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Locking compression plate as a sequential external fixator following the distraction phase for the treatment of tibial bone defects caused by fracture-related infection: experiences from 22 cases

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Abstract

Background The purpose of this study was to report the clinical and psychological outcomes of using a locking compression plate (LCP) as a sequential external fixator following the distraction phase in the treatment of tibial bone defects caused by fracture-related infection (FRI).

Methods We retrospectively analyzed the clinical records and consecutive X-ray images of patients with tibial bone defects who were treated with an LCP as a sequential external fixator following the distraction phase, between June 2017 and December 2022. The ASAMI criteria were applied to assess the bone and functional outcomes, and postoperative complications were evaluated by using the Paley classification. The SCL-90-R questionnaire was used to evaluate patients' psychological symptoms, documented and compared at Time 1 (before bone transport), Time 2 (after distraction phase), and Time 3(final follow-up). Statistical significance was set at $P < 0.05$.

Results This study included 22 participants with a mean age of 37.72 ± 9.65 years, comprising 17 males (77.2%) and 5 females (22.7%). The mean postoperative follow-up time was 29 ± 2.65 months. The mean number of previous surgical interventions per patient was 5.22 ± 1.26. Twenty-two patients with tibial bone defects caused by FRI were successfully treated using an LCP as a sequential external fixator following the distraction phase, with a mean bone union time of 9.95 ± 1.52 months. Bone union was achieved in all cases (100%) without the use of bone grafts at the docking sites. Following the completion of distraction, the Ilizarov apparatus or monorail fixator was retained for an additional 2.20 ± 0.53 weeks before being exchanged for the external locking compression plate (ELCP). The mean

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external fixation time (EFT) was 12.29 ± 1.67 months, with a mean external fixation index (EFI) of 1.83 ± 0.22 month/cm (Table 2). At the final follow-up, bone and functional outcomes were evaluated using the ASAMI criteria. Bone outcomes included 10 excellent and 12 good results, while functional outcomes included 12 excellent, 9 good, and 1 fair result. Statistically significant differences in psychological impacts were observed among the three time points (Time 1 vs. Time 2, $P = 0.034$; Time 2 vs. Time 3, $P = 0.020$; Time 1 vs. Time 3, $P = 0.012$). Complications were observed in 6 patients (27.2%), including joint stiffness ($n = 3$), pin-track infection ($n = 3$), and refracture ($n = 1$). All complications were successfully managed.

Conclusion LCP used as a sequential external fixator following the distraction phase is an effective method for treating massive tibial bone defects caused by FRI and is also suitable for patients with scars and poor tissue conditions resulting from multiple previous debridement. Furthermore, this combined technique could be more beneficial in alleviating psychological burdens, supporting patients' engagement in rehabilitation, and facilitating a return to normal life.

Clinical trial number Not applicable.

Keywords Tibia, Bone defect, Ilizarov bone transport, Locking compression plate, External fixation

Background

Massive tibial bone defects caused by direct trauma and fracture-related infections (FRI) remain a significant medical burden for public healthcare systems. The definition of massive bone defects in long bones is controversial [1]. Generally, massive bone defects are defined as those exceeding 2 to 2.5 times the diameter of the involved long bone or involving 50% of its circumference [2]. Hence, massive tibial bone defects usually necessitate surgical intervention with a multi-procedure treatment strategy, such as Ilizarov bone transport [3], Masquelet technique [4], and autogenous bone grafting [5]. Compared with the Masquelet technique and autologous bone grafting, Ilizarov bone transport has been reported to offer effective infection clearance, repair bone defects while correcting deformities, and provide a personalized treatment approach. However, the risks of complications and psychological burdens associated with prolonged external fixation times and the cumbersome appearance of the Ilizarov apparatus have also been widely recognized.

Patients with tibial bone defects caused by FRI, who were treated with the Ilizarov bone transport technique, often face numerous challenges including extensive soft tissue scars and fragile psychological conditions caused by multiple previous surgical interventions [6]. To address these issues, various treatment strategies have been proposed to reduce the external fixation time, including multi-level bone transport [7], bone transport combined with internal fixation (such as plates or intramedullary nails) [8, 9], and the use of a locking compression plate (LCP) as sequential external fixation following bone transport [10, 11]. Compared to multi-level bone transport and bone transport combined with internal fixation, employing an locking compression plate as a sequential external fixator has been noted for its advantages, including low-profile appearance, less surgical damage, fewer requirements for tissue coverage, and better facilitation of adjacent joint rehabilitation. However, there remains a lack of comprehensive analysis regarding the bone and functional outcomes, as well as the psychological well-being of patients using this technique.

Therefore, the purpose of this study was to report the clinical outcomes and psychological impact of using an LCP as a sequential external fixator following the distraction phase for the treatment of massive tibial bone defects caused by FRI.

Methods

This study was approved by our hospital's ethics committee, and informed consent was obtained from all participants. We retrospectively analyzed the clinical records and consecutive X-ray images of patients with tibial bone defects who were treated with an LCP as a sequential external fixator following the distraction phase, between June 2017 and December 2022. Inclusion criteria were tibial bone defects caused by FRI, previous surgical interventions > 4, sinus tracts, or abscesses of the affected limbs, treated with LCP as a sequential external fixator following the distraction phase. Exclusion criteria included patients under 18 years of age, tibial bone defects resulting from tumor resection or congenital limb discrepancies, incomplete medical records, poor compliance, and follow-up periods of less than 20 months.

Demographic data, details of the initial injury, previous treatments, antimicrobial use, and culture results of secretions were documented. Physical examination records included the assessment of knee and ankle range of motion (ROM) and the condition of the soft tissues. Inflammatory markers such as C-reactive protein (CRP), white blood cell (WBC) count, procalcitonin, and erythrocyte sedimentation rate (ESR) were recorded. The severity of bone infection was evaluated using Cierny and Mader's (CM) classification. All patients received appropriate intravenous antibiotics for 2 weeks preoperatively, according to the sensitivity profile of the identified bacteria.

Surgical technique

Stage 1

Bone transport surgery was performed using either the Ilizarov apparatus or a monorail fixator, depending on the specific case, once the patient's inflammatory markers returned to normal levels. Following the removal of the previous internal fixators, as detailed in our previous study [12], a radical debridement procedure was conducted. Subsequently, the Ilizarov apparatus or monorail fixator was positioned parallel to the axial force line along the tibia in an anteromedial orientation. Three 4.5 mm Schanz screws were placed in both the proximal and distal segments of the tibia, with two additional 4.5 mm Schanz screws were inserted into the transport bone segment. After assembling the external frame and slide clamp, a minimal osteotomy was performed invasively using a Gigli saw at the metaphysis to ensure adequate blood supply. Soft tissue defects were addressed through direct suturing with appropriate tension or the local advancement of flaps. The distraction phase was initiated at a rate of 0.5 mm every 12 h, beginning 7 to 10 days after the Stage 1 surgery. During this distraction phase, all patients were encouraged to begin early functional activities, and their load-bearing capacity was progressively increased from partial to full-weight bearing based on clinical and radiological assessments of bone healing. Bone regeneration in the distracted area was monitored radiographically every 2 weeks throughout the distraction phase.

Stage 2

Replacement of the Ilizarov apparatus or monorail fixator with an ELCP was conducted at 2 to 4 weeks following the completion of the distraction phase, once three-quarters of the cortical bone had formed in the distracted area. A femoral locking plate was utilized as a sequential external fixator and was positioned 3–5 cm above the skin. As determined by the preoperative screw fixation design, four or five 4.5-mm or 6.0-mm locking screws were inserted in the proximal and distal tibia respectively, and at least six locking screws perforated the bilateral cortex to stabilize the diaphysis. Following intraoperative fluoroscopic imaging in both planes to determine fixation position and stable screw placement, each screw was tightened sequentially.

Postoperative management

Bone regeneration in the distracted area was monitored radiographically monthly during the consolidation phase. Patients were instructed to follow a standardized pin tract care regimen during both the Ilizarov (or monorail) and ELCP fixation phases. This involved daily cleansing with an antiseptic solution, gentle removal of any debris, and application of sterile dressings. They were advised to remain alert for signs of infection such as redness, swelling, or discharge, and to report any concerns promptly. After the removal of the external fixator and placement of the ELCP, patients were initially encouraged to walk without weight-bearing, using a brace or crutches for 2 weeks, and subsequently to progress to full weight-bearing walking.

The clinical data were documented, including defect size (DS), bone union time (BUT), external fixation time (EFT), and external fixation index (EFI). EFT was defined as the sum of bone transport using Ilizarov apparatus or a unilateral monorail fixator and ELCP. EFI was defined as the ratio of EFT to DS. The ASAMI criteria were applied to assess the bone and functional outcomes, and postoperative complications were evaluated by the Paley classification [13]. The SCL-90-R questionnaire was used to evaluate the psychological symptoms of the patients [14, 15], documented and compared at Time 1 (before bone transport surgery), Time 2 (termination of distraction phase), and Time 3(final follow-up). According to the SCL-90-R, the total scores were divided by 90 to indicate the degrees of no symptoms (1 point) to very severe symptoms (5 points).

Statistical analysis

Data were analyzed using SPSS version 23.0 (Chicago, IL, USA). The Shapiro-Wilk test was employed to assess the normality of the data. Continuous variables were presented as means and standard deviations. The independent samples t-test or Mann-Whitney U test was used to compare differences between the two groups, depending on the data distribution. Statistical significance was set at $P<0.05$.

Results

This study included 22 participants with a mean age of 37.72±9.65 years, comprising 17 males (77.2%) and 5 females (22.7%, Table 1). The mean postoperative follow-up time was 29±2.65 months. The mechanisms of initial tibia fractures were as follows: vehicle accidents (59.1%), falls from height (18.1%), direct trauma (13.6%), and other causes (9.1%). According to the C&M classification, there were 15 cases of type III and 7 cases of type IV. The mean number of previous surgical interventions per patient was 5.22±1.26. Microbiological analysis presented positive results in 18 cases (81.8%), including Staphylococcus aureus in 14 cases (63.6%), Staphylococcus epidermidis in 3 patients (13.6%), and Escherichia coli in 3 patients (13.6%).

Table 1 Baseline data

Number	Gender/Age (years)	Etiology of bone defect	Previous surgery	DS (cm)	Time to exchange fixator (week)	Follow-up time (month)
1	M/62	PTO	5	6.6	1.8	28
2	M/36	PTO	4	7	2.1	26.5
3	M/48	PTO	4	6.3	1.7	27.7
4	M/47	PTO	6	6.8	2.1	28.8
5	M/32	PTO	4	6.8	1.8	31.4
6	F/45	PTO	4	6.5	2	29.3
7	M/24	PTO	5	6.7	2.1	29.5
8	M/42	PTO	6	6.5	3.9	28.3
9	M/23	PTO	5	6.7	2.2	33.3
10	F/53	PTO	6	7.1	3.2	30.7
11	F/38	PTO	4	7	2.9	32
12	M/32	PTO	7	6.7	1.8	26.8
13	F/27	PTO	9	6.6	1.9	26.9
14	M/39	PTO	6	7.2	2	26
15	M/34	PTO	4	6.8	2.5	25.5
16	M/46	PTO	5	6.9	1.9	34
17	M/41	PTO	5	6.5	2.1	31.1
18	M/29	PTO	6	6.5	2.1	27
19	F/34	PTO	4	6.1	1.7	26
20	M/35	PTO	6	7.1	2.2	25.6
21	M/29	PTO	6	6.4	2.6	32.7
22	M/34	PTO	4	6.7	2.2	31

BUT, bone union time; DS, defect size; F, female; M, Male; PTO, post-traumatic osteomyelitis

Twenty-two patients with massive tibial bone defects caused by FRI were successfully treated using an LCP as a sequential external fixator following the distraction phase, with a mean bone union time of 9.95±1.52 months. The mean DS was 6.7±0.27 cm, and the bone union was achieved in all cases (100%). The mean time to exchange the fixator was 2.20±0.53 weeks. The mean EFT was 12.29±1.67 months, with a mean EFI of 1.83±0.22 month/cm (Table 2). At the final follow-up, the ASAMI criteria were used to evaluate bone and functional outcomes. For bone results, there were 10 cases rated as excellent and 12 cases rated as good. For functional outcomes, there were 12 cases rated as excellent, 9 cases as good, and 1 case as fair. For psychological impacts, there were statistical differences were observed among three time points (Time 1 vs. Time 2, $P=0.034$; Time 2 vs. Time 3, $P=0.020$; Time 1 vs. Time 3, $P=0.012$, Table 3). Typical cases were illustrated in Figs. 1 and 2.

According to Paley's classification, complications were observed in 6 patients (27.2%). Pin tract infection occurred in 2 patients (9%) and was managed with dressing changes and oral antibiotics. Adjacent joint stiffness was noted in 3 patients (13.6%) and improved with physical rehabilitation. Additionally, one case (4.5%) experienced a re-fracture in the distraction area due to a secondary injury, which was successfully treated with open reduction and internal fixation.

Discussion

The Ilizarov technique has proven to be effective in the treatment of massive tibial bone defects, offering adequate skeletal stability and satisfactory bone healing. Ilizarov circular external fixators and Orthofix unilateral monorail external fixators are highly versatile and reproducible, providing a stable platform for bone regeneration and soft tissue reconstruction. However, a major drawback of the Ilizarov technique is the prolonged treatment duration and the associated risk of complications, which can be uncomfortable and inconvenient for patients. In this study, twenty-two massive tibial bone defects caused by FRI were successfully treated with an LCP as a sequential external fixator following the distraction phase. These findings indicate that this combined technique is as effective as the bone transport using a unilateral external fixator. Importantly, it is also advisable to replace the LCP with its low-profile configuration 2 to 4 weeks following the termination of the distraction phase. During the distraction phase, regenerated bone in the distraction area gradually formed and mineralized. Allowing a 2 to 4-week interval after the distraction phase might promote further mineralization of the regenerated bone in both the distraction area and the docking site. This approach could help reduce the risk of refractures in these areas during the Stage 2 procedure.

Table 2 Clinical data

Number	EFT (month)	EFI (month/cm)	BUT (month)	Complication	Additional procedure	Outcome
1	9.5	1.44	8.3	-	-	Union
2	12	1.71	9.8	JS	physical rehabilitation	Union
3	9.6	1.52	7.7	-	-	Union
4	12.6	1.85	10.7	JS	physical rehabilitation	Union
5	14	2.06	12.1	PTI	dressing change	Union
6	13	2.00	11.3	-	-	Union
7	15	2.24	13.8	-	-	Union
8	13.2	2.03	10.3	JS, PTI	physical rehabilitation, dressing change	Union
9	10	1.49	8.9	-	-	Union
10	13	1.83	10.9	-	-	Union
11	63.5	9.07	10	Refracture	revision surgery	Union
12	13.6	2.03	10.4	-	-	Union
13	13.4	2.03	10.3	-	-	Union
14	13	1.81	9.7	-	-	Union
15	14	2.06	10.7	-	-	Union
16	13	1.88	10.5	-	-	Union
17	13.6	2.09	10.2	PTI	dressing change	Union
18	11	1.69	9.3	-	-	Union
19	10.7	1.75	7.8	-	-	Union
20	13	1.83	10.9	-	-	Union
21	9.6	1.50	7.8	-	-	Union
22	10.2	1.52	7.7	-	-	Union

EFI, external fixation index; EFT, external fixation time; JS, joint stiffness; PTI, pin tract infection

Table 3 SCL-90-R scores of different times

	Time 1	Time 2	Time 3
Total scores	1.72 ± 0.34	1.42 ± 0.2	1.28 ± 0.12
Comparison	Time 1 vs. Time 2 $P = 0.034$	Time 2 vs. Time 3 $P = 0.020$	Time 1 vs. Time 3 $P = 0.012$

Patients with massive tibial defects caused by FRI often present with significant soft tissue scars and sinus on the affected limb due to previous surgical interventions. This scarring poses a considerable challenge and increases the risk of complications if internal fixation as a sequential fixator following the distraction phase of bone transport, as there is a heightened risk of exposure to the internal fixation plate or screws. In such cases, flap transfer may be necessary to improve soft tissue coverage and mitigate the risk of complications such as skin necrosis and exposure to internal fixation. Compared to internal fixation, the sequential external fixator with LCP may offer several advantages, including reduced surgical damage, fewer demands for soft tissue coverage, and better preservation of the periosteum. Kerkhoffs et al. [16] reported 31 patients with infectious nonunion or open fractures

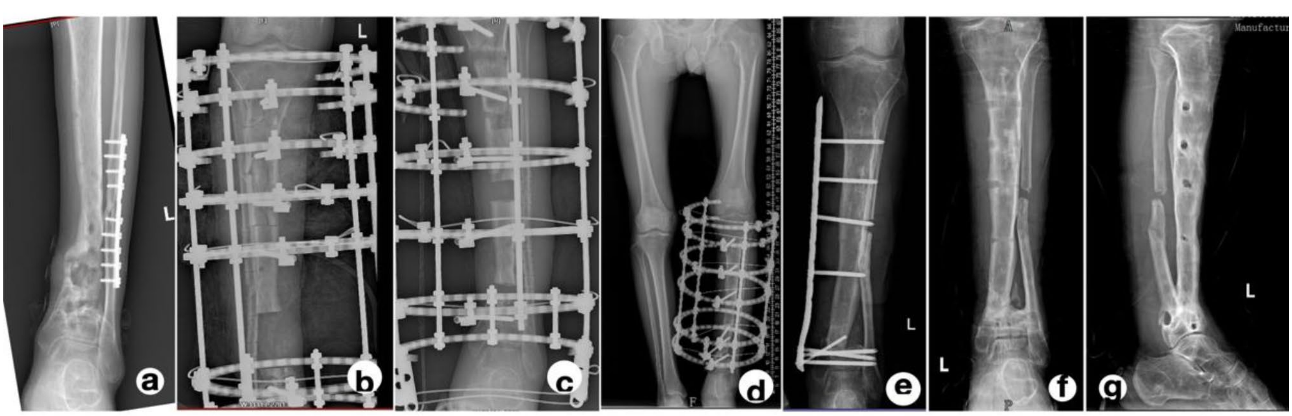

Fig. 1 A 62-year-old male with a left tibial bone defect caused by FRI was treated with an LCP as a sequential external fixator following the distraction phase. (**a**) X-ray of left tibia before Ilizarov bone transport surgery. (**b**) Postoperative X-ray of the left tibia showed that DS after debridement was almost 6.6 cm. (**c**) X-ray of distraction phase. (**d**) The termination of the distraction phase and docking site was connected in the 10th postoperative week. (**e**) LCP as a sequential external fixator following the distraction phase, with an interval of 1.8 weeks. (**f**, **g**) Satisfactory bone result after 8.3 postoperative months

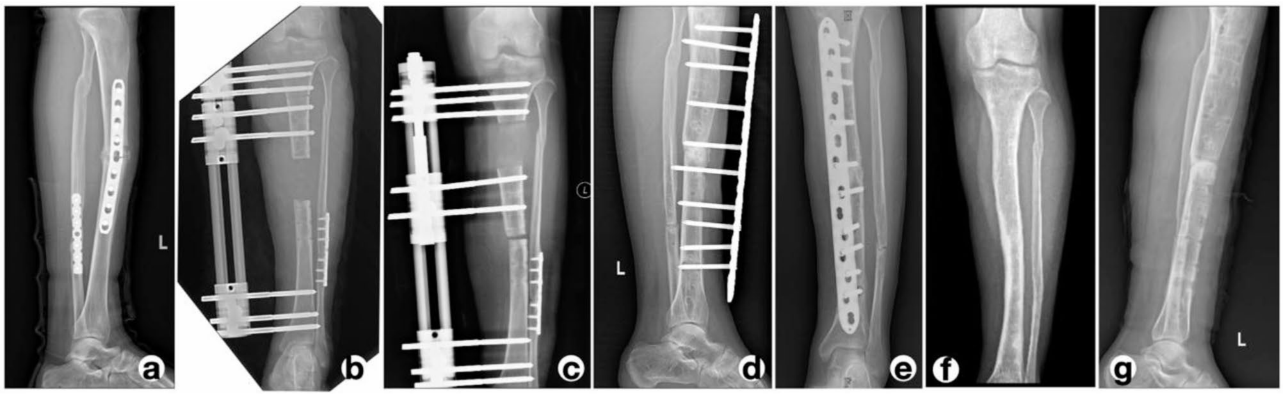

Fig. 2 A 42-year-old male with a left tibial bone defect caused by FRI was managed by an LCP as a sequential external fixator following the distraction phase. (**a**) X-ray of left tibia before Ilizarov bone transport surgery. (**b**) DS after radical debridement was approximately 6.5 cm. (**c**) The termination of the distraction phase and docking site was connected in the 9th postoperative week. (**d**, **e**) LCP as a sequential external fixator following the distraction phase, with an interval of 3.9 weeks. (**f**, **g**) Satisfactory bone result after 10.3 postoperative months

successfully treated by AO plates as external fixators. Janssen et al. [10] reported a series of 14 patients (88%) successfully treated by supercutaneous locking compression plate without major complications. Ma et al. [11] conducted a prospective study on 15 patients with open proximal tibial fractures treated with less invasive stabilization system plates as external fixators and found that this technique could achieve stable fixation and high healing rates. In our cohort, we used LCP as a sequential external fixator following the distraction phase for definitive external fixation via minimally invasive percutaneous osteosynthesis. Twenty-two massive tibial bone defects (100%) received satisfactory bone and functional outcomes, with a mean bone union time of 9.95 ± 1.52 months.

Published studies [17–20] have reported that LCP showed superior longitudinal compressive resistance, as well as enhanced axial and torsional stability compared to conventional external fixators. The biomechanics of the locking plate differ from those of traditional compression plates; specifically, the stable connection between the locking screw and the plate is not reliant on friction between the plate and the bone [21, 22]. Compared to unilateral external fixators, locking plates are characterized as multifunctional, low-profile, and well-tolerated by patients for the treatment of nonunions caused by FRI. Additionally, LCP is designed to stabilize short metaphyseal segments, and the numerous metaphyseal screw holes allow for flexible placement based on the distraction area. However, attention must be given to stress concentration and occlusion to avoid bone resorption or fracture at the distraction area, when using LCP as a sequential fixation device. In this cohort, all tibial defects were exceeding 6 cm. Consequently, a femoral LCP was chosen to provide a longer moment arm for reliable fixation of the distraction area. A previous study [22] recommended placing 4 to 5 screws in both the proximal and distal tibia, with a plate-screw density of less than 0.5. Furthermore, a specifically designed LCP, intended for use as a sequential external fixator for massive tibial bone defects, is urgently needed to optimize this combined technique.

The EFT required for Ilizarov bone transport often impacts both the physical and mental well-being of patients, a frequently overlooked factor. Mitigating the adverse psychological effects associated with long-term EFT is crucial for the successful reconstruction of massive tibial defects caused by FRI. Yildiz et al. [23] assessed psychological distress using the SCL-90-R questionnaire in 40 patients treated with a circular external fixator and found that psychiatric issues developed during treatment, highlighting the need for careful monitoring of patients' mental health. Similarly, Jia et al. [24] evaluated the psychological distress of 96 patients with distal radius fractures who underwent surgical treatment and found that external fixation significantly affected anxiety and depression in the early postoperative period. Consistent with these findings, patients assessed in this study demonstrated a decreasing trend in the total SCL-90-R score at three different time points. This improvement might be attributed to the effectiveness of Ilizarov bone transport in the reconstruction of bone defects. Additionally, the use of LCP as a sequential external fixator appeared to be more beneficial in alleviating psychological burdens, supporting patients' engagement in rehabilitation, and facilitating a return to normal life.

Several potential limitations existed in this study. First, this study was conducted retrospectively with a small sample size. Secondly, there was no unified algorithm for the management of massive tibial bone defects caused by FRI. Thirdly, there was a lack of comparison with the bone and functional results of other treatment methods. Thus, a prospective multi-center study with a large sample size was still crucial for the clinical application of LCP as a sequential external fixator following the distraction phase of Ilizarov bone transport.

Conclusion

LCP used as a sequential external fixator following the distraction phase proved to be an effective method for the treatment of massive tibial bone defects caused by FRI, and was particularly suitable for patients with scars and poor tissue conditions resulting from multiple previous debridement. A 2 to 4-week interval after the distraction phase could help reduce the risk of re-fractures in both the distraction area and the docking site. This combined technique could be more beneficial in alleviating psychological burdens, supporting patients' engagement in rehabilitation, and facilitating a return to normal life.

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Author contributions
XK, KL, AK and AY developed the research questions and scope of the study. XK and YH conducted preoperative and postoperative data screening and data charting. XK drafted the manuscript and prepared tables, and figures with SLW's contribution. XK, XY and AS developed the literature search strategies in collaboration with the other authors. XK, AK and AY contributed to the organization, analysis, and interpretation of the results. All authors read and approved the final manuscript.

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Data availability
The data sets generated and analyzed during the current study are not publicly available due to restrictions on ethical approvals involving patient data and anonymity but can be obtained from the corresponding author as reasonably required.

Declarations

Ethics approval and consent to participate
This retrospective study was approved by the Ethics Committee of the First Affiliated Hospital of Xinjiang Medical University and carried out by the ethical standards set out in the Helsinki Declaration. Informed consent was received from all participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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