ORIGINAL PAPER/PŮVODNÍ PRÁCE

Analysis of the Efficacy of Arthroscopic Suture Anchor "X" Fixation for Lateral Femoral Condyle Osteochondral Fractures

Analýza účinnosti artroskopické fixace pomocí kotev ve tvaru „X" u osteochondrálních zlomenin laterálního femorálního kondylu

CHENGSHANG YAN[1], SHIJUAN LI[2], MIN CAI[3], CHUANKAI ZHANG[1], GUANGWANG LIU[4], SONG ZHOU[1], ZEWEN ZHENG[2]

[1] Department of Orthopedics and Joint Surgery , Xuzhou Renci Hospital, Jiangsu, Xuzhou, China

[2] Department of Orthopaedic Surgery, The Second People's Hospital of Qinzhou, Guangxi, Qinzhou,China

[3] Department of Orthopedic and Sports Medicine Surgery, The People's Hospital of Guangxi Zhuang Autonomous Region, Guangxi, Nanning, China

[4] Department of Orthopaedic Surgery, Xuzhou Central Hospital, Jiangsu, Xuzhou, China

ChengShang Yan and ShiJuan Li are co-first authors of this article.
Zhou Song and ZeWen Zheng are the co-corresponding authors of this article.

Corresponding authors:

ZeWen Zheng
Department of Orthopaedic Surgery
The Second People's Hospital of Qinzhou
Guangxi, Qinzhou, 535000 China

2477270788@qq.com

Song Zhou
Department of Orthopedics and Joint Surgery
Xuzhou Renci Hospital
Jiangsu, Xuzhou, 530021 China

zhousong0118@163.com

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ABSTRACT

Purpose of the study

To evaluate and compare the clinical efficacy of arthroscopic suture anchor "X" fixation and hollow compression screw fixation in treating lateral femoral condyle osteochondral fractures.

Material and methods

This retrospective study analyzed 31 patients diagnosed with lateral femoral condyle osteochondral fractures, treated at our hospital between June 2015 and July 2024. Patients were divided into two groups based on the surgical approach: Group A received arthroscopic suture anchor "X" fixation, while Group B underwent arthroscopic hollow compression screw fixation combined with a spacer. HSS scores and excellent outcome rates were assessed at postoperative day 3, 1 month, 3 months, and 6 months. Additionally, postoperative complications were evaluated through a second arthroscopic procedure.

Results

The surgical duration in Group A was significantly longer than in Group B ($P < 0.05$). No significant differences in HSS scores were found between the groups at postoperative day 3 and 1 month, while Group A showed significantly higher HSS scores at 3 months and 6 months compared to Group B ($P < 0.05$). The incidence of postoperative knee joint complications was lower in Group A than in Group B, with a statistically significant difference ($P < 0.05$).

Conclusions

The suture anchor system is effective for both non-weight-bearing and weight-bearing areas of the lateral femoral condyle, especially for small bone fragments, showing favorable clinical results. Compared to traditional hollow compression screw fixation, the suture anchor system significantly reduces postoperative complications and improves knee joint function.

Key words: lateral condyle of femur, osteochondral fracture, internal fixation of fracture, suture anchor system, arthroscopy.

INTRODUCTION

Lateral femoral condyle osteochondral fractures (OCFs) are relatively rare intra-articular injuries, predominantly observed in adolescent patients (11). During adolescence, the cartilage-bone interface is the weakest structure in the knee joint, where the boundary between calcified and

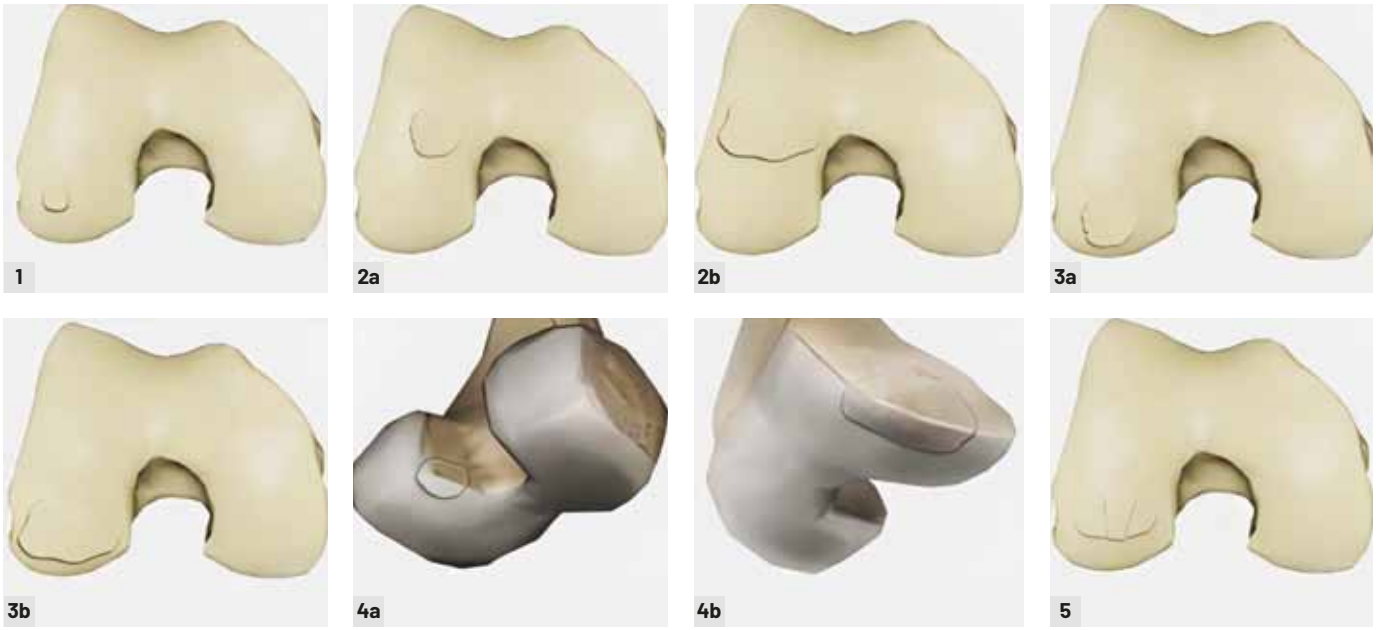

Fig. 1. **Classification of lateral femoral condyle osteochondral fractures.**

uncalcified cartilage is poorly defined (3). Compared to the mature cartilage-bone interface, the biomechanical strength of the immature bone-cartilage interface is significantly lower. As a result, when external forces are applied to the surface of the lateral femoral condyle, the cartilage-bone interface is particularly susceptible to rupture. This anatomical characteristic underscores the vulnerability of both cartilage and bone tissues in adolescent patients (10, 30). An osteochondral fracture refers to an injury that involves both the cartilage and the underlying subchondral bone (8). Lateral femoral condyle osteochondral fractures are commonly associated with acute patellar dislocation (4,30). However, isolated osteochondral fractures of the weight-bearing surface of the lateral femoral condyle are relatively uncommon and are typically linked to acute shear forces exerted on the condylar surface during knee joint hyperflexion (5, 15).

While intra-articular osteochondral fractures exhibit some self-healing potential, their reparative capacity significantly declines when the cartilage defect surpasses a certain threshold (31). Insufficiently treated cartilage or osteochondral injuries can lead to severe complications, including intense joint pain, restricted mobility, decreased quality of life, and even early-onset osteoarthritis (9). Consequently, early fixation and repair of fracture fragments are commonly recommended in clinical practice, with arthroscopic surgery being the preferred minimally invasive approach. However, the primary challenge in such surgeries lies in the effective fixation of fracture fragments under arthroscopic guidance and the selection of appropriate internal fixation materials. Although traditional metal screws are widely used for the internal fixation of intra-articular fractures, they may cause mechanical wear to the cartilage and meniscus. Moreover, for smaller fracture fragments, traditional methods often involve direct excision, which lacks ideal fixation techniques.

To reduce postoperative complications and explore optimized treatment strategies for lateral femoral condyle osteochondral fractures, our hospital was the first to introduce the suture anchor system for fracture fixation, achieving favorable clinical outcomes. This study retrospectively analyzed 31 patients diagnosed with acute lateral femoral condyle osteochondral fractures at our institution between June 2015 and July 2024, comparing the postoperative outcomes of two different surgical approaches.

MATERIAL AND METHODS

General information

This retrospective study analyzed 43 patients diagnosed with acute lateral femoral condyle osteochondral fractures at our hospital between June 2015 and July 2024. After excluding 12 patients lost to follow-up, 31 patients were included based on inclusion and exclusion criteria. All patients presented with acute injuries to the lateral femoral condyle, with a clear history of knee trauma. The typical symptoms included knee pain and swelling, with physical examination revealing significant swelling, localized tenderness, a positive patellar floating test, and restricted knee flexion and extension. To standardize and classify the fractures, a classification system was developed

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Table 1. **Characteristics of included patients**

	A	B	STATISTIC	P-VALUE
SEX				
Male	13 (65%)	7 (35%)	**0.327**	**0.567**
Female	6 (54.5%)	5 (45.5%)		
Age	17.74 ± 0.81	17.5 ± 0.67	0.847	0.404
BMI	20.57 ± 2.25	21.63 ± 2.42	–1.238	0.226
Preoperative concurrent injuries				
Acute patellar dislocation (or subluxation)	6 (60%)	4 (40%)	**0.412**	**0.938**
With meniscal and/or collateral ligament injuries	4 (57.1%)	3 (42.9%)		
Not having patellar dislocation, also had meniscal and/or collateral ligament injuries	4 (57.1%)	3 (42.9%)		
Isolated femoral lateral condyle fracture	5 (71.4%)	2 (28.6%)		

at our hospital for lateral femoral condyle osteochondral fractures (Fig. 1). The classification is as follows:

Type 1: Fracture area ≤ 4mm × 4mm

Type 2: Fracture located in the non-weight-bearing area:

2a: Horizontal diameter of the fracture fragment ≤ 50% of the lateral femoral condyle›s horizontal diameter

2b: Horizontal diameter of the fracture fragment > 50% of the lateral femoral condyle›s horizontal diameter

Type 3: Fracture located in the weight-bearing area:

3a: Horizontal diameter of the fracture fragment ≤ 50% of the lateral femoral condyle›s horizontal diameter

3b: Horizontal diameter of the fracture fragment > 50% of the lateral femoral condyle›s horizontal diameter

Type 4: Wedge-shaped fractures involving the femoral condylar surface (or intercondylar notch):

4a: The articular surface and femoral condylar surface fracture areas are equal

4b: The articular surface fracture area is smaller than the femoral condylar surface fracture area

Type 5: Comminuted fractures, where the bone fragment is separated into two or more pieces (clinically rare)

Inclusion criteria

Patients included in the study had a clear history of knee injury, with the time from injury to treatment not exceeding two weeks. The patients aged 15–30 year and had no significant prior trauma or surgery in the affected knee. Imaging clearly diagnosed lateral femoral condyle osteochondral fractures, and the fracture classification met the following criteria: Type 2, Type 3, Type 4, or partial Type 1 with an area approximately 4 mm × 4 mm.

Exclusion criteria

Patients with a history of chronic knee fractures, previous surgeries, or severe trauma in the affected knee, or with other knee pathologies such as discoid meniscus, pigmented villonodular synovitis, or meniscal cysts, were excluded. Additionally, patients with systemic diseases such as hematological disorders, tumors, or liver and kidney dysfunction were excluded. Fractures classified as Type 5 were also excluded from the study.

Case data

A total of 31 patients were included in the study, consisting of 20 males and 11 females. 19 cases involved the right knee, and 12 involved the left knee. Based on the surgical approach used, patients were divided into two groups: Group A and Group B. Group A consisted of 19 patients (13 males, 6 females) with an average age of 17.74 years (± 0.81), including 6 patients with acute patellar dislocation (or subluxation) and 4 patients with concomitant meniscal and/or collateral ligament injuries. Additionally, 4 patients, although not having patellar dislocation, also had meniscal and/or collateral ligament injuries. Group B consisted of 12 patients (7 males, 5 females) with an average age of 17.5 years (± 0.67), including 4 patients with acute patellar dislocation (or subluxation) and 3 patients with meniscal and/or collateral ligament injuries. Another 4 patients, despite not having patellar dislocation, also had meniscal and/or collateral ligament injuries. There were no significant differences between the two groups in terms of gender, age, BMI, or preoperative concurrent injuries (Table 1, $P > 0.05$). No statistical differences were found in the fracture classification between the two groups (Table 2, $P > 0.05$).

Table 2. **Statistics of the number of fracture types and Wilcoxon rank sum test (nasty 31, examples)**

	1	2A	2B	3A	3B	4A	4B	TOTAL	P-VALUE
A	1	3	5	3	6	-	1	19	P = 0.74 > 0.05
B	-	1	3	2	3	-	3	12	

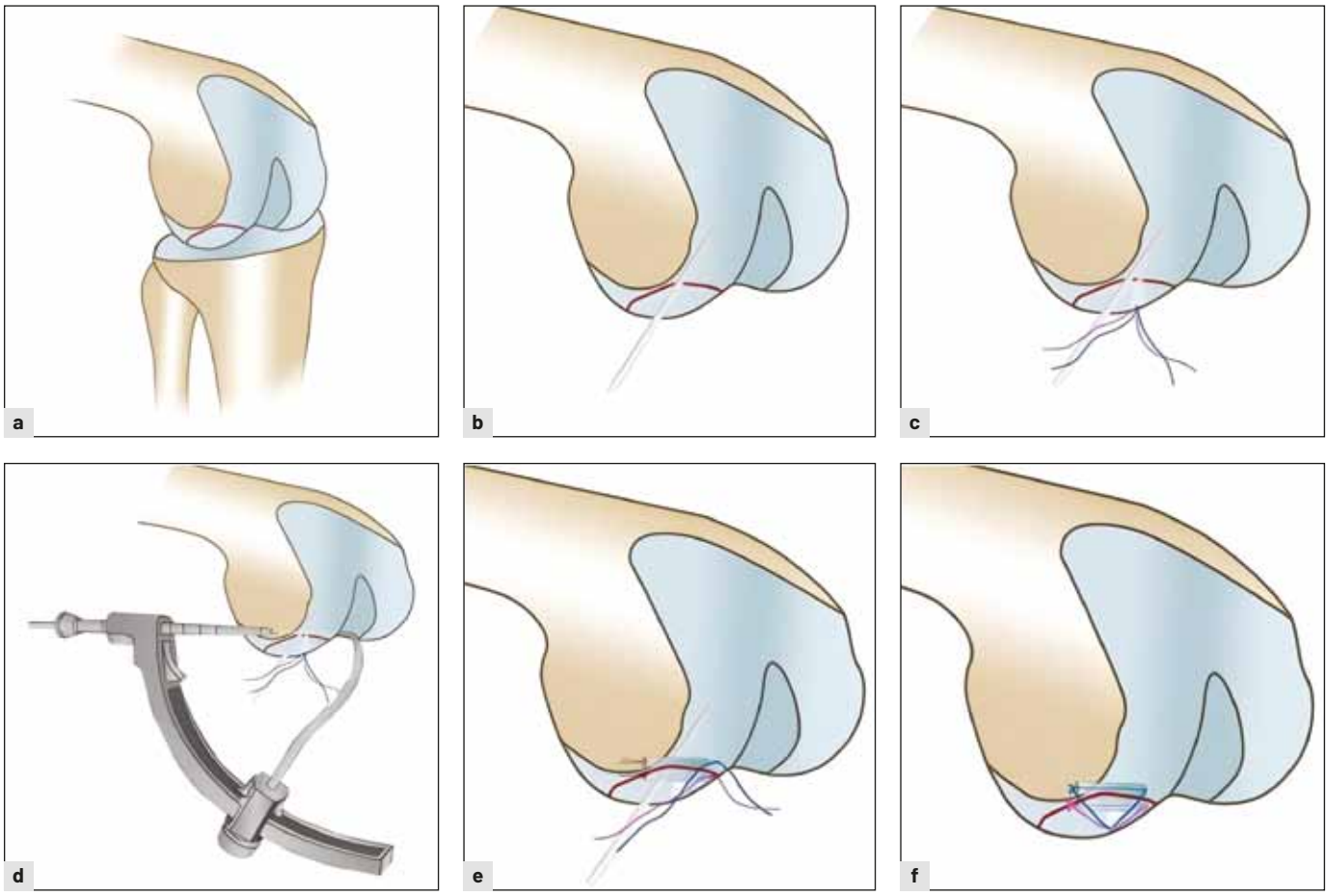

Fig. 2. **Surgical diagrams: a: Osteochondral fracture of the lateral femoral condyle; b: Fixation of fracture block with Kirschner wire; c: Fixation of fracture block with anchor; d: Preparation of bone tunnel; e: Penetration of PDS line and PDS guidance of anchor suture to the outer entrance of femoral tunnel; f: Operation completion diagram.**

Surgical method

Arthroscopic Suture Anchor "X" Fixation of Fractures

A detailed description of the surgical technique, including illustrative diagrams and intra-operative arthroscopic images, has been previously published and can be referred to for visual guidance (38).

The surgical procedure is illustrated in Figure 2. The steps are as follows: After ensuring adequate anesthesia, the knee is disinfected and draped, and a blood pressure cuff is applied to the affected knee at 350 mmHg. A routine arthroscopic approach is utilized, with incisions made at the infrapatellar medial and lateral anterior positions to explore the location and size of the osteochondral injury and identify any free bone fragments (Figs 3a, 3b). The knee is positioned at the edge of the operating table and allowed to naturally hang down. Flexion of the knee facilitates better exposure of the lateral femoral condyle wound, and the flexion angle is adjusted according to the fracture site and surgical requirements.

Under arthroscopic guidance, the fracture surface is debrided and cleaned, and the free bone fragments are reduced according to their shape and the texture of the femoral defect (Fig. 2A). After the bone fragment is reduced, one or two 1.5mm Kirschner wires are used to temporarily fix the lateral femoral condyle fracture fragment (Fig. 2B) to prevent rotation (38). Next, an appropriate suture anchor (TwinFix anchor, Smith & Nephew, Andover, MA) is selected based on the size of the bone fragment. The insertion point is determined, and a 1.0mm, 1.5mm, or 2.0mm Kirschner wire is used to gradually enlarge the anchor insertion point to avoid damaging the bone fragment during insertion. The anchor is then inserted through the surgical incision from the center of the free bone fragment into the femoral condyle, fixing the bone fragment (38). The tail of the anchor should be slightly below the cartilage surface (Fig. 2C).

After clearing the intercondylar notch, the medial outlet of the femoral condyle bone tunnel is located, and a ligament locator is used to assist in drilling. The AIMER tool is employed

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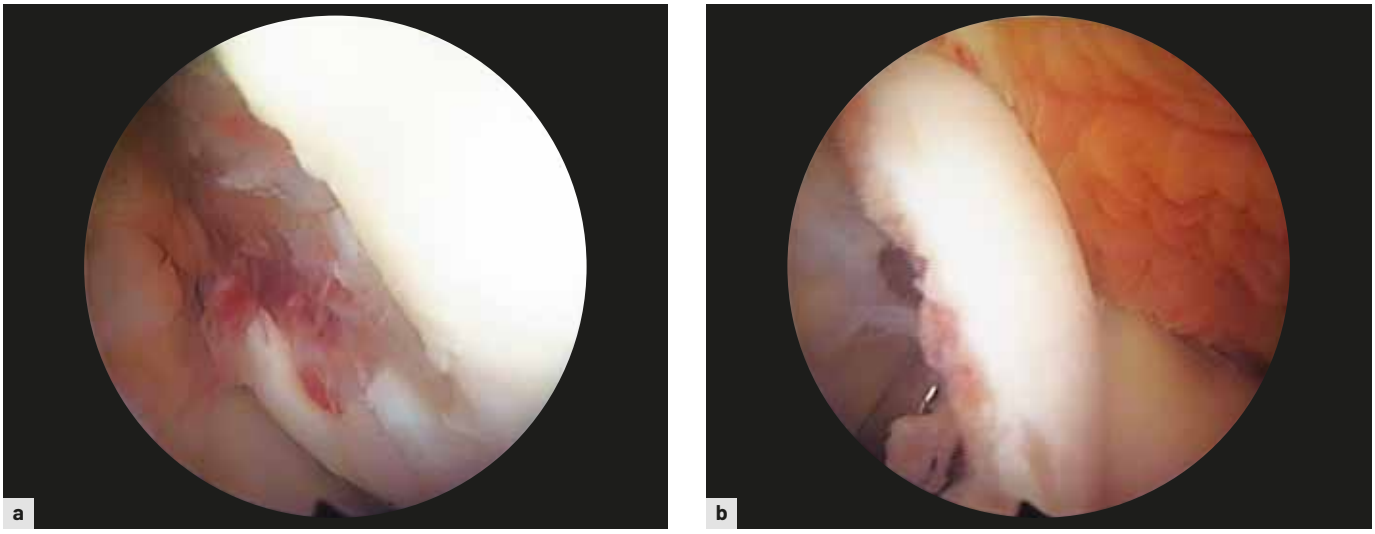

Fig. 3a. **The fresh 1.5cm × 1.5cm fracture surface of the lateral condyle of femur was found under arthroscopy. The bone mass is missing at the fracture. Fig. 3b. 1.5cm × 1.5cm free bone was found in the knee joint cavity, and the bone fracture was intact.**

to position the medial outlet of the femoral condyle bone tunnel through the surgical hole, adjusting the HANDLE to an appropriate angle (50°–60°). The BULLET is then fixed directly on the lateral side of the femur (Fig. 2D). A small lateral incision is made on the knee to drill two 2.0mm bone tunnels from the distal femur toward the intercondylar notch. The distance between the tunnels should not be less than 1.5-2 cm to ensure proper fixation. Dual bone tunnels were drilled 1.5-2 cm apart to prevent tunnel convergence and ensure independent suture tensioning. The ‹X›-shaped configuration distributed stress evenly across the fragment, minimizing shear forces at the tunnel entrances (38).

After the drill bit is withdrawn, a 2.0mm hollow needle is inserted into the bone tunnel to create a temporary working channel (an anesthesia needle may be used as a substitute). The PDS suture is folded, and both ends are passed through the hollow needle and exposed in the femoral intercondylar notch (Fig. 2E). A midline incision at the patella allows a suture grasping forceps to pull both ends of the suture out, withdrawing the hollow needle. The tail of the folded PDS suture must remain outside the femoral bone tunnel entry. The suture grasping forceps are then used through the anterior patella incision to pull one suture from the anchor through the folded suture loop. The suture is threaded through the bone tunnel, with the corresponding suture from the anchor tightened and tied on the lateral surface of the femoral condyle (Fig. 2F). This process is repeated for the second suture. Finally, the temporary Kirschner wire is removed, and the alignment and fixation of the fracture are verified to ensure smooth joint surface and secure fixation.

Arthroscopic metal hollow compression screw + spacer fixation of fractures

After the administration of general or epidural anesthesia, the area is disinfected, draped, and a tourniquet is applied. A standard arthroscopic approach is performed, with incisions at the infrapatellar medial and lateral anterior positions to explore the location and size of the osteochondral injury and identify any free bone fragments. The knee is positioned similarly to facilitate exposure of the lateral femoral condyle wound, and the flexion angle is adjusted according to surgical needs.

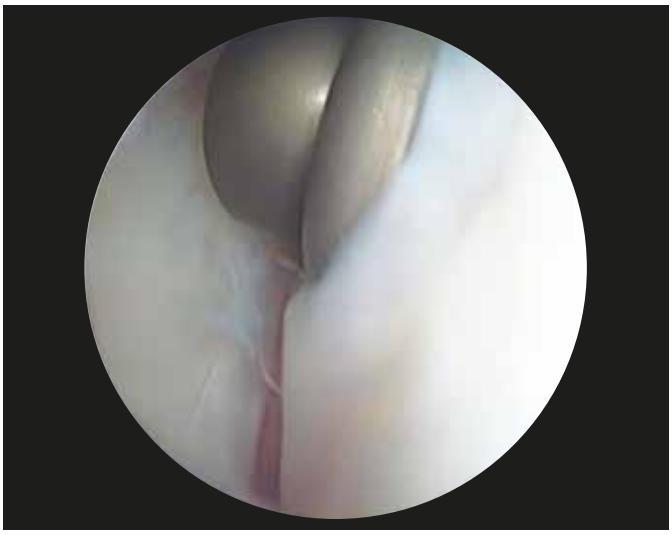

Fig. 4. **Screw inserted from the center of the bone mass to secure the bone fragment.**

Under arthroscopic guidance, the cartilage surface is trimmed and cleaned, and the free bone fragments are reduced according to their shape and the texture of the femoral defect. One or two 1.5 mm Kirschner wires are used to temporarily fix the fracture fragment. After reducing the bone fragment, screws are selected based on fragment size, and the insertion point is determined. The Kirschner wire is gradually used to enlarge the anchor point with sizes of 1.0mm, 1.5mm, or 2.0 mm. The screw is then inserted through the surgical incision, with the screw head positioned as closely as possible to the cartilage-bone surface, leaving a mild indentation on the cartilage surface as acceptable. A 3.5mm hollow compression screw with a spacer is typically used for smaller bone fragments, while larger bone fragments require appropriately sized screws.

Postoperative management

Within one week of surgery, patients are instructed to perform knee flexion and extension exercises, ankle pump exercises, and quadriceps strengthening exercises while confined to bed. The knee joint range of motion is limited to –10° to 90°. The affected limb is supported with an adjustable knee brace for rehabilitation exercises for three months, after which full weight-bearing is allowed. Patients are followed up with outpatient visits, with a minimum follow-up of six months and a maximum of two years. HSS scores were assessed during outpatient visits by an independent physiotherapist. Active ROM was measured using a goniometer, while pain and function domains relied on patient reporting.

Second arthroscopic surgery

Sutures and metal screws are both considered intra-articular foreign bodies that protrude from the articular surface. While the sutures showed favorable results in recent follow-ups without causing significant damage, one patient in Group A developed mild damage to the femoral cartilage surface and the anterior horn of the meniscus upon re-evaluation 18 months post-surgery. To prevent long-term fixation of sutures and metal screws from causing wear on intra-articular soft tissues, it is generally recommended that sutures be removed from Group A patients and metal screws from Group B patients six months postoperatively (38). Among the 29 patients, 23 patients returned for a second surgery six months after the initial procedure; 2 patients returned for the second surgery between six months and one year postoperatively (both from Group A); 4 patients returned between one and two years after surgery (2 from Group A and 2 from Group B).

Observation indicators

The primary indicators for this study included comparisons of surgical duration, postoperative complication rates, fracture recurrence, and functional evaluations of the knee joint before and after surgery. Knee joint function was assessed using the HSS scoring system, as well as intraoperative findings during the second arthroscopic knee examination.

Table 3. **Comparative analysis of operation duration (T-test, n=31, minutes, `x±s)**

	SURGICAL TIME (MINUTES)	P-VALUE
A	90.95 (± 8.33)	<0.05
B	40.17 (± 6.01)	

Statistical analysis method

Data were analyzed using SPSS 22.0 software. Continuous variables were presented as mean ± standard deviation (`x±s). Statistical comparisons were conducted using t-tests, rank sum tests, Wilcoxon rank sum test, and Fisher's exact test. A *P*-value of < 0.05 was considered statistically significant.

RESULTS

Fracture reduction was confirmed radiographically (Figs 6a,b, 9) and arthroscopically (Figs 7, 10). The study found that the surgical duration in Group A (suture anchor fixation) was 90.25 (±8.33) minutes, whereas in Group B (hollow compression screw fixation) it was 40.17 (±6.01) minutes. The surgical time in Group A was significantly longer than in Group B, with a statistically significant difference ($P < 0.05$) (Table 3). Both groups of patients received elastic bandage compression on the affected limb for three days postoperatively. HSS knee joint functional scoring was performed on the third day, one month, three months, and six months post-surgery (9). A *T*-test of each HSS score revealed that at three and six months post-surgery, Group A showed significantly higher HSS scores compared to Group B ($P < 0.05$), indicating a statistically significant difference (Table 4). At six months post-surgery, both groups had a 100% excellent-good rate, with 17/19 in Group A and 8/12 in Group B achieving an excellent outcome. However, the difference was not statistically significant ($P > 0.05$) (Table 4).

Second arthroscopic examination results revealed the following findings (Table 5): Meniscal injury occurred in 2 cases in Group A and 5 cases in Group B; cartilage damage was observed in 2 cases (Grade I–II) in Group A and 7 cases (5 Grade I, 2 Grade II) in Group B. Of these, 1 case of combined injury occurred in Group A and 4 cases in Group B. The postoperative complication rate in the knee joint was lower in Group A than in Group B, with the difference being statistically significant ($P < 0.05$) (Table 5).

There were no significant bleeding events during or after surgery in any patients, and no cases of deep vein thrombosis, wound dehiscence, or persistent wound complications were observed. One patient in Group B experienced occasional knee pain 1.5 years post-surgery, but no other patients

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Table 4. **Postoperative HSS scores and comparison of excellent HSS scores 6 months after surgery**

	POSTOPERATIVE HSS SCORES					EXCELLENT HSS SCORES	
	PREOPERATIVE	3 DAYS POSTOPERATIVE	1 MONTH POSTOPERATIVE	3 MONTHS POSTOPERATIVE	6 MONTHS POSTOPERATIVE	EXCELLENT	GOOD
A	59.95 ± 4.5	65.95 ± 4.27	79.67 ± 4.07	88.26 ± 5.27	91.21 ± 3.34	17	2
B	60.08 ± 3.58	65.92 ± 3.34	77.92 ± 5.82	83.83 ± 3.64	85.75 ± 7.64	8	4
T-value	−0.088	0.021	0.892	2.547	2.338	2.451	
P-value	> 0.05	> 0.05	> 0.05	< 0.05	< 0.05	> 0.05	

Table 5. **Results of the second arthroscopic examination**

	GROUP A (SUTURE ANCHOR GROUP, N = 19)			GROUP B (HOLLOW COMPRESSION SCREW GROUP, N = 12)		
	MENISCAL INJURY	CARTILAGE DAMAGE	COMBINED INJURY	MENISCAL INJURY	CARTILAGE DAMAGE	COMBINED INJURY
1	-	-	-	-	-	-
2a	-	-	-	-	-	-
2b	-	-	-	1	-	-
3a	1	-	-	1	2	1
3b	1	2	1	3	3	3
4a	-	-	-	-	-	-
4b	-	-	-	-	-	-
Total	2	2	1	5	7	4
Postoperative knee joint complications	3/19			8/12		
χ^2	8.316					
P-value	P < 0.05					

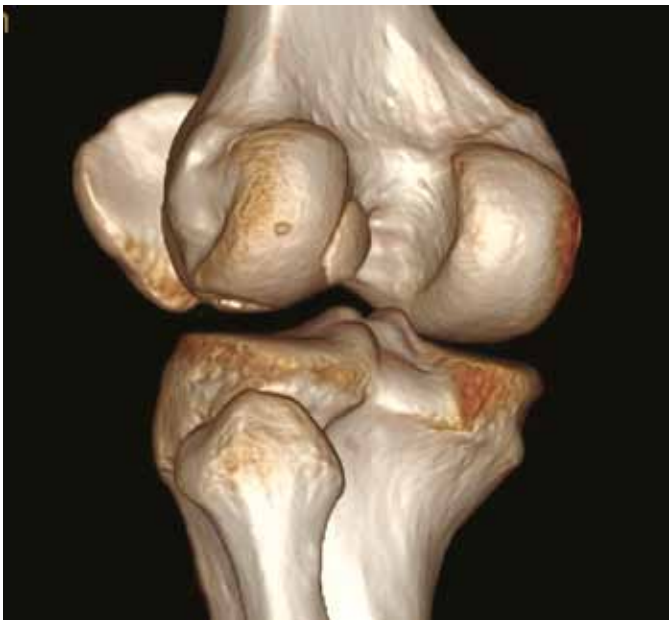

Fig. 5. **CT examination of the left knee joint revealed free bone mass at the anterior edge of the femur in the knee joint.**

reported significant complaints of knee stiffness, restricted mobility, or pain after surgery.

Typical cases

Case 1 (Type 3a fracture): A 21-year-old male patient presented with a left knee injury after jumping from a height a few days prior. Following the injury, the patient experienced pain in the left knee and mild limitation in knee joint motion. Lateral X-ray of the left knee revealed poor continuity of the bone at the lateral femoral condyle edge, along with the presence of free bone fragments within the knee joint (Fig. 5).

After admission, the patient underwent arthroscopic suture anchor fixation for the lateral femoral condyle osteochondral fracture. Three months postoperatively, during a follow-up visit, the patient had been using an adjustable lower limb brace for rehabilitation exercises. The patient was able to walk and move normally, with knee flexion from 0° to 130° and full extension at 0°. There was no significant discomfort in the affected limb. The knee joint HSS score was 93 points. Six months later, X-ray examination (Figs 6a, 6b) showed proper alignment of the lateral femoral condyle fracture, with no visible fracture

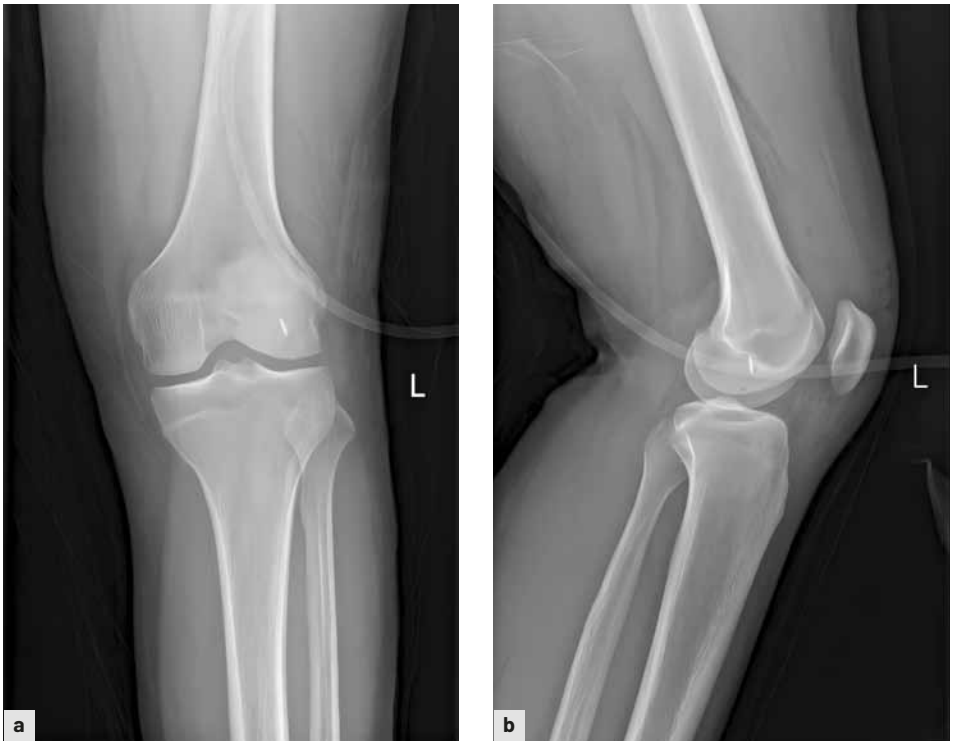

Fig. 6a, 6b. **Six-month postoperative X-ray follow-up showing one screw internal fixation, proper alignment at the fracture site, and callus growth with an unclear fracture line in the right lateral femoral condyle.**

line. A second arthroscopic knee examination confirmed that the anchor and suture fixation were intact, and the fracture site had healed, leaving only a faint fracture line. The femoral fixation sutures were removed, and the articular surface was smooth, with no significant cartilage damage (Fig. 7).

Case 2 (Type 3b Fracture): A 17-year-old female patient sustained a left knee injury 3 days ago while playing badminton. The patient presented with clinical symptoms and signs similar to those in Case 1. Arthroscopic examination revealed an osteochondral fracture of the lateral femoral condyle in the left knee (Fig. 8).

After admission, the patient underwent arthroscopic fixation of the lateral femoral condyle osteochondral fracture using a hollow compression screw and metal spacer. Three months postoperatively, during a follow-up visit, the patient

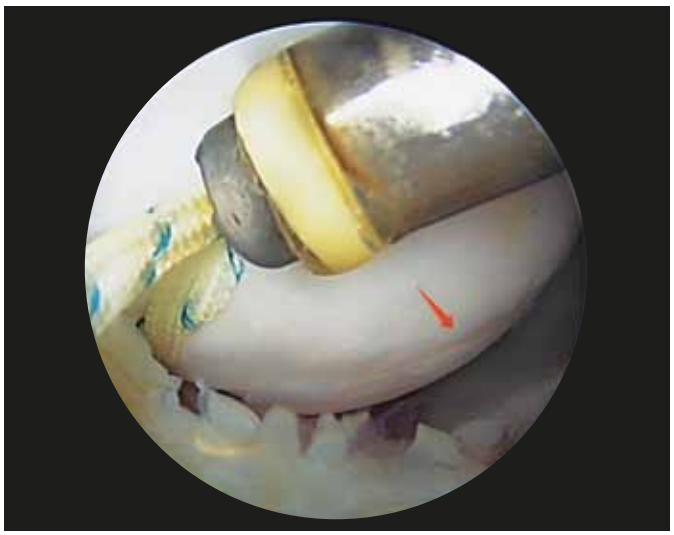

Fig. 7. **A faint fracture line can be observed at the fracture site of the lateral femoral condyle.**

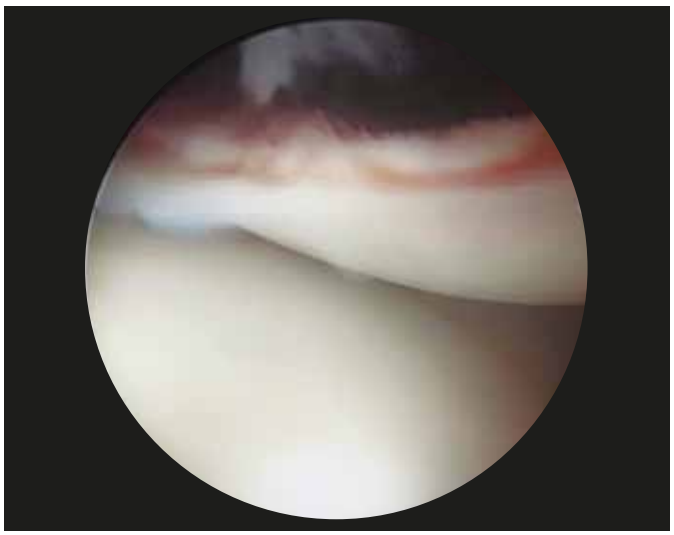

Fig. 8. **Knee arthroscopy revealed an obvious fracture line and osteochondral fracture of the lateral femoral condyle.**

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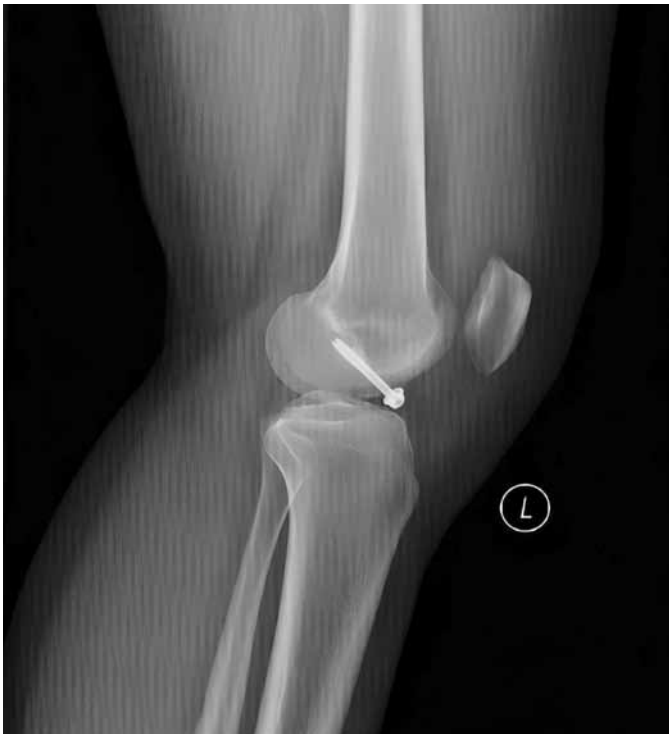

Fig. 9. **X-ray examination showing good alignment of the lateral femoral condyle fracture, with no visible fracture line and metal screw fixation.**

was using an adjustable lower limb brace for rehabilitation exercises. She was able to walk and move normally, with left knee flexion from 0° to 110° and full extension at 0°. There was no significant discomfort in the affected limb. The knee joint HSS score was 86 points.

Two years post-surgery, X-ray examination (Fig. 9) showed proper alignment and positioning of the lateral femoral condyle fracture, with no visible fracture line. The metal screw remained in place. A second arthroscopic knee examination was performed, and the screw was removed. During the procedure, the metal screw was found to protrude 3-4mm outward, with surrounding soft tissue congestion and proliferative inflammatory synovitis (Fig. 10).

DISCUSSION

Self-repair and external repair after osteochondral fractures

Bone tissue is a dynamic structure composed of biologically active cells arranged within a rigid bone matrix. After a fracture occurs, osteoclasts, osteoblasts, and mesenchymal stem cells are activated, contributing to a series of complex healing mechanisms (23). In the case of acute articular fractures, some bone and cartilage defects are filled by fibrin clots (25). However, the healing process of osteochondral injuries is often significantly hindered by synovial fluid infiltration and relative movement at the fracture site, which impedes the formation of bone callus (1). The high density and avascular nature of osteochondral tissue restrict the migration of repair cells from surrounding subchondral tissue and synovial tissue to the damaged area, resulting in insufficient self-repair capacity of the osteochondral tissue (9). Even when some repair potential exists, self-repair is typically limited to smaller defects. When the cartilage defect exceeds 16 mm^2, spontaneous repair is generally not possible (31).

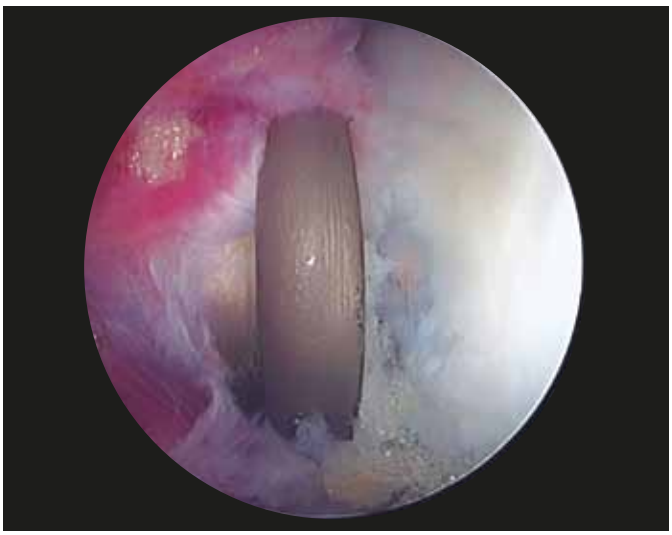

Fig. 10. **The screw had migrated outward, accompanied by mild synovitis.**

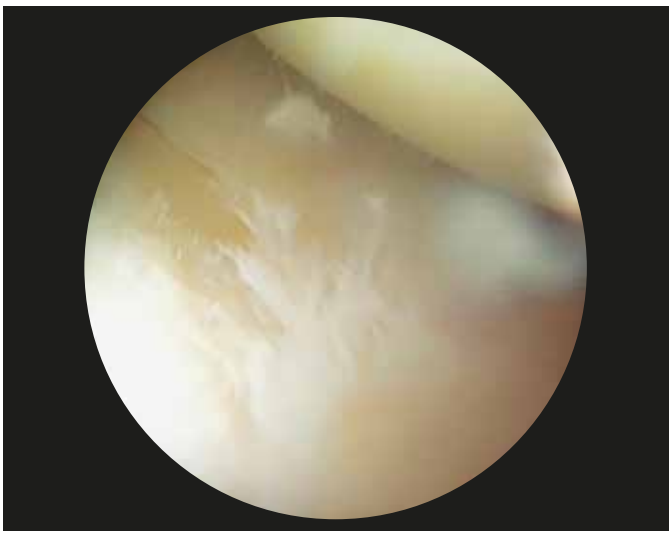

Fig. 11. **The free edge of the anterior foot of the meniscus was rough.**

Studies suggest that fractures should be reduced and fixed within two weeks of injury, as after ten days, fracture fragment volume increases, and fibrous tissue formation may prevent precise repositioning of the fracture fragments (16). In traditional surgeries, excision of free fracture fragments is a common approach. However, this method increases friction between the femur and tibia, as well as between the femur and patella, potentially leading to the early onset of osteoarthritis (9). If cartilage and osteochondral injuries are inadequately treated, they can result in severe knee pain, restricted movement, and a significant decrease in the patient›s quality of life. A study by Chotel et al. (6) demonstrated that early internal fixation surgery for femoral condyle osteochondral fractures resulted in favorable outcomes for all patients. This highlights the importance of early reduction and internal fixation of femoral condyle osteochondral fractures during the acute phase to achieve favorable clinical results (12).

Preliminary exploration and definition of fracture classification

A review of the literature on lateral femoral condyle osteochondral fractures has revealed that, to date, no standardized classification system exists for this type of fracture. CT and MRI are frequently employed imaging techniques for knee joint lesions. While CT offers higher resolution and superior imaging quality for detecting subchondral bone injuries (20, 29), it is less sensitive than MRI for identifying cartilage and osteochondral lesions (35). MRI, on the other hand, allows for clear diagnosis of fractures, cartilage damage, and bone contusions (35), but it generally serves as a qualitative diagnostic tool with limited precision in measuring the exact area of osteochondral fractures. As a result, clinical practice often combines preoperative CT scans to estimate the osteochondral injury area, followed by arthroscopic surgery to more accurately measure the size and location of the fracture.

To enhance the understanding of lateral femoral condyle osteochondral fractures and refine treatment strategies, our hospital has proposed an initial classification system for these fractures. This classification is based on previous literature (2, 4, 13, 7, 18, 30, 34) and clinical case data, using arthroscopic measurements of fracture size and location (Figs 3a, 3b).

Clinical Significance and Treatment Options for Each Type: Type 1: These are microfractures with some self-healing potential. Traditional surgery may not be effective for repair, and typically the fracture fragment is excised. Type 2: These fractures occur in non-weight-bearing areas and generally have a better healing potential. Treatment options include either traditional internal fixation or suture anchor fixation. Type 3: These fractures are located in the weight-bearing area, leading to poorer healing outcomes and a higher rate of postoperative complications. Suture anchor fixation is often recommended. Type 4: Wedge fractures involving the femoral condylar surface (or intercondylar notch) are typically characterized by thicker bone fragments. For Type 4b fractures, metal screws can be used for fixation, with the screws inserted from the femoral condylar surface to avoid interfering with the articular surface. Type 5: Comminuted fractures are challenging to fix surgically and generally result in poorer outcomes.

Type 1 fractures (< 4 × 4 mm) were excluded from fixation due to their self-healing potential. For weight-bearing fragments <4 mm (excluded per protocol), fragment excision would be indicated, though such cases were not encountered in this cohort. Our classification directly guided management: Type 1 → excision; Type 2/3 → anchor/screw fixation; Type 4 → screw fixation from condylar surface; Type 5 → exclusion. This classification system is intended as a preliminary exploration and serves as a reference for clinical treatment and further research. However, due to the limited number of cases, further refinement and validation are needed to enhance its applicability and clinical utility.

Arthroscopic metal screw fixation of fractures

Hollow compression screws achieve effective fixation of fracture fragments through the interaction of their threads and the screw head. These screws are widely used for treating separated bone fragments (38) and are commonly applied in patellar fractures (19) and avulsion fractures of the intercondylar eminence (22). However, the smallest diameter of hollow compression screws is typically 3.5 mm, which poses challenges for fixing smaller bone fragments, particularly in Type 1 and some Type 2a fractures (with fragment diameters ≤ 1 cm). The insertion process for larger screws may cause damage to surrounding cartilage. Therefore, these screws are better suited for larger bone fragments, such as those seen in Type 2b and 3b fractures. Among Group B patients, the smallest bone fragment diameter successfully fixed with hollow compression screws was approximately 1.5 cm.

Metal screw heads are relatively large and blunt, which may lead to complications if they protrude beyond the cartilage surface (Fig. 4). Protruding screws can damage adjacent articular cartilage, while over-insertion increases the risk of bone fractures and fixation failure (32). Two primary approaches to managing screw heads have been proposed:

1. Retain the screw head in close contact with the bone surface and remove the screw within six months postoperatively (38); and
2. Use countersinking techniques or enlarge the insertion point (21, 24).

Countersinking, however, requires the bone fragment to be sufficiently thick (at least 2 mm greater than the screw head) and may increase damage at the insertion site. Regardless of the approach, metal screws should generally be removed within six months post-surgery. Balancing these

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considerations, this study favored leaving the screw head in place to minimize further insertion site trauma.

Second arthroscopic examinations in Group B revealed mild meniscal or tibial cartilage damage (Grade I–II) in six weight-bearing fractures (2 cases of Type 3a, 3 cases of Type 3b, and 1 case of Type 4b). Among non-weight-bearing fractures, one patient exhibited meniscal damage, and another showed Grade I tibial cartilage damage. Notably, two patients in the non-weight-bearing group had internal fixation removal times exceeding one year. One case involved a screw that had migrated approximately 2 mm outward, accompanied by knee joint synovitis (Fig. 10). While all patients demonstrated satisfactory knee function scores and fracture healing, the arthroscopic evaluations revealed varying degrees of pathological damage to the meniscus, tibial plateau cartilage, and surrounding synovial tissue. These findings suggest that such damage is likely related to mechanical erosion caused by screw head protrusion and prolonged fixation. Synovitis is attributed to an aseptic inflammatory response induced by mechanical friction between the metal screw and soft tissues (18, 28). Careful screw head management and timely removal of internal fixation are therefore essential to reduce potential complications.

Arthroscopic suture anchor system fixation of fractures

Features and advantages of the TwinFix Ti suture anchor system

To address the limitations of metal screw fixation, the suture anchor system has gained popularity for treating lateral femoral condyle osteochondral fractures. Our institution was one of the first to implement this system clinically, achieving favorable outcomes. The TwinFix Ti suture anchor system offers several advantages: minimal surgical trauma, simplicity of operation, reliable fixation, high tensile strength, and a reduced risk of complications. Unlike metal screws, the TwinFix Ti system lacks a screw head, relying solely on threads for fixation. This design minimizes disruption to the cartilage surface and negates the need for a second surgery to remove the anchor.

Suture anchors are primarily made from absorbable or non-absorbable materials. Absorbable anchors, which degrade gradually, eliminate the need for removal but may have limitations, including insufficient strength, poor tissue compatibility, and complications such as synovitis, foreign body reactions, or uneven degradation (14, 33). Structural differences between absorbable and non-absorbable anchors also contribute to performance disparities. Metal anchors, typically made of titanium alloy, have thinner threads and a smaller central column, causing less compression and damage to cartilage and bone compared to bioabsorbable anchors with thicker threads (36).

The TwinFix Ti suture anchor employs a dual-helix design to enhance fixation. This design broadens the compression zone around the anchor, with lower threads applying additional pressure to stabilize the bone fragment. The result is increased tensile strength and extended fixation areas beyond the anchor threads. Studies indicate that a 0.1 mm displacement requires a tensile force of 400 N, and cyclic tests under physiological loads show excellent mechanical stability with failure occurring after 331 ± 190 cycles (17, 26).

In this study, 19 patients treated with TwinFix Ti anchors demonstrated no signs of anchor pull-out or loosening during follow-up arthroscopic examinations. Additionally, the system's multiple anchor sizes and configurations allowed surgeons to select appropriate models tailored to individual fracture characteristics, further enhancing clinical outcomes. The Ultrabraid suture, used in conjunction with the TwinFix Ti anchor, also contributes to superior performance. This fine-diameter suture matches the specifications of the Fast-Fix meniscus repair system and is widely used in intra-articular procedures. Clinical observations from this study confirm that the 2.0 mm Ultrabraid suture did not cause adverse effects on the articular surface or meniscus, ensuring smoothness and functionality of the knee joint.

Indications for the TwinFix Ti suture anchor system

Seeley et al. (27) suggested that for small osteochondral fragments (< 1 cm in diameter) located in non-weight-bearing areas, fragment excision may be considered. However, even non-weight-bearing surfaces contribute to patellofemoral and tibiofemoral joint motion. Long-term neglect of osteochondral defects may result in wear-induced degeneration, with bone defects expanding due to ongoing joint activity. This risk is especially pronounced in weight-bearing fractures, where excision often leads to high revision rates (23).

Clinical consensus supports achieving anatomical reduction and fixation for cartilage defects larger than 4 mm × 4 mm, including non-weight-bearing areas, to restore articular surface smoothness (31). Traditional hollow screws, due to their larger diameter, are ineffective for fixing fragments smaller than 1 cm. To address this limitation, we utilized the suture anchor system for small fragments. Among three patients in this study, one had a fragment approximately 4 mm in diameter, while two had fragments between 4 mm and 1 cm. All achieved satisfactory outcomes following surgery. For fragments ranging from 4 mm to 1.5 cm, the 2.8 mm TwinFix Ti anchor proved highly effective, overcoming the limitations of traditional metal screws while ensuring secure fixation and reduced complication risks.

Surgical Techniques and "X" Shape Fixation Characteristics

When performing TwinFix Ti suture anchor fixation, precise technique is paramount. Patients are positioned with their knee joints hanging off the operating table, with the knee

flexion angle adjusted based on surgical requirements. The anchor insertion point is typically located in the most structurally stable region of the fragment. To prevent fragmentation during insertion, progressively larger Kirschner wires are used to enlarge the entry point.

Proper placement ensures that the anchor tail is flush with or slightly below the cartilage surface, maintaining smoothness. Dual suture tunnels spaced 1.5–2 cm apart prevent convergence and enhance fixation stability. The TwinFix Ti system's "X" shaped fixation structure distributes tensile stress evenly across the fragment, forming a robust three-dimensional mesh that stabilizes the osteochondral fragment. Compared to traditional methods, this approach minimizes disruption to the articular surface while optimizing fixation for complex fractures.

Postoperative re-examination of the TwinFix Ti suture anchor system

To confirm the success of the surgical procedure and evaluate potential adverse effects on the knee joint, a second arthroscopic examination was performed with patient consent. During this examination, it was observed that the suture anchor and sutures were securely fixed, with the fracture site having healed, leaving only a faint fracture line. Fibrous tissue had filled the suture exit points on the femoral surface, and the articular surface remained smooth.

In Group A, postoperative knee joint findings revealed 2 cases of meniscal injury, 1 case of femoral cartilage injury, 1 case of tibial cartilage injury, and 1 case of combined meniscal and femoral cartilage injury. The combined injury patient, who returned for re-evaluation 18 months post-surgery, exhibited mild roughness (Grade I–II) of the femoral cartilage surface and roughness at the anterior free edge of the meniscus (Fig. 11). Notably, the body and posterior horn of the meniscus showed no abnormalities. This patient, diagnosed with a weight-bearing osteochondral fracture (Type 3b), returned to work in manual labor two months post-surgery and engaged in sports activities early in recovery. The combined injury could be associated with premature return to physical labor and delayed removal of the sutures. Another patient with tibial cartilage injury suffered a re-injury 6 weeks post-surgery due to non-compliance with the recommended knee brace usage during rehabilitation exercises.

For patients presenting with similar conditions, we recommend limiting physical activity for the first three months post-surgery and avoiding strenuous sports for at least six months. To minimize the potential impact of sutures on the articular surface and meniscus, we suggest removing the sutures during the second knee examination within six months post-surgery.

Comprehensive analysis

Through retrospective analysis, this study underscores the advantages of the suture anchor system in the fixation of osteochondral fractures, particularly in reducing postoperative complications and improving knee joint function scores. The study demonstrated that within six months of surgery, the osteochondral fracture typically heals nearly completely when internal fixation is removed, thereby preventing or minimizing the adverse effects associated with prolonged internal fixation. However, in three patients (3/4) whose internal fixation was removed after more than one year, arthroscopic examinations revealed significant pathological changes in the joint, suggesting that prolonged fixation could have negative consequences for the articular surface.

The suture anchor system, due to its design, is especially suitable for fixing smaller bone fragments with diameters less than 1 cm. It has shown excellent results in weight-bearing areas and offers a reliable fixation solution. Furthermore, by avoiding the protrusion issues seen with traditional hollow screws, the suture anchor system reduces mechanical damage to the articular surface and interference with functional recovery, thereby lowering the risk of post-surgical osteoarthritis. Nonetheless, the long-term presence of sutures within the joint may still have some negative effects on the articular surface. Consequently, patients in both groups required a second surgery to remove the internal fixation. This reinforces the importance of timely removal of internal fixation to improve postoperative outcomes and reduce complications associated with long-term fixation.

Compared to the suture anchor system, hollow screws are more efficient and easier to use for fixing larger bone fragments (≥1 cm in diameter) and wedge fractures in non-weight-bearing areas (such as the femoral condylar surface or intercondylar notch). However, hollow screws may be less effective for smaller bone fragments due to their larger diameter, and their protruding screw heads can interfere with joint function recovery and potentially induce osteoarthritis. At both three months and six months post-surgery, Group A (suture anchor fixation) demonstrated significantly better knee joint function scores than Group B (hollow screw fixation). Despite both groups achieving a 100% excellent rate, with 15/17 patients in Group A and 8/12 patients in Group B showing excellent outcomes, the functional advantage in Group A was statistically significant ($P < 0.05$) (Table 3). This functional advantage is likely due to the less invasive nature of the suture anchor system, which causes minimal disruption to the knee joint compared to the protruding screw heads of the hollow screws in Group B.

In summary, both the suture anchor system and hollow screws offer distinct advantages and are applicable in different scenarios: the suture anchor system is ideal for fixing small bone fragments and offers effective results in weight-bearing areas, while hollow screws are more suitable for larger bone fragments in non-weight-bearing areas. Both

methods are effective for treating osteochondral fractures, but the selection of an appropriate fixation method and the timely removal of internal fixation post-surgery are critical to enhancing surgical outcomes and minimizing postoperative complications. Our findings highlight the need for further research to refine the criteria for selecting fixation methods and to develop optimal strategies for postoperative care, including the timely removal of internal fixation.

Limitations of the study

The present study has several limitations that should be acknowledged. First, the retrospective nature of the study introduces potential biases, including selection bias and information bias. The lack of randomization and the reliance on historical controls may have influenced the results. Second, the sample size is relatively small, which limits the statistical power and generalizability of the findings. Third, the study did not account for all potential confounding variables, such as patient lifestyle factors and compliance with postoperative rehabilitation protocols. Additionally, the classification system used in this study is preliminary and requires further validation with a larger cohort. Finally, the long-term effects of the suture anchor system and hollow screws on joint function and patient quality of life remain to be elucidated through longer follow-up periods and larger prospective studies.

CONCLUSIONS

Suture anchors are optimal for small fragments (≤1 cm) and weight-bearing zones, while screws suit larger non-weight-bearing fragments. Timely implant removal (≤6 months) is critical to avoid joint erosion. ■

Ethics approval: All patients were treated in accordance with the Declaration of Helsinki. All patients have signed the surgical consent form. All authors had full access to the data, contributed to the study, approved the final version for publication, and take responsibility for its accuracy and integrity.

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