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Comparison and predictive factors analysis for efficacy and safety of Kirschner wire, anatomical plate fixation and cannulated screw in treating patients with open calcaneal fractures

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Abstract

This study aimed to compare the efficacy and safety among Kirschner wire, anatomical plate fixation and cannulated screw treatments in patients with open calcaneal fractures, and to explore the predictive factors for treatment response and complication occurrence.

The 142 open calcaneal fracture patients were enrolled in this study, who received fixation procedures of Kirschner wire, anatomical plate fixation or cannulated screw on demand. Treatment efficacy was assessed by AOFAS score and occurrence of complications was recorded.

No difference of AOFAS score was observed among Kirschner wire, anatomical plate fixation and cannulated screw groups ($P = .792$), and the numbers of patients with excellent, good, medium, and poor AOFAS score in Kirschner wire group were 16 (16.2%), 42 (42.4%), 32 (32.3%), and 9 (9.1%), which in anatomical plate fixation group were 4 (16.7%), 11 (45.8%), 7 (29.2%), and (8.3%), and in cannulated screw group were 1 (5.3%), 10 (52.6%), 6 (31.6%), and 2 (10.5%), respectively. No difference of total complication occurrence ($P = .709$) or specific complications including skin graft ($P = .419$), flap graft ($P = .229$), deep infection ($P = .644$) or amputation ($P = .428$) was discovered among 3 groups. Logistic regression analysis revealed that fixation options did not affect treatment response and complication occurrence (all $P > .05$), while higher Gustilo type correlates with decreased treatment response ($P < .001$) and elevated complication occurrence ($P < .001$) independently.

Kirschner wire, anatomical plate fixation, and cannulated screw are equally efficient and tolerated in treating patients with open calcaneal fractures, and higher Gustilo type correlates with decreased treatment response and increased complication occurrence independently.

Abbreviations: ANOVA = one-way analysis of variance, AOFAS = American Orthopaedic Foot and Ankle Society.

Keywords: anatomical plate fixation, AOFAS score, cannulated screw, Kirschner wire, open calcaneal fractures

1. Introduction

Calcaneal fracture is one of the most common tarsal fractures, which is usually caused by several accidents including traffic accident, falling from heights and so on.[1,2] Among calcaneal fracture cases, open calcaneal fracture is a rare type accounting for just 0.8% to 10% of total cases, while it is considered as a potentially devastating traumatic injury, usually accompanying with synarthrophysis, stiffness, or calcaneal malunion and leading to intense pain and functional impairment.[3–5] Although various treatments are available for open calcaneal fracture, most of these patients still have worse prognosis probably due to poor stabilization caused by complex anatomical structure of calcaneus.[5–7]

Recent decades, surgical treatment is widely applied in patients with open calcaneal fracture, which has prominent advantage in retaining the geometry and structure of calcaneus.[8] During the processes of surgery, fixation plays an important role in keeping structural stability for open calcaneal fracture through restoring the normal biomechanics of disrupted calcaneus. There are many types of fixations, including Kirschner wire, anatomical plate fixation as well as cannulated screw. Among these fixations, Kirschner wire, a kind of frequently-used material for internal fixation, has been reported to achieve promising outcomes with less functional impairment compare with other fixations.[9,10] As for anatomical plate fixation, it is often used in open reduction and internal fixation and able to offer sufficient support to the impaired calcaneus with a suited angle, while post-treated complications still existed, such as deep infection, amputation and other complications.[11,12] As to cannulated screw fixation, it is a simple method allowing early mobilization and weight-bearing, moreover, it produces better subtalar and ankle joint

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range of motion.[13,14] Although these previous studies have been performed about the effects of Kirschner wire, anatomical plate fixation and cannulated screw respectively in patients with open calcaneal fracture, little is known about the comparison of these three fixation methods in open calcaneal fractures.[15,16] Hence, we conducted this prospective cohort study to compare the efficacy and safety among Kirschner wire, anatomical plate fixation and cannulated screw treatments in patients with open calcaneal fractures, and to explore the predictive factors for treatment response and occurrence of complications.

2. Materials and methods

2.1. Patients

The 142 patients with open calcaneal fracture treated at hospital between Jan 2011 and Dec 2016 were consecutively enrolled in this prospective cohort study. Inclusion criteria were as follows:

(1) Diagnosed as open calcaneal fracture according to clinical and iconography findings;
(2) Age above 18 years;
(3) About to undergo operation and receive Kirschner wire, anatomical plate fixation or cannulated screw as internal fixation material on demand;
(4) Able to complete the questionnaire assessment.

Exclusion criteria were:

(1) Combined with Ipsilateral limb comminuted fracture;
(2) Had physical abnormality;
(3) Had severe internal medicine diseases;
(4) Unlikely to be followed up regularly;
(5) Had injuries both sides.

The Ethics Committee of The Third Hospital of Hebei Medical University approved this study and all participants signed the informed coonsents. The present study was conducted in accordance with the Declaration of Helsinki.

2.2. Study design

In this prospective cohort study, all patients received the open calcaneal fracture operations, and Kirschner wire, anatomical plate fixation or cannulated screw was selected as the fixation material based on the severity of soft-tissue injury and Gustilo classification. According to the fixation materials which were selected on demand, patients were allocated into Kirschner wire group, anatomical plate fixation group, and cannulated screw group, respectively.

2.3. Preoperative treatment

All open calcaneal fractures were treated by emergency operations and each patient received an intravenous antibiotic (first-generation cephalosporins 2.0 g), which was administered in the emergency room just before surgery. Subarachnoid block or epidural anesthesia was given, and then the sterilized dressing, temporary immobilization to hind foot and tetanus antitoxin were used for the wound management. More than 6-litre of 0.9% saline was used for wound irrigation and the severity of soft-tissue injury was assessed.

2.4. Kirschner wire fixation procedure

After anesthesia, patient was placed at lateral position with the injured limb upwards. The injured limb was placed under c-arm X-ray, 2 3.5 mm Kirschner wires were used to pry the fracture fragments at the only points of the Achilles tendon and drilled into anterior part of bone nodules. When the wires reached below the fracture end, 4 fingers and the thumb held the wires and pushed against the foot bottom respectively, meanwhile, the 4 fingers and thumb of the other hand held the midfoot and foot bottom, respectively, and subsequently pulled up the collapsed astragalus until the normal position of Bohler angle and Gissane angle were restored. Then, push the calcaneus below internal and external malleolus to make the protrusion restore to normal position and correct the transverse diameters. Confirmed the appearance of calcaneus were restored to normal shape under c-arm X-ray, another 2 wires were drilled into calcaneus to maintain the reduction. Finally, plaster immobilization was performed.

2.5. Cannulated screw fixation procedure

The reduction procedure was as well as described above. After reduction, two 2.5 mm Kirschner wires were drilled into calcaneus from the rear to the upper part through the subtalar joint to fix the articular facet. Then, two 6.5 mm cannulated screws were drilled into calcaneus from front to rear to crosswise fix the fracture fragments. After fixation, the stability of fixation determined whether the Kirschner wires were pulled out.

2.6. Anatomical plate fixation procedure

Internal plate fixations were performed through a minimally invasive lateral approach.[17] During operation, one or two 3.5 mm Kirschner wires were introduced from the calcaneus tubercle into the fracture fragment along its axis to restore the posterior facet. Then two 2.5 mm Kirschner wires were drilled into anterior part of calcaneus for temporary fixation once the posterior facet and Bohler angle were restored. After reduction and temporary fixation of the calcaneal fracture, a longitudinal incision about 3.5 cm was made in the outer side of calcaneus along the margin of Achilles tendon, and then the anatomical plate was placed on the lateral calcaneus. Each calcaneus, which was fixed by anatomical plate, had enough soft-tissue covered in medial side. Placed a suction drainage tube after washed the wound cavity, and then Allgower-Donati suture was applied to close the incision. Finally, plaster support was performed.

2.7. Data collection

Age, gender, wound location, cause of fracture, and Gustilo type of all patients were recorded in detail before and during operation. Gustilo type was assessed according to Gustilo classification.[18]

2.8. Post-operation management

After operation, wounds were irrigated and debrided thoroughly every 48 to 72 hours until the wounds were cleaned or cured. And all patients received intravenous antibiotic (first-generation cephalosporins) within 7 days post operation. Management of open wound varied from skin graft to flap graft coverage depending on the severity of the sort-tissue injury.

2.9. Follow up and assessment

All patients were followed up regularly post operation, and median follow-up was 48 months (range: 12–80 months). At last

follow-up, patients' hind foot functions were respectively assessed by 2 experienced orthopedic surgeons using the American Orthopedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Scale.[19] The AOFAS Ankle-Hindfoot Scale consists of 3 domains including function, pain as well as alignment, and total score was 100 points. According to the AOFAS scores, treatment efficiency was classified as: 90 to 100 points, excellent; 80 to 89 points, good; 70 to 79 points, medium; <70 points, poor,[20] and in order to further analyze the factors affecting the treatment efficiency, we defined the "excellent" and "good" as objective response to the treatment. In addition, wound complications, such as infection, need for skin graft or flap coverage and amputation were also recorded at each follow-up.

2.10. Statistical analysis

Statistical analysis was performed using SPSS 22.0 software (IBM, USA) and Graphpad Prism 6 software (GraphPad Software Inc, USA). Data were mainly presented as mean value ±standard deviation or count (percentage). Comparison among 3 groups was determined by 1-way analysis of variance (ANOVA), Chi-square test or Kruskal-Wallis H rank sum test. Univariate logistic regression was used to determine factors affecting objective response and complication occurrence, and multivariate logistic regression was applied to further assess independent predictive factors for objective response and complication occurrence. $P < .05$ was considered significant.

3. Results

3.1. Baseline characteristics

No difference in age ($P = .658$), gender ($P = .287$), wound location ($P = .066$), cause of fracture ($P = .715$) or Gustilo type ($P = .125$) was found among Kirschner wire group, anatomical plate group and cannulated screw group (Table 1). Mean age of patients in Kirschner wire group (N = 99), anatomical plate group (N = 24) and cannulated screw group (N = 19) were 38.35 ± 8.58 years, 37.63 ± 8.67 years and 40.05 ± 10.27 years, respectively. And there were 80 males and 19 females in Kirschner wire group, 21 males and 3 females in anatomical plate group and 13 males and 6 females in cannulated screw group. The other detailed features of patients in each group were shown in Table 1.

3.2. Comparison of treatment efficacy among three groups

AOFAS scores was used to evaluate the treatment efficacy, which disclosed that no difference of AOFAS score was found among Kirschner wire group, anatomical plate fixation group and cannulated screw group ($P = .792$, Fig. 1). In detail, 16.2%, 42.4%, 32.3%, and 9.1% cases were classified into excellent, good, medium and poor efficacy in Kirschner wire group, respectively; while the corresponding percentages were 16.7%, 45.8%, 29.2%, and 8.3% in anatomical plate fixation group, and 5.3%, 52.6%, 31.6%, and 10.5% in cannulated screw group.

3.3. Comparison of complication occurrence among 3 groups

No difference of total complication occurrence was discovered among Kirschner wire group, anatomical plate fixation group and cannulated screw group ($P = .709$, Table 2), and the rates were 24.2%, 25.0%, and 15.8%, respectively. As to specific complications, no difference of occurrence in skin graft ($P = .419$), flap graft ($P = .229$), deep infection ($P = .644$) or amputation ($P = .428$) among 3 groups was observed either.

3.4. Analysis of factors affecting objective response

In order to further evaluate the predictive factors for treatment efficiency, univariate and multivariate logistic regression analyses were performed (Table 3), which disclosed that application of Kirschner wire, anatomical plate fixation and cannulated screw did not affect the achievement of objective response (all $P > .05$), while higher Gustilo type was found to be an independent factor for predicting decreased possibility of objective response in patients with open calcaneal fractures ($P < .001$)

Table 1

Baseline characteristics of patients with open calcaneal fractures among 3 groups.

Parameters	Kirschner wire group (N = 99)	Anatomical plate fixation group (N = 24)	Cannulated screw group (N = 19)	*P* value
Age (yr)	38.35 ± 8.58	37.63 ± 8.67	40.05 ± 10.27	.658
Gender (male/female)	80/19	21/3	13/6	.287
Wound location (n/%)				.066
Medial	80 (80.8)	24 (100.0)	16 (84.2)	
Lateral	19 (19.2)	0 (0.0)	3 (15.8)	
Cause of fracture (n/%)				.715
Falling	81 (81.8)	17 (70.8)	16 (84.2)	
Traffic accident	16 (16.2)	6 (25.0)	3 (15.8)	
Others	2 (2.0)	1 (4.2)	0 (0.0)	
Gustilo type				.125
I	4 (4.0)	2 (8.3)	0 (0.0)	
II	46 (46.5)	13 (54.2)	16 (84.2)	
IIIa	40 (40.4)	9 (37.5)	3 (15.8)	
IIIb	5 (5.1)	0 (0.0)	0 (0.0)	
IIIc	4 (4.0)	0 (0.0)	0 (0.0)	

Data was presented as mean value ± standard deviation or count (%). Comparison was determined by 1-way ANOVA or Chi-square test. *P* value < .05 was considered significant.

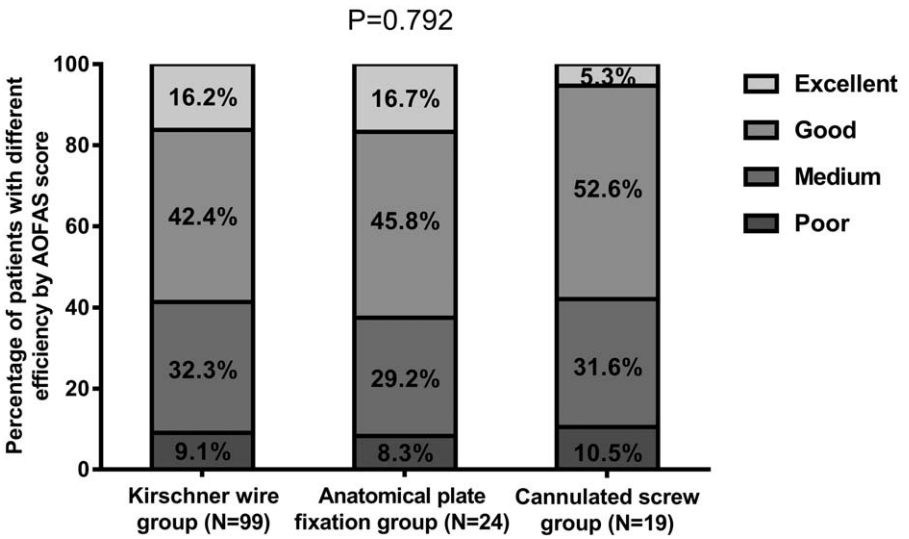

Figure 1. Treatment efficacy assessed by AOFAS score. Percentage of patients with excellent score was 16.2% (n = 16), 16.7% (n = 4), and 5.3% (n = 1) in Kirschner wire group, anatomical plate fixation group and cannulated screw group, respectively; the percentage of patients with good score was 42.4% (n = 42), 45.8% (n = 11), and 52.6% (n = 10) in 3 groups, respectively; the percentage of patients with medium score was 32.3% (n = 32), 29.2% (n = 7), and 31.6% (n = 6) in 3 groups, respectively; the percentage of patients with poor score was 9.1% (n = 9), 8.3% (n = 2), and 10.5% (n = 2) in 3 groups, respectively. No difference of AOFAS score was found among the 3 groups. Kruskal-Wallis H rank sum test was used to compared the difference among groups. $P < .05$ was considered significant. AOFAS = American Orthopaedic Foot and Ankle Society.

3.5. Analysis of factors affecting the complication occurrence

Univariate and multivariate logistic regression analyses were also performed to determine the predictive factors for complications (Table 4), which revealed that application of Kirschner wire, anatomical plate fixation or cannulated screw did not influence the occurrence of complications (all $P > .05$), while higher Gustilo type independently predicted elevated complication occurrence in patients with open calcaneal fractures ($P < .001$).

4. Discussion

In the present study, we observed that:

(1) Kirschner wire, anatomical plate fixation and cannulated screw were equally efficient and tolerated in treating patients with open calcaneal fractures.
(2) Higher Gustilo type was an independent predictive factor for decreased objective response and increased complication occurrence in open calcaneal fractures patients.

Table 2

Complications occurrence among 3 groups.

Parameters	Kirschner wire group (N = 99)	Anatomical plate fixation group (N = 24)	Cannulated screw group (N = 19)	*P* value
Skin graft (n/%)	11 (11.1)	5 (20.8)	2 (10.5)	.419
Flap graft (n/%)	10 (10.1)	0 (0.0)	1 (5.3)	.229
Deep infection (n/%)	2 (2.0)	0 (0.0)	0 (0.0)	.644
Amputation (n/%)	1 (1.0)	1 (4.2)	0 (0.0)	.428
Total complications (n/%)	24 (24.2)	6 (25.0)	3 (15.8)	.709

Data was presented as count (%). Comparison was determined by Chi-square test. *P* value $< .05$ was considered significant.

Table 3

Logistic regression model analysis of factors affecting objective response.

Parameters	Univariate logistic regression				Multivariate logistic regression			
	P value	OR	95% CI		*P* value	OR	95% CI	
			Lower	Higher			Lower	Higher
Kirschner wire vs others	.834	0.925	0.446	1.920	.249	1.919	0.633	5.817
Anatomical plate fixation vs others	.715	1.184	0.479	2.922	.575	1.486	0.372	5.929
Cannulated screw vs others	.904	0.942	0.354	2.507	–	–	–	–
Age	.207	0.975	0.939	1.014	.110	0.965	0.924	1.008
Gender (male vs female)	.538	0.764	0.324	1.801	.204	0.526	0.195	1.418
Wound location (medial vs lateral)	.159	1.930	0.772	4.826	.073	2.613	0.914	7.469
Cause of fracture (falling vs others)	.538	0.764	0.324	1.801	.636	0.789	0.295	2.107
Higher Gustilo type	**<.001**	0.230	0.116	0.455	**<.001**	0.185	0.087	0.395

Data was presented as *P* value, OR (odds ratio) and 95% CI (confidence interval). Factors affecting objective response were determined by univariate and multivariate logistic regression analysis. Gustilo type was scored as: Gustilo I-1, Gustilo II-2, and Gustilo III-3. *P* value $< .05$ was considered significant.

Table 4

Logistic regression model analysis of factors affecting the complication occurrence.

Parameters	Univariate logistic regression				Multivariate logistic regression			
	P value	OR	95% CI		*P* value	OR	95% CI	
			Lower	Higher			Lower	Higher
Kirschner wire vs others	.668	1.209	0.508	2.876	.569	0.643	0.140	2.941
Anatomical plate fixation vs others	.823	1.123	0.406	3.112	.859	1.175	0.199	6.943
Cannulated screw vs others	.413	0.581	0.158	2.133	–	–	–	–
Age	.819	0.995	0.952	1.040	.999	1.000	0.950	1.053
Gender (male vs female)	.800	1.138	0.418	3.095	.530	1.455	0.451	4.694
Wound location (medial vs lateral)	.304	0.593	0.219	1.606	.150	0.415	0.125	1.375
Cause of fracture (falling vs others)	.092	2.976	0.837	10.577	.074	3.578	0.886	14.459
Higher Gustilo type	**<.001**	7.442	2.989	18.527	**<.001**	9.039	3.245	25.176

Data was presented as *P* value, OR (odds ratio) and 95% CI (confidence interval). Factors affecting the complication occurrence were determined by univariate and multivariate logistic regression analysis. Gustilo type was scored as: Gustilo I-1, Gustilo II-2 and Gustilo III-3. *P* value <.05 was considered significant.

Application of optimal fixation is beneficial to keeping long-term stability and improving fracture healing, while it is not easy to select the appropriate fracture method for each patient, particular in patients with open calcaneal fracture, there is no specific guideline reached about the choice of ideal fixation.[5] Recent decades, various types of fixations, such as Kirschner wire, anatomical plate, and cannulated screw have been widely used to maintain the fracture reduction or stability in open calcaneal fractures patients. A previous study conducted by Berry et al enrolls 30 open calcaneal fractures: 12 of them are treated by Kirschner wire and others receive anatomical plate. Both the 2 fixations in their study present potential in avoiding complications: only 4 of the total patients suffer complications.[3] In addition, anatomic plate fixation is applied in a study enrolling 13 patients with open calcaneal fractures, and Kirschner wire is also included, and the mean AOFAS score in their study is 80.0 ± 7.4 (ranging from 55 to 95), suggesting the excellent performance of anatomic plate fixation and Kirschner wire in treating open calcaneal fractures, whereas the sample size was too small to present strong statistic efficacy.[21] Comparison of efficiency between cannulated screw and anatomic plate fixation is also performed in another interesting study, which displays that cannulated screw and anatomic plate fixation have equal therapeutic effects according to angle, width and height observations of calcaneus, while cannulated screw shows superior trend in avoiding infections.[4] Although these previous data suggest that Kirschner wire, anatomic plate fixation, and cannulated screw achieve satisfactory outcomes, few study has been performed to explore the superiority among these 3 fixations in open calcaneal fractures patients. In this present study, we observed that Kirschner wire, anatomic plate fixation and cannulated screw presented with similar efficacy and complication occurrence in treating open calcaneal fractures patients, which provided more evidence for the treatment choice of these 3 fixations in open calcaneal fractures. And the explanations of these results might be as follows:

(1) All these 3 fixations were stable fixations with powerful forces for reduction and less possibility of migration, break and fall off, thus they all presented great outcomes in restoring calcaneal structure and function;
(2) The experienced skills of physicians for surgery decreased the influence of different fixations on outcomes;
(3) The careful management of post-operation and operation timing did play important roles in avoiding infections, which might lead to indiscrimination of post-operation infection and complication occurrence in our study.

Meanwhile, we also found that the higher Gustilo type was an independent predictive factor for worse objective response and increased complication occurrence in open calcaneal fracture patients. This might result from that higher Gustilo type, which indicated higher severity of fractures, were associated with deeper wound, multiple injury mechanisms, severer soft-tissue impairment and raised requirement of sophisticated operating skill, and all these conditions would lead to decreased treatment outcomes and elevate the risk of complications.[15,16]

4.1. Limitations of the study

There were still some limitations existed in our study:

(1) Sample size in our study was relatively small (N=142), especially for cannulated screw group (N=19), thus the statistical power might be decreased, and the extreme value would affect the statistical analysis a lot;
(2) This was a cohort study without balanced sample size in each group, which also reduced the statistical power;
(3) Long-term outcome was not assessed;
(4) Patients with injuries both sides were excluded, and only patients with injury only one side were included in our study;
(5) only Gustilo classification was applied to assess the severity of open calcaneal fracture.

Thus, further study with larger sample size, balanced allocation, more classification systems and long-term follow-up duration is needed.

5. Conclusion

In conclusion, Kirschner wire, anatomical plate fixation, and cannulated screw are equally efficient and tolerated in treating patients with open calcaneal fractures, and higher Gustilo type correlates with decreased treatment response and increased complication occurrence independently.

Author contributions

Conceptualization: Yingze Zhang.
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Formal analysis: Weiguang Zhao, Yingze Zhang.
Investigation: Weiguang Zhao, Yingze Zhang.

Methodology: Weiguang Zhao, Yingze Zhang.
Supervision: Yingze Zhang.
Writing – original draft: Weiguang Zhao.
Writing – review & editing: Yingze Zhang.

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