DOI: http://dx.doi.org/10.1590/1413-785220223002e256896

DISTAL FEMORAL FRACTURES FROM HIGH-ENERGY TRAUMA: A RETROSPECTIVE REVIEW OF COMPLICATION RATE AND RISK FACTORS

FRATURAS DISTAIS DO FÊMUR POR TRAUMA DE ALTA ENERGIA: UMA REVISÃO RETROSPECTIVA DA TAXA DE COMPLICAÇÕES E FATORES DE RISCO

MICAEL DE MESQUITA PAIVA[1], *DANIEL PEIXOTO LEAL*[1], *PAULO KEN KUROKI*[1], *BARBARA GARCIA BARROSO*[1], *MARCO ANTONIO AVALOS REYNA*[1], *MARCOS DE CAMARGO LEONHARDT*[1], *JORGE DOS SANTOS SILVA*[1], *KODI EDSON KOJIMA*[1]

1. Universidade de São Paulo, Faculty of Medicine, Hospital das Clínicas, Institute of Orthopedics and Traumatology, Trauma Group, HC-DOT/FMUSP, São Paulo, SP, Brazil.

ABSTRACT

Objective: Determine complications' incidence and risk factors in high-energy distal femur fractures fixed with a lateral locked plate. Methods: Forty-seven patients were included; 87.2% were male, and the average age was 38.9. The main radiographic parameters collected were distal lateral femoral angle (DFA), distal posterior femoral angle (DPLF), comminution length, plate length, screw working length, bone loss, and medial contact after reduction and plate-bone contact, location of callus formation, and implant failure. The complications recorded were nonunion, implant failure, and infection. Results: Complex C2 and C3 fractures accounted for 85.1% of cases. Open fractures accounted for 63.8% of cases. The mean AFDL and AFDP were 79.8 4.0 and 79.3 6.0, respectively. The average total proximal and distal working lengths were 133.3 42.7, 60.4 33.4, and 29.5 21.8 mm, respectively. The infection rate was 29.8%, and the only risk factor was open fracture (p = 0.005). The nonunion rate was 19.1%, with longer working length (p = 0.035) and higher PDFA (p = 0.001) as risk factors. The site of callus formation also influenced pseudoarthrosis (p = 0.034). Conclusion: High-energy distal femoral fractures have a higher incidence of pseudoarthrosis and infection. Nonunion has greater working length, greater AFDL, and absence of callus formation on the medial and posterior sides as risk factors. The risk factor for infection was an open fracture. ***Level of Evidence III; Retrospective Cohort Study.***

Keywords: Femoral Fractures. Shock, Traumatic. Femoracetabular Impingement. Pseudarthrosis.

RESUMO

Objetivos: Determinar a incidência e os fatores de risco de complicações nas fraturas de alta energia das fraturas distais do fêmur fixadas com placa bloqueada lateral. Métodos: Foram incluídos 47 pacientes, sendo 87,2% homens e idade média de 38,9 anos. Os principais parâmetros radiográficos coletados foram o ângulo femoral distal lateral (AFDL), ângulo femoral distal posterior (AFDP), comprimento da cominuição, comprimento da placa, comprimento de trabalho dos parafusos, perda óssea, contato medial após a redução e contato placa-osso, localização da formação do calo e falha do implante. As complicações registradas foram não união, falha do implante e infecção. Resultados: Fraturas complexas C2 e C3 representaram 85,1% dos casos. As fraturas expostas corresponderam a 63,8% dos casos. O AFDL e AFDP médios foram 79,8° ± 4,0° e 79,3°± 6,0°, respectivamente. Os comprimentos de trabalho total, proximal e distal médios foram 133,3 ± 42,7, 60,4 ± 33,4 e 29,5 ± 21,8 mm, respectivamente. A taxa de infecção foi de 29,8% e o único fator de risco foi a fratura exposta (p = 0,005). A taxa de não união foi de 19,1%, com maior comprimento de trabalho (p = 0,035) e maior PDFA (p = 0,001) como fatores de risco. O local de formação do calo também influenciou na pseudoartrose (p = 0,034). Conclusões: Fraturas distais do f ˆmur de alta energia apresentam maior incidência de pseudoartrose e infecção. A não união tem como fatores de risco maior comprimento de trabalho, maior AFDL e ausência de formação de calo nos lados medial e posterior. O fator de risco para infecção foi a fratura exposta. ***Nível de evidência III; Estudo de Coorte Retrospectivo.***

Descritores: *Fraturas do Fêmur. Choque Traumático. Impacto Femoroacetabular. Pseudoartrose.*

Citation: Kojima KE, Munari BM, Kubota BS, Zanesco L, Proença DS, Leonhardt MC, Silva JS. Radiographic evaluation of immediate loading safety after surgical reduction in acetabular fractures: A comparative-retrospective study. Acta Ortop Bras. [online]. 2022;30(2)Esp.: Page 1 of 6. Available from URL: http://www.scielo.br/aob.

All authors declare no potential conflict of interest related to this article.

The study was conducted at the Universidade de São Paulo, Faculty of Medicine, Hospital das Clínicas, Institute of Orthopedics and Traumatology, Trauma Group, HC-DOT/FMUSP, São Paulo, SP, Brazil.

Correspondence: Kodi Edson Kojima. Universidade de São Paulo, Faculty of Medicine, Hospital das Clínicas, Institute of Orthopedics and Traumatology, Trauma Group, 333 Dr. Ovídio Pires de Campos Street – São Paulo. kodi.kojima@hc.fm.usp.br

Article received on 10/01/2021, approved in 12/03/2021.

INTRODUCTION

Distal femur fractures are common orthopedic problems affecting individuals across varied age groups, ranging from young patients with high-energy trauma to elderly patients with an injury associated with osteoporosis and a lower energy mechanism of trauma such as simple falls. For both groups, surgical fixation is the treatment of choice.[1]

Lateral locking plate (LLP) has become the standard method of fixation because of its biomechanical property to resist varus collapse, multiple fixation points in the short distal fragment, and technical ease implant.[2,3] As this technique has been used in various fracture patterns, ranging from low-energy fractures to high-energy fractures, moderate nonunion, infection, and implant failure rates have been reported.[4,5]

The risk factors for complications after LLP include patient-related factors (such as age, sex, habits, and comorbidities), fracture characteristics (such as type of fracture, comminution, bone loss, and soft tissue injury), and fixation-related factors (such as reduction, plate length, working length, and number of screws).[6] Factors associated with complications and failures should be determined separately according to the mechanism of trauma. Both patients and fractures are different in low-energy and high-energy trauma, and most likely, the complication rates and risk factors may also be different between them.

The goals of this study were to examine a population of patients with high-energy distal femur fractures treated with LLP to determine the incidence and risk factors of complications.

MATERIAL AND METHODS

This retrospective study was performed at the Instituto de Ortopedia e Traumatologia da Faculdade de Medicina da Universidade de São Paulo, an urban university-based level 1 trauma center, between 2012 and 2018. Data were collected through a retrospective chart review and review of existing radiographs. Ethical approval was provided by the Scientific and Ethical Committee of the University under the protocol 2.827.192. Written informed consent was obtained from all patients.

The inclusion criteria were as follows: type A and type C distal femur fractures, open reduction and internal fixation with LLP, age > 18 years, victims of high-energy trauma, no previous procedures in the knee, a minimum of 9 months of follow-up, complete radiographic examination, and signed informed consent.

The exclusion criteria included low-energy fractures, periprosthetic fractures, type B distal femur fracture, intramedullary fixation, dual plating fixation, contraindication for surgery or anesthesia, would infection prior to internal fixation, pathologic fractures, and associated neurovascular injury.

Demographic data on the following were collected: age, sex, mechanism of trauma, associated injuries, OTA/AO classification,[7] and Gustilo classification[8] for open fractures.

The surgical technique followed established recommendations provided in the literature.[9,10] All patients were fixed with a stainless-steel LLP (De Puy Synthes, USA). Weight-bearing as tolerated was allowed during the postoperative rehabilitation.

The radiographic parameters evaluated were the quality of articular reduction, lateral distal femoral angle (LDFA), posterior distal femoral angle (PDFA), length of comminution, length of the plate, screw working length, number of screws proximal and distal, bone loss, medial contact after reduction and plate bone contact, location of callus formation, and implant failure. (Figure 1)

The quality of reduction was classified binarily as anatomical or nonanatomical reduction.

The coronal plane alignment was measured using the LDFA. AP radiographs were used to measure the angle on the lateral side between the anatomical axis of the femoral shaft and the articular line. The PDFA measured the sagittal alignment on the lateral view with the angle between the femoral shaft and the line parallel to the articular line with the Blumensaat line as a reference. (Figure 1)

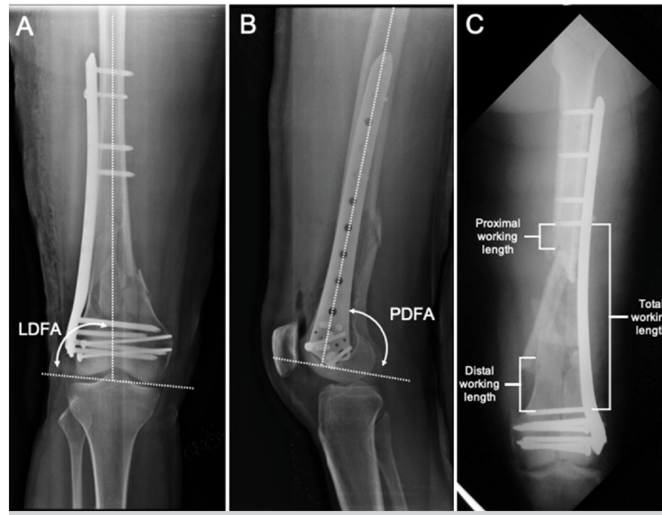

Figure 1. Radiographic measurements. - A- Lateral distal femoral angle (LDFA), B- Posterior distal femoral angle (PDFA), C- Total working length, proximal and distal working length.

The length of the plate was defined by the number of holes proximal to the articular cluster, and the total working length was defined as the distance spanning the fracture site between the two screws on each side closest to the fracture.[11] The proximal working length was defined as the distance between the fracture and the immediate proximal screw, and the distal working length as the distance between the fracture and the immediate distal screw. (Figure 1)

According to its location (anterior, posterior, medial and lateral) the location of the callus formation was noted. Union was defined as the presence of a minimum of three of four bridging cortices on AP and lateral X-rays at 6 months.[12] Failure to meet the minimum requirement of the bridging cortices was recorded as nonunion.

The following complications were recorded: implant failure, deep infection, nonunion, and reoperation. Mechanical implant failure was defined as any failure of the implant, including plate break, screw breakage, plate loosening, bending of the plate, and screw disengagement.[13] Infection was defined according to the fracture-related infection criteria published by Metzemakers et al in 2018.[14]

Descriptive statistics included means and standard deviations for continuous variables and counts (percentages) for categorical variables. Statistical analysis of infection and nonunion was performed using the chi-square test or Fisher's exact test. Comparative analysis was performed according to the outcome and compared using Student's t-test. Odds ratios were estimated with the respective 95% confidence intercal and adjusted with the model of multiple logistic regression with the variables that presented with a descriptive level of bivariable analysis less than 0.10 ($p<0.10$). Statistical analysis was performed using IBM SPSS software for Windows version 22.0, with a significant level of 5%.

RESULTS

During the observation period (2012-2018), a total of 56 patients with high-energy distal femur fracture were treated with LLP. Nine patients were excluded from the study due to incomplete follow-up or radiographic control. Among the 47 included patients, 41 (87.2%) were men and six (12.8%) were women, with an overall average age of 38.9 ± 12.9 years.

The most frequent trauma mechanism was motorbike accidents in 27 (57.4%) cases, followed by motor vehicle accidents in nine (19.!1%) cases, and falls from height and run over by a car in four (8.5%) cases each. Associated injuries occurred in 31 (65.9%) cases. (Table 1)
According to the OTA/AO classification, 24 (51.1%) fractures were type 33C3, 16 (34.0%) were type 33C2, and the remaining seven (14.9%) were type A (Table 1). The average length of comminution was 50.1 ± 31.3 mm.
Thirty (63.8%) fractures were open, of which 28 (80.0%) were Gustilo type 3A and two (6.7%) were Gustilo 3B (Table 1).
Articular anatomical reduction was achieved in 35 (74.5%) patients. The plate length was 13 holes in 34 (72.3%) patients, 11 holes in two (4.3%) and nine holes in 11 (23.4%) patients. The coronal alignment measured by the LDFA average was 79.8°± 4.0° and that by the sagittal plane PDFA was 79.3°± 6.0°. The average total working length was 133.3 ± 42.7 mm. The proximal working length was 60.4 ± 33.4 mm, and the distal working length 29.5 ± 21.8 mm. More details can be seen by comparing radiographical parameters and nonunion in Tables 2 and 3.
The overall deep infection rate was 29.8% (14 fractures). Of the 17 closed fractures, only one developed a postoperative deep infection, and of the 30 open fractures, 43.4% (13 fractures) developed deep infection. Open fracture was a statistically significant factor for infection (p=0.005) (Table 4). The presence of associated injuries almost reached a statistically significant risk factor (p=0.055). None of the other patient characteristics had a positive effect on the postoperative infection rate (p>0.05).
Nonunion was noted in nine (19.1%) cases. Statistical analysis revealed a strong correlation between nonunion and a longer total working length (p=0.035) and higher values of PDFA (p=0.001). The likelihood of nonunion increased by 31% for each unit with a higher PDFA (Table 5). The location of the callus formation was

Table 1. Demographic characteristics of the patients.

Variable	Description (n = 47)
Age (years)	
Mean ± SD	38.9 ± 12.9
Median (min.; max.)	39 (18; 69)
Gender, n (%)	
Female	6 (12.8)
Male	41 (87.2)
Mechanism of injury, n (%)	
Motorbike accident	27 (57.4)
Motor vehicle accident	9 (19.1)
Fall from height	4 (8.5)
Run over by car	4 (8.5)
Other	3 (6.5)
Associated injuries, n (%)	
No	16 (34.1)
Yes	31 (65.9)
AO/OTA classification, n (%)	
A1	1 (2.1)
A2	2 (4.2)
A3	4 (8.5)
C2	16 (34.1)
C3	24 (51.1)
Open fractures, n (%)	
No	17 (36.2)
Yes	30 (63.8)

also correlated with the development of nonunion (p=0.034). The least influenced nonunion development location was medial callus formation, followed by posterior callus formation. (Table 4)
Some results emphasized the lack of correlation between nonunion and length of comminution (p=0.165), bone loss (p=0.071), and medial contact after reduction (p=0.138).
Infection did not correlate with the development of nonunion (p>0.05).

DISCUSSION

Distal femoral fractures have a bimodal distribution - high-energy trauma in young patients and low-energy trauma in elderly patients.[15] The systemic condition of the patients and the characteristics of the fracture are completely different between the two groups, In young patients multiorgan injury (polytrauma) is the main systemic concern, followed by other associated orthopedic injuries. In contrast, in elderly patients, the frail systemic condition, comorbidities, and polypharmacy are the main concerns.
In young patients with high-energy injuries, fractures tend to be intra-articular, have more displacement and comminution, and more severe soft tissue compromise. In contrast, in elderly patients, fractures tend to be simple, non-comminutes, and extra-articular and the main concern in fixation is bone quality.[16,17]
Despite occurring in the same anatomical area, high- and low-energy fractures are two completely different types of fractures. In our view, studies to analyze the risk of complications should separate the risk of high-energy fractures from that of low-energy fractures. This is because the risks and consequences of both are different. This may explain the wide range of incidence of complications, such as nonunion varying from 6%[18] to 38%[19] and infection from 3%[20] to 15%.[17]
To our knowledge, this is the first study to include only high-energy fractures with a significant number of patients (n=47) to determine the incidence and risk factors of complications. In a review by Ebraheim et al.,[19] among the 19 studies, the number of patients varied from 1 to 31.
Similar to that reported in the literature, in our study, the average age was 38.9%, most patients were young, and there was a male predominance (87.2%). In contrast to the predominant cause of injury (motor vehicle accident) reported in the literature, due to the characteristics of the traffic in the city, the main cause of injury was motorbike accidents (57.4%) in our study.
In contrast to low-energy trauma, where an isolated injury is more common, associated injuries were reported in 65.9% patients in our study. Another characteristic of high-energy trauma is the type of fracture with more complex, comminuted, and articular involvement. In our series, 85.2% fractures were C2 and C3 types.
The nonunion rate was 19.1% (9/47 patients). The incidence of nonunion was highly correlated with a longer working length (p=0.035) and higher PDFA (0.001).
Two factors influence the total working length - the extension of the comminution and the decision of the surgeon to insert the screws closest to the fracture. Longer comminutions lead to longer working length; however, with the use of long plates, the surgeon can increase the proximal working length and position the screw distant from the fracture. We did not observe the influence of extension of comminution on the nonunion rate (p=0.165). However, the proximal working length was almost double the distal working length (63.8 mm vs. 29.6 mm), causing an imbalance in the total working length. One may consider decreasing the total working length by inserting the proximal screw closer to the fracture, thus decreasing the proximal working length. This aligns with what Peschiera et al.[21] called in their article as unbalanced fixation as risk factor for nonunion. In a study conducted by Ricci et al.,[11] longer working length was

Table 2. Description of the non-union according to the radiographic measurements and the statistical analysis.

Variable	Non-union		OR	IC (95%)		p
	No	Yes		Inferior	Superior	
LDFA (79 - 83)			**0.86**	**0.71**	**1.04**	**0.104****
mean ± SD	80.5 ± 4	78 ± 4.2				
median (min.; max.)	80 (72; 88)	80 (70; 82)				
PDFA (79 - 87)			**1.23**	**1.03**	**1.48**	**0.001***
mean ± SD	78.4 ± 6.1	83.8 ± 3.3				
median (min.; max.)	78 (66;90)	84 (78; 88)				
Length of comminution (mm)			**1.02**	**0.99**	**1.04**	**0.165****
mean ± SD	74.4 ± 29.8	63.5 ± 33.9				
median (min.; max.)	43 (8; 127)	79 (12; 100)				
Total working length (mm)			**1.02**	**1.00**	**1.04**	**0.035****
mean ± SD	126.6 ± 40.5	159.1 ± 40.7				
median (min.; max.)	118 (41; 221)	149 (113; 253)				
Proximal working length (mm)			**1.00**	**0.98**	**1.03**	**0.767****
mean ± SD	60.1 ± 32.9	63.8 ± 36.6				
median (min.; max.)	51 (11; 182)	59 (22; 127)				
Distal working length (mm)			**1.00**	**0.97**	**1.03**	**0.982****
mean ± SD	29.4 ± 23.2	29.6 ± 16.5				
median (min.; max.)	28 (3; 148)	26 (13; 67)				
Plate length (holes)			**1.26**	**0.77**	**2.04**	**0.287****
mean ± SD	11,7 ± 1.9	12.3 ± 1.4				
median (min.; max.)	13 (9; 13)	13 (9; 13)				
Bone-plate contact, n (%)						**> 0.999***
No	11 (23.4)	2 (14.3)	1.00			
Yes	27 (76.6)	7 (20.6)	1.56	0.28	8.62	
Proximal screws			**1.50**	**0.43**	**5.28**	**0.536****
mean ± SD	4.0 ± 0.6	4.1 ± 0.3				
median (min.; max.)	4 (2; 6)	4 (4; 5)				
Distal screws			**1.37**	**0.54**	**3.48**	**0.522****
mean ± SD	5.4 ± 0.8	5.6 ± 0.7				
median (min.; max.)	5 (4; 7)	6 (4; 6)				
Bone loss, n (%)						**0.071***
No	35 (85.4)	6 (14.6)	1.00			
Yes	3 (50.0)	3 (50.0)	6.00	0.97	36.99	

** Fischer exact test, * Student t test.

Table 3. Description of the non-union according to the radiographic measurements and the statistical analysis.

Variable	Non-union		OR	IC (95%)		p
	No	Yes		Inferior	Superior	
Medial contact after reduction, n (%)						**0.138**
No	10 (66.6)	5 (33.3)	1.00			
Yes	28 (87.5)	4 (12.5)	0.31	0.07	1.39	
Callus formation, n (%)						**0.034**
Anterior	3 (100)	0 (0)	1.00			
Medial	17 (100)	0 (0)	&			
Posterior	11 (64.7)	6 (35.3)	&			
Lateral	2 (66.7)	1 (33.3)	0.55	0.03	10.37	
Postero-medial	2 (66.7)	1 (33.3)	0.55	0.02	19.56	
Implant failure, n (%)						**0.188**
No	38 (82.6)	8 (17.3)	1.00			
Yes	0 (0)	1 (100)	&			

** Fischer exact test, * Student t test.

Table 4. Description of the infection according to demographical characteristics and the statistical analysis.

Variable	Infection		OR	IC (95%)		p
	No	Yes		Inferior	Superior	
Age (years)			**0.98**	**0.93**	**1.03**	**0.416****
mean SD	40.6 13.5	37 13.9				
median (min.; max.)	40 (18; 61)	38.5 (19; 69)				
Gender, n (%)						**0.656***
Female	5 (83.3)	1 (16.7)	1.00			
Male	28 (68.3)	13 (31.7)	2.24	0.24	21.15	
Associated injuries, n (%)						**0.055***
No	8 (50.0)	8 (50.0)	1.00			
Yes	25 (80.6)	6 (19.4)	0.27	0.07	1.00	
AO/OTA classification, n (%)						**0.183****
A1	1 (100)	0 (0)	1.00			
A2	2 (100)	0 (0)	&			
A3	4 (100)	0 (0)	&			
C2	10 (62.5)	6 (37.5)	&			
C3	16 (66.7)	8 (33.3)	&			
Open fracture, n (%)						**0.005**
No	16 (94.1)	1 (5.9)	1.00			
Yes	17 (56.7)	13 (43.3)	13.00	1.53	110.73	

** Fischer exact test, * Student t test.

Table 5. Result of regression analysis to explain non-union.

Variable	OR	IC (95%)		p
		Inferior	Superior	
PDFA (79 - 87)	1.31	1.03	1.65	0.025
Total working length	1.03	1.00	1.06	0.053

Multiple logistic regression analysis (full model).

an independent risk factor for nonunion. Based on the results reported by Kiyono et al.,[22] leaving one hole empty on either side of the fracture may decrease the incidence of nonunion in both simple and comminuted fractures.

A higher PDFA also had a positive correlation with nonunion (p=0.001). Each increase in the angle increased the risk of nonunion (p=0.025). A high PDFA indicates a lack of reduction of the extension deformity caused by the gastrocnemius muscle. The result is the creation of a gap in the posterior side of the femur. The callus formation results showed that the two most important locations for callus formation to avoid nonunion were medial and posterior. During surgery, it is important to pay attention to the reduction in the sagittal plane, which is occasionally difficult because of the external guide of the plate that interferes with the C-arm image.

In contrast to the findings reported by Karam et al.[23] and Ebraheim et al.,[19] the presence of comminution or extension of comminution was not a risk factor for nonunion (p=0.165) in our study.

There was no correlation between bone loss and nonunion (p=0.071), but analysis of the absolute numbers showed that 50% cases with bone loss developed nonunion (3/6). In addition, there was also no correlation with medial contact after reduction (p=0.138), but analysis of absolute numbers showed that almost 50% cases with nonunion did not have medial contact.

Individual analysis of the nine cases of nonunion showed that they all had a hypotrophic type of nonunion with little callus formation on the medial and posterior side.

The low implant failure, regardless of the 19.1% nonunion rate, may be explained with the use of long plates (11- and 13-holes plates in 95.7%). The long plates and the long lever arm prevented plate pullout. This is in line with the recommendation of many authors to use long plates to avoid failure.[11,15,22] Long plates allow for longer working lengths, but care should be taken even in long plates to keep the working length short.[23]

The deep infection rate was 29.8% (14/47 patients), and the only predictive factor was open fracture (p=0.005). In this study including only high-energy fractures, the incidence of open fracture was 63.8% (30/47), and among these cases, 43.3% (13/30) developed deep infection. Regardless of initial care with abundant lavage and debridement and staged treatment with external fixation, the incidence of infection was high. The combination of severe soft tissue injury and the comminution of the fracture puts this injury at a high risk of infection when caused by high-energy trauma.

Bai et al.[20] studied the incidence of infection in 665 distal femur fractures and found an infection rate of 3.6%. The low number of infections can be explained by the inclusion of low-energy fractures, representing 30% cases and representing $< 20\%$ of the infected cases. Looking at only the high-energy cases, they represented 83.3% of the infections and also had open fractures as risk factor.

This study has several limitations. This study was retrospective, therefore, the final decision about the implant and its application was made by the operating surgeon and could not be controlled experimentally. A low number of patients may have influenced the results. Several patients who initially met the inclusion criteria were unable to complete the 9-month follow-up. Any radiographic measurement may be inconsistent because of the magnification of the image and imprecise measurement.

In conclusion, the incidence of complications is higher in high-energy distal femur fractures than in low-energy fractures. We found a strong correlation between nonunion and the total working length of the fixation and the increase in the PDFA. Callus formation on the medial and posterior sides had a negative influence on the nonunion rate. The only risk factor for infection was open fracture.

AUTHORS' CONTRIBUTION: Each author contributed individually and significantly to the development of this article. MMP, DPL, PKK, BGB, Marco AAR, KEK: were the main contributors in writing the manuscript. MCL, JSS, KEK: performed the surgery, followed the patients and gathered clinical data. MMP, DPL, PKK, BGB, Marco AAR, MCL, JSS, KEK: performed the literature search, reviewed the manuscript and contributed to the intellectual concept of the study.

REFERENCES

1. Zlowodzki M, Bhandari M, Marek DJ, Cole PA, Kregor PJ. Operative treatment of acute distal fêmur fractures: systematic review of 2 comparative studies and 45 case series (1989-2005). J Orthop Trauma. 2006;20(5):366-71.
2. Koval KJ, Hoehl JJ, Kummer FJ, Simon JA. Distal femoral fixation: a biomechanical comparison of the standard condylar buttress plate, a locked buttress plate, and the 95-degree blade plate. J Orthop Trauma. 1997;11(7):521-4.
3. Markmiller M, Konrad G, Südkamp N. Femur-LISS and distal femoral nail for fixation of distal femoral fractures: are there differences in outcome and complications?. Clin Orthop Relat Res. 2004;426:252-7.
4. Ehlinger M, Dujardin F, Pidhorz L, Bonnevialle P, Pietu G, Vandenbussche E, et al. Locked plating for internal fixation of the adult distal femur: influence of the type of construct and hardware on the clinical and radiological outcomes. Orthop Traumatol Surg Res. 2014;100(5):549-54.
5. Koso RE, Terhoeve C, Steen RG, Zura R. Healing, nonunion, and re-operation after internal fixation of diaphyseal and distal femoral fractures: a systematic review and meta-analysis. Int Orthop. 2018;42(11):2675-83.
6. Lujan TJ, Henderson CE, Madey SM, Fitzpatrick DC, Marsh JL, Bottlang M. Locked plating of distal femur fractures leads to inconsistent and asymmetric callus formation. J Orthop Trauma. 2010;24(3):156-62.
7. Meinberg EG, Agel J, Roberts CS, Karam MD, Kellam JF. Fracture and dislocation classification compendium - 2018. J Orthop Trauma. 2018;32(Suppl 1):S1-170.
8. Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma. 1984;24(8):742-6.
9. Kregor PJ, Stannard JA, Zlowodzki M, Cole PA. Treatment of distal femur fractures using the less invasive stabilization system: surgical experience and early clinical results in 103 fractures. J Orthop Trauma. 2004;18(8):509-20.
10. Schütz M, Müller M, Krettek C, Höntzsch D, Regazzoni P, Ganz R, et al. Minimally invasive fracture stabilization of distal femoral fractures with the LISS: a prospective multicenter study. Results of a clinical study with special emphasis on difficult cases. Injury. 2001;32(Suppl 3):SC48-54.
11. Ricci WM, Streubel PN, Morshed S, Collinge CA, Nork SE, Gardner MJ, et al. Risk factors for failure of locked plate fixation of distal femur fractures: an analysis of 335 cases. J Orthop Trauma. 2014;28(2):83-9.
12. Corrales LA, Morshed S, Bhandari M, Miclau T 3rd. Variability in the assessment of fracture-healing in orthopaedic trauma studies. J Bone Joint Surg Am. 2008;90(9):1862-8.
13. Dang KH, Armstrong CA, Karia RA, Zelle BA. Outcomes of distal femur fractures treated with the Synthes 4.5 mm VA-LCP curved condylar plate. Int Orthop. 2019;43(7):1709-14.
14. Metsemakers WJ, Morgenstern M, McNally MA, Moriarty TF, McFadyen I, Scarborough M, et al. Fracture-related infection: a consensus on definition from an international expert group. Injury. 2018;49(3):505-10.
15. Rodriguez EK, Boulton C, Weaver MJ, Herder LM, Morgan JH, Chacko AT, et al. Predictive factors of distal femoral fracture nonunion after lateral locked plating: a retrospective multicenter case-control study of 283 fractures. Injury. 2014;45(3):554-9.

16. Smith JRA, Halliday R, Aquilina AL, Morrison RJM, Yip GC, McArthur J, et al. Distal femoral fractures: the need to review the standard of care. Injury. 2015;46(6):1084-8.
17. Southeast Fracture Consortium. LCP versus LISS in the treatment of open and closed distal femur fractures: does it make a difference?. J Orthop Trauma. 2016;30(6):212-6.
18. Henderson CE, Lujan TJ, Kuhl LL, Bottlang M, Fitzpatrick DC, Marsh JL. Mid- America Orthopaedic Association Physician in Training Award: healing complications are common after locked plating for distal femur fractures. Clin Orthop Relat Res. 2011;469(6):1757-65.
19. Ebraheim NA, Martin A, Sochacki KR, Liu J. Nonunion of distal femoral fractures: a systematic review. J Orthop Surg. 2013;5(1):46-50.
20. Bai Y, Zhang X, Tian Y, Zhang B. Incidence of surgical-site infection following open reduction and internal fixation of a distal femur fracture: an observational case-control study. Medicine. 2019;98(7):e14547.
21. Peschiera V, Staletti L, Cavanna M, Saporito M, Berlusconi M. Predicting the failure in distal femur fractures. Injury. 2018;49(Suppl 3):S2-7.
22. Kiyono M, Noda T, Nagano H, Maehara T, Yamakawa Y, Mochizuki Y, et al. Clinical outcomes of treatment with locking compression plates for distal femoral fractures in a retrospective cohort. J Orthop Surg Res. 2019;14(1):384.
23. Karam J, Campbell P, David M, Hunter M. Comparison of outcomes and analysis of risk factors for non-union in locked plating of closed periprosthetic and non-periprosthetic distal femoral fractures in a retrospective cohort study. J Orthop Surg Res. 2019;14(1):150-60.