and appropriate ACL tension, the suture limbs were tensioned through the tibial tunnel and fixed over the distal anterior tibial cortex using a cortical screw and washer as a post-fixation construct. The washer was used to distribute the compressive force and prevent suture slippage during tying. The sutures were securely tied around the screw–washer construct while maintaining reduction under arthroscopic visualization. The knee was then cycled through flexion and extension, and

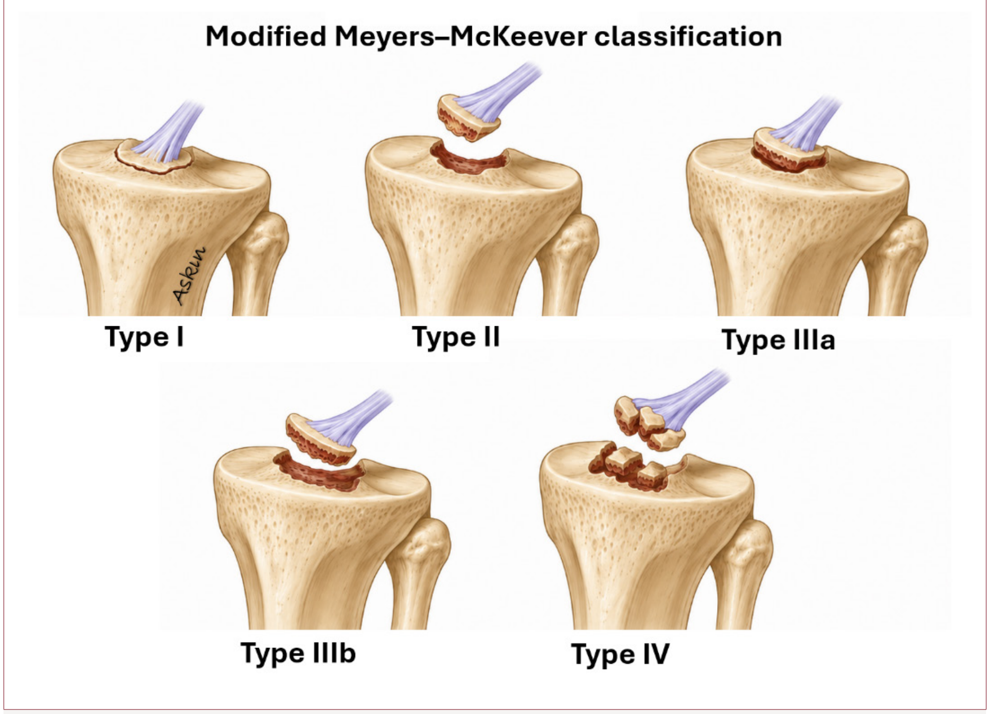

Figure 2. Modified Meyers–McKeever classification of tibial eminence fractures[5,6]. Schematic illustration showing the fracture patterns of anterior cruciate ligament tibial eminence avulsion fractures. Type I represents a nondisplaced fracture. Type II represents a partially displaced fracture with posterior hinging. Type IIIA represents complete displacement of the avulsed fragment involving the ACL insertion. Type IIIB represents complete displacement involving the entire intercondylar eminence. Type IV represents a comminuted displaced fracture fragment.

the stability of the fixation, ACL tension, and maintenance of fracture reduction were confirmed arthroscopically and fluoroscopically.[13–15]

In the double-loop cortical button fixation group, the fracture fragment was reduced arthroscopically after preparation of the fracture bed, as previously described for Endobutton- and cortical button-based fixation techniques.[4,8,9] A tibial tunnel was created from the anteromedial proximal tibial cortex toward the tibial eminence using an ACL tibial guide. A double-loop cortical button construct was then passed through the tibial tunnel and positioned over the avulsed fragment under direct arthroscopic visualization. The loop was tensioned to compress the fragment against the fracture bed and restore ACL tension.[4,9] The distal loop was secured on the anteromedial tibial cortex using a cortical button fixation system. Reduction, compression of the avulsed fragment, and fixation stability were checked arthroscopically. The knee was cycled several times through the range of motion to confirm that reduction was maintained and that there was no impingement or loss of fixation. Final reduction was confirmed by fluoroscopy.[4,8,9] The fixation principles of the two arthroscopic techniques are illustrated schematically in Figure 3, demonstrating pull-out suture fixation with distal tibial cortical screw–washer fixation and double-loop cortical button fixation with cortical button stabilization.

Postoperative Rehabilitation

The same postoperative rehabilitation protocol was used for both groups. After surgery, the knee was immobilized in a hinged knee brace locked in extension, consistent with previously described postoperative protocols for arthroscopic fixation of tibial eminence fractures.[3,4] Isometric quadriceps exercises, ankle pump exercises, and straight-leg raises were started in the early postoperative period as tolerated.[3] Partial weight-bearing with crutches was allowed during the first two weeks, as tolerated, with adjustments based on pain, swelling, and fixation stability. Passive and active-assisted range-of-motion exercises were gradually initiated after 2 weeks, with progressive flexion according to the rehabilitation protocol.[4] Full weight-bearing was allowed once radiological signs of healing were present

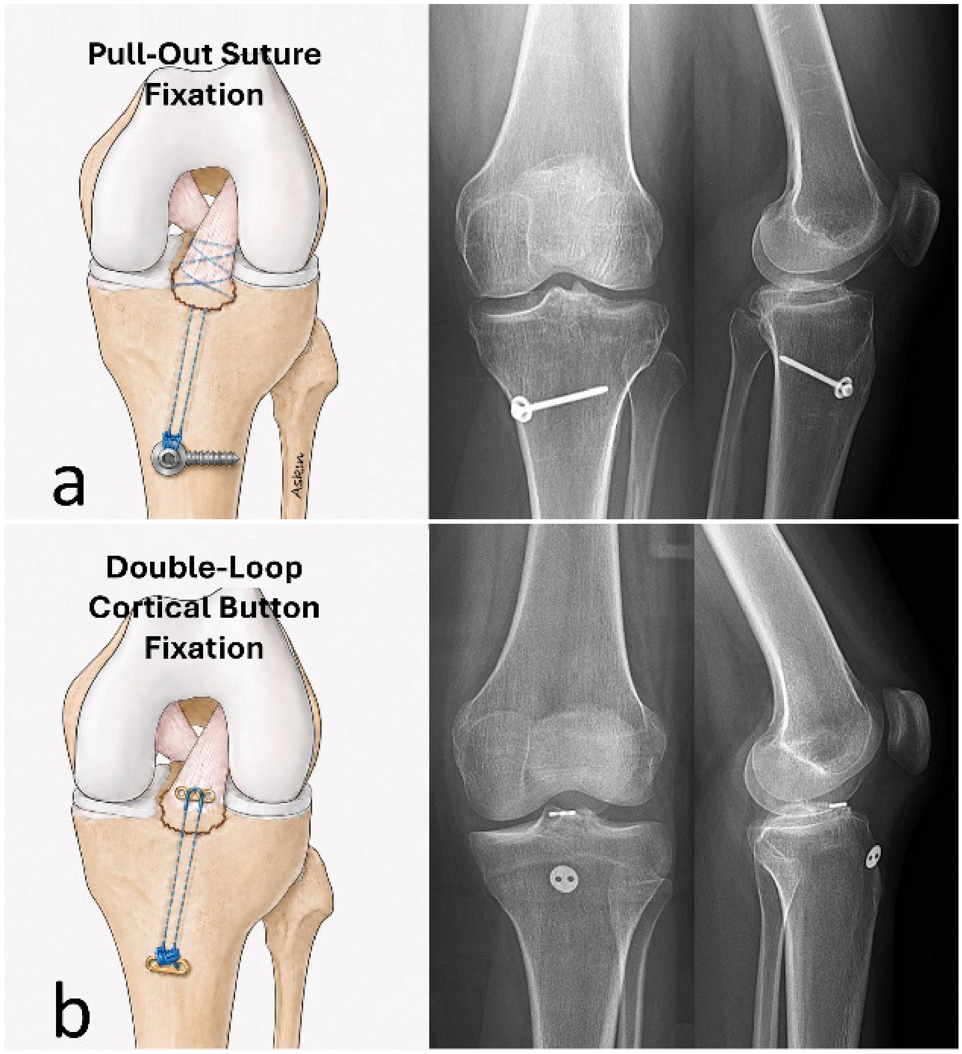

Figure 3. Schematic illustrations and representative postoperative radiographs of the two arthroscopic fixation techniques for ACL tibial eminence avulsion fractures. **(a)** Arthroscopic pull-out suture fixation. High-strength sutures are passed through the ACL substance and around the avulsed tibial eminence fragment, then retrieved through the tibial tunnel and fixed over the distal anterior tibial cortex with a cortical screw and washer construct. **(b)** Arthroscopic double-loop cortical button fixation. The avulsed fragment is reduced arthroscopically and compressed using a double-loop cortical button construct, with proximal cortical button fixation over the fragment and distal cortical button fixation on the anterior tibial cortex.

and adequate quadriceps control was achieved.[3] Running and sport-specific activities were permitted after clinical and radiological union, restoration of range of motion, absence of instability, and sufficient muscle strength.[16] The rehabilitation protocol was adjusted as needed based on fracture stability, concomitant intra-articular lesions, pain, swelling, and range-of-motion recovery.

Follow-up and Outcome Assessment

Patients were followed clinically and radiologically according to each institution's routine postoperative follow-up protocol. Because of the retrospective nature of the study, follow-up intervals were not identical for all patients. Available postoperative radiographs and clinical records were reviewed to assess fracture union, maintenance of reduction, range of motion (ROM), knee stability, complications, and the need for revision surgery. Range of motion was measured in degrees relative to the contralateral knee. For the categorical analysis, any measurable loss of extension or flexion (>0°) was recorded as a ROM deficit. Because this definition also captures minor motion loss, clinically relevant ROM loss was additionally defined as an extension deficit of ≥5° or a flexion deficit of ≥10°. All eligible patients were invited for a final follow-up examination, during which clinical outcomes were assessed using the Lysholm Knee Score, ROM measurements, and the Lachman test. At each participating center, the Lachman test was performed at the final follow-up by the designated orthopedic surgeon responsible for clinical follow-up at that center; thus, two assessors were involved overall, with one assessor at each center. The test was performed using the same clinical examination approach at both centers, and laxity was recorded according to the predefined grading system.

Radiological union was evaluated using the available postoperative and final follow-up radiographs. Radiological union was assessed on anteroposterior and lateral knee radiographs and was defined as disappearance or substantial blurring of the fracture line, with restoration of trabecular continuity across the fracture site and maintenance of fracture reduction without secondary displacement. Radiological assessments were performed by a single experienced orthopedic surgeon who reviewed the available postoperative and final follow-up radiographs. One patient who underwent revision surgery with subsequent ACL reconstruction was retained in the baseline, perioperative, and revision surgery analyses. However, post-revision clinical examination findings were excluded from the final clinical outcome comparison because these values could be influenced by the secondary ACL reconstruction rather than the index fixation technique. Revision surgery was analyzed separately as a treatment-failure endpoint.

Statistical Analysis

No formal a priori sample size calculation or power analysis was performed because of the retrospective study design; all eligible patients who met the inclusion criteria during the predefined study period were included. Statistical analysis was performed to compare baseline characteristics, perioperative variables, and clinical outcomes between the pull-out suture fixation and double-loop cortical button fixation groups. Continuous variables were reported as mean±standard deviation and median [interquartile range], whereas categorical variables were reported as number and percentage. Because of the relatively small sample size, continuous variables were compared between the groups using the Mann–Whitney U test. Categorical variables were compared using Fisher's exact test. The final clinical outcome analysis included only patients who did not undergo revision surgery. One patient in the double-loop cortical button fixation group underwent revision surgery with subsequent anterior cruciate ligament reconstruction; therefore, post-revision clinical examination findings were excluded from the final clinical outcome analysis to avoid confounding by the secondary procedure. However, this patient was retained in the baseline, perioperative, and revision surgery analyses. Revision surgery was analyzed separately as a treatment-failure endpoint. All statistical tests were two-sided, and a p-value <0.05 was considered statistically significant.

RESULTS

A total of 37 patients who met the inclusion criteria were included in the study. Nineteen patients underwent arthroscopic pull-out suture fixation, and 18 patients underwent arthroscopic double-loop cortical button fixation. At the first center, 4 patients underwent pull-out suture fixation and 11 underwent double-loop cortical button fixation, whereas at the second center, 15 patients underwent pull-out suture fixation and 7 underwent double-loop cortical button fixation. The distribution of fixation techniques differed between the two centers (Fisher's exact test, p=0.020). The baseline demographic and perioperative characteristics of the two groups are summarized in Table 1. There were no statistically significant differences between the groups in terms of age, sex distribution, affected side, body mass index, fracture type, time from injury to surgery, operation time, length of hospital stay, or follow-up duration. The mean age was 28.1±12.4 years in the pull-out suture fixation group and 25.7±8.4 years in the double-loop cortical button fixation group. The median time from injury to surgery was 4.0 days in both groups. Operation time was comparable between the groups, with a mean of 69.6±7.0 minutes in the pull-out suture fixation group and 67.9±7.8 minutes in the double-loop cortical button fixation group. The median follow-up duration was 26.0 months in the pull-out suture fixation group and 24.0 months in the double-loop cortical button fixation group.

Radiological union was evaluated using available postoperative and final follow-up radiographs. Radiological union of the tibial eminence fracture was observed in all patients except the patient who underwent revision surgery. No nonunion or secondary displacement was detected among patients who completed follow-up without revision surgery. Final clinical outcomes are summarized in Table 2. One patient in the double-loop cortical button fixation group underwent revision surgery with ACL reconstruction due to persistent anterior knee laxity after the index fixation; therefore, post-revision clinical examination findings were excluded from the

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Table 1. Baseline and perioperative characteristics of the patients

Variable	Data Units	Pull-out Suture Fixation (n=19)	Double-Loop Cortical Button Fixation (n=18)	p
Age	years±SD	28.1±12.4	25.7±8.4	0.915
	median [IQR]	23.0 [17.0–37.5]	23.5 [19.0–32.5]	
Sex	Male, n (%)	14 (73.7)	17 (94.4)	0.180
	Female, n (%)	5 (26.3)	1 (5.6)	
Side	Right, n (%)	8 (42.1)	8 (44.4)	1.000
	Left, n (%)	11 (57.9)	10 (55.6)	
BMI	kg/m^2±SD	26.7±5.4	25.6±5.1	0.503
	median [IQR]	26.0 [23.0–30.0]	25.5 [22.0–28.0]	
Fracture Type	Type IIIa, n (%)	12 (63.2)	12 (66.7)	1.000
	Type IIIb, n (%)	7 (36.8)	6 (33.3)	
Center	Center 1	4 (21.1)	11 (61.1)	0.020
	Center 2	15 (78.9)	7 (38.9)	
Time to surgery	days±SD	4.9±1.9	4.3±2.3	0.294
	median [IQR]	4.0 [3.5–6.0]	4.0 [3.0–5.8]	
Operation time	min.±SD	69.6±7.0	67.9±7.8	0.538
	median [IQR]	70.0 [65.0–75.0]	67.5 [64.2–73.0]	
LOS	days±SD	2.8±1.0	2.7±0.8	0.895
	median [IQR]	2.0 [2.0–3.0]	3.0 [2.0–3.0]	
Follow-up	months±SD	25.6±5.0	26.1±5.6	0.903
	median [IQR]	26.0 [22.0–28.0]	24.0 [22.2–29.8]	

Data are presented as mean±standard deviation and median [interquartile range] for continuous variables, and as number (%) for categorical variables. Continuous variables were compared between groups using the Mann–Whitney U test. Categorical variables were compared using Fisher's exact test. BMI: body mass index; IQR: interquartile range; LOS: length of hospital stay; SD: standard deviation.

final clinical outcome comparison. This patient was retained in the analysis of revision surgery. Accordingly, final clinical outcomes were compared between 19 patients in the pull-out suture fixation group and 17 patients in the double-loop cortical button fixation group.

The Lysholm Knee Score was comparable between the groups. The mean Lysholm score was 84.7±8.6 in the pull-out suture fixation group and 87.1±8.9 in the double-loop cortical button fixation group, with no statistically significant difference. Extension and flexion deficits were also similar between the groups. The mean extension deficit was 0.8±3.4° in the pull-out suture fixation group and 0.6±2.4° in the double-loop cortical button fixation group. The mean flexion deficit was 6.3±5.0° and 6.8±6.1°, respectively.

Lachman test findings were similar between the groups. Grade 0 Lachman was observed in 14 patients in the pull-out suture fixation group and 13 patients in the double-loop cortical button fixation group. Grade 1 Lachman was observed in 5 and 4 patients, respectively. No patient had grade 2 Lachman laxity in the final clinical outcome analysis.

Revision surgery was required in one patient in the double-loop cortical button fixation group and in none of the patients in the pull-out suture fixation group. The revision surgery rate did not differ statistically between the groups. Overall, no statistically significant differences were detected between arthroscopic pull-out suture fixation and double-loop cortical button fixation in the perioperative, radiological, or clinical outcomes evaluated in this cohort.

DISCUSSION

The most important finding of the present study was that arthroscopic pull-out suture fixation and double-loop cortical button fixation provided comparable perioperative, radiological, and clinical outcomes in patients with type IIIa and IIIb ACL tibial eminence avulsion fractures. No significant differences were observed between the two techniques in terms of operation time, length of hospital stay, follow-up

Table 2. Clinical outcomes according to fixation technique

Variable	Data Units	Pull-out Suture Fixation (n=19)	Double-Loop Cortical Button Fixation (n=17*)	p
Lysholm Knee Score	score±SD	84.7±8.6	87.1±8.9	0.231
	median [IQR]	80.0 [80.0–90.0]	90.0 [80.0–95.0]	
Extension deficit	°±SD	0.8±3.4	0.6±2.4	1.000
	median [IQR]	0.0 [0.0–0.0]	0.0 [0.0–0.0]	
Flexion deficit	°±SD	6.3±5.0	6.8±6.1	0.961
	median [IQR]	5.0 [2.5–10.0]	5.0 [0.0–10.0]	
Flexion deficit ≥10°	n, (%)	8/19 (42.1)	7/17 (41.2)	1.000
Extension deficit ≥5°	n, (%)	1/19 (5.3)	1/17 (5.9)	1.000
Lachman	Grade 0, n (%)	14 (73.7)	13 (76.5)	1.000
	Grade 1, n (%)	5 (26.3)	4 (23.5)	
	Grade 2, n (%)	0 (0.0)	0 (0.0)	
Revision surgery	n (%)	0/19 (0.0)	1/18 (5.6)	0.486

Data are presented as mean±standard deviation and median [interquartile range] for continuous variables, and as number (%) for categorical variables. Continuous variables were compared between groups using the Mann–Whitney U test. Binary categorical variables were compared using Fisher's exact test. *One patient in the double-loop cortical button fixation group underwent revision surgery with ACL reconstruction; therefore, post-revision clinical examination findings were excluded from the final clinical outcome analysis, whereas the patient was retained in the revision surgery analysis. IQR: interquartile range; SD: standard deviation.

duration, Lysholm Knee Score, range-of-motion deficits, Lachman grade distribution, or revision surgery rate. Radiological union was achieved in all patients who completed follow-up without revision surgery, and no nonunion or secondary displacement was detected. Although one patient in the double-loop cortical button fixation group required revision ACL reconstruction, the overall revision rate did not differ significantly between the groups. These findings suggest that double-loop cortical button fixation may be a safe and effective alternative to conventional pull-out suture fixation in selected displaced tibial eminence avulsion fractures with a single large fragment.

Tibial eminence avulsion fractures are relatively uncommon injuries, and the optimal fixation method remains debated because several arthroscopic techniques have been described without a clearly established gold standard.[1,17,18] Recent literature has emphasized that arthroscopic fixation is the predominant surgical approach for displaced fractures, as it allows anatomic reduction, assessment of associated intra-articular lesions, and stable fixation with less soft-tissue morbidity.[1,4,17,18] In the present study, radiological union was achieved in all patients who completed follow-up without revision surgery, and no secondary displacement or nonunion was observed. These findings are consistent with previous reports showing high union rates and satisfactory clinical outcomes after arthroscopic fixation of displaced tibial eminence avulsion fractures.[3,4,8,16,19,20]

Pull-out suture fixation is one of the most commonly used arthroscopic techniques for tibial eminence avulsion fractures, particularly when the fragment is small or when screw fixation may increase the risk of fragmentation.[2,9,13] Previous studies have reported favorable functional outcomes, restoration of knee stability, and high union rates after arthroscopic pull-out suture fixation.[3,16,19,20] Kocher et al.[16] reported excellent long-term functional outcomes after arthroscopic-assisted pull-out suture fixation, with high Lysholm scores, restored anterior knee stability, and return to sport without significant impairment. Similarly, other clinical series have described the pull-out suture technique as a straightforward and reliable method for fixation of ACL tibial avulsion fractures.[3,20] In the present study, the pull-out suture fixation group also demonstrated satisfactory functional outcomes, with a mean Lysholm score of 84.7 and no revision surgery.

Cortical button-based fixation has been introduced as an alternative technique to improve fixation stability and fragment control.[4,8–10,21] The proposed advantages of Endobutton or cortical button constructs include compression over a broader implant–bone interface, reduced risk of suture cut-through, and avoidance of intra-articular screw-related problems.[8–10,21] Yıldırım et al.[4] reported successful short-term outcomes in 13 patients treated with a double-loop Endobutton device, with radiological union in all patients and negative Lachman and pivot-shift tests at the final follow-up. Sekiya et al.[8] also described secure fixation with an Endobutton technique, reporting bone union, stable knees, excellent range of motion, and negative Lachman and pivot-shift tests in all five patients. In the present study, the double-loop cortical button fixation group showed Lysholm scores, range-of-motion outcomes, and Lachman grade distribution comparable to those of the pull-out suture group, supporting the use of this method as an alternative fixation strategy for selected type IIIa and IIIb fractures.

An important point in interpreting the present study is fracture selection. Type IV comminuted fractures were excluded because these fractures are less suitable for double-loop cortical button fixation and are more commonly managed with suture-based techniques that can capture multiple small fragments and the ACL substance.[2,6,9] By including only type IIIa and IIIb fractures with a single large displaced fragment, the present study attempted to create a more homogeneous cohort and a more balanced comparison between the two fixation methods. This design may help reduce bias that could arise if comminuted fractures were disproportionately treated with pull-out sutures.

The revision case in the double-loop cortical button group should be interpreted cautiously. Although this patient required subsequent ACL reconstruction, the overall revision rate did not differ statistically between the groups. In addition, post-revision clinical findings were excluded from the final clinical outcome analysis to avoid confounding by the secondary ACL reconstruction. This approach allowed the revision event to be analyzed as a treatment-failure endpoint while preventing post-reconstruction knee function from being incorrectly attributed to the index fixation technique.

The present study has several strengths. First, it directly compared two arthroscopic fixation techniques for ACL tibial eminence avulsion fractures, whereas most previous studies have reported outcomes of a single technique without a control group. Second, only modified Meyers and McKeever type IIIa and IIIb fractures were included, creating a more homogeneous cohort with a single large displaced fragment and allowing a more balanced comparison between pull-out suture fixation and double-loop cortical button fixation. Third, the study was conducted at two centers and included clinically relevant perioperative, radiological, and functional outcomes, such as operative time, radiological union, Lysholm Knee Score, range of motion, Lachman test findings, and the need for revision surgery.

This study also has limitations. The retrospective design carries an inherent risk of selection bias, and the fixation technique was not randomized but was selected according to the operating surgeon's preference. Moreover, the distribution of the two fixation techniques differed between the participating centers, raising the possibility of center- and surgeon-related confounding. Therefore, differences in institutional practice and surgeon-related factors may have influenced the observed outcomes and should be considered when interpreting the comparisons between the two techniques. The sample size was relatively small, and no a priori sample size calculation or formal equivalence or non-inferiority analysis was performed. Therefore, the study may have been underpowered to detect clinically relevant between-group differences, particularly for uncommon outcomes such as revision surgery, nonunion, or secondary displacement. Accordingly, the absence of statistically significant differences should not be interpreted as evidence of equivalence between the two fixation techniques. Follow-up intervals and radiographic assessments were not fully standardized because of the retrospective nature of the study. Radiological union was assessed using available postoperative and final follow-up radiographs rather than a uniform computed tomography protocol. In addition, objective instrumented measurements of laxity, such as KT-1000 or Rolimeter testing, were not available. Patient-reported outcomes other than the Lysholm Knee Score, as well as detailed return-to-sport data, were not evaluated. Finally, because type IV comminuted fractures were excluded, the findings cannot be generalized to all patterns of tibial eminence avulsion fractures.

CONCLUSION

In conclusion, no statistically significant differences were detected between arthroscopic pull-out suture fixation and double-loop cortical button fixation in the perioperative, radiological, and clinical outcomes evaluated in patients with modified Meyers and McKeever type IIIa and IIIb ACL tibial eminence avulsion fractures. Radiological union was achieved in all patients who completed follow-up without revision surgery, and no secondary displacement or nonunion was observed. However, because of the small sample size and the absence of an equivalence or non-inferiority analysis, these findings should not be interpreted as demonstrating equivalence between the two techniques. Double-loop cortical button fixation may be an alternative for selected fracture patterns, but larger prospective studies are needed to establish its comparative effectiveness and safety.

DECLARATIONS

Ethics Committee Approval: This study was approved by the Ethics committee of Antalya Training and Research Hospital (Approval No.: 3/7, Date: 05.02.2026).

Informed Consent: Written informed consent was obtained from all patients who participated in the study.

Conflict of Interest: The authors declared no conflict of interest.

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ABBREVIATIONS

ACL: Anterior cruciate ligament

BMI: Body mass index

CT: Computed tomography

IQR: Interquartile range

LOS: Length of hospital stay

MRI: Magnetic resonance imaging

ROM: Range of motion

SD: Standard deviation

REFERENCES

1. Landré V, Teuben M, Klingebiel FK, Shehu A, Ensle F, Pape HC, et al. Tibial anterior cruciate ligament avulsion fractures in pediatric and adult populations: a systematic literature review. J Clin Med 2025;14:6316. [CrossRef]
2. Leeberg V, Lekdorf J, Wong C, Sonne-Holm S. Tibial eminentia avulsion fracture in children - a systematic review of the current literature. Dan Med J 2014;61:A4792.
3. Kumar Das T, Dash M, Dash A, Mishra J, Zion N. Evaluation of the suture pull-out technique in anterior cruciate ligament avulsion fractures at different weeks post-fracture. Cureus 2024;16:e69126. [CrossRef]
4. Yıldırım A, Aydın BK, Çiftci S, Güleç A. Arthroscopic treatment of tibial eminence fractures using double-loop endobutton device: Surgical technique and short-term treatment outcomes. Jt Dis Relat Surg 2020;31:456–62. [CrossRef]
5. Meyers MH, Mckeever FM. Fracture of the intercondylar eminence of the tibia. J Bone Joint Surg Am 1959;41-A:209–20; discussion 220–2. [CrossRef]
6. Zaricznyj B. Avulsion fracture of the tibial eminence: treatment by open reduction and pinning. J Bone Joint Surg Am 1977;59:1111–4. [CrossRef]
7. McLennan JG. The role of arthroscopic surgery in the treatment of fractures of the intercondylar eminence of the tibia. J Bone Joint Surg Br 1982;64:477–80. [CrossRef]
8. Sekiya H, Takatoku K, Kimura A, Kanaya Y, Fukushima T, Takeshita K. Arthroscopic fixation with EndoButton for tibial eminence fractures visualised through a proximal superomedial portal: a surgical technique. J Orthop Surg (Hong Kong) 2016;24:417–20. [CrossRef]
9. Pape D, Giffin R. Arthroscopic endobutton fixation for tibial eminence fractures: surgical technique. J Knee Surg 2005;18:203–5. [CrossRef]
10. Hapa O, Barber FA, Süner G, Özden R, Davul S, Bozdağ E, et al. Biomechanical comparison of tibial eminence fracture fixation with high-strength suture, EndoButton, and suture anchor. Arthroscopy 2012;28:681–7. [CrossRef]
11. Bong MR, Romero A, Kubiak E, Iesaka K, Heywood CS, Kummer F, et al. Suture versus screw fixation of displaced tibial eminence fractures: a biomechanical comparison. Arthroscopy. 2005;21:1172–6. [CrossRef]
12. Sawyer GA, Hulstyn MJ, Anderson BC, Schiller J. Arthroscopic suture bridge fixation of tibial intercondylar eminence fractures. Arthrosc Tech 2013;2:e315–8. [CrossRef]
13. Hunter RE, Willis JA. Arthroscopic fixation of avulsion fractures of the tibial eminence: technique and outcome. Arthroscopy 2004;20:113–21. [CrossRef]
14. Kogan MG, Marks P, Amendola A. Technique for arthroscopic suture fixation of displaced tibial intercondylar eminence fractures. Arthroscopy 1997;13:301–6. [CrossRef]
15. Matthews DE, Geissler WB. Arthroscopic suture fixation of displaced tibial eminence fractures. Arthroscopy 1994;10:418–23. [CrossRef]
16. Kocher FM, Galofaro L, Schwab JM, Raabe I, Tannast M, Petek D. Tibial eminence avulsion fracture in pediatric patients reinserted with arthroscopy and pull-out suture technique: clinical and functional outcomes in a long-term follow up with return to sport. Children (Basel) 2025;12:499. [CrossRef]
17. Osti L, Buda M, Soldati F, Del Buono A, Osti R, Maffulli N. Arthroscopic treatment of tibial eminence fracture: a systematic review of different fixation methods. Br Med Bull 2016;118:73–90. [CrossRef]
18. Gans I, Baldwin KD, Ganley TJ. Treatment and management outcomes of tibial eminence fractures in pediatric patients: a systematic review. Am J Sports Med 2014;42:1743–50. [CrossRef]

19. Pan RY, Yang JJ, Chang JH, Shen HC, Lin LC, Lian YT. Clinical outcome of arthroscopic fixation of anterior tibial eminence avulsion fractures in skeletally mature patients: a comparison of suture and screw fixation technique. J Trauma Acute Care Surg 2012;72:E88–93. [CrossRef]

20. Ahn JH, Yoo JC. Clinical outcome of arthroscopic reduction and suture for displaced acute and chronic tibial spine fractures. Knee Surg Sports Traumatol Arthrosc 2005;13:116–21. [CrossRef]

21. Kelly S, DeFroda S, Nuelle CW. Arthroscopic assisted anterior cruciate ligament tibial spine avulsion reduction and cortical button fixation. Arthrosc Tech 2023;12:e1033–8. [CrossRef]