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Locked plating as an external fixator in treating tibial fractures

A PRISMA-compliant systematic review

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Abstract

Objectives: This article is a systematic review of the published literature about the biomechanics, functional outcomes, and complications of a locked plate as an external fixator in treating tibial fractures.

Methods: We searched the PubMed, Ovid Medline, Embase, ScienceDirect, and Cochrane Library databases to retrieve the relevant studies. Studies published in English and Chinese which assessed adult patients and more than 4 cases who had sustained any type of fresh tibial fracture treated with the external locking plate, provided that they reported functional outcomes, range of motion (ROM), union or complication rates, and the biomechanical studies of external locked plating are also included.

Results: The electronic search strategy revealed 248 studies, and 2 studies were identified as relevant through manual search of references. Finally, 12 studies were included in this systematic review. These consist of 3 pure biomechanical studies, 8 case series, and 1 study including both of biomechanics and case series. Due to the heterogeneity of biomechanical studies, we can only conclude that external locked plate shows inferior structural stiffness than internal locked plate. The clinical studies reported that external locked plating gave a satisfactory ROM of the knee and ankle, functional outcomes, union rate, and low complication rate.

Conclusions: We can only conclude that external locked plate shows inferior structural stiffness than internal locked plate because of the heterogeneity of biomechanical studies. The clinical studies showed locked plating as an external fixator in treating tibial fractures can be considered as a safe and successful procedure. However, as yet, there is unconvincing evidence that it is superior to standard techniques with regards to clinical and functional outcomes. More and well-designed studies about this technique should be carried out.

Abbreviations: AO/OTA = AO Foundation and Orthopaedic Trauma Association, AOFAS = American Orthopaedic Foot and Ankle Society, EF = external fixation, ELPF = external locked – fixation, HSS = hospital for special surgery, ILPF = internal locked plate fixation, LCP = locked compression plate, LISS = less invasive stabilization system, MIPPO = minimally invasive percutaneous plate osteosynthesis, ORIF = open reduction and internal fixation, PRISMA = preferred reporting items for systematic reviews and meta-analysis, ROM = range of motion.

Keywords: external fixator, fracture fixation, locked plating, tibia

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1. Introduction

Tibial fractures are the most common fracture of long bones. These injuries result from high-energy trauma, such as fall from height and car accidents; the latter are a major cause of fractures and lead to disability, with high socioeconomic costs.[1] Proximal and distal tibial fractures with a compromised soft tissue envelop still pose a treatment dilemma or challenge for the orthopedic surgeon.[2–4] Treatment methods include conservative management, internal fixation, and the use of external fixation devices. Nonoperative management may require a long period of immobilization in a cast. It not only can lead to discomfort of the patient but also fracture displacement during healing. Open reduction and internal fixation (ORIF) often requires extensive soft tissue disruption, which may be associated with complications such as soft tissue damage and infection and nounion.[5,6] Minimally invasive percutaneous plate osteosynthesis (MIPPO) minimizes the soft tissue trauma to the injured zone. It preserves a better blood supply around the fracture area; thus rapid fracture healing can be achieved theoretically.[7] However, the precontoured and angular stable plates may be prominent under the skin may and potentially cause soft tissue complications such as secondary skin necrosis.[7,8] Intramedullary nailing can provide rigid stability in diaphyseal fractures of the tibia. It is beneficial to maintain appropriate length rotation and alignment consequently.[9] But antegrade intramedullary nailing is a technically challenging procedure because of the hourglass shape of the medullary canal at the metaphysis of the distal tibia. Additionally, intramedullary nailing for the tibial fractures has a higher incidence of malalignment, implant failure, and anterior knee pain.[10] External fixation has seen renewal in modern trauma management as a temporary fixator or definitive treatment for the high-energy tibial injury, especially for open fractures. Nevertheless, most external fixators for the lower extremities are bulky and cumbersome for the patients, leading to problems with sleeping and dressing.[11] External fixators sometimes can even interfere with the contralateral extremity during walking. Also, fixation with a joint-spanning external fixator may result in joint stiffness and leg muscle atrophy.

Kerkhoffs et al firstly described that they used a locked compression plate (LCP) as an external fixation for treating open fractures, inferior non-union, and arthritis,[12] and Kloen et al called this method as a "supercutaneous plating technique."[13] LCPs have advantages of angular stability from the locking-head mechanism and less irritation when compared with traditional external fixators due to their low profiles. However, the application of supercutaneous plating technique is still not generally acknowledged. Recently, many authors[3,14–21] reported the good clinical results of using external locked plating for treating tibial fractures. Thus, we systematically reviewed the published literature on the biomechanics, outcomes, and complications of the locking plate used as an external fixator to treat fractures of the tibia.

2. Materials and methods

2.1. Search strategy

This systematic review of the literature was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement,[22] and the register number in PROSPERO is CDR42017058829. Comprehensive databases including PubMed, Ovid Medline, Embase, Sciencedirect, and Cochrane Library have been used to identify the relevant studies published up to February 23, 2017. The following search terms were employed: "supercutaneous plating," "supercutaneous technique," "locking plate," "locking compress plate," "LCP," "external fixation," "external fixator," "tibia," and "tibial fracture." The search string utilized in PubMed was as follows: (((((((external fixation) OR external fixator)) AND (((((locking plate) OR locking compression plate) OR LCP) OR locked plate) OR locked compression plate))) OR ((ssupercutaneous plating) OR supercutaneous technique))) AND ((tibia) OR tibial fracture). We also manually searched the references of selective articles to identify additional potentially relevant studies. This study was approved by the ethics committee of The Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University.

2.2. Selection criteria

We included all studies published in English and Chinese which assessed adult patients who had sustained any type of fresh tibial fracture treated with the external locking plate, provided that they reported functional outcome, range of motion (ROM), union, or complication rates. The biomechanical studies of external locked plating are also included. With regards to the articles written by the same authors or departments are treated with caution because the patients may overlap among these articles. Only the latest published study was selected if any overlapping patients may exist among the articles. Exclusive criteria were as follows: (1) case reports with 4 or fewer patients were excluded due to low scientific effect; (2) duplicate studies; (3) reviews, letters, and comments; (4) studies exclusively focused on children; and (5) full-text articles that could not be obtained.

2.3. Data extraction and quality assessment

Two independent reviewers (DX and PL) screened the titles and abstracts. Studies meeting the selection criteria were retrieved for full-text evaluation. Any discrepancy was resolved by consensus. Remnant studies were assessed according to the Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence. The data including first author's name, publication year, level of evidence, sample size, and data in terms of clinical features and outcomes were extracted from each included study in standardized forms using Microsoft Excel. Data on clinical outcomes and complications were extracted from each study so that pooled results could be reported, but formal data synthesis was not possible due to the heterogeneity of the studies.

3. Results

3.1. Selection of the studies

A total of 248 studies were found through the electronic searching engines, and 2 studies were identified as relevant through manual search of references. Finally, 12 studies[3,14–21,23–25] were included in this systematic review. These consist of 3 pure biomechanical studies,[23–25] 8 case series,[3,14,16–21] and 1 study including both of biomechanics and case series.[15] The overall population included 254 patients (112 cases of closed fractures), with 167 males and 87 females. The mean age was 41.7 years, and mean follow-up was 20.05 months (5–38). The study selection process is shown in Fig. 1. The details of clinical studies were summarized in Tables 1–3.

3.2. Biomechanical studies

Four studies[15,23–25] evaluated the use of the locking plate in a model of a fracture of the tibia. Kanchanomai and Phiphobmongkol[23] evaluated the effects of different fracture gap sizes (1, 5, and 10 mm) on the stability and endurance of fractured tibia externally fixed with a fourteen holes broad LCP (30-mm plate-bone distances). Results showed the stiffness of 1 mm fracture gap group (stable fractured tibia) was similar to that of the intact tibia. Whereas the stiffness of 5 and 10 mm fracture gap groups was significantly lower than those of intact tibia and tibia with 1-mm fracture gap. Thus, partial weight bearing for stable fractured patients is possible, but should be considered carefully in the early phase of treatment for unstable tibial shaft fracture situation. Zhang et al[25] presented a finite element analysis by utilizing the contralateral femoral less invasive stabilization system plate in distal tibial facture. The plate was placed on the anteromedial of tibia with different distances between plate and bone: 1, 10, 20, and 30 mm. They found the stiffness of construct in all groups were higher than intact tibia under single axial load, and the stiffness of construct with 1 and 10-mm plate-bone distances were similar to that of an intact tibia, which was higher than that of 20 and 30-mm plate-bone distances under axial load

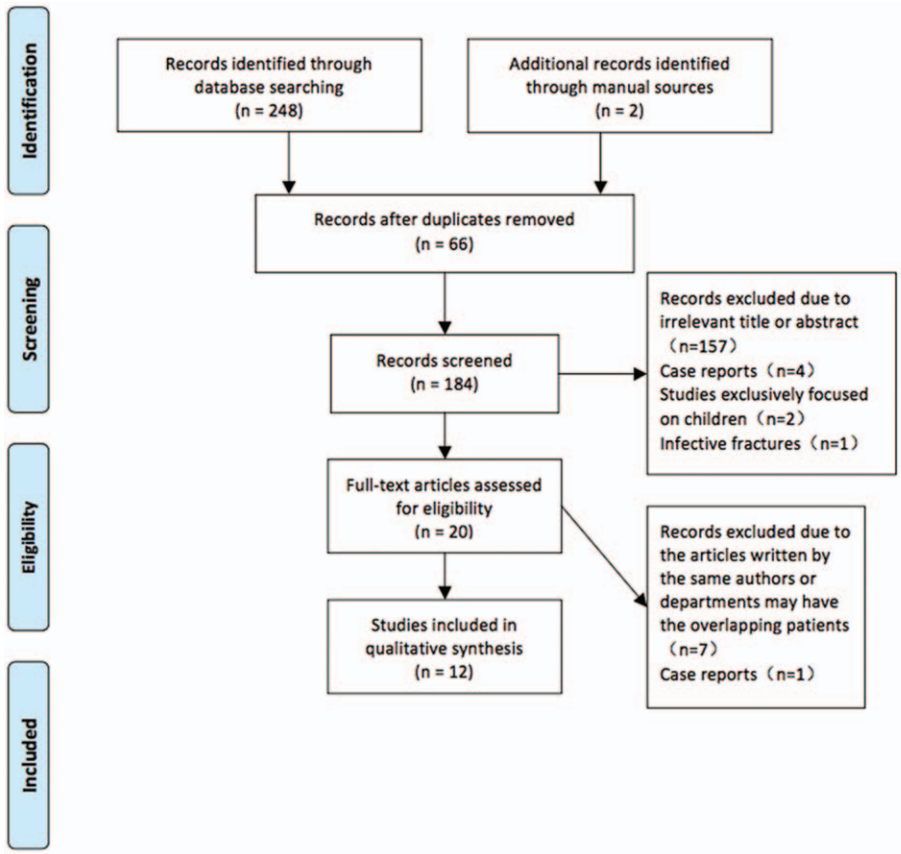

Figure 1. The flow diagram for study selection process.

with an internal rotational force. However, the stiffness of the construct in all groups was lower than that of an intact tibia under axial load combined with an external rotational force. Thus, they suggested the plate-bone distance should be less than 30 mm to guarantee a stable external plate fixation in the distal tibial fracture. Liu et al[24] compared 3 different configurations in fixing distal tibia fracture: medial distal tibial locking compression plates (LCP group), medial distal tibial locking compression

Table 1

Summary of the demographic characteristics of clinical studies included (n=9).

Study	Level of evidence	Number of patients (closed fracture)	Follow-up time (mos)	1 or 2 stage	Type of fracture AO/OTA type	Soft tissue injury
Ma et al, 2011[16]	IV	25 (3)	32 (20–44)	2	Segmental fracture 42-C2: 25	Gustilo classification for open fractures (22): II:3; III-A: 6; III-B:10; III-C: 3
Qiu et al, 2014[3]	IV	12 (3)	33 (24–44)	1	41-A: 1; 41-B: 1; 41-C: 1; 42-B: 2; 42-C: 5; 43-C: 2; 44-C: 2	Gustilo classification for open fractures (9): IIIA: 6; II:33. AO/ASIF soft tissue injury classification for closed fractures (3): IC4: 2; IC5: 1
Wu et al, 2013[18]	III	36	15.2 (9–28)	1	A: 9; B:19; C:8	Gustilo classification: II: 21; III: 15
Mei et al, 2014[17]	IV	18 (12)	11 (6–15)	1	A:4; B:11; C:3	Gustilo classification for open fractures (6): I: 2; II: 3; III: 1
Lian and Huang, 2015[14]	III	25 (25)	16.08±2.96	1	42-A:9; B:13; C:3	—
Zhang et al, 2015[19]	IV	35 (25)	18 (13–22)	1	41-A2:18; 41-A3:17	Gustilo classification for open fractures (10): I: 3; II: 4; III-A: 3
Zhou et al, 2015[21]	IV	23 (23)	19.6 (5 to 38)	1	42-A1: 2; 42-A3: 1; 42-B1: 4; 42-B3:2; 42-C1: 2; 42-C2: 2; 43-A1: 2; 43-A2: 3; 43-A3: 1; 43-B2: 1; 43-C1: 2; 43-C2: 1	AO/ASIF soft tissue injury classification CI: 4; CII: 15; CIII: 4
Ma et al, 2017[15]	IV	52 (54 open fracture)	38	1	41-A: 2; 41-B: 4; 41-C: 6; 42-A: 2; 42-B: 5; 42-C: 19; 43-A: 8; 43-C: 8	Gustilo classification for open fractures (54): IIIA: 20; IIIB: 23; IIIC: 2
Zhang et al, 2016[20]	IV	28 (21)	16.2 (12–21)	1	43-A1: 9; 43-A2: 9; 43-A3: 10	Gustilo classification for open fractures (7): I: 2; II: 3; IIIA: 2

Table 2

Summary of the outcome of clinical studies included (n=9).

Study	Time to definitive fixation (d or h)	Operation time (min)	Time for union (wks)	Union rate (%)	Function outcomes
Ma et al, 2011[16]	6–12wks	—	Proximal fracture: 23 (12–30); distal fracture: 27 (12–46)	100	Final mean ROM: Knee:0–145°; ankle: 0–35°; Functional outcomes*: Excellent: 21; good: 4
Qiu et al, 2014[3]	10 d (5–18 d)	—	37.8 (20–56); proximal, distal, and shaft fracture: 21.2, 23.5, and 48.1, respectively	100	Final mean ROM: knee: extension 0 to flexion 135°; ankle: dorsi flexion 12° to plantar flexion 32° Functional outcomes*: All were excellent or good
Wu et al, 2013[18]	3 h (1–8 h)	—	23.0±5.5	100	ROM of knee: At removing external fixation/last follow-up: 104.3°±21.1°/115.3°±13.3°; ROM of ankle: At removing external fixation/last follow-up: 51.4°± 6.5°/55.0°±7.8°
Mei et al, 2014[17]	8 h (2–72 h) in 8 elective patients; others were fixed urgently	52.2 (38–84)	—	100	Johner-Wruhs criteria: Excellent: 10; good: 6; fair: 2; poor: 0 Excellent and good rate: 89%
Lian and Huang, 2015[14]	2.76 d (1–5 d)	63.88±10.59	16.12±5.33	96	Johner-Wruhs criteria: Excellent: 15; good: 8; fair: 1; poor: 1 Excellent and good rate: 92%
Zhang et al, 2015[19]	3 d (2–7 d) in closed fracture; others were fixed urgently	32 (20–65) in closed fracture	14 (10–20)	100	Mean HSS score 4 wks/final: 91 (85–100) and 98 (93–100); Mean AOFAS score 4 wks/final: 94 (90–100) and 98 (95–100)
Zhou et al, 2015[21]	20 patients within 24 h; 3 patients (3–14 d)	—	29.4 (14–52)	95.7	—
Ma et al, 2017[15]	—	—	34	100	Mean ROM: Knee (extension-flexion):1° (0–7°) to 141° (85°–145°) Ankle (dorsiflexion-plantar flexion):8° (0–20°) to 35° (0–50°) HSS score: 4 wks/final: 85 (81–100)/94 (88–100) AOFAS: 4 wks/final:88 (80–100)/96 (90–100)
Zhang et al, 2016[20]	3 d (2–5 d) in closed fracture; others were fixed urgently	38 (25–60) in closed fracture	16.7 (12–24) A1 fracture: 14.6±2.67; A2 fracture: 17.5±3.66; A3 fracture: 18.4±3.37	100	Final AOFAS score: 93 (88–100)

* Functional results were based on five criteria: Presence of a limp; Stiffness of the knee or the ankle; Pain; Soft-tissue sympathetic dysfunction; Inability to perform previous activities of daily living. Excellent result: absence of all of the five outcomes; Good result: presence of one of the outcome criteria; Fair result: presence of two of the outcome criteria; Poor result: presence of three or more of the five criteria.
AOFAS=American Orthopaedic Foot and Ankle Society ankle score, HSS score=The Hospital for Special Surgery (HHS) knee score, ROM=Range of motion.

plates with 30-mm plate-bone distances (EF-tibia group), and medial distal femur locking compression plates with 30-mm plate-bone distances (EF-femur group). As they reported, the mean compression stiffness in EF-tibia and EF-femur groups was 14.07% and 47.43% of that in LCP group, respectively. The mean torsional rigidity in EF-femur and EF-tibia groups was 144.66% and 38.25% of that in LCP group, respectively. Ma et al[15] made a comparison among 3 different fixations in proximal tibial fracture: internal locked plate fixation with proximal tibia LISS plate (ILPF group), external locked plate fixation with distal femur LISS plates (ELPF group), and conventional external fixation (EF group), and the distance of the longitudinal connecting bar from the bone was 6 cm in the latter 2 groups. Based on the testing results, the ILPF group had the highest axial stiffness 347.06±17.06 N/mm (P=.002), the ELPF group was stiffer than the EF group (66.75±7.95 and 22.80±2.10 N/mm, respectively). No significant difference was observed in the regard of the torsional stiffness of ILPF, ELPF, and EF group (1.17±0.05, 1.15±0.02, and 1.00±0.11 Nm/degree, respectively; P=.068).

Table 3

Summary of the complications of clinical studies included (n=9).

Study	Complications	Complication rate (%)
Ma et al, 2011[16]	Pin track infection: 3; delayed union: 3; malunion (>5°): 2; shortening (>1 cm): 2	40
Qiu et al, 2014[3]	Pin tract infection: 1	8.3
Wu et al, 2013[18]	Superficial infection: 3; deep infection: 1; deep vein thrombosis: 5; delayed union: 5	31
Mei et al, 2014[17]	Skin necrosis: 2 (1 case occurred bone exposure); pin infection:1; delayed union: 2	28
Lian and Huang, 2015[14]	Ununion: 1; plating broken: 1; pin infection: 1	12
Zhang et al, 2015[19]	Superficial effusion: 2	5.7
Zhou et al, 2015[21]	Pin tract infection: 2	9.7
Ma et al, 2017[15]	Pin tract infection: 7; malunion (>5°): 2; shortening (>1 cm): 2; Screw loosening: 6 screws in 5 cases; screw broken: 4 screws in 3 cases	37
Zhang et al, 2016[20]	Local superficial pin site effusion: 3	10.7

Table 4

Johner-Wruhs criteria.

	Excellent (Left=Right)	Good	Fair	Poor
Nonunion, osteitis, amputation	None	None	None	Yes
Neurovascular disturbances	None	Minimal	Moderate	Severe
Deformity				
Varus/valgus	None	2°–5°	6°–10°	>10°
Anteversion/recurvation	0°–5°	6°–10°	11°–20°	>20°
Rotation	0°–5°	6°–10°	11°–20°	>20°
Shortening, mm	0–5	6–10	11–20	>20
Mobility				
Knee	Normal	>80%	>75%	<75%
Ankle	Normal	>75%	>50%	<50%
Subtalar joint	>75%	>50%	<50%	
Pain	None	Occasional	Moderate	Severe
Gait	Normal	Normal	Insignificant limp	Significant limp
Strenuous activities	Possible	Limited	Severely limited	Impossible

3.3. One stage or 2-stage

Eight of the studies used the external locking plate as a definite treatment in 1 stage.[3,14,15,17–21] The mean time to operation in open fracture reported by Wu et al[18] was 3.5 hours, and ranged from 0.5 to 9 hours. The time to perform the definitive operation for closed fractures ranging from less than 1 to 14 days.[14,19–21] Qiu et al[3] reported that patients with open fractures were performed thorough debridement, and the wounds were closed. Skeletal traction was used in some patients to prevent further injury to the soft tissues. Finally, locking plates were applied on the patients as definitive external fixators until loss of swelling. The time between injury (admission) and definitive surgery was 10 days (5–18 days). Ma et al[16] utilized the locking plate as a temporarily external fixation for the first stage. The second stage involved definitive internal fixation with a locking plate using a minimally invasive percutaneous plate osteosynthesis technique. The time between the 2-stage operations ranged from 6 to 12 weeks, depending on the condition of the soft tissue and the patient.

3.4. Function outcomes

The function outcome measures reported in studies were different, which makes comparison difficult. Two studies[15,19] measured the Hospital for Special Surgery (HSS) knee scoring system to evaluate the function of the knee (87patients with 89 fractures). The mean HHS knee score was 87 (81–100) at 4 weeks postoperatively and 96 (88–100) at final follow-up, which reflected the satisfactory condition of the knee joint. American Orthopaedic Foot and Ankle Society (AOFAS) ankle score was measured in 3 studies.[15,19,20] The mean AOFAS ankle score pooled by Ma et al[15] and Zhang et al[19] was 90 (80–100) at 4 weeks postoperatively and 97 (90–100) at final follow-up (87 psatients with 89 fractures). The results showed the functional recovery of knee and ankle joint was satisfactory. Zhang et al[20] treated 28 patients with distal tibial fractures by using external locking plate. By the end of the follow-up, the mean AOFAS score was 96.11±2.32, 92.67±1.80, and 92.00±2.06 ($P>.05$) in AO/OTA 43-A1, 43-A2, and 43-A3-type fractures, respectively. No significant difference was observed in AOFAS between the different groups related to age, sex, and type of fractures ($P>.05$).

Ma et al[16] reported the functional outcomes of 25 patients treated by 2 stages: locking plate was adopted as a temporarily external fixator then using internal locking plate as a definitive treatment. The criteria included 5 aspects: presence of a limp, stiffness of the knee or the ankle, pain, soft-tissue sympathetic dysfunction, and the inability to perform previous activities of daily living (Table 2). The results showed 21 patients were excellent and 4 patients were good. Qiu et al[3] used the same criteria to assessed the functional outcomes of 12 patients with compromised soft tissue envelop utilizing external locking plate; all of these patients had excellent or good functional results.

A total of 2 studies measured the Johner-Wruhs criteria (Table 4).[14,17] Mei et al[17] reported the excellent and good rate was 89% according to Johner-Wruhs criteria: excellent in 10, good in 6, fair in 2, and poor in 0. The excellent and good rates were 92.00% showed by Lian and Huang.[14] There was no significant difference compared among external fixation group, intramedullary nail group, and minimally invasive locking plate group.

3.5. Range of motion

The ROM was reported in 4 studies of 9 clinical studies (n=125).[3,15,16,18] The overall mean range of knee and ankle motion (extension-flexion) at final follow-up was 133.4° and 40.0°, respectively. Wu et al[18] found that patients who suffered from open tibial fractures and treated with external locked plates had larger ROM of knee and ankle than those who undertook standard external fixators, not only at the moment of removing constructs, but also at final follow up (P value from .000 to .002). In the external locked plate group, there was a significant improvement of ankle's ROM at final follow-up when compared with that at the moment of removing external locked plate (from 51.4°±6.5° to 55.0°±7.8°) ($P=.009$). However, no statistical difference of knee's ROM was found in the same group between the final follow-up and the moment of removing external locked plate (104.3°±21.1° and 115.3°±13.3°, respectively) ($P=.121$).

3.6. Union time and union rate

All of the clinical studies reported the union cases.[3,14–21] Only 2 cases of nonunion were found in 254 cases; the pooled union rate was 99.2% (95.7%–100%) then. Eight of the studies showed the average time to union was 24.3 weeks.[3,14–16,18–21] The time of union reported by Wu et al[18] was 23.0±5.5 weeks, shorter than that of patients who were fixed with standard external fixation (28.3±6.6 weeks; $P=.002$). Whereas Lian and Huang[14] found no significant difference in fracture union time among external locking plate, intramedullary nail, and minimally invasive locking plate groups ($P=.186$). Zhang et al[20] reported the mean time to fracture healing were 14.6 ± 2.67, 17.5 ± 3.66, and 18.4 ± 3.37 ($P<.05$) weeks in AO/OTA 43-A1, 43-A2, and 43-A3-type fractures, respectively. The type 43-A3 fracture demonstrated a prolonged healing time, compared with type 43-A1 fracture ($P=.038$).

3.7. Operation time

Four studies included the operation time.[14,17,19,20] The mean operation time was 45.8 minutes. Lian and Huang[14] found the operation time during operation in external locking plate and minimally invasive locking plate groups were significantly less than those in intramedullary nail group ($P<.05$), but there was no significant difference between groups external locking plate and minimally invasive locking plate ($P>.05$).

3.8. Complications

All of the clinical studies reported complications range from 5.7% to 40%.[3,14–21,23–25] The overall mean complication rate was 23.6%. The most common complication was the superficial pin-tract infection, which was present in 7.1% of cases. Delayed union rate was 3.9%. The remaining complications occurred with a frequency of 0.4% to 2% each and included deep infection; deep vein thrombosis; skin necrosis; ununion; broken plate; screw loosening; broken screw; shortening; malunion and superficial effusion. Lian and Huang[14] found the complication incidences of external locking plate (12.00%, 3/25), and minimally invasive locking plate groups (15.55%, 5/35) were significantly lower than that of group intramedullary nail (44.12%, 15/34) ($P<.05$) at 12 months after operation, but no significant difference was found between groups external locking plate and minimally invasive locking plate ($P>.05$).

4. Discussion

Recently, the locking plates used as an external fixator have been reported by several surgeons.[3,14,15,17–21] The indication includes infected nonunion,[12,26] open fracture,[3,15–20] closed fracture,[3,14,16,17,19–21] and even as an adjunct in distraction osteogenesis.[9] When a LCP is used as the internal fixator, stable connection of the locking screws to the plate does not rely on friction between the plate and bone.[13] The principle of the LCP is similar to the external fixator, which is an angle-stabilizing property. Thus, LCPs are being used as external fixators with increasing frequency. This technique has several benefits reported by some authors, as follows[3,19,21]:

1. It could minimize the damage to the soft tissues, decrease the complications after immediate open reduction. and internal fixation of tibial fractures with compromised soft tissue envelop.
2. With low-profile external fixator plate, patients can easily conceal under regular clothing, it seems more acceptable to patients because it overcomes the shortcomings of standard external fixators.
3. Using the locking plate as a definitive external fixator does not need to across the joint, which makes early functional exercise possible.
4. The external fixator can be easily removed in the clinic without using anesthesia. However, external fixation with a locking plate in tibial fractures, especially in closed fractures, is still controversial.

The main aim of this systematic review was to evaluate whether the LCP as an external fixator in fixing tibial fractures can be considered as a successful procedure and to evaluate the function outcomes and complications of this technique. Someone may be concerned whether the external locking plate provides appropriate stability to maintain reduction until fracture healing. According to Kanchanomai and Phiphobmongkol's[23] biomechanical experiment, partial weight bearing is possible for stable fractured tibia fixed by locking plate fixators, but for those patients who suffered from unstable tibial fractures, partial weight bearing should be considered cautiously in the early phase of treatment. All LCP-tibial models were cyclically loaded beyond 500,000 cycles which simulated as approximately 6 months of healing, and no failure of LCP was observed. They thought the failure of LCP is unlikely a critical issue for the cases who had the fracture gap sizes of 1, 5, and 10 mm. The biomechanical results of Ma et al[15] demonstrated that the axial stiffness of the external LCP group decreased by about 80% when compared with that of the internal LCP group, but remained greater than that of the EF group. Furthermore, the external LCP group had sufficient torsional stiffness compared with the internal LCP and EF groups. They inferred the locking plate (femoral less invasive stabilization system) offset at a distance of 6 cm from the bone surface is biomechanically feasible as a definitive treatment of tibial metaphyseal fracture. Whereas, to guarantee a stable external plate fixation in the distal tibial fracture, Zhang et al[25] suggested the plate-bone distance should be less than 30 mm based on a finite element analysis by utilizing the contralateral femoral less invasive stabilization system plate in the distal tibial fracture. These 2 studies confirmed the biomechanical safety of external LCP in treating the tibial fracture, but had different opinions on how far the distance between the bone and plates should be offset to ensure the stability of the constructs. Regardless of the type of fixation,[27,28] a close distance of the load carrier (bone plate or linkage) from the bone provides stronger structural stiffness. Theoretically, it may provide stronger stiffness if we offset the plate in 3-cm distance from bone surface. Due to the heterogeneity of biomechanical studies, we can only conclude that external locked plate shows inferior structural stiffness than internal locked plate. However, the clinical results of 254 cases in 9 studies showed a low implant complication rate with only 1 broken plate, 5 cases with 6 loose screws, and 3 cases with 4 broken screws.

Nonunion of the tibia is a common problem, which seems hard to deal with for the trauma surgeon. In a review, Phieffer and Goulet[29] reported the pooled nonunion rate of tibia was 2.5%, which was calculated from 5517 fractures. Velazco et al[30] reported that the rate of nonunion for type II and type III open tibial fractures was 14%. We found there were only 2 cases with nonunion in 254 cases. The combined union rate of 99.2% showed the locking plate as an external fixator to treat tibial fractures had a satisfactory fracture healing result. The time of union reported by Wu et al[18] was 23.0 ± 5.5 weeks, shorter than that of patients who fixed with traditional external fixator. The reason for high union rate of external LCP may be as follows[21,31]:

1. Locked compression plates provide good stability for distal tibial fractures.
2. Little blood supply to the tibia is destroyed.
3. Screw loosening or broken can be found in some cases which reduced the stiffness of the external fixator, but did not affect

the overall external locking plate construct. This phenomenon may be similar to the effect of dynamization of a static interlocking nail on fracture healing.

With respect to infection, Cannada et al[32] reported the rate is 1% in closed tibial fractures, 5% for Gustilo type I, 10% for type II, and >15% for type III. In a meta-analysis, Fang et al[33] reported that the combined deep infection rate of Gustilo grade III tibial fractures was 8.9% (19/214) for the patients treated with the external fixator and 10.4% (22/212) for the patients treated with unreamed intramedullary nailing. The superficial pin-tract infection rate in this review was 7.1%, which was calculated from 254 patients (112 cases of closed fractures). Only one deep infection occurred (0.4%). Deep infection becomes less of a concern after using external plating due to maintenance of the integrity of the soft tissue envelope.[20] Several authors[16,34] have described the use of a 2-stage protocol for treating open or severe high-energy tibial fractures. But most inclusive clinical articles in this review demonstrated 1-stage LCP treatment, because an external fixator obtained a good result.[3,14,15,17–21] It may dramatically decrease the cost and duration of hospitalization of the patients.

Overall, review of the selected studies revealed that excellent union rates and satisfactory clinical outcome can be expected with external locked plate fixation. Finally, it worth for us to note that LCPs also have the disadvantage: the plate as external fixator can be harder to manipulate and adjust because highly accurate anatomical reduction of the fracture site should be achieved.[3]

There are several limitations of this review: we failed to pool data for true meta-analysis due to the heterogeneity of individual studies; high-quality studies were insufficient because most reviewed articles are case series. In addition, most of the inclusive studies in this review were written by Chinese authors (2 from Taiwan). The lack of studies from western countries may be explained by the specific indications for each implant required by the implant approval process in these countries. For example, the femoral LISS plate was designed for femoral fixation and could not be used in patients who sustained tibial fractures. Another possible cause for this phenomenon may be the different costs of constructs between China and western countries. In the western world, locked plate constructs are more expensive than external fixators; however, the price difference between these 2 instruments was not so huge in China. Although it may be hard, we still suggest that adequately powered randomized controlled trials comparing well-matched patient groups with long-term follow-up are required to limit systematic error and enhance external validity. Specific outcome measures should include union, functional assessment, complications, and cost–benefit analysis.

5. Conclusions

Due to the heterogeneity of biomechanical studies, we can only conclude that external locked plate shows inferior structural stiffness than internal locked plate. But, based on the clinical studies, locked plating as an external fixator in treating tibial fractures can be considered as a safe and successful procedure. However, as yet, there is unconvincing evidence that it is superior to standard techniques with regards to clinical and functional outcomes. More and well-designed studies about this technique should be carried out.

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