Gao *et al. Journal of Orthopaedic Surgery and Research* (2025) 20:497
https://doi.org/10.1186/s13018-025-05899-6

Journal of Orthopaedic Surgery and Research

RESEARCH Open Access

Separate vertical wiring versus conventional tension band fixation for inferior pole patellar fractures: a prospective cohort study on postoperative patella baja and functional outcomes

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Abstract

Objective To compare the clinical efficacy of the separate vertical wiring (SVW) technique and conventional tension band fixation in managing AO/OTA type A1 inferior pole patellar fractures, focusing on postoperative patella baja incidence and functional recovery.

Methods From January 2019 to January 2023, 242 patients with AO/OTA A1 inferior pole patellar fractures undergoing surgical treatment were assigned to the SVW group ($n=117$) or tension band (TB) group ($n=125$). The primary outcome was the incidence of patella baja (Insall-Salvati index < 0.8) at the 12-month follow-up. Secondary outcomes included knee range of motion (ROM), Böstman functional score, and complications.

Results The SVW group demonstrated a significantly lower incidence of patella baja compared to the TB group (25.6% vs. 52.1%, $P<0.001$), with higher mean (Insall-Salvati index) ISI values (0.87 ± 0.16 vs. 0.76 ± 0.12, $P<0.01$). Knee ROM was superior in the SVW group (124.0°±14.2° vs. 119.9°±12.4°, $P=0.017$), though no significant difference was observed in Böstman scores (25.1 ± 3.5 vs. 24.6 ± 3.6, $P=0.33$). The overall complication rate was 5.8% (14/242), primarily comprising surgical site infections (3.5%, 8/242: 1.2% superficial, 2.1% deep), fixation failure (1.2%, 3/242), and nonunion (0.8%, 2/242). Notably, soft tissue irritation occurred exclusively in the TB group (8.8%, 11/125 vs. 0% in SVW; $P=0.005$).

Conclusion The SVW technique significantly reduces the risk of patella baja and improves knee range of motion by optimizing vertical tension distribution, establishing it as a biomechanically superior fixation strategy for AO/OTA A1 inferior pole patellar fractures. These findings support SVW as a first-line treatment for such complex injuries.

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Keywords Inferior pole patellar fracture, Separate vertical wiring, Conventional tension band, Patella Baja, Functional outcomes

Introduction

Patellar fractures constitute approximately 1% of all skeletal injuries, with inferior pole fractures (AO/OTA type A1) representing 9.3-22.4% of these cases [1, 2]. These fractures pose distinctive surgical challenges due to characteristic features including small fragment size, compromised cancellous bone density, and frequent comminution—factors that collectively contribute to fragment displacement and disruption of the extensor mechanism [3]. Compared with other patellar fracture subtypes, inferior pole injuries demonstrate a higher risk of postoperative knee dysfunction, primarily attributed to compromised patellofemoral kinematics [4, 5].

While diverse fixation techniques have been developed, achieving stable fixation while preserving knee mobility remains technically demanding [6–10]. Emerging evidence highlights a critical yet under-investigated association: inferior pole fractures exhibit an increased likelihood of progressing to patella baja (pathological patellar tendon shortening) compared to mid-body fractures [11]. This malalignment, defined radiographically by an Insall-Salvati index (ISI) < 0.8, correlates strongly with restricted range of motion (ROM) and accelerated patellofemoral arthritis [12, 13]. Despite its clinical significance, current protocols lack evidence-based strategies to prevent this complication, underscoring an urgent need for biomechanically optimized fixation approaches.

Conventional tension band (TB) wiring—the historical gold standard—relies on transverse Kirschner wires to convert tensile forces into fracture compression. However, recent biomechanical analyses reveal critical limitations in inferior pole applications [14]. TB constructs demonstrate lower load-to-failure in distal fragment fixation compared to proximal patellar fractures, with 42% of cases showing > 2 mm displacement during early motion [15, 16]. In addition, its high complication rate (such as skin irritation and Kirschner wire displacement) cannot be ignored [17]. These deficiencies have spurred interest in vertical fixation strategies. The Separate Vertical Wire (SVW) technique innovates through longitudinal bone tunnels positioned 2–3 mm from the fracture interface, generating perpendicular tensile forces to counteract inferior fragment migration [18].

This prospective cohort study addresses two unresolved questions: (1) Whether SVW reduces radiographically confirmed patella baja incidence compared to TB in surgically managed AO/OTA A1 fractures; (2) Whether biomechanical superiority translates to clinically meaningful improvements in functional recovery. By analyzing 242 patients with at least one year follow-up, we provide comparative evidence to refine surgical decision-making for these complex injuries.

Methods

Study design and ethical approval

This prospective cohort study was conducted at the National Center for Orthopaedics and Shanghai Jiaotong University Affiliated Sixth People's Hospital, China, from January 2019 to January 2023. The study protocol received ethical approval from the Institutional Review Board of Shanghai Jiaotong University Affiliated Sixth People's Hospital in 2017, with patient enrollment commencing in January 2019. Written informed consent was obtained from all participants, and the study adhered strictly to the ethical principles of the Declaration of Helsinki.

Patients

Inclusion criteria

The inclusion criteria of this cohort were as follows: (1) Adults (18–70 years) with acute, isolated AO/OTA type A1 patellar fractures (≤ 14 days post-injury) [19]; (2) Surgical intervention performed by senior orthopedic surgeons. The exclusion criteria of the cohort were as follows: (1) Open fractures, bilateral injuries, or concomitant fractures (proximal tibia/distal femur); (2) Pre-existing knee arthritis (radiographically confirmed Kellgren-Lawrence grade ≥ 2) or pre-injury severe knee dysfunction (VAS > 70 mm/100 mm for functional impairment); (3) Severe systemic comorbidities (Supplementary Materials 1).

After the exclusion criteria and inclusion criteria, 289 patients were enrolled in this study. 16.3% (47 of 289) were lost to follow-up before two years. Among them, 40 patients were reluctant to undergo further imaging examinations, and 7 patients experienced subsequent fractures (excluding patellar fractures) in the same affected limb after the surgery. A total of 242 patients were finally enrolled in this study. (Fig. 1)

Surgical procedures

Patients were randomly allocated to two groups receiving either the Separate Vertical Wire (SVW) technique or conventional tension band (TB) fixation according to their admission time. The SVW technique is specifically indicated for inferior pole patellar fractures. Briefly, after the fracture site is exposed and debrided, three vertical bone tunnels are drilled from inferior to superior, positioned 2–3 mm beneath the subchondral bone. Stainless steel wires are then passed through these tunnels and

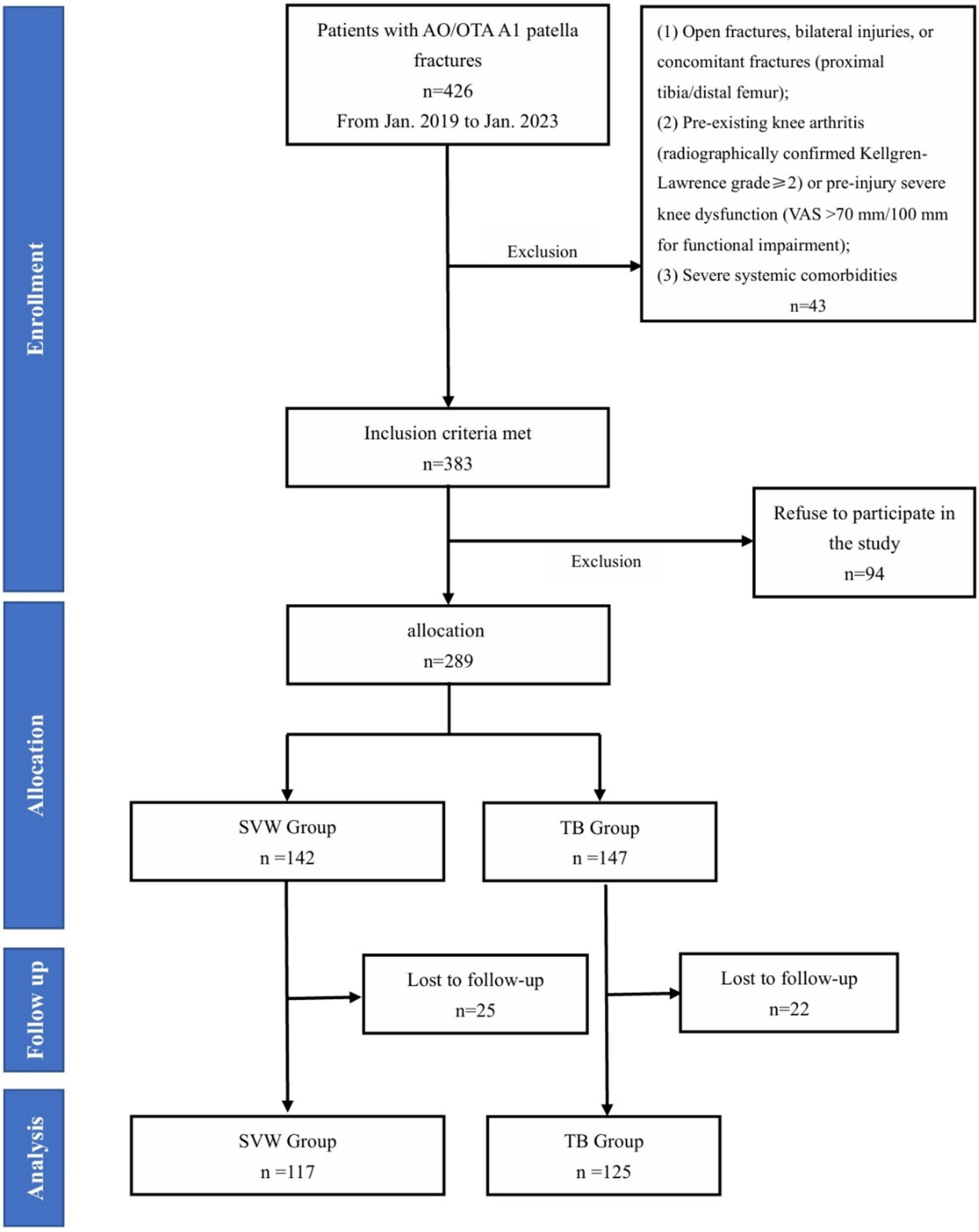

Fig. 1 Patient Enrollment Flow Diagram

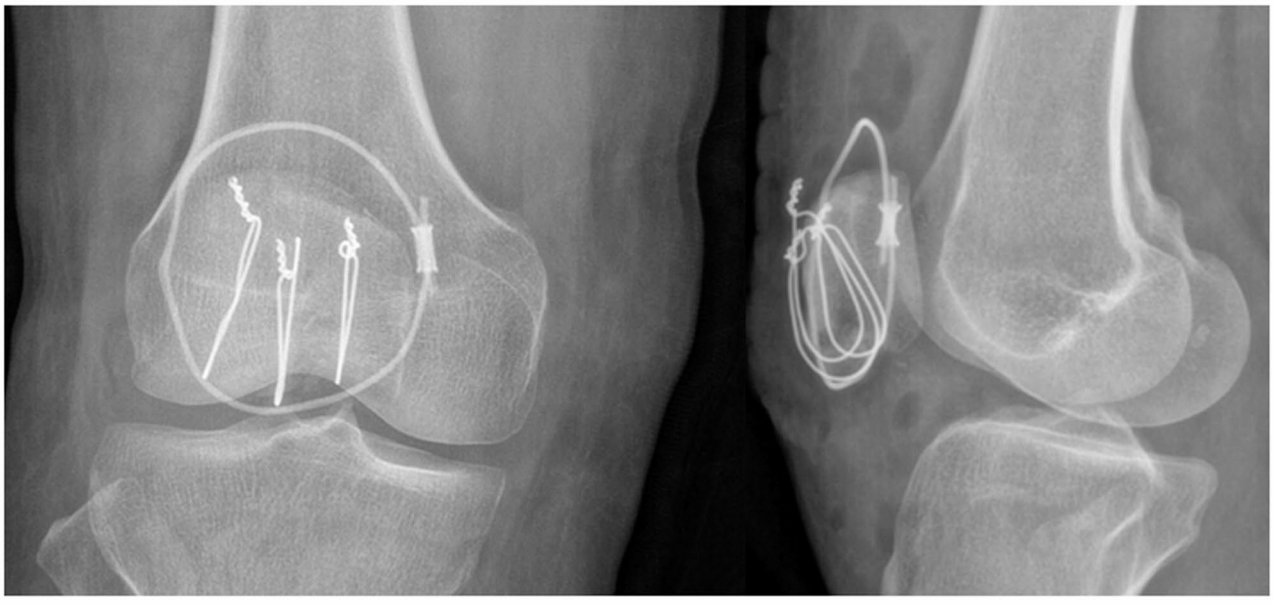

Fig. 2 A 54-year-old male patient with an inferior pole patellar fracture treated using the SVW technique. Postoperative anterior-posterior and lateral knee radiographs demonstrate stable fixation of the fracture fragment through SVW technique

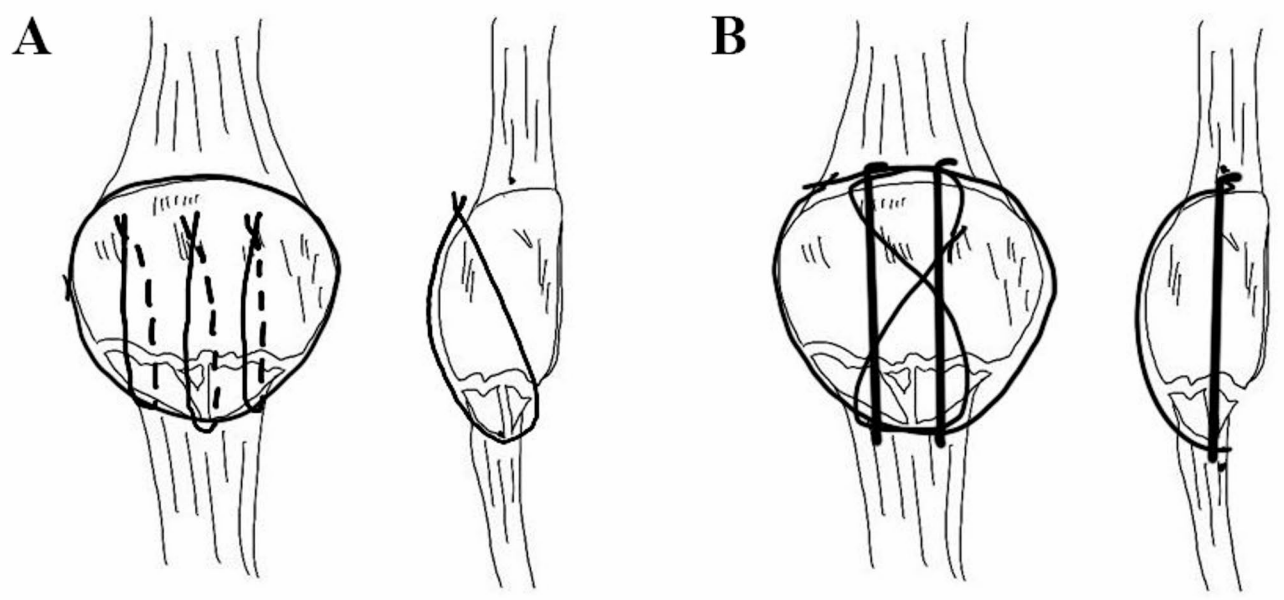

Fig. 3 A the treatment of inferior pole fracture of the patella with the modified separate vertical wire technique. B The treatment of inferior pole fracture of the patella with the tension band combined with cerclage wire

securely wrapped around the inferior pole fragment to achieve compression fixation. This method is widely recognized in clinical practice for its reliable stability and biomechanical strength in stabilizing small distal fragments. The cerclage wire is used to enhance the grip on the inferior fracture fragment [20]. (Fig. 2)

In contrast, the conventional TB technique utilizes Kirschner wires transversely penetrating fracture fragments to form a figure-of-8 wire loop, converting tensile forces into compressive forces to promote union. Cerclage wires and sutures are used to reduce fracture displacement and strengthen the fixation of the inferior pole fracture fragment. (Fig. 3)

Each patient received a postoperative rehabilitation plan, including non-weight-bearing ambulation for 2 weeks, progressive ROM exercises from postoperative day 2, and full weight-bearing at 6 weeks.

Table 1 Demographic characteristics and postoperative outcomes

		% (*n*)
Male		43.0% (104)
Age in years		53.3 ± 12.9
BMI in kg/m2		24.9 ± 2.3
Affected side	Left	49.2% (119)
	Right	50.8(123)
Follow-up (mon)		25.7 ± 10.1
ISI		0.82 ± 0.14
Patellar Baja		42.9% (104)
ROM (degree)		121.9 ± 13.4
Böstman functional score		24.9 ± 3.5

BMI Body Mass Index

ROM Range of Motion

ISI Insall-Salvati Index

Data collection and outcome measures

Prospective data collection included baseline demographics, surgical details, and serial postoperative evaluations at predefined intervals (6 weeks, 3/6/12 months, and annually thereafter). The primary outcome was the incidence of patella baja, defined as an Insall-Salvati index (ISI) < 0.8 on standardized lateral knee radiographs at 12-month follow-up, with measurements performed independently by two blinded orthopedic surgeons. The patient's ISI was measured and recorded on the lateral knee radiograph with the knee in a 30° flexed posture [21, 22]. Secondary outcomes encompassed functional recovery metrics: active knee range of motion (ROM) was quantified using a goniometer during maximal flexion-extension, while the Böstman functional score (0–30; higher scores indicating superior function) assessed pain, mobility, and stability. Complications were rigorously documented per CDC criteria for surgical site infections (superficial/deep) and radiographic evidence of fixation failure (hardware loosening, fragment displacement > 2 mm, or reoperation).

Statistical analysis

Continuous variables were presented as the mean and SD, and categorical data were expressed as the number and percentage. The Hosmer-Lemeshaw test was employed to assess the fit of the logistic regression model between actual observations and predicted probabilities. Independent *t*-tests for normally distributed data. Differences between groups for each categorical variable were assessed for significance using either a chi-square test. All statistical analyses were performed using IBM SPSS version 26.0 (IBM Corp). Significance levels for all statistical assessments were set at 0.05.

Table 2 Binary logistic regression analysis of risk factors for patella Baja

	B	OR(95% C.I.)	*P*
Sex	-0.035	0.97(0.05–1.70)	0.90
Age	-0.004	1.00 (0.97–1.02)	0.69
BMI	0.031	1.03 (0.92–1.16)	0.60
Fixation Method	-1.457	0.23 (0.16–0.41)	< 0.01

Result

Demographic data and functional outcomes

Between January 2019 and January 2023, 642 consecutive patients with AO/OTA type A1 patellar fractures underwent surgical intervention at our institution. After applying predefined inclusion/exclusion criteria, 302 patients were initially enrolled, with 242 (80.1%) completing ≥ 12 months of follow-up. The cohort comprised 104 males (43.0%) and 138 females (57.0%), aged 18–70 years (mean 53.3 ± 12.9). Fracture laterality was balanced (left: 49.2%, $n = 119$; right: 50.8%, $n = 123$), with a mean follow-up duration of 25.7 ± 10.1 months. Postoperative functional assessments revealed a mean BMI of 24.88 ± 2.33, ISI of 0.81 ± 0.14, knee range of motion (ROM) of 121.9°±13.4°, and Böstman functional score of 24.9 ± 3.5. Using ISI < 0.8 as the diagnostic threshold, 42.9% (104/242) of patients exhibited patella baja, highlighting a clinically significant incidence of post-traumatic patellar malalignment (Table 1).

Risk factors for Patella Baja

Binary logistic regression analysis identified fixation method as the sole independent predictor of patella baja ($OR = 0.23$; 95% *CI*: 0.16–0.41; $P < 0.001$). Demographic variables including sex ($OR = 0.97$; 95% *CI*: 0.05–1.70; $P = 0.90$), age ($OR = 1.00$; 95% *CI*: 0.97–1.02; $P = 0.69$), and BMI ($OR = 1.03$; 95% *CI*: 0.92–1.16; $P = 0.60$) showed no statistically significant associations. Notably, SVW fixation was associated with a 77% risk reduction for patella baja compared to TB techniques (Table 2).

Functional outcomes by fixation technique

Comparative analysis between SVW ($n = 117$, 48.3%) and TB fixation ($n = 125$, 51.7%) demonstrated significant advantages of the SVW technique. Radiographic evaluation showed higher ISI values in the SVW group (0.87 ± 0.16 vs. 0.76 ± 0.12; $P < 0.01$), corresponding to a 51% lower incidence of patella baja (25.6% vs. 52.1%; $P < 0.001$). Functional outcomes revealed superior knee ROM with SVW fixation (124.0°±14.2° vs. 119.9°±12.4°; $P = 0.017$), though Böstman functional scores showed no significant intergroup difference (25.1 ± 3.5 vs. 24.6 ± 3.6; $P = 0.33$) (Table 3). These findings underscore the biomechanical efficacy of SVW fixation in optimizing patellofemoral kinematics.

Table 3 Comparative analysis of functional outcomes

	SVW	TB	*P*
ISI	0.87 ± 0.16	0.76 ± 0.12	< 0.01
Patella Baja	25.6%(30)	52.1% (74)	< 0.01
ROM	124.0 ± 14.2	119.9 ± 12.4	0.017
Böstman score	25.1 ± 3.5	24.6 ± 3.6	0.33

Table 4 Postoperative complication rates stratified by fixation technique

	SVW	TB	Total
Deep Infection	0.9%(1)	1.4%(2)	1.2%(3)
Superficial infection	2.6%(3)	2.1%(3)	2.1%(5)
Faliure	0.9%(1)	1.4%(2)	1.7% (4)
Nonunion	0	1.4%(2)	0.8%(2)
Soft Tissue Irritation	0	8.8%(11)	4.5%(11)

Postoperative complications

The overall complication rate was 5.8% (14/242), predominantly attributed to surgical site infections (3.5%, 8/242), including superficial (1.2%, 3/242) and deep infections (2.1%, 5/242). Fixation failure requiring revision occurred in 1.2% (3/242) of cases, while bone nonunion was observed in 0.8% (2/242). Notably, soft tissue irritation was exclusively reported in the TB group (8.8%, 11/125), with no cases in the SVW group ($p = 0.005$) (Table 4).

This prospective cohort study systematically evaluated the clinical efficacy of the Separate Vertical Wire technique versus traditional tension band fixation in managing AO/OTA type A1 inferior pole patellar fractures. The results revealed significant advantages of SVW in preventing patella baja and improving knee function. Key findings included: (1) a 51% reduction in postoperative patella baja incidence in the SVW group compared to the TB group, with SVW identified as an independent protective factor ($OR = 0.23$); (2) significantly superior knee range of motion (ROM) in the SVW group (124.0°±14.2° vs. 119.9°±12.4°, $P = 0.017$), though no statistical difference was observed in Böstman functional scores between groups ($P = 0.33$). These findings support the biomechanical superiority of vertical fixation in counteracting inferior fragment migration, thereby optimizing patellofemoral kinematics [15, 18].

Discussion

Inferior pole patellar fractures involve fractures of the distal patellar segment, a rare yet complex injury. The inferior pole serves as a critical junction for transmitting quadriceps contraction forces to the tibial tubercle; its disruption compromises lower limb mechanical integrity [5]. Previous studies have highlighted a strong association between inferior pole fractures and patella baja, a focus of this investigation in postoperative AO/OTA A1 fractures.

The primary goal of surgical intervention for these fractures is to restore knee extensor mechanism integrity. Conventional TB fixation, relying on transverse wire loops to convert tensile forces into compression, often fails to address the biomechanical challenges of comminuted inferior pole fractures, leading to high rates of patella baja [18, 23]. In this study, the 42.9% overall incidence of patella baja underscores the limitations of TB constructs, which struggle to resist patellar tendon traction forces [14]. The SVW group demonstrated significantly higher Insall-Salvati index (ISI) values (0.87 vs. 0.76), likely attributable to its biomechanical design: vertical fixation via longitudinal bone tunnels generates perpendicular tensile forces that counteract fragment displacement. For comminuted fractures, traditional TB often requires supplemental suturing to stabilize fragments, which may induce early patellar tendon shortening and chronic inflammation. In contrast, SVW achieves stable fixation without additional sutures, mitigating these risks. The reduced patella baja incidence with SVW reflects its ability to address the mechanistic drivers of this complication, though further research is needed to fully elucidate these pathways.

Since its invention, the SVW technique has undergone several modifications and verifications, and it is considered a reliable fixation method for treating inferior pole fractures of the patella [24–26].

In this stud, despite comparable Böstman scores between groups, the clinically meaningful ROM improvement in the SVW group may reduce long-term patellofemoral arthritis risk [13]. However, the relationship between patella baja and osteoarthritis remains debated. While some studies implicate patella alta as a risk factor, others emphasize that patellofemoral joint mismatch and elevated contact pressure contribute to chondral degeneration [27–30]. Unfortunately, arthritis-related metrics were excluded here due to imaging interference from internal fixation. Additionally, while both groups followed identical rehabilitation protocols (6-week weight-bearing), SVW's inherent stability could theoretically permit earlier mobilization. Adherence to this protocol may explain SVW's functional advantages, suggesting potential for further optimization of postoperative rehabilitation [20].

Soft tissue irritation has long been a criticized complication of patellar tension band fixation. Protrusion of implants such as wires or Kirschner wires through the skin surface can directly irritate surrounding soft tissues, leading to pain and discomfort [31, 32]. A significant proportion of patients undergo implant removal after fracture healing, which not only increases physical distress but also imposes additional financial burdens [33–35]. Consequently, the development of novel and effective internal fixation strategies for patellar fractures has been

a key research focus. The SVW technique, which utilizes bone tunnels instead of K-wires and secures wires closely along the bone surface, minimizes wire micromotion. Previous studies suggest its potential to avoid high rates of soft tissue irritation [36, 37]. While our current SVW (Separate Vertical Wiring) technique employs metallic fixation, this approach inherently necessitates secondary hardware removal procedures. Recent advances in non-metallic fixation methods for patellar fractures have demonstrated promising clinical acceptance due to their biocompatibility advantages [38–40]. Building upon this technological evolution, future research directions should focus on adapting the biomechanical principles of SVW fixation using absorbable or composite materials, potentially eliminating the need for implant removal while maintaining fracture stabilization efficacy.

This study has several limitations: (1) The non-randomized design may introduce selection bias; (2) The mean follow-up duration of 25.7 months is insufficient to evaluate long-term complications, such as post-traumatic osteoarthritis; (3) The lack of biomechanical indicators (e.g., gait analysis or patellofemoral joint contact pressure) limits the in-depth exploration of the mechanisms underlying patella baja. Future research should focus on randomized controlled trials with extended follow-up periods and integrate imaging-based biomechanical modeling to clarify the causal relationship between patella baja and degenerative joint changes.

Conclusion

The SVW technique significantly reduces the risk of postoperative patella baja and improves knee range of motion by optimizing vertical tension distribution. It provides a more reliable fixation strategy for AO/OTA type A1 inferior pole patellar fractures. Supported by its biomechanical advantages and clinical efficacy, SVW should be considered as a first-line treatment option for these complex injuries.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-025-05899-6.

Supplementary Material 1

Author contributions

All authors contributed to the study's conception and design. Yanchun Gao and Yun Qian revised substantial contributions to the research design and revised the paper critically; Shichang Zhao acquired, analyzed, and interpreted data; Dehao Fu developed the surgical plan and revised the article. Xingang Yu approved the submitted and final versions. Yanchun Gao and SHichang Zhao contributed equally to this study. We All authors have read and approved the final submitted manuscript.

Funding

This work was funded by Shanghai Sixth People's Hospital Cultivation Project, YNHG202301.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethical approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Shanghai Sixth people's hospital. Informed consent was obtained from all individual participants included in the study. The authors affirm that human research participants provided informed consent for the publication of the images.

Consent to participate

Informed consent was obtained from all individual participants by phone call.

Consent to publish

All authors have agreed to the publication of the article.

Competing interests

The authors declare no competing interests.

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Received: 4 April 2025 / Accepted: 6 May 2025
Published online: 22 May 2025

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