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Comparative clinical efficacy of "Figure-8" Banding and double-row anchor suture-bridge fixation in arthroscopic management of tibial intercondylar eminence avulsion fractures

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Abstract

Objective The objective of this study is to assess and compare the clinical efficacy of "Figure-8" banding and double-row anchor suture-bridge fixation techniques in the arthroscopic management of tibial intercondylar eminence avulsion fractures.

Method A retrospective analysis was conducted on the medical records of 42 patients who underwent arthroscopic surgery for tibial intercondylar eminence fractures at our institution from June 2017 to June 2022. This cohort included 20 cases treated with "Figure-8" banding and 22 cases managed using double-row anchor suture-bridge fixation. Comparative assessments were made regarding operative duration, duration of fracture consolidation, postoperative knee joint range of motion, joint stability as assessed by the Lachman test, Lysholm score, and International Knee Documentation Committee (IKDC) functional score for both treatment groups.

Results The mean follow-up duration was 13.8 months. The analysis indicated that the double-row anchor suture-bridge group had a significantly longer operative duration compared to the "Figure-8" banding group ($p < 0.05$). Postoperative computed tomography (CT) scans confirmed successful reduction in both groups, with fracture consolidation achieved within an average of three months. Both groups showed significant improvements in postoperative knee range of motion, joint stability, and functional scores compared to preoperative measurements ($p < 0.05$). During the initial two-month post-surgery, the double-row anchor suture-bridge group demonstrated superior knee joint range of motion and functional scores compared to the "Figure-8" banding group ($p < 0.05$); however, these differences were not statistically significant beyond three months post-surgery ($p > 0.05$). By the one-year postoperative mark, joint stability outcomes were comparable between the two treatment groups ($p > 0.05$).

Conclusion Both "Figure-8" banding and double-row anchor suture-bridge fixation techniques in the arthroscopic management of tibial intercondylar eminence avulsion fractures can achieve precise reduction and stable fixation.

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In addition, the figure-8 suture group has the characteristics of shorter surgery time and less cost. Notably, early postoperative knee function appears to be superior with double-row anchor suture-bridge fixation compared to "Figure-8" banding.

Keywords Arthroscopy, Fracture fixation, Suture anchor, Suture techniques, Tibial intercondylar eminence fractures

Introduction

Tibial intercondylar eminence avulsion fractures primarily affect adolescents; however, their incidence in adults is increasing due to sports injuries and traffic accidents. Ensuring anatomical reduction and stable internal fixation is crucial for restoring knee function across all age groups [1, 2]. These fractures were initially categorized by Meyers and McKeever into three types, with Zaricznyj later expanding the classification to include a comminuted fracture type. Surgical intervention is typically recommended for Types II, III, and IV fractures. Type I involves incomplete displacement; Type II features a beak-like displacement with the anterior part elevated but the posterior part not fully displaced; and Type III is characterized by complete displacement [3].

Arthroscopic reduction and fixation have become the preferred method due to its minimal invasiveness, reduced pain, and lower complication rates [4]. The "Figure-8" suture technique has gained wide acceptance in China and internationally due to its minimal trauma and rapid recovery benefits for managing these fractures [5–7]. However, recent findings indicate potential limitations in posterior fixation, leading to hindered postoperative knee rehabilitation, particularly for Types III and IV fractures with rotatory displacement [8, 9].

Alternative approaches, such as the mesh suture technique and the double-row anchor suture-bridge technique, have demonstrated promising results in improving fracture fixation [10, 11]. Despite these advancements, there is a scarcity of comparative studies assessing these fixation techniques, and a comprehensive assessment of their advantages and disadvantages is lacking.

In this retrospective study, we analyzed clinical data from patients with ACL tibial intercondylar eminence avulsion fractures treated with either the "Figure-8" banding or double-row anchor suture-bridge fixation technique. We compared surgical durations and postoperative knee function recovery to determine any significant differences in surgical time and early clinical outcomes between the two techniques, with the goal of identifying the most effective treatment approach.

Materials and methods

General materials

Surgeries and follow-up assessments in this study were randomly assigned and conducted by two experienced surgeons without the involvement of a third-party objective assessor, which could introduce bias in the evaluation of knee joint functionality.

This study included a cohort of 45 patients who underwent surgery for tibial intercondylar eminence fractures at the Department of Sports Medicine in our hospital between June 2017 and June 2022. Three patients with complications were excluded based on the inclusion and exclusion criteria, resulting in a final study cohort of 42 patients. These patients were divided into two groups based on the surgical technique employed: the "Figure-8" banding group ($n=20$) and the double-row anchor suture-bridge group ($n=22$). The "Figure-8" banding group consisted of 11 males and 9 females, aged between 19 and 39 years, with an average age of 31.10±6.13 years. The double-row anchor suture-bridge group comprised 12 males and 10 females, aged between 20 and 38 years, with an average age of 31.32±5.21 years. The primary causes of injury in both groups included traffic accidents, falls, or sports injuries, with fractures classified as Type II, Type III, or Type IV. No significant differences in demographic data were observed between the groups, as detailed in Tables 1 and 2.

Inclusion and exclusion criteria

Inclusion criteria:

1. Patients clinically diagnosed with Type II, Type III, or Type IV tibial intercondylar eminence fractures, as per the modified Meyers–McKeever classification, and deemed suitable for surgical intervention.
2. Patients with optimal limb function prior to the tibial intercondylar eminence fracture.
3. Patients who exhibited good adherence to treatment protocols and could reliably provide clinical data feedback.

Exclusion criteria:

1. Patients with conditions compromising knee joint stability, such as multiple ligament injuries, osteochondral lesions, or tibial plateau fracture displacement.
2. Patients with severe cardiac, hepatic, or renal diseases.
3. Patients with bone metastases from malignant tumors or congenital skeletal abnormalities.
4. Adolescents under 18 years of age with incomplete growth plate closure.

Table 1 Comparison of basic data between the two patient groups

Group	Gender ratio [a](male/female, *n*/*n*)	Age [c] ($\bar{x} \pm s$, years)	Cause of injury [a] (sports injuries/traffic accidents/falls, *n*/*n*/*n*)	Fracture types [a] (ii/iii/iv, *n*/*n*/*n*)	Interval from injury to surgery [c] (m(p_{25},p_{75}), days)	Follow-up duration [b] ($\bar{x} \pm s$, months)
"Figure-8" banding group	11/9	31.10 ± 6.13	6/10/4	7/10/3	3.00(2.25,3.75)	13.75 ± 1.32
Double-row anchor suture-bridge group	12/10	31.32 ± 5.21	5/14/3	8/12/2	3.00(2.00,4.00)	14.01 ± 1.45
χ^2 value / *t*-value	0.001	-0.125	0.807	0.354	− 0.013	-0.614
P-value	0.976	0.901	0.668	0.838	0.989	0.543

Note: a: Fisher's exact test; b: Wilcoxon rank-sum test; c: Independent samples *t*-test

Table 2 Comparison of surgical duration between the two patient groups

Group	Surgical duration (minutes)	Postoperative fracture healing time (month)	T-value	*P*-value
Figure-8" banding group	67.55 ± 3.90	3.06 ± 0.13	-16.422a/1.272[b]	< 0.001[a]/0.211[b]
Double-row anchor suture-bridge group	86.00 ± 3.38	3.01 ± 0.11		

Note: a: Surgical duration; b:Postoperative fracture healing time

The study received approval from the ethics committee (approval number: Yan Shan Lun Zheng 2024042) of the hospital. Informed consent was obtained from all participants. All surgical procedures were conducted by the same experienced surgeon.

Surgical technique

Continuous epidural anesthesia was administered as the primary anesthesia. Patients were positioned supine with a sterilized towel pad placed underneath the knee, which was flexed at a 90-degree angle for arthroscopy. The procedure was performed through standard anterolateral and anteromedial portals. Initial steps included the inspection and cleansing of the joint cavity to eliminate hemarthrosis, blood clots, and synovial tissue that could obstruct visibility. Scar fibrous tissue on the avulsed bone fragments was excised. The avulsed bone fragments were then repositioned using a medical probe or curette to ensure the accurate placement and tension of the ACL.

"Figure-8" Banding group

After reducing the fracture fragments, 2.0 mm Kirschner wires were inserted into the anteromedial and anterolateral edges of the attachment area of the bone fragment, positioned 2 to 3 mm from the edge under locator guidance. PDS sutures were introduced using a spinal needle, and a suture hook was used to navigate between the ACL and the avulsed bone fragment. Double strands of OrthoCord suture were threaded in a figure-8 configuration, pulled through the tibial bone tunnel, and tightened to secure the reduced bone fragment into place with an extracortical anchor (as depicted in Figs. 1A and 2A).

Double-row anchor suture-bridge group

In this approach, following the reduction of the fracture bed attachment, internal suture anchors (4.5 mm, produced by Johnson & Johnson) were positioned into the posterior medial or lateral locations of the attachment. A suture hook was then used to draw the anchor suture through the bone. Subsequently, 2.0 mm Kirschner wires were drilled into the anteromedial and anterolateral edges of the attachment area, positioned 2 to 3 mm from the edge, under locator guidance. PDS sutures were introduced using a spinal needle, and the anchor sutures were pulled through the tibial bone tunnel and tightened. The bone fragment was pressed down in a suture-bridge manner under arthroscopic observation, effectively restoring the tension of the ACL. An extracortical anchor at the tibial end secured the suture in place (as illustrated in Figs. 1B and 2B).

Postoperative management for all patients included pain management, prevention of lower limb venous thrombosis, and antibiotic prophylaxis against infection. Follow-up computed tomography (CT) scans post-surgery demonstrated effective reduction (as shown in Fig. 3).

Rehabilitation

The rehabilitation protocol comprised of 2 weeks of non-weight-bearing ambulation with crutches for the affected limb and passive flexion exercises for the knee, followed by 4 weeks of active flexion exercises up to 90° with partial weight-bearing using crutches. Subsequently, 8 weeks of complete knee joint activity and full weight-bearing were implemented, succeeded by 3 months of low-intensity exercise.

Observational indicators

The degree of reduction and healing of avulsion fractures in the two groups were evaluated by CT and magnetic resonance imaging at the first, second, and third months postoperatively. Operation duration, fracture healing

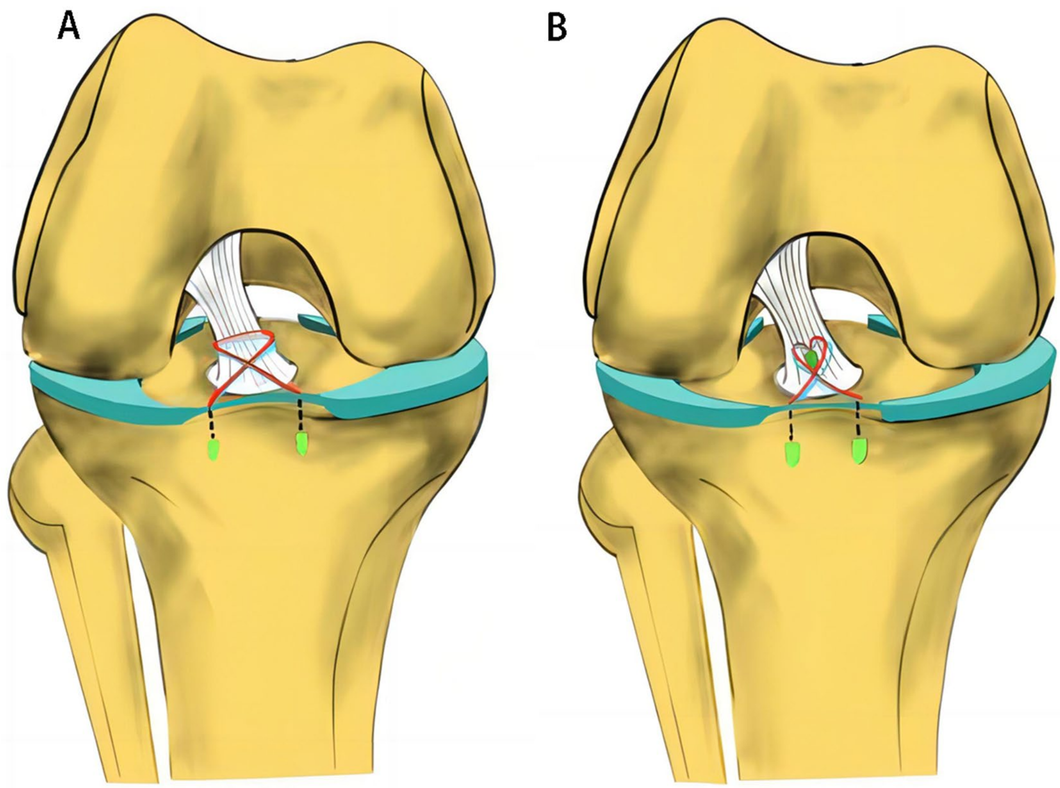

Fig. 1 (**A**) Schematic Diagram of "Figure-8" Banding. Two sutures passed through the ACL stop and crossed. The sutures were drawn from the medial tibial cortex by the bone passages on both sides in front of the avulsion bone mass of the ACL, and then fixed outside the tibial cortex with 2 anchors. (**B**) Schematic Diagram of Anchor Suture. An internal row of anchors was driven into the bone bed under the avulsion bone block, suture hooks were inserted through the bone block to extract sutures, which were crossed, and the sutures were extracted from the medial tibial cortex by the bone canal on both sides in front of the avulsion bone block of the ACL, and then fixed outside the tibial cortex with 2 external row anchors

duration, knee joint range of motion at 1, 2, 3, 6, and 12 months postoperatively, and knee joint stability (assessed by the Lachman test for tibial displacement) at 1 year postoperatively were analyzed between the two groups. Additionally, knee joint function (Lysholm score and IKDC score: preoperative, and at 1, 2, 3, 6, and 12 months postoperatively) was compared between the two groups.

Statistical methods

Statistical analysis was performed using SPSS 26.0 software. Normally distributed data, confirmed via the Shapiro–Wilk test, are expressed as mean±standard deviation, while skewed data are presented as median (P_{25}, P_{75}). Gender composition ratio, cause of injury, and types of fractures between the groups were analyzed using the chi-squared test. Age and follow-up time were compared using the independent samples *t*-test, while the interval from injury to surgery was assessed with the Wilcoxon rank-sum test. Early postoperative stability, mobility, Lysholm scores, and IKDC scores at various time points between the groups were assessed using two-way repeated measures ANOVA, followed by the LSD-t test for multiple comparisons. Long-term postoperative mobility, Lysholm scores, and IKDC scores comparisons between the groups were analyzed using the Wilcoxon rank-sum test and the independent samples t-test, respectively. A confidence interval (CI) of 95% was employed, and a *p*-value <0.05 was considered statistically significant.

Results

After 1, 2, and 3 months, CT scans confirmed that successful reduction of fracture was achieved during surgery in both groups, and bone healing of avulsed fragments was completed within 3 months. No complications, such as infection or impairment in knee extension, were reported.

Operation duration

The average operation duration was 67.55±3.90 min for the "Figure-8" banding group and 86.00±3.38 min for the double-row anchor suture-bridge group ($p<0.001$). The mean healing time between the two groups was 3.06 months and 3.01 months, and there was no significant difference, as depicted in Table 2.

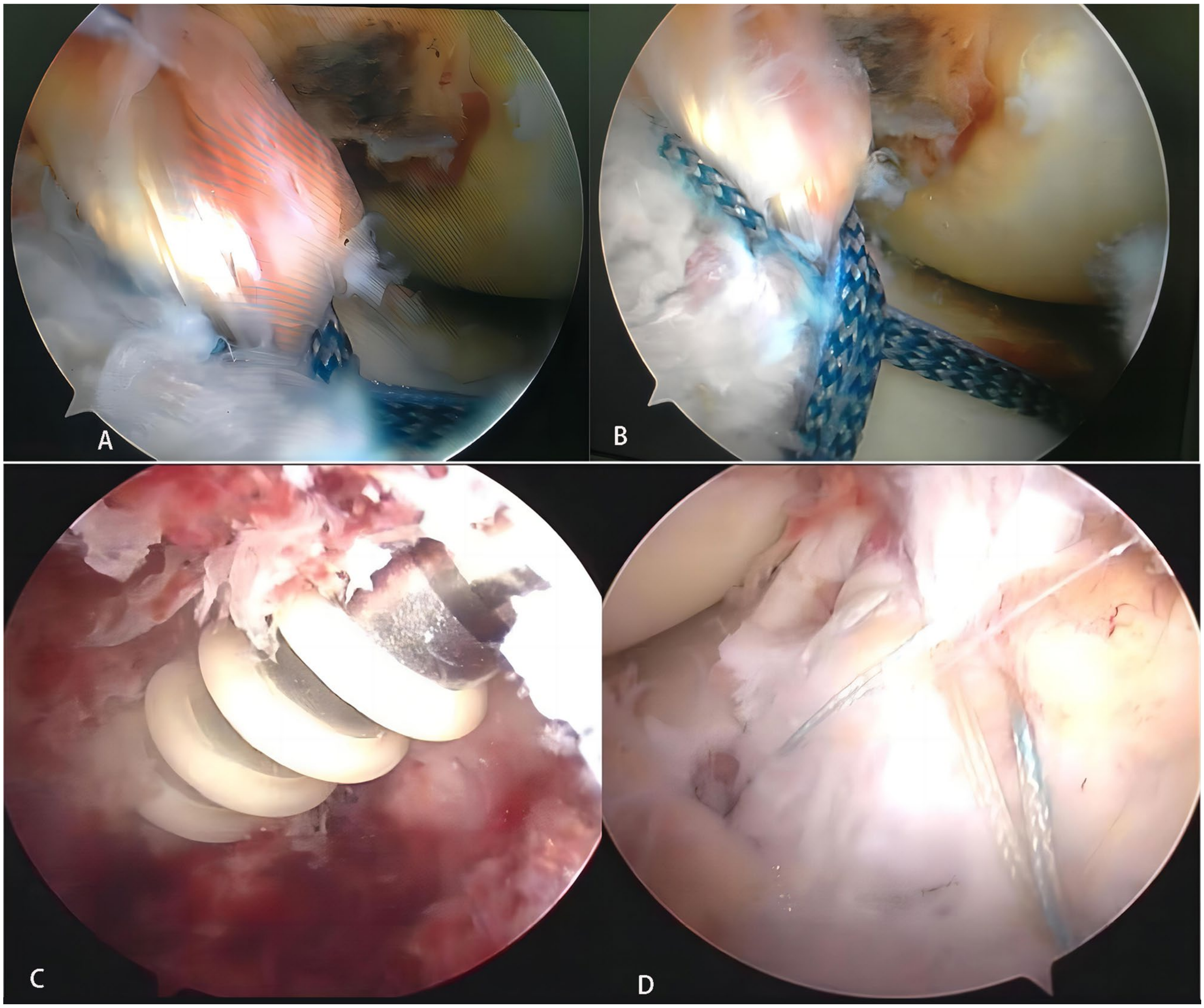

Fig. 2 (**A, B**) Arthroscopic Image of "Figure-8" Banding. (**C**) Arthroscopic images of internal row anchors driven into the bone bed of avulsion bone mass in the double-row suture bridge technique. (**D**) Arthroscopic image of the avulsion bone mass under suture pressure with double row suture bridge technique

Postoperative knee range of motion

Early postoperative comparison (first and second months) of knee range of motion between the two groups revealed a statistically significant difference ($p<0.001$). However, later comparisons (third, sixth, and twelfth months) showed no significant difference in range of motion at 3, 6, and 12 months postoperatively ($p>0.05$), as presented in Fig. 4.

Postoperative 12-month joint stability Lachman test

Pre-operative comparisons of the Lachman test results between the two groups indicated no significant difference (chi-squared value 0.456, $p=0.910$). Postoperative comparisons also indicated no significant difference (chi-squared value 0.612, $p=0.886$). Within-group comparisons pre- and postoperatively in the "Figure-8" banding group indicated a significant difference (chi-squared value 28.867, $p<0.001$), as was the case in the double-row anchor suture-bridge group (chi-squared value 38.509, $p<0.001$), as illustrated in Fig. 5.

Lysholm score

There was a significant difference in Lysholm scores between the groups in the first and second month postoperatively ($p<0.001$), but no significant difference was observed in the third, sixth, and twelfth month ($p>0.05$), as depicted in Fig. 6.

IKDC score

IKDC scores differed significantly between the two groups at the first and second month postoperatively ($p<0.001$). However, there was no significant difference

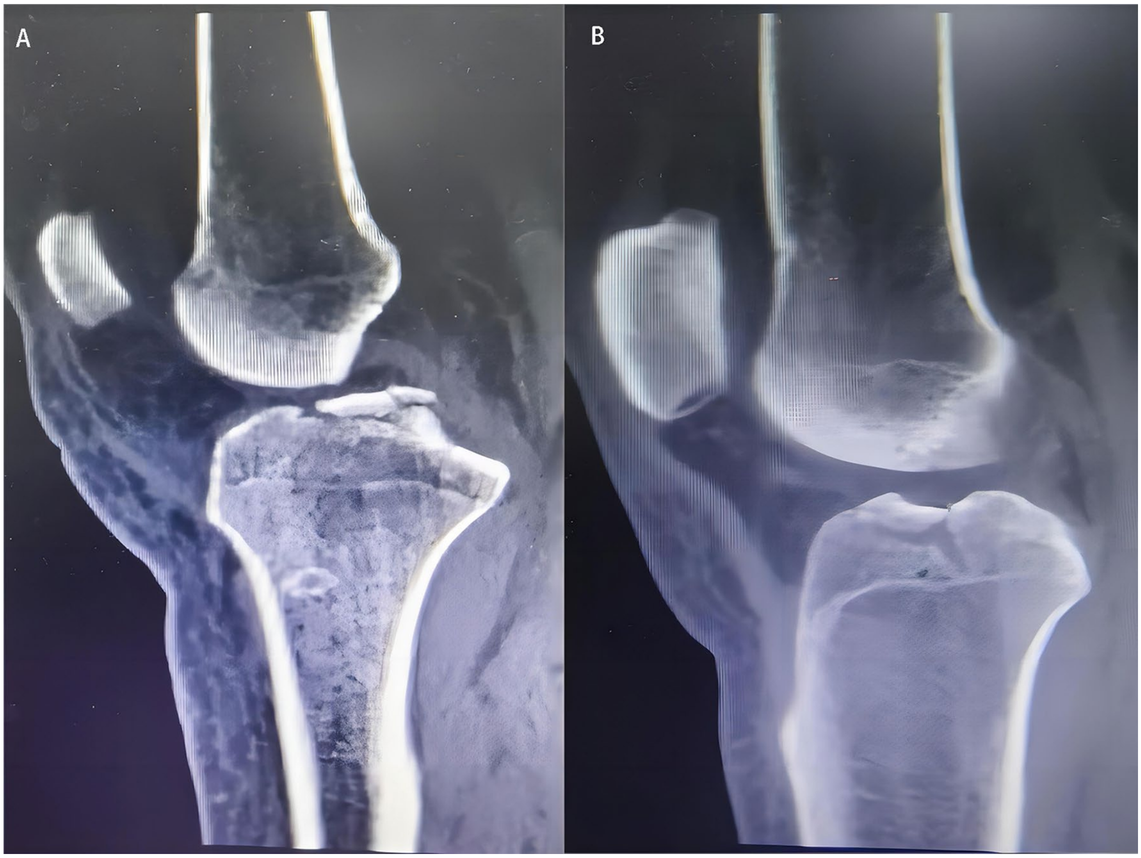

Fig. 3 (**A**) Preoperative CT, fracture avulsion comminution and displacement in a 35-year-old male patient with fracture Type 4. (**B**) CT examination after 3 months of surgery, anchor implantation and fracture healing

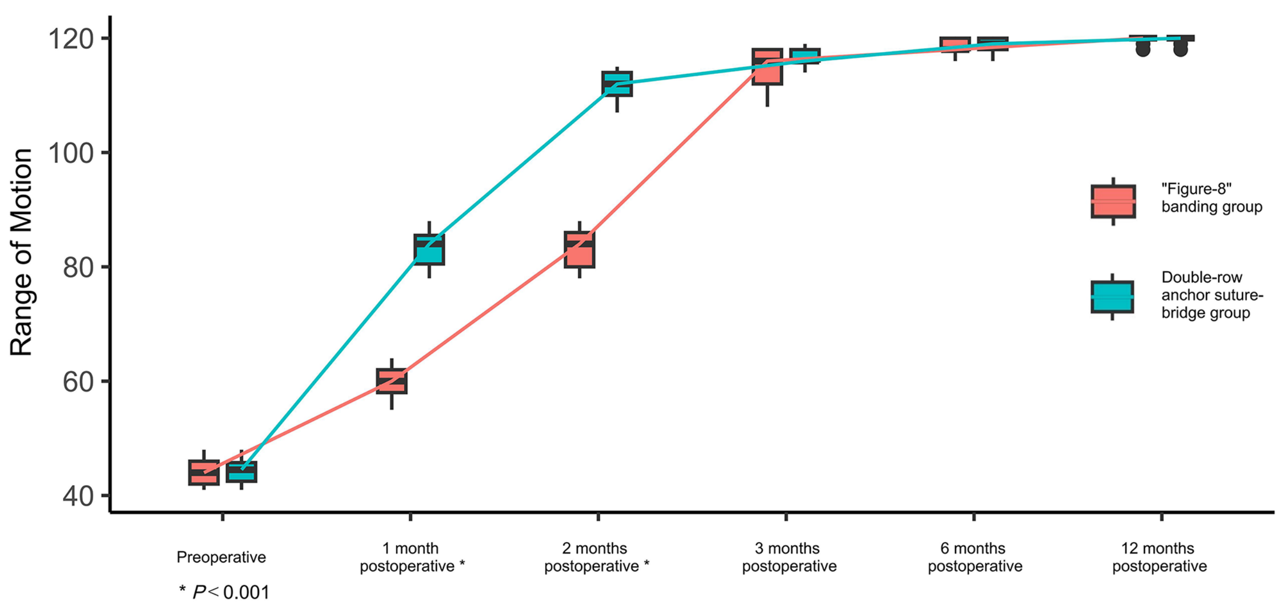

Fig. 4 Comparison of range of motion between the two patient groups for 12 months

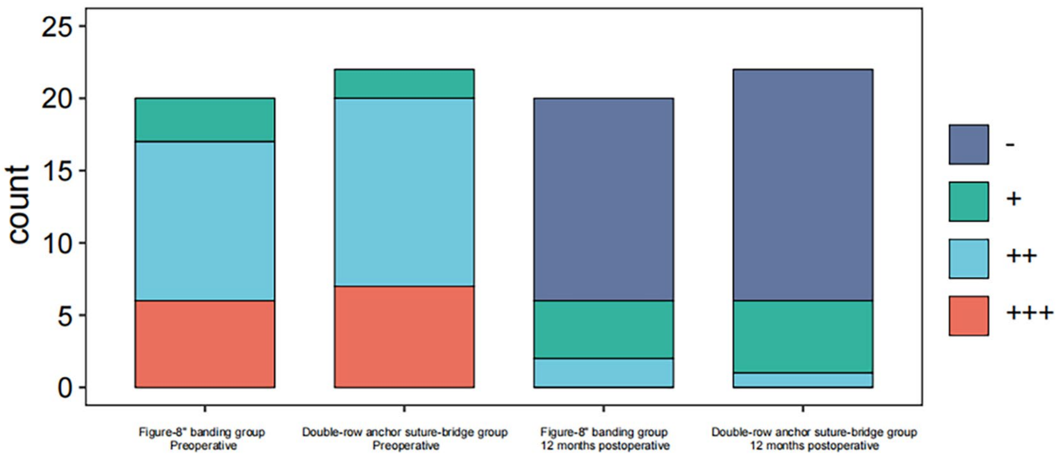

Fig. 5 Comparison of Lachman test results between the two patient groups for 12 months

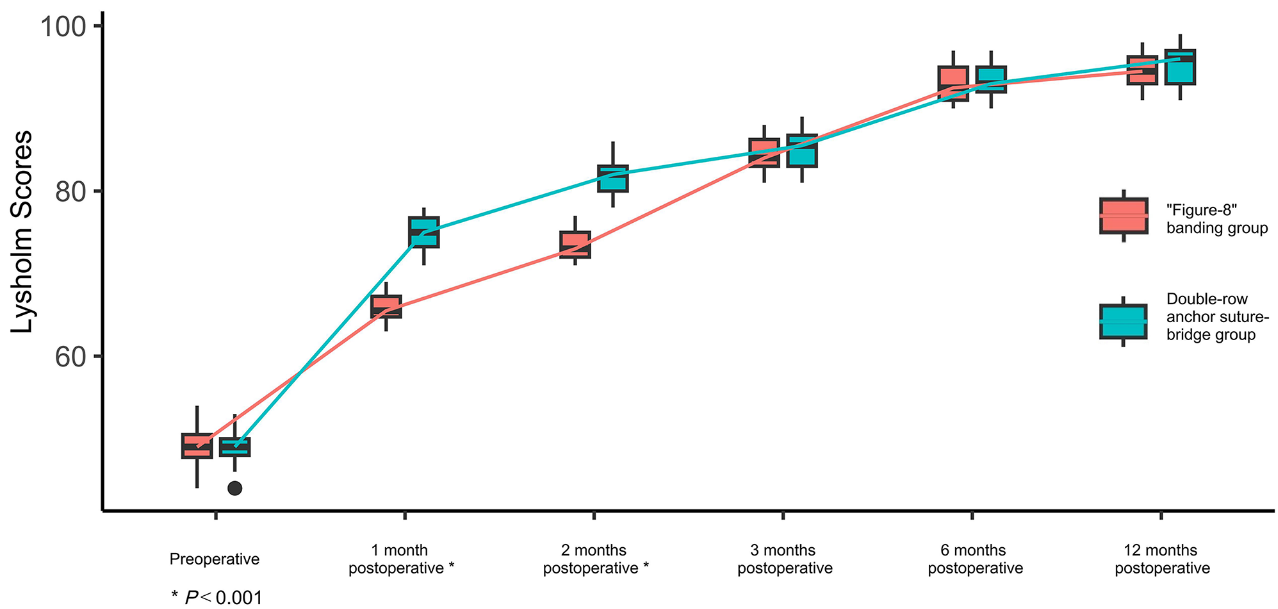

Fig. 6 Comparison of Lysholm scores between the two patient groups for 12 months

in the third, sixth, and twelfth month ($p > 0.05$), as presented in Fig. 7.

Discussion

In clinical practice, the significance of achieving anatomical reduction of intercondylar eminence avulsion fractures is frequently emphasized to improve internal fixation and restore the length and tension of the ACL. This restoration facilitates the early initiation of joint function exercises. While Type I fractures and certain Type II fractures that achieve anatomical reduction can be managed with knee extension or slight flexion (20°-30°) using plaster external fixation for 6 to 12 weeks, the optimal treatment approach for Type II tibial intercondylar eminence fractures remains a subject of debate among clinicians [4]. Some researchers advocate for percutaneous drainage of hemarthrosis coupled with closed reduction surgery to enhance pain relief and increase the success rate of reduction [12]. However, arthroscopic examinations have revealed soft tissue interposition at the fracture site in a subset of patients, rendering closed reduction ineffective. Additionally, plaster fixation may lead to complications such as nonunion and knee instability. Consequently, there is a growing consensus recommending surgical intervention for Type III and IV fractures to maximize knee joint stability, reduce the necessity for ACL reconstruction, shorten fixation duration, enhance joint flexion and extension range, and minimize complication risks [13].

Currently, common surgical approaches include arthroscopic fracture reduction with internal fixation and traditional open reduction with internal fixation

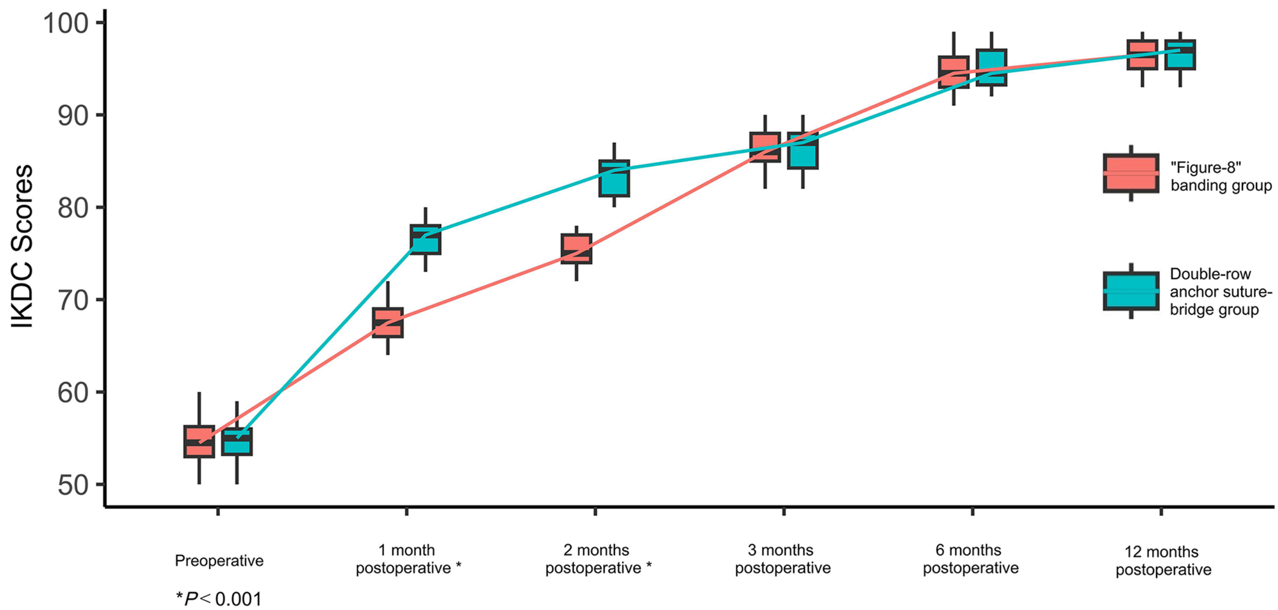

Fig. 7 Comparison of IKDC scores between the two patient groups for 12 months

(ORIF) [14]. Various internal fixation materials like wires, screws, sutures, and suture anchors are employed, with a reliable fixation method needing to withstand a cyclic load of 300–450 N to avoid failure [15]. Screw fixation, noted for its cost-effectiveness, ease of operation, and strong initial fixation strength, has demonstrated significant treatment success [16]. However, challenges include potential impingement in the intercondylar notch, cartilage damage, further bone fragment fragmentation during screw insertion, and growth plate damage in patients with incomplete skeletal development [17]. Additionally, some studies indicate suture fixation provides greater strength than screw fixation, effectively securing small or comminuted fragments [18]. As a result, suture fixation has emerged as the preferred method in arthroscopic surgery.

Arthroscopic reduction and internal fixation represent a minimally invasive treatment approach. Although initial studies indicated that arthroscopic surgery generally required more time than traditional open reduction and internal fixation, advancements in arthroscopic techniques have resulted in surgical durations comparable to or even shorter than those of open procedures [19]. Arthroscopy provides a less invasive method to approach these lesions, reducing the risks related to open techniques such as soft-tissue damage, post-operative pain, infection, and a longer period of hospital stay [20]. Arthroscopy enables the assessment of intra-articular avulsion fractures and ACL injuries, allowing for precise reduction and secure fixation. This method facilitates early rehabilitation, involves smaller incisions, promotes rapid recovery, reduces postoperative pain, and shortens the length of hospital stays, thereby providing distinct advantages [5]. Consequently, arthroscopic reduction and internal fixation has become the favored treatment for such fractures.

"Figure-8" Suture fixation

The "Figure-8" suture fixation technique is widely utilized in clinical practice due to its simplicity, cost-effectiveness, reliability, and significant therapeutic outcomes [21]. To mitigate the risk of tibial physeal fractures in patients with immature skeletal development, clinical researchers have introduced modifications to the suture fixation approach. Mutchamee et al. proposed a method involving the passage of a high-strength suture through two crossed bone tunnels, securing it at the tunnel exits either by knotting or with screw fixation, thus providing stable fixation via a suture-bridge without intra-articular involvement and avoiding associated complications [22]. Mann et al. advocated for the use of four 2.9 mm bone tunnels to minimize the potential complications associated with the utilization of two 5 mm tunnels [23]. Zhou et al. employed two soft tissue tunnels and a single transverse bone tunnel beneath the tibial tuberosity instead of the conventional trans-tibial bone tunnel, reducing the impact on the tibial physis [24]. Suture fixation also lessens the adverse effect on the blood supply of the ACL by creating a circumferential ligature at its base [25]. There are numerous studies on refining suture fixation techniques. However, "Figure-8" suture fixation primarily compresses the anterior segment, leading to challenges in effectively securing the posterior segment of the avulsed bone fragment. Long-term observations have identified an increased risk of posterior loosening and displacement.

In our study cohort, due to concerns regarding the risk of posterior displacement, a more cautious approach was taken for postoperative knee rehabilitation exercises. This may account for the lower knee joint range of motion and functional scores observed during the first and second months postoperatively compared to the double-row anchor suture-bridge group. However, subsequent follow-ups after three months confirmed the healing of the avulsed bone fragment, with no significant differences in knee joint range of motion and functional scores.

Double-row anchor suture-bridge fixation

The double-row anchor suture-bridge fixation method is well-suited for addressing various types of tibial intercondylar eminence fractures, including the more complex Type IV fractures, by providing robust fixation capable of withstanding tension effectively. Additionally, it circumvents potential risks associated with implant damage and collisions in the intercondylar fossa, unlike traditional internal fixation methods, thereby eliminating the need for secondary surgery to remove the fixation device. The even distribution of force across multiple sutures ensures a more stable reduction and fixation without increasing the likelihood of penetrating bone fragments [26]. She et al. successfully applied the multiple tape suture anchor bridge technique to decompress fracture fragments, achieving anatomical reduction and stable internal fixation for tibial intercondylar eminence fractures [27]. In the center of the tibial bed, Li et al. adopted a suture anchor fixation strategy to both reduce fractures and enhance ligament stability during movement, by using two to three suture anchors at the edge of the bed for mattress sutures to secure the stability of the bone fragment [28]. Although tape anchors are effective in treating tibial intercondylar eminence fractures, they demand higher arthroscopic skill levels compared to suture fixation. The surgical duration for this group tends to exceed that of the "Figure-8" banding group, primarily due to the time involved in inserting intraosseous anchors and using a suture hook to thread the suture anchor through the bone. Hapa et al. observed that suture anchor fixation leads to less displacement in tibial tuberosity fractures than suture tie fixation [29]. The technique mirrors the suture-bridge method used in rotator cuff repair—applying a suture-bridge for ACL ligament avulsion bone fragments and compressing the fragment from various angles in a planar manner. This approach not only mitigates the risk of bone penetration but also ensures a robust fixation, thereby enabling early commencement of knee joint functional exercises. Furthermore, the exit of the suture through the tibial bone tunnel and its fixation with an extracortical anchor under arthroscopic observation ensure closer adhesion of the avulsed bone fragment to the bone bed, achieving a firmer fixation. Consequently, in the initial postoperative one and two months, this group exhibited superior outcomes in terms of knee joint stability, mobility, and functional scores compared to the "Figure-8" banding group. For these reasons, from a biomechanical point of view, the double-row anchor bridge group is particularly suitable for Type 3 and Type 4 avulsion fractures.

Both groups achieved fracture healing at three months postoperatively, with postoperative knee joint stability follow-up (drawer test, Lachman test) and functional scores all surpassing preoperative levels. However, there was no statistical difference between the groups, indicating that both double-row anchor suture-bridge fixation and "Figure-8" suturing could achieve favorable fixation effects.

Limitations

This study is constrained by several limitations. On the one hand, the small sample size may lead to an uneven distribution of patients with different types of fractures, potentially impacting the comparative effectiveness between the two groups. On the other hand, due to financial constraints, postoperative patient follow-up was conducted at 1 month, 2 months, 3 months, 6 months, and 12 months using radiography, CT, and functional scoring. This approach lacks precision in determining the exact timing of fracture healing and functional recovery scores. Future research should aim to increase the sample size, enhance the frequency of follow-up assessments, and incorporate third-party assessments to ensure more accurate and reliable comparative study results.

Conclusion

Both arthroscopic "Figure-8" banding and double-row anchor suture-bridge fixation are effective in achieving precise reduction and stable fixation of tibial intercondylar eminence avulsion fractures. In addition, the figure-8 suture group has the characteristics of shorter surgery time and less cost. However, the double-row anchor suture-bridge fixation technique offers superior outcomes in terms of early postoperative knee joint range of motion and knee joint functional scores when treating ACL avulsion fractures.

Abbreviations

IKDC International knee documentation committee
ACL Anterior cruciate ligament

Author contributions

Zhang GD and Qu WQ conceived the idea and conceptualised the study.Zou Y, Sun XJ and Liu KG collected the data.Zhang GD and Qu WQ analysed and interpreted the data.Zhang GD, Sun XJ and Liu KG statistically analyzed the data.Zhang GD, Qu WQ and Zou Y drafted the manuscript. Zhang GD, Qu WQ made critical revisions to the intellectual content of the manuscript.All authors read and approved the final draft.

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Data availability
The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was conducted with approval from the Ethics Committee of Yantaishan Hospital (No. 2024042). This study was conducted in accordance with the declaration of Helsinki. Written informed consent was obtained from all participants.

Competing interests
The authors declare no competing interests.

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