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Clinical efficacy of suture bridge versus hollow screw fixation for PCL tibial avulsion fractures: a comparative study

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Abstract

Objective To evaluate and compare the clinical outcomes of the suture bridge technique and hollow screw fixation in treating posterior cruciate ligament (PCL) tibial avulsion fractures.

Methods A retrospective analysis was conducted on 40 patients treated between January 2013 and December 2023. Patients were divided into two groups: the suture bridge group (20 cases) and the hollow screw group (20 cases). Both groups underwent minimally invasive surgery with a small posteromedial arc incision. The suture bridge technique utilized high-strength sutures and suture anchors, while the hollow screw group employed 3.5 mm hollow screws. Postoperative outcomes were assessed using Lysholm, Tegner and International Knee Documentation Committee (IKDC) scores, with radiographic imaging performed at regular intervals to monitor fracture healing.

Results Both groups showed significant improvements in Lysholm, Tegner and IKDC scores postoperatively ($P < 0.05$). The Tegner score in the suture bridge group was slightly higher than that in the hollow screw group ($P = 0.038$). The postoperative drainage volume in the suture bridge group was slightly higher than that in the hollow screw group ($P = 0.011$), with no significant differences in surgical time, intraoperative blood loss or joint mobility ($P > 0.05$). Most fractures healed within 3 to 6 months. In the suture bridge group, two cases of malunion were observed due to small bone fragment displacement. In the hollow screw group, two cases of screw head retraction and one case of bone fragment displacement were noted.

Conclusion Both the suture bridge technique and hollow screw fixation are effective for treating PCL tibial avulsion fractures, each with unique advantages and potential complications. The suture bridge technique provides secure fixation, particularly for comminuted fractures, and is suitable for pediatric patients to avoid growth plate injury.

Clinical trial number Not applicable.

Keywords Suture bridge technique, Hollow screws, PCL tibial avulsion fracture, Minimally invasive surgery, Clinical efficacy

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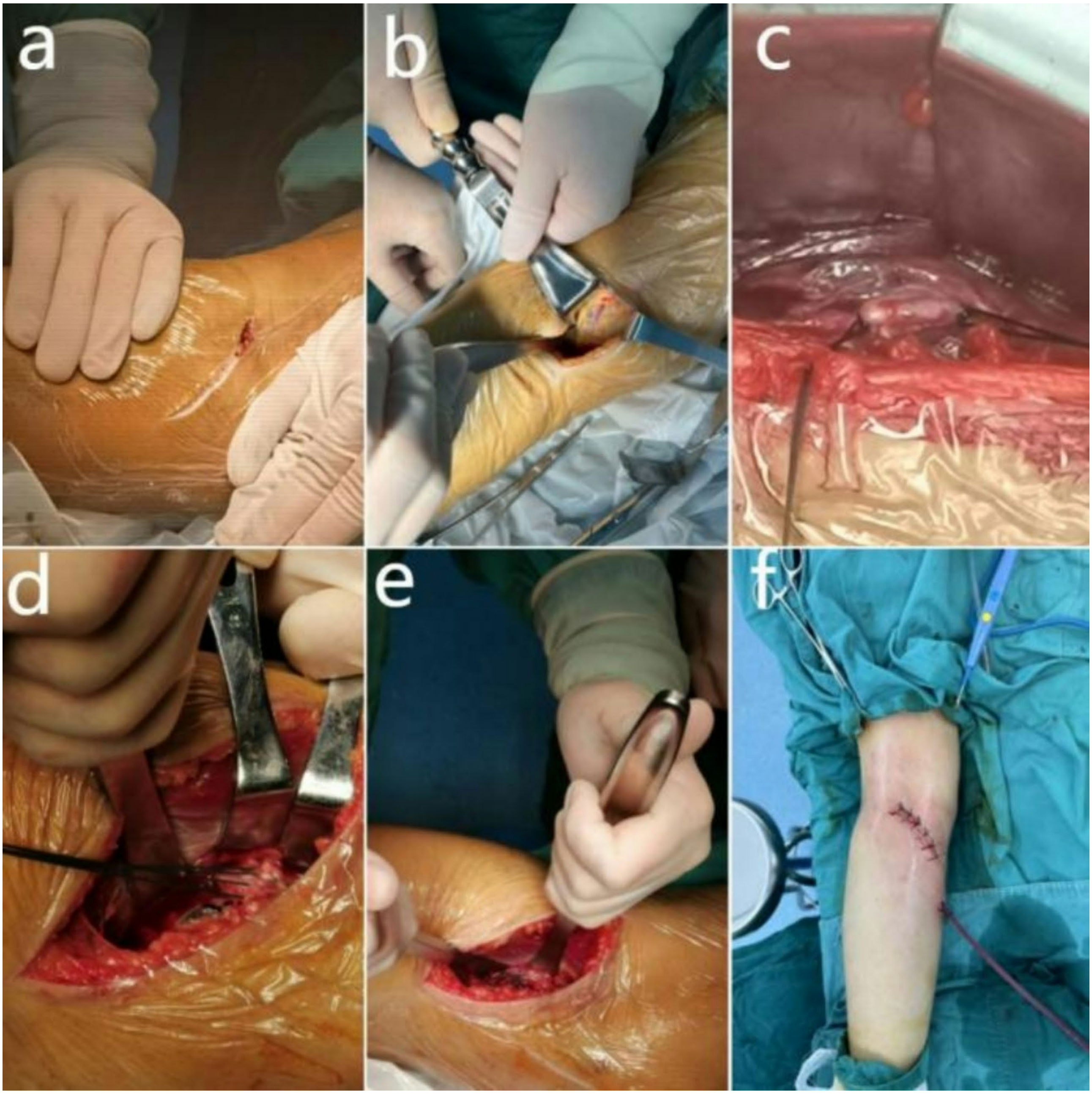

Fig. 1 Suture Bridge Technique for PCL Tibial Avulsion Fracture Repair: **a**. A 5–7 cm posteromedial arc incision; **b**. Inferior branches of the popliteal vessels on the surface of the popliteus muscle; **c**. Ligation of the inferior branches of the popliteal vessels; **d**. Weaving and suturing the PCL ligamentous tissue with high-strength sutures; **e**. Placement of two locking suture anchors 1 cm distal to the bone bed to secure the sutures and reduce the bone fragment; f. Wound closure and placement of a drainage tube

Introduction

Posterior cruciate ligament (PCL) tibial avulsion fractures are relatively uncommon but can lead to significant knee instability and functional impairment if not properly managed. Surgical intervention is often required for displaced fractures to restore knee stability and function [1, 2]. Surgical treatment options for PCL tibial avulsion fractures have evolved over time, with various techniques reported in the literature. Traditional methods, such as open reduction and screw fixation, have been effective for large, non-comminuted fragments but are less suitable for smaller or comminuted fractures. Moreover, screw fixation has been associated with a notable risk of fixation failure, particularly in cases with poor bone quality or small fragments [3, 4].

In recent years, the advent of arthroscopic techniques has introduced alternative approaches, such as transosseous tunnel fixation with high-strength sutures or suture plates [5]. These methods have shown promising results, particularly in terms of biomechanical stability and reduced soft tissue disruption. However, they often require extensive exposure of the posterior compartment, making the procedure technically demanding and less accessible for surgeons with limited arthroscopic experience [6–9].

Despite these advancements, there remains a significant gap in the literature regarding the optimal surgical technique for PCL tibial avulsion fractures, particularly in cases involving small or comminuted fragments. Current studies have not adequately compared the outcomes of different fixation methods, nor have they addressed the technical challenges associated with arthroscopic approaches in less experienced hands [10, 11]. This gap highlights the need for a simplified yet effective surgical technique that can be widely adopted, even by surgeons with limited arthroscopic expertise.

This study hypothesizes that the suture bridge technique, combined with a small posteromedial arc incision, offers a superior alternative to traditional screw fixation for PCL tibial avulsion fractures, particularly in cases involving small or comminuted fragments. The unique contribution of this study lies in its direct comparison of the suture bridge technique and hollow screw fixation, with a focus on clinical outcomes and surgical feasibility. By addressing the limitations of existing methods and introducing a simplified approach, this study aims to fill a critical gap in the literature and provide a practical solution for the surgical management of PCL tibial avulsion fractures.

Materials and methods

General case data

A retrospective analysis was conducted on 40 patients with PCL tibial avulsion fractures treated in our department between January 2013 and December 2023. The patients were divided into two groups: 20 cases treated with the suture bridge technique and 20 cases treated with hollow screw fixation. The cohort included 25 males and 15 females, aged 13 to 60 years (mean age: 30.8 years). All patients had a clear history of trauma, including traffic accidents, falls from height, and sports injuries. They presented with varying degrees of pain, swelling, and limited mobility, along with a positive posterior drawer test. Preoperatively, all patients underwent CT scan and MRI of the knee joint to confirm the fracture type and assess for any concomitant injuries.

Inclusion Criteria: Displaced PCL tibial avulsion fractures, Fractures within 2–3 weeks of injury, failure of Conservative Treatment and No Contraindications to Surgery;

Exclusion Criteria: Minimally Displaced or non-displaced fractures, Fractures older than 3 weeks, associated multi-ligamentous knee injuries, Severe Osteoporosis and contraindications to surgery.

The Research Ethics Committee of the Affiliated Hospital of North Sichuan Medical College has approved this study (2024ER0056). Adhering to the ethical principles of the 1964 Declaration of Helsinki, we obtained informed consent forms signed by all patients' guardians prior to the operation.

1.2 Surgical Procedure and Rehabilitation.

All surgeries were performed by the same surgical team. Under lumbar or general anesthesia, patients were positioned prone with a tourniquet applied at the thigh root. A 5–7 cm posteromedial arc incision was made at the knee joint. Dissection was performed along the interval of the medial head of the gastrocnemius muscle to expose the posterior joint capsule. The medial head of the gastrocnemius was retracted laterally, and the joint capsule was incised longitudinally to reveal the fracture site. Hematomas were cleared.

In the suture bridge group, a suture anchor (InLoc anchor, Hangzhou Rejoin Mastin Medical Device Co, P.R. China) with attached sutures was placed at the anterior part of the tibial bed. The sutures were then crossweaved through the PCL. Finally, two knotless anchors (GripLoc knotless anchor, Hangzhou Rejoin Mastin Medical Device Co, P.R. China) were used to secure the tail sutures through holes drilled distal to the tibial bed. Exposure of the deep surface of the popliteus muscle was required, which often involved ligating inferior branches of the popliteal vessels(Fig. 1).

In the hollow screw group, the deep surface of the popliteus muscle was not exposed. Instead, two 3.5 mm hollow screws (SYNTHES, Switzerland Synthes GmbH) were directly fixed onto the bone fragment without additional dissection.

The knee joint was flexed and extended to ensure the bone fragment was firmly fixed and the PCL had regained tension. The tourniquet was released to check for popliteal vascular injury. After thorough hemostasis, the area was irrigated with saline, a drainage tube was placed, and the wound was closed in layers. The limb was bandaged with large cotton pads and an elastic bandage from the foot to above the knee joint.

Postoperatively, the affected limb was bandaged with an elastic bandage, and the knee joint was fixed at a 5–10° flexion angle with a brace for 4 weeks. Isometric contraction exercises for the quadriceps muscles began on the first postoperative day. Knee flexion was limited to 30° within the first 2 weeks, 90° by 4 weeks, and 120° by 8 weeks. Partial weight-bearing with crutches and a hinged knee brace was allowed at 4 weeks, progressing to full weight-bearing by 8 weeks. Hyperextension movements were avoided for 6 months, and competitive sports were resumed after one year.

Table 1 General case data

Parameter	Suture Bridge Group	Hollow Screw Group	P-value
Case Number	20	20	
Gender (Male/Female)	12/8	13/7	0.5
Age (years)	13–48 (mean 29.75)	19–60 (mean 31.90)	0.512
Mechanism of Injury			0.314
- Traffic accident	10	8	
- Sports injuries	8	6	
- Falls	2	6	
Modified Meyers-McKeever Classification[12]			0.527
- Type II	12	9	
- Type III	8	11	
Pain Level (0–10)	5–9 (mean 6.9)	4–8 (mean 6.9)	1.0
Posterior Drawer Test	Positive	Positive	
Concomitant Meniscal Injuries	2	4	0.661

Table 2 Perioperative and Follow-up parameters

Parameter	Suture Bridge Group	Hollow Screw Group	P-value
Operation Time (min)	48.70 ± 7.234	50.20 ± 9.682	0.582
Intraoperative Blood Loss (ml)	67.50 ± 15.174	62.50 ± 15.517	0.309
Postoperative Drainage (ml)	100.00 ± 22.243	84.00 ± 25.131	0.011
Range of Motion (Final Follow-up)	136.0 ± 5.026	133.50 ± 8.288	0.256
Follow-up Duration (months)	15.15 ± 2.519	14.35 ± 2.159	0.288
Complications:			0.661
- Malunion	2	1	
- Screw Loosening	0	2	
- Knee Stiffness	0	1	

Efficacy observation

During patient follow-up, the surgical time and intraoperative blood loss were recorded, as well as the postoperative drainage volume. Observations included symptoms of swelling and pain, joint effusion, and the status of postoperative fracture reduction and joint mobility. X-rays or CT scans were taken at 6 weeks, 3 months, and 6 months postoperatively to understand changes in fracture position and the healing process. Complications such as nonunion, malunion, implant failure, infection, and knee stiffness were recorded. At the final follow-up, knee stability was evaluated using the posterior drawer test (PDT) and range of motion (ROM). Functional outcomes were assessed using the Lysholm Knee Score, Tegner Activity Scale, and International Knee Documentation Committee (IKDC) functional scores [13–15].

Statistical methods

Statistical analysis was performed using SPSS 22.0 (IBM, Armonk, New York, USA). Quantitative data with a normal distribution were expressed as mean ± standard deviation. Preoperative and postoperative Lysholm, Tegner, and IKDC scores were compared using the Student's t-test. A P-value < 0.05 was considered statistically significant.

Results

All patient's general case data were summarized (Table 1). All patients were followed up for a period ranging from 12 to 18 months, with an average of 14.7 months. There were no significant differences in surgical time, intraoperative blood loss, joint mobility, or follow-up duration between the two groups (Table 2). The postoperative drainage volume in the suture bridge group was slightly higher than that in the hollow screw group, which may be related to the deeper surgical dissection required. Most fractures healed within 3 to 6 months postoperatively (Fig. 2). At the final follow-up, all patients exhibited negative posterior drawer tests, indicating restored knee stability. Significant improvements were observed in the Lysholm, Tegner, and IKDC scores postoperatively. The Tegner score in the suture bridge group was slightly higher than that in the hollow screw group, indicating a superior recovery of sports activity level in the suture bridge group (Table 3).

In the suture bridge group, in cases of comminuted fractures with bone fragment separation, displacement of small bone fragments at the edges was observed after suture locking. Although this did not affect the tension of the PCL ligament or the healing of the avulsion fracture, two cases of malunion occurred (Fig. 3). A 13-year-old girl with a PCL tibial avulsion fracture was treated by directly securing a small bone fragment using high-strength sutures woven through the ligament tissue. The tail sutures were locked onto the cortical bone beneath the bone bed, achieving reliable fixation without the use of suture anchors within the bone bed, thereby avoiding injury to the growth plate (Fig. 4).

In the hollow screws group, two cases of screw head retraction and one case of fragmentation and displacement of small bone fragments at the edge of the bone block were observed (Fig. 5). Moreover, during screw fixation, we encountered two cases where the bone fragments were crushed, ultimately necessitating a switch to the suture bridge technique for re-fixation.

The advantages and disadvantages of the suture bridge technique and hollow screw fixation in treating PCL tibial avulsion fractures were summarized (Table 4).

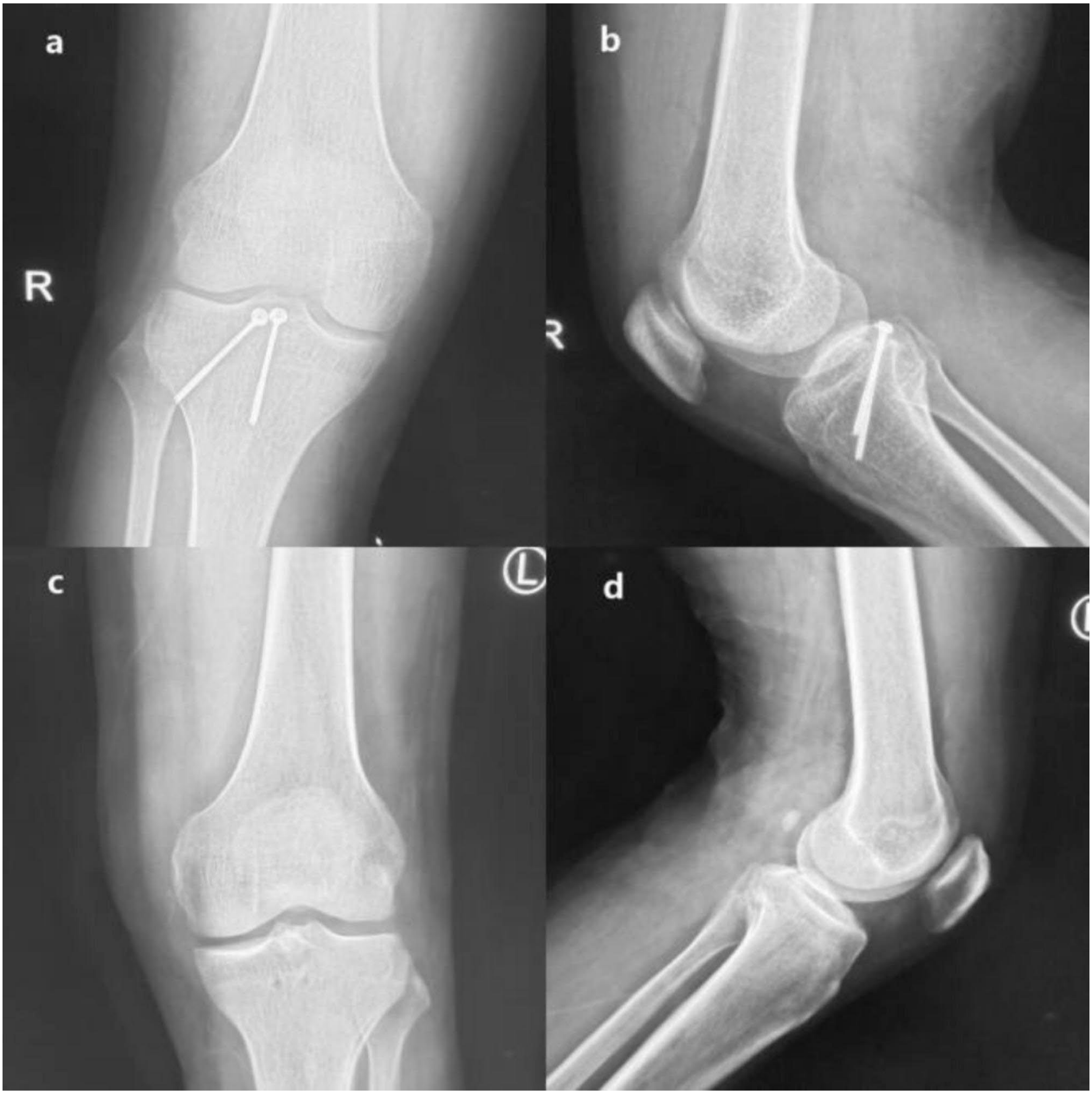

Fig. 2 Fracture Healing Timeline. Most fractures healed within 3 to 6 months postoperatively. In the hollow screws group, two hollow screws were used to fix the PCL avulsion bone block from different directions, with the threads placed as close as possible to the anterior bone cortex to achieve greater tensile strength (X-rays: **a**. Anteroposterior view; **b**. Lateral view). In the suture bridge group, The locking suture anchors were placed in the harder cortical bone beneath the bone bed, with the two anchors spaced approximately 1 cm apart. Together with the suture anchor within the bone bed, they formed a three-point fixation pattern (X-rays: **c**. Anteroposterior view; **d**. Lateral view)

Discussion

The results of this study demonstrated that both the suture bridge technique and hollow screw fixation achieved favorable therapeutic outcomes, with all fractures healing within 3 to 6 months postoperatively. At the final follow-up, all patients exhibited negative posterior drawer tests, indicating restored knee stability. Additionally, significant improvements were observed in the Lysholm, Tegner and IKDC functional scores compared to preoperative levels, consistent with findings from similar international studies [16].

The complication rate in the hollow screw fixation group was slightly higher than that in the suture bridge group, primarily manifested as screw loosening and bone fragment fragmentation, which consequently impacted the recovery of patients' motor function. Additionally,

Table 3 Comparison of knee joint function scores preoperative and final Follow-up

Parameter	Suture Bridge Group	Hollow Screw Group	*P*-value
Lysholm Score			
- Preoperative	36.7 ± 10.443	42.75 ± 8.795	0.055
- Final Follow-up	90.35 ± 6.953*	88.95 ± 6.236*	0.507
IKDC Score			
- Preoperative	39.25 ± 8.091	44.20 ± 8.557	0.068
- Final Follow-up	92.3 ± 4.879*	92.30 ± 5.121*	1.00
Tegner Activity Scale			
- Preoperative	0.90 ± 0.852	1.05 ± 0.826	0.575
- Final Follow-up	6.55 ± 0.605*	6.00 ± 0.973*	0.038

*Indicates significant improvement compared to preoperative scores

in the suture bridge group, two cases of small bone fragment displacement caused by compression from the tightened sutures resulted in malunion. This highlights the importance of ensuring even distribution of the sutures during the weaving process in surgery, and that even small bone fragments must be properly secured. If necessary, a 1.0 Kirschner wire can be used to temporarily fix the bone fragment, followed by evenly distributing the anchor tail sutures. Once the tail sutures are securely locked, the Kirschner wire can then be removed.

The evolution of surgical techniques for PCL tibial avulsion fractures has been driven by the need to address the limitations of traditional methods. Early approaches, such as open reduction and screw fixation, were effective for large, non-comminuted fragments but posed challenges in cases of comminuted fractures or pediatric patients with incompletely ossified bone fragments [17, 18]. The two cases encountered in this study, where the intact bone fragments were crushed during intraoperative screw fixation, further demonstrate that screw fixation is less suitable for smaller bone fragments or cases with poor bone quality.

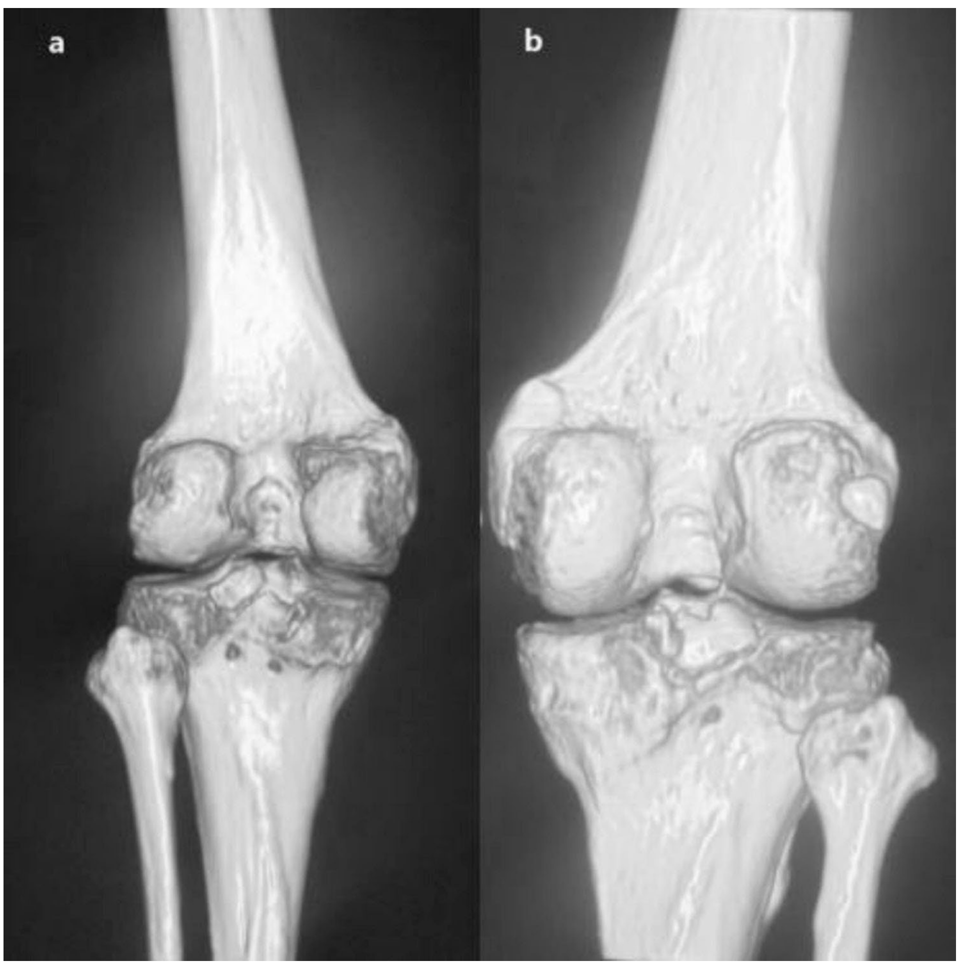

Fig. 3 Complications in the Suture Bridge Group. Displacement of small bone fragments at the edges was observed after suture locking. Although this did not affect the tension of the PCL ligament, a malunion occurred. (**a**. The larger bone fragments healed, but the smaller bone fragments remained flipped up. **b**. Postoperatively, small bone fragments on the lateral side of the bone block were flipped up due to compression from the sutures)

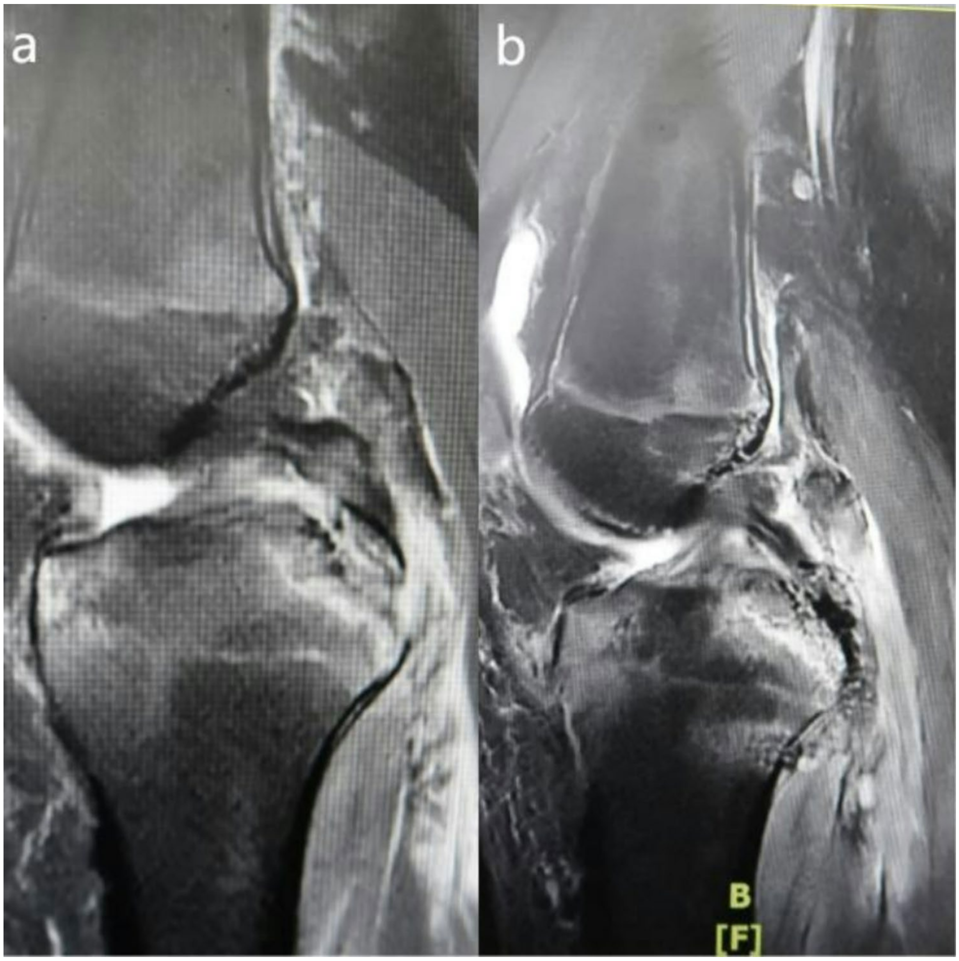

Fig. 4 A 13-year-old girl with a PCL avulsion fracture achieved satisfactory fixation using the suture bridge technique, successfully avoiding injury to the growth plate. From the preoperative MRI images, the flipped thin bone fragment and the retracted PCL ligament can be observed. The postoperative MRI images show the PCL ligament restored to tension and the fracture well-compressed.(**a**. Preoperative. **b**. Postoperative)

With advancements in arthroscopic technology, minimally invasive techniques have gained popularity. Kim et al. [8] pioneered the use of arthroscopic techniques for PCL avulsion fractures, employing high-strength sutures and transosseous tunnels. Rhee et al. [5] further refined this approach with cross-linked pull-out sutures, achieving good outcomes. However, as Li et al. [19] noted, while arthroscopic methods offer the advantage of being minimally invasive, they often struggle to provide stable fixation, particularly in complex fractures. This highlights the ongoing challenge of balancing minimal invasiveness with biomechanical stability.

The suture bridge technique has emerged as a promising alternative, particularly for comminuted fractures and pediatric cases. Forkel et al. [20] demonstrated that the suture bridge technique offers superior biomechanical properties, with significantly lower ligament structure elongation rates under cyclic loading compared to traditional pull-out techniques. This aligns with the tension-side fixation principle, making it particularly suitable for PCL tibial avulsion fractures. In our study, the successful fixation in that 13-year-old girl serves as a good example. The suture bridge technique proved effective in securing avulsed fragments, reducing the risk of further fragmentation, and avoiding growth plate injury in pediatric patients.

In this study, both groups utilized a posterior curved approach, with the difference lying in the fixation principles. For the screw fixation group, hollow screws were inserted perpendicular to the fracture surface, with the threads extending as far as the anterior cortex of the tibia to achieve compression at the fracture site. In contrast, the suture bridge technique employs the tension band principle, using high-strength sutures to pull the ligament and bone fragment, while the tail sutures are secured to the distal bone bed with locking anchors. This not only restores ligament tension but also ensures excellent compression at the fracture site under the tension of the sutures. Therefore, we believe that the suture bridge technique is more suitable for fixing this type of tendon

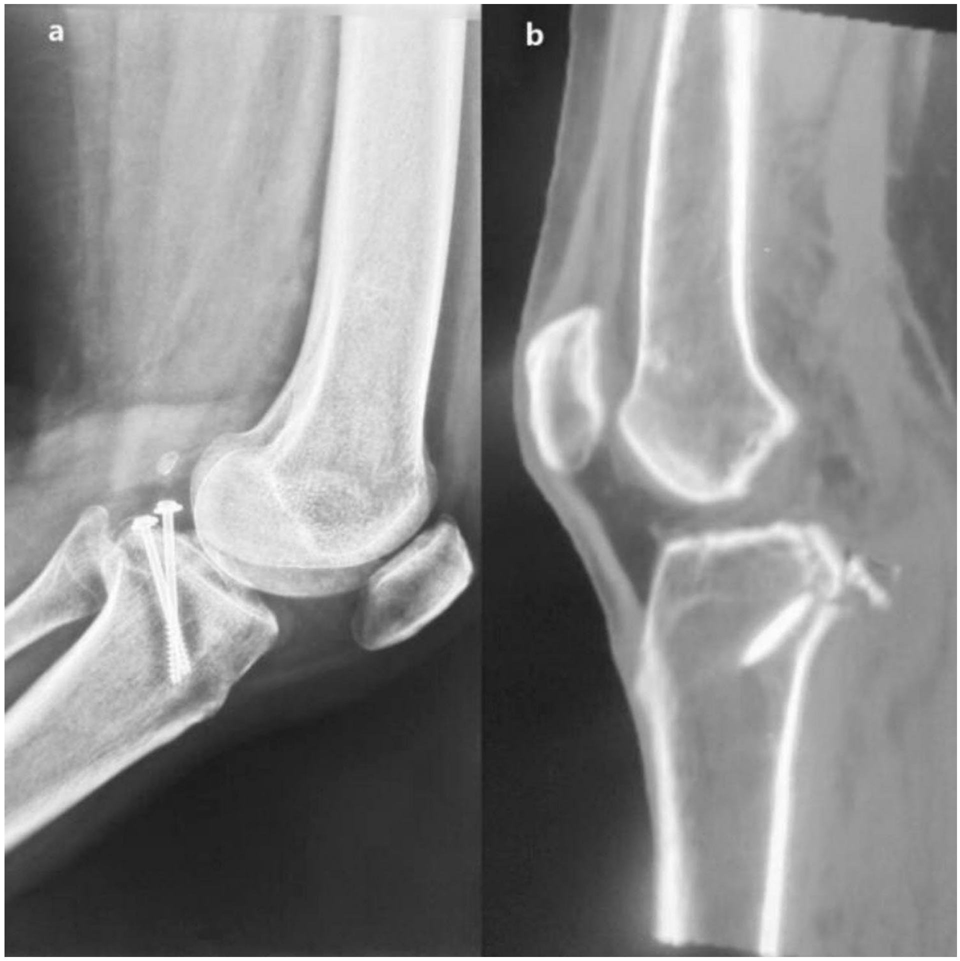

Fig. 5 Complications in the hollow screw fixation group. **a**. Lateral X-ray showing screw head retraction. **b**. Sagittal CT reconstruction showing fragmentation and displacement of small bone fragments at the edge of the bone block

Table 4 Advantages and disadvantages of suture Bridge technique and Hollow screw fixation

	Suture Bridge Technique	Hollow Screw Fixation
Advantages	- Effective for comminuted fractures - Avoids growth plate injury in pediatric patients - Provides secure fixation and lower risk of bone fragment displacement - Suitable as a salvage procedure when screw fixation fails	- Traditional and well-established method - Suitable for large, single bone fragments - Simple technique with minimal learning curve
Disadvantages	- Requires exposure of the deep surface of the popliteus muscle, potentially increasing the risk of vascular injury - Risk of malunion due to small bone fragment displacement during suture tightening - More complex technique with a steeper learning curve	- Higher risk of fixation failure in comminuted fractures - Not suitable for pediatric patients due to potential growth plate injury - Risk of screw loosening or retraction, requiring potential secondary surgery for hardware removal

or ligament avulsion fracture. This is theoretically supported by the biomechanical studies conducted by Domnick et al. [11]

This study has several limitations. The retrospective design and small sample size may introduce bias and limit the generalizability of the findings. Additionally, the lack of long-term follow-up data restricts our ability to assess the durability of the outcomes. Future studies with larger cohorts and extended follow-up periods are needed to validate these findings and further refine surgical techniques.

In conclusion, both the suture bridge technique and hollow screw fixation are effective treatments for PCL tibial avulsion fractures. However, the suture bridge technique demonstrates superior outcomes in terms of fracture union, functional recovery, and complication rates, particularly for small or comminuted fractures. Hollow screw fixation remains a viable option for large, non-comminuted fragments but is associated with a higher risk of complications. Surgeons should consider the fracture morphology, patient age, and their technical expertise when selecting the appropriate fixation method. The suture bridge technique, with its secure fixation and applicability to pediatric patients, represents a significant advancement in the treatment of PCL tibial avulsion fractures.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12893-025-02926-5.

Supplementary Material 1

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Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by P JS, Z L and J CC. The first draft of the manuscript was written by P JS and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability

Data is provided within the manuscript or supplementary information files.

Declarations

Ethical approval

This is an retrospective study. The Research Ethics Committee of the Affiliated Hospital of North Sichuan Medical College has approved this study (2024ER0056). Adhering to the ethical principles of the 1964 Declaration of Helsinki, we obtained informed consent forms signed by all patients' guardians prior to the operation.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent to publish

The authors affirm that the patients provided informed consent for publication of the present study.

Competing interests

The authors declare no competing interests.

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