



Working length and proximal screw constructs in plate osteosynthesis of distal femur fractures



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ABSTRACT

Background: The study purpose is to evaluate the working length, proximal screw density, and diaphyseal fixation mode and the correlation to fracture union after locking plate osteosynthesis of distal femoral fractures using bridge-plating technique.

Methods: A four-year retrospective review was performed to identify patients undergoing operative fixation of distal femur fractures with a distal femoral locking plate using bridge-plating technique for the metadiaphyseal region. Primary variables included fracture union, secondary surgery for union, plate working length, and diaphyseal screw technique and configuration. Multiple secondary variables including plate metallurgy and coronal plane fracture alignment were also collected.

Results: Ninety-six patients with distal femur fractures with a mean age 60 years met inclusion criteria. None of the clinical parameters were statistically significant indicators of union. Likewise, none of the following surgical technique parameters were associated with fracture union: plate metallurgy, the mean working length, screw density and number of proximal screws and screw cortices. However, diaphyseal screw technique did show statistical significance. Hybrid technique had a statistically significant higher chance of union when compared to locking ($p=0.02$). All proximal locking screw constructs were 2.9 times more likely to lead to nonunion.

Conclusions: Plating constructs with all locking screws used in the diaphysis when bridge-plating distal femur locking plates were 2.9 times more likely to incur a nonunion. However, other factors associated with more flexible fixation constructs such as increased working length, decreased proximal screw number, and decreased proximal screw density were not significantly associated with union in this study.

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Introduction

Distal femur fractures account for less than 1% of all fractures and 3%–6% of all femur fractures. Epidemiological studies indicate 2 primary distributions of patients: elderly individuals with low-energy mechanisms such as a fall from standing, and younger patients with high-energy mechanisms such as motor vehicle accidents [1–3]. When compared to non-operative management, studies indicate that patients treated with surgery have better outcomes related to alignment, union and function [2]. Simple metaphyseal fractures that are amenable to direct reduction with absolute stability do sometimes occur; however, due to the increasing number of elderly patients with osteoporosis and the

higher energy injuries that younger patients are now surviving, distal femur fractures are often associated with highly comminuted metaphyseal segments that are more amendable to indirect reduction techniques and relative stability. Surgical treatment options include plate or intramedullary nail fixation. Non-locking plates have fallen out of favor due to the increased incidence of late varus displacement [4]. Fixed-angle plates have proven to be more effective in resisting the high forces in multiple planes about the distal femur [5]. Anatomically pre-contoured locking plates are popular due to improved fixation in osteoporotic bone and highly complex articular fractures compared to blade or dynamic condylar plates [6,7]. However, locking plates still fail either with proximal or distal screw, or plate breakage. These failures occur in fractures with extensive metaphyseal comminution and in instances of early weight bearing [8,9].

Fixation of distal femur fractures using bridge plating techniques with anatomically pre-contoured locking plates uses

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relative stability principles with the intent of secondary bone healing. Rigid fixation in the setting of a fixed fracture gap results in high strain and is less likely to induce fracture callus or secondary bone healing. However, flexible fixation allows for decreased gap and strain leading to callus formation [10]. Controversy exists as to how to relate this ideal environment to current plating techniques, and numerous biomechanical studies have explored how plate design, plate length, screw length and screw configuration can alter the overall construct stability [11–15].

Working length of a plate construct is defined as the distance between the first screws on either side of the fracture [16]. Some biomechanical studies indicate that increasing the working length of a relative stability fracture construct results in increased flexibility, less strain, and in theory, improves fracture healing [17,18]. However, very few clinical studies have tried to relate working length to fracture union for distal femur fractures [19,20]. The primary purpose of this study is to evaluate if the working length of lateral anatomically pre-contoured locking plates in distal femur fracture fixation using relative stability techniques affects union rate. We hypothesize that longer working lengths will be associated with higher fracture union rates.

Materials & methodology

Following Institutional Review Board approval, we identified all patients from January 2007 to December 2011 who presented with an acute distal femur fracture (AO/OTA 33) [21,22] to our American College of Surgeons (ACS) Level I academic trauma center. In total, 180 patients were identified. Patients at least 18 years old who underwent open reduction and internal fixation (ORIF) of acute distal femur fractures (open and closed) with a laterally-based locking plate using bridge plate technique were included. Patients were excluded if: they were less than 18 years old, their injury could be treated non-operatively, there was inadequate clinical follow-up, and if operative fixation did not include a lateral-based distal femur locking plate. Plates that were used include the Polyax (DePuy Orthopaedic Inc, Warsaw, IN); Synthes (West Chester, PA); Less Invasive Stabilization System (LISS DF), Locking Condylar Plate, Variable Angle Locking Condylar Plate-first generation, Variable Angle Locking Condylar Plate-second generation; and Non-Contact Bridging Plate (Zimmer, Warsaw, IN). All surgeries were performed by 1 of 5 fellowship-trained traumatologists.

All patient radiographs were reviewed using Centricity Enterprise Web PACS (General Electric Healthcare, Milwaukee, WI). “Working length” of the plate construct was defined as the length from the most distal screw proximal to the fracture to the most proximal screw distal to the fracture measured in millimeters (mm). Plate manufacturers publish the plate length in millimeters and these lengths were used as radiographic markers to template actual working lengths to account for radiographic magnification differences. “Screw density” was defined as the length of the plate proximal to the fracture divided by the number of screws proximal to the fracture. Proximal screw mode refers to the type of screws used in the proximal segment (non-locking, locking, or hybrid). Hybrid mode refers to a proximal screw construct with a combination of locking and non-locking screws.

There were 2 primary endpoints: union without unplanned surgery and all eventual unions including those with unplanned surgeries. Fracture healing status was determined after a review of the attending physician’s clinical documentation and radiographic imaging. If there was a discrepancy, then one of the authors reviewed the final radiographs. Radiographic union was defined as at least 3 of 4 cortices with bridging callus on orthogonal plain radiographs. If there was any question of union, the radiographs were reviewed with one of the fellowship-trained orthopaedic surgeons. If union was inconclusive, it was considered to be a

nonunion. Unplanned surgeries were classified as all fracture healing surgeries that were not planned at the time of initial fracture management. Fractures with antibiotic spacers and secondary bone grafting procedures were considered planned surgeries.

These endpoints were correlated to patient age, sex, mechanism of injury, history of diabetes, history of nicotine use, open fracture type, the AO/Orthopaedic Trauma OTA Classification (33 A, B, C) [21,22], presence of a prosthesis, and metal alloy type. The primary endpoints were also correlated to working length, proximal screw density, proximal screw mode, and coronal plane alignment after fixation relative to 95°.

Statistical analysis included the Fisher exact test for comparative data and an odds ratio for significant differences. A *p*-value of <0.05 was considered statistically significant.

Results

Out of 180 patients identified, 96 patients met inclusion criteria and were evaluated. Patients were excluded for the following reasons: 22 fractures with absolute stability constructs with lag screw fixation, 21 patients died prior to union, 12 fractures treated with alternative fixation constructs (intramedullary nailing, medial and lateral plating), 4 partial articular fractures, 4 pathological fractures, 3 patients treated by surgeons who were not fellowship trained trauma surgeons, and 2 patients with simultaneous revision arthroplasty procedures. Another 16 patients were excluded due to a lack of clinical follow-up. The mean follow-up for patients was 584 days (range, 85–2119 days) and 88.5% (85) of patients either had a minimum one-year follow-up or were followed until fracture union.

During the follow-up period, 62 fractures (64.6%) healed without unplanned surgeries while 34 fractures (35.4%) were classified as nonunions. Twelve of thirty-four (35.3%) of the nonunions went on to heal after an additional unplanned fracture surgery. Twenty-two patients (22.9%) were classified as having recalcitrant nonunions. There were 24 males and 38 females with an average age of 60 who healed without additional intervention. Those patients with nonunions averaged 62 years of age and included 11 males and 23 females. Patients with a nonunion were more likely to be smokers (35.3% vs. 25.8%; *p*=0.36) and have an open fracture (35.3% vs. 27.4%; *p*=0.49). Nonunion patients were less likely to present with a periprosthetic fracture (20.6% vs. 35.5%; *p*=0.17) and more likely to present with an intra-articular distal femur fracture (33-C) (61.8% vs. 51.6%; *p*=0.39). There were no statistically significant differences in rate of fracture union between the cohorts when considering demographic and fracture characteristics (Table 1). Fall was the most common mechanism of injury (51.0%) followed by motor vehicle accident (35.4%) (Table 2).

Of the 96 fractures, 50 stainless steel plates (52.1%) and 46 titanium (47.9%) were used. There were 12 (12.5%) Polyax plates

Table 1
Demographic and fracture characteristics.

Parameter	Healed (N=65)	Non-union (N=34)	<i>P</i>
Age (range)	60 (16–96)	62 (29–97)	0.64
>65 years (%)	24 (38.7)	12 (35.3)	0.83
Sex	24M; 38F	11M; 23F	0.66
ASA (range)	3 (2–4)	3 (2–4)	0.42
DM (%)	18 (29.0)	9 (26.5)	1.00
Tobacco (%)	16 (25.8)	12 (35.3)	0.36
Open Fractures (%)	17 (27.4)	12 (35.3)	0.49
AO Classification			
A (%)	8 (12.9)	6 (17.6)	0.56
C (%)	32 (51.6)	21 (61.8)	0.39
Periprosthetic Fracture (%)	22 (35.5)	7 (20.6)	0.17

Table 2
Mechanism of injury.

Parameter	Healed (N = 62)	Non-Union (N = 34)	Total
Fall (%)	30 (48.4)	19 (55.9)	49 (51.0)
Motor Vehicle Accident (%)	23 (37.1)	11 (32.4)	34 (35.4)
Motorcycle Accident (%)	5 (8.1)	3 (8.8)	8 (8.3)
Other (%)	4 (6.5)	1 (2.9)	5 (5.2)

(DePuy Inc), 17 (17.7%) LISS plates (Synthes), 28 (29.2%) Locking condylar plates (Synthes), 17 (17.7%) first generation VA locking condylar plates, 5 (5.2%) second-generation VA locking condylar plates, and 17 (17.7%) NCB plates (Zimmer). Titanium plates were 1.6 times more likely to develop a nonunion, although this difference was not statistically significant (95% CI, 0.71; 3.8; $p=0.25$) (Table 2).

The type of proximal plate screw fixation technique did affect union rate. Hybrid proximal screw constructs were used in 52 fractures (54.2%), all locking screw constructs in 43 fractures (44.8%), and all non-locking construct in 1 fracture (1%). Thirty-nine of the 52 (75.5%) hybrid constructs and 22 of the 43 (51.2%) locking constructs healed without an unplanned surgery. All proximal locking screw constructs were 2.9 times more likely to develop nonunion (95% CI, 1.2; 7.0; $p=0.01$). The number of proximal screws and the number of proximal screw cortices were not associated with a significant difference in total union. The mean proximal screw density was 47.08 ± 12.63 mm. Proximal screw density (greater than or less than the mean) was not associated with a significant difference in union (Table 3).

Mean working length was $90.8 \text{ mm} \pm 38.6$ mm. When grouping fractures with working lengths greater or less than 90.5 mm, there was no significant difference between longer and shorter constructs relative to union ($p=0.36$). To investigate coronal plane alignment, fractures were grouped as to whether greater or less than 5° from 95° . Fifty-two fractures (54.2%) had alignment within 5° while 44 fractures (45.8%) had greater than 5° of malalignment. There was no significant difference in union rate when considering coronal plane alignment ($p=0.50$) (Table 3).

Discussion

Laterally-based pre-contoured locking plates have become the mainstay in treatment of distal femur fractures due to increased resistance to multi-planar forces about the knee and improved

fixation in osteoporotic bone [6,7]. Several studies indicate good to excellent results with lateral locked plates, with reported union rates ranging from 80% to 100% [8,23–26]. However, locking plates are not without fault and healing complications occur. Several studies cite concerns that locking plates are too stiff and do not allow induction of callus necessary for secondary bone healing [9,11,19,20].

The results of this study indicate that all proximal screw locking constructs were the most significant predictor of nonunion. Twenty-one of 43 fractures (48.8%) with all proximal locking screws developed a nonunion as compared to 13 of 52 fractures (25.0%) treated with hybrid proximal screw constructs. These fractures with all proximal locking screw constructs were 2.9 times more likely to develop nonunion ($p=0.01$). Previous studies have elaborated on the fact that in some instances locking plate constructs may be too stiff. Lujan et al. found 40% of fractures treated with locking plates had little or no callus formation [20]. While Zlowodzki et al. noticed that locking plates had an increased relative risk of fixation failures and secondary surgeries when compared to compression plating techniques [27]. In efforts to make locking constructs more flexible, far cortical locking (Zimmer, Warsaw, IN) was developed in order to reduce construct stiffness by 84% [28]. In a bovine model, Bottlang et al. found significantly more callus formation and increased torsional stiffness with far cortical locking when compared to standard locking constructs [28]. Early clinical studies indicate high union rates with far cortical locking, however long term comparative clinical studies are lacking [29,30].

Some studies further examine the characteristics associated with failure following lateral locked plating of distal femur fractures. Henderson et al. retrospectively reviewed 86 distal femur fractures treated with lateral locking plates. While bridge span length, plate length and bridge span to plate length ratio was not significantly associated with union, leaving the hole adjacent to the fracture open (without a screw) resulted in significantly more unions than nonunions [19]. Further, Rodriguez et al., reviewed 278 consecutive patients treated with lateral locked plating for distal femur fractures and found that obesity, open fractures, infection and stainless steel plates were risk factors for non-union [31]. Rodriguez et al. also retrospectively reviewed mechanical construct characteristics associated with union in a cohort of 270 supracondylar femur fractures treated with lateral locked plating. The authors determined that stainless steel plates were more likely to result in nonunion however, there were no difference with

Table 3
Patient device & fixation characteristics.

Parameter (n)	Healed (N = 62)	Non-Union (N = 34)	Odds Ratio (95% CI)	P
Plate Material				
Titanium (%)	27	19	1.6 (0.71; 3.8)	0.25
Stainless Steel (%)	35	15	0.61 (0.26; 1.4)	0.25
Proximal Screw Construct				
Locking (%)	22	21	2.9 (1.2; 7.0)	0.01
Hybrid (%)	39	13	0.37 (0.15; 0.86)	0.02
Non-locking (%)	1	0	0.59 (0.02; 15.0)	0.75
Working Length				
Short (<90.5 mm) (%)	37	17	0.67 (0.29; 1.6)	0.36
Long (>90.5 mm) (%)	25	17	1.5 (0.64; 3.4)	0.36
Coronal Alignment				
≥ 5 malalignment (%)	30	14	0.75 (0.32; 1.7)	0.50
Proximal Segment Screws				
>3 screws (%)	60	30	0.25 (0.04; 1.4)	0.51
Proximal Segment Cortices				
>6 cortices (%)	49	24	0.64 (0.24; 1.7)	0.36
Proximal Screw Density (PSD)				
≤ 42.2 (%)	20	13	1.3 (0.54; 3.1)	0.56
>47.2 (%)	28	14	0.85 (0.36; 2.0)	0.71

respect to number of proximal screws, proximal screw density or any other plate characteristics [32]. While none of the differences with respect to demographic factors in this study were deemed significant, patients with open fractures were more likely to develop a nonunion. We, however, did not see a difference when comparing implant materials. In an unpublished series of 109 distal femur fractures, Gaines et al. reported a significantly lower nonunion rate with titanium plates compared to stainless steel plates (7% vs 23%, $p=0.05$) [Gaines RJ; Unpublished 2008]. On the other hand, Henderson et al. reported more callus with titanium plates; there was no significant difference in union rates between titanium and stainless steel [11]. Our patients treated with titanium implants were actually more likely to experience a nonunion when compared to stainless steel implants. It appears that there may ultimately be numerous factors associated with nonunion. Further prospective work must be done to illuminate the demographic and mechanical characteristics most associated with this complication.

Numerous biomechanical studies describe how multiple different adaptations of locking or hybrid constructs can alter plate biomechanics strength, and flexibility [5,6,12–15]. Stoffel et al. found that leaving the hole adjacent to the fracture open reduced the plate construct stiffness in compression and torsion by 50% [12]. Hoffmeier et al. found that for stainless steel plates, increasing the working length only decreased construct stiffness by 10% at the longest working lengths. For titanium plates, surprisingly, increasing the working length increased the stiffness, but without statistical significance [16]. Lujan et al. reported that there was no significant difference in callus size between longer and shorter bridging spans at 12 and 24 month follow-up [20]. In our study, working lengths ranged from 21 mm to 190 mm with a mean working length of 90.8 mm. There was no significant difference in union rates with or without a secondary surgery between fracture constructs with longer versus shorter working lengths. With these mixed results, our understanding of how working length, plate stiffness and secondary fracture healing are associated may be more confusing than originally thought. But it appears that increasing the plate working length does not reliably increase union rates.

There are inherent limitations to our study. It is retrospective in nature with a heterogeneous population in regards to patient demographics, fracture patterns and plate-screw constructs. Each surgeon participating in this study was able to select the plate construct they deemed necessary for the fracture. Multiple implants were used with different variables, such as geometry and metallurgy, however all plates were anatomically contoured specifically for the treatment of distal femur fractures. These variables affect plate flexibility and therefore, potentially make comparisons of measurements, like working length, less accurate but ultimately these variations are slight. It is possible, that there was a selection bias with respect to implant selection, but the increased non-union rate seen in patients with titanium plates parallels what has been reported in other studies. Despite these challenges, we feel that the study conditions better mimic the real-world environment where there is a diverse patient population and surgeons with various preferences. We analyzed numerous independent variables to determine how they impacted fracture healing, however it is possible that other variables that were not considered may contribute to outcomes. The nonunion rate for patients in this study is higher than what has been previously reported in similar studies, however this can be attributed to the percentage of patients with open fractures included in this trial. Finally, of the 180 patients identified, only 96 were included in the final analysis. Due to our institutional referral patterns, many of our patients live greater than 2 h away from our campus and they often choose to attend follow up appointments at regional centers

closer to their residency. As a result, there are numerous challenges associated with maintaining follow up. However, our average follow-up was 584 days which contributes to the strength of our results. There is an interest in identifying factors associated with complications following lateral locked plating of distal femur fractures, therefore prospective studies with a more robust patient population may be necessary to better elucidate the factors associated with nonunion following lateral locked plating of distal femur fractures.

Conclusions

Our findings indicate that constructs with all proximal locking screws result in a significant increase in nonunion incidence. We were unable to find any other significant risk factors for nonunion when considering patient demographics, plate composition and mechanical construct characteristics. Future clinical studies comparing proximal non-locking, locking, hybrid and far cortical locking screws may be necessary to identify which construct provides the optimal healing environment for distal femur fractures.

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Conflict of interest statement

The following are disclosures for all authors in this manuscript:

William H. Harvin, MD

- Nothing to declare.

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Gregory J. Della Rocca, MD, PhD

- American Academy of Orthopaedic Surgeons: Committee member.
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