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Research Article

Interfragmentary lag screw and locking plate combination in simple distal femoral fractures: A finite element analysis

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ABSTRACT

Objective: The aim of this study was to evaluate the strength of the locking plate and lag screw construct that is applied in two different working lengths on the simple distal femur fracture model with a finite element analysis (FEA) method.

Methods: From the computerized tomography scan data of a 60-year-old healthy male, the AO/OTA 33A1-type fracture model was simulated; the fracture gap was stabilized with the models of locking plate construct with (groups C and D) or without an interfragmentary lag screw (groups A and B). Furthermore, 102-mm plate (groups A and C) and 82-mm plate working lengths (groups B and D) were tested using FEA. Two loading conditions (axial compression and torsion) were applied at the center of the femoral head. Construct stiffness, interfragmentary micromotion, and the peak von Mises stress (VMS) on the plate were assessed.

Results: Group D provided the highest axial stiffness (1347 N/mm), and group A was the weakest (439 N/mm). With the lag screw, shear micromotion remained generally low compared with that without the screw for all axial and torsional load levels and for both plate working lengths, i.e., 0.23 mm with lag screw versus 0.43 mm without lag screw (102 mm working length, 700 N). The percentage decreases of shear micromotion under axial (350/700/1400 N) and torsional loads for the 102-mm working length were >22% and 73%, respectively; while those for the 82-mm working length were >28% and 33%, respectively. The reduction of axial micromotion was observed with the lag screw for all axial load levels as well as for both plate working lengths, i.e., 0.33 mm with lag screw versus 0.87 mm without lag screw (102-mm working length, 700 N). The percentage decreases of axial micromotion under axial loading (350/700/1400 N) for 102 mm and 82 mm working lengths were >42% and 50%, respectively. The peak VMS on the plate stayed generally low with lag screw compared with without lag screw throughout all tested load levels, as well as for both plate working lengths, i.e., 124.26 MPa versus 244.39 MPa (102 mm working length, 700 N). The percentage decreases of the peak VMS under axial (350/700/1400 N) and torsional loads for the 102-mm working length were >40% and 69%, respectively, while those for the 82-mm working length were >47% and 61%, respectively.

Conclusion: The current FEA concludes that in a simple distal femur fracture, adding a lag screw to a locking plate construct provides better torsional stability with a 102-mm plate working length and better axial stability with a 82-mm plate working length. Additionally, the strength of the materials is increased and implant failure can be minimized by using this technique.

Introduction

Distal femoral fractures are severe, with an estimated frequency of 3%–6% of all femoral fractures (1, 2). This fracture is found in young patients commonly involved in high-energy injuries and in elderly patients with osteoporosis predominantly suffering from low-energy trauma (3).

Before locking plates were introduced, open reduction and internal fixation using conventional plates was considered as the gold standard for many years (4, 5). The combination of lag screws and conventional plates, accomplished the compression between fragments rigidly, however, required fairly extensive surgical approaches to the bones resulting in further damage to the soft tissue and eventual devascularisation of the fragments with high complication rates such as delayed union, nonunion, infection, and implant failure (6, 7). In recent years, the introduction of minimally invasive plate osteosynthesis (MIPO) with limited soft tissue exposure of the fracture zone and atraumatic insertion of a locking plate led to minimal surgical trauma and preserved the periosteal blood supply (8, 9). Locking plates, with fixed-angle screws, have improved the fixation strength of plate constructs compared with conventional plates, thus working best in comminuted metaphyseal fractures and osteoporotic bones (10).

In spite of these advantages, however, locking plates have also been associated with inconsistent and asymmetric callus formation (11). Owing to the increased stiffness under the plate, callus formation at the near cortex was reduced when compared with the far cortex (11). This is the reason why dynamic fixation concepts were applied to reduce the stiffness and create controlled interfragmentary motion for enhancing fracture healing (12, 13). However, in a clinical series of simple distal femoral fractures, Chung et al. demonstrated a faster radiologic union when using an interfragmentary lag screw in a locking plate construct (14). Although the internal fixation of fractures has changed from mechanical to biological priorities (8), some authors have questioned the philosophy of a relatively stable fixation (locking plate) for simple fractures (14-16). Complications such as malrotation

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and malalignment were reported in simple fractures when using indirect reduction techniques (17, 18), while obviously faster bone fracture healing was achieved when an additional lag screw was used (14, 15).

In order to promote fracture healing and overcome reported complications, an interfragmentary lag screw could be beneficial in simple fracture treatment together with a locking plate construct. In addition, different plate working lengths in between the nearest screw to the fracture side will influence the micromotion at the fracture site. The purpose of this study was to evaluate the strength of the locking plate and lag screw construct which was applied in two different working lengths on the simple distal femur fracture model with a finite element analysis (FEA) method. Two plate working lengths (102 mm and 82 mm) and two loading conditions (axial compression and torsion) would be applied. Construct stiffness, interfragmentary micromotion, and the peak von Mises stress (VMS) on the plate would be evaluated. The study hypothesis was that (1) adding a lag screw to a locking plate construct would enhance the strength of the materials and so implant failure could be minimized by this technique and (2) an additional screw to the 102-mm plate working length would have better stability compared with the 82-mm plate working length.

Materials and Methods

Volunteer and CT scan

This study was approved by the Ethics Committee of Shanghai Pudong New Area Peoples' Hospital (No. 2019-17). The volunteer signed the informed consent and then participated in the study. A 60-year-old healthy male (height: 172 cm; weight: 70 kg) was selected as the volunteer for this study. Standard radiographs were performed to exclude lower-extremity fractures, abnormities, and pathologic bone lesions, and his right lower extremity was scanned to obtain a set of slices by using computerized tomography (CT) (Philips Brilliance 64CT, Philips Healthcare, The Netherlands). The scan range was from the anterior superior iliac spine to the tibial tubercle. The scan parameters were as follows: 140 KV; 350 mAs; slice thickness, 1 mm; scanning interval, 0.5 mm. The Digital Imaging and Communications in Medicine (DICOM) data of 1196 layers were copied and recorded.

Finite element model

The DICOM data were input into the interactive medical image control system (Mimics) 14.0 software by Materialize (Materialize Company, Leuven, Belgium), and segmentation was performed on the CT images with different gray values of the volunteer's femur. Smoothing and creation of Non-Uniform Rational B-Spline (NURBS) were accomplished with the reverse engineering software Geomagic Studio 2015 (3D system Inc, Rock Hill, SC, USA). We then constructed the fracture model in the software to simulate AO/OTA 33A1-type fracture, which was established by creating a spiral gap (height: 50 mm) between the distal and proximal fragments 60 mm above the medial condyle (Figure 1).

The fracture gap was stabilized with the model of an 11-hole locking compression plate (Less Invasive Stabilization System, DePuy Synthes, Switzerland) according to the manufacturer's standard surgical technique using the software SolidWorks 2016 (Dassault Systemes, Concord, Massachusetts). The screws were modelled as solid elements, which was the most common method as published elsewhere (19, 20). In the control groups, assemblage of the plate/screws and bones was fulfilled using the software Geomagic Studio 2015. Seven 5.0-mm locking screws were placed in the distal fragment, and four bicortical standard 5.0-mm screws were inserted in the proximal fragment, two plate working length groups were simulated (group A: without a lag screw, a long working length of 102 mm; group B: without a lag screw, a short working length of 82 mm) as shown in Figure 2. a, b. In the interfragmentary lag screw groups, the fracture was stabilized by using a 4.5-mm lag screw at a 90° angle to the fracture line,

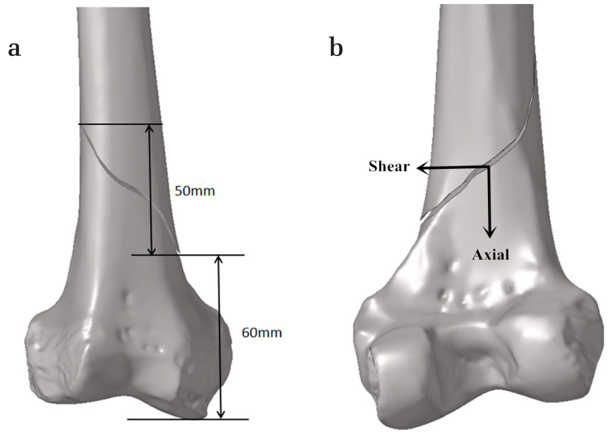
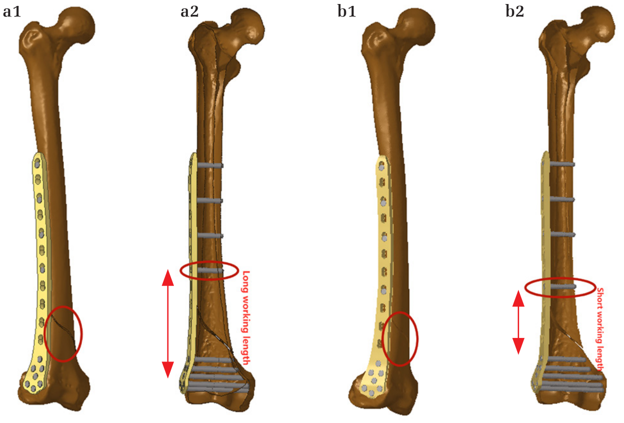
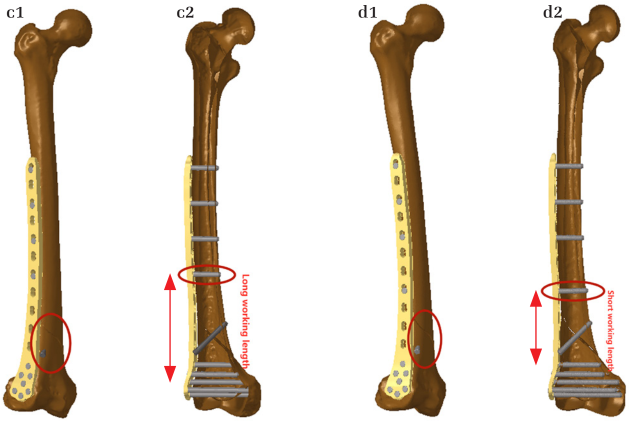


Figure 1. a, b. a) The front view of the fracture model (AO/OTA 33A1-type). b) The back view of the fracture model and the micromotion directions (axial, shear)



102 mm working length 82 mm working length



102 mm working length 82 mm working length

Figure 2. a-d. Groups with the long (A, C, 102 mm) and short (B, D, 82 mm) plate working length, and without interfragmentary lag screw (A, B) and with interfragmentary lag screw (C, D). Locking screws in the proximal fragment were placed in two different screw locations (11, 9, 7, 5 or 11, 9, 7, 4) A1) Oblique view of the assemblage model of the plate/screws and bones of group A. A2) Sectional view of the assemblage model of the plate/screws and bones of group A. B1) Oblique view of the assemblage model of the plate/screws and bones of group B. B2) Sectional view of the assemblage model of the plate/screws and bones of group B. C1) Oblique view of the assemblage model of the plate/screws and bones of group C. C2) Sectional view of the assemblage model of the plate/screws and bones of group C. D1) Oblique view of the assemblage model of the plate/screws and bones of group D. D2) Sectional view of the assemblage model of the plate/screws and bones of group D

and then the plate was inserted and fixed as a neutralization plate (group C: with a lag screw, a long working length of 102 mm; group D: with a lag screw, a short working length of 82 mm) as presented in Figure 2. c, d.

All the models were meshed using the software ANSYS Workbench 13 (ANSYS, Inc, Canonsburg, PA, USA), which was imported into construct the finite element models. All materials involved in the models were assigned to be homogeneous, isotropic, linear elastic material properties as reported by previous studies (19, 21). The elastic moduli were 16,800 and 620 MPa for the cortical bone and the cancellous bone, respectively. The Poisson's ratios were assumed to be 0.3 and 0.29, respectively. The plate and screws were made of titanium alloy (Ti-6Al-7Nb) with an elastic modulus of 110,000 MPa and a Poisson's ratio of 0.33 (21-23). Three-dimensional 10-node tetrahedral elements (solid 92) were applied to the finite element models (24, 25).

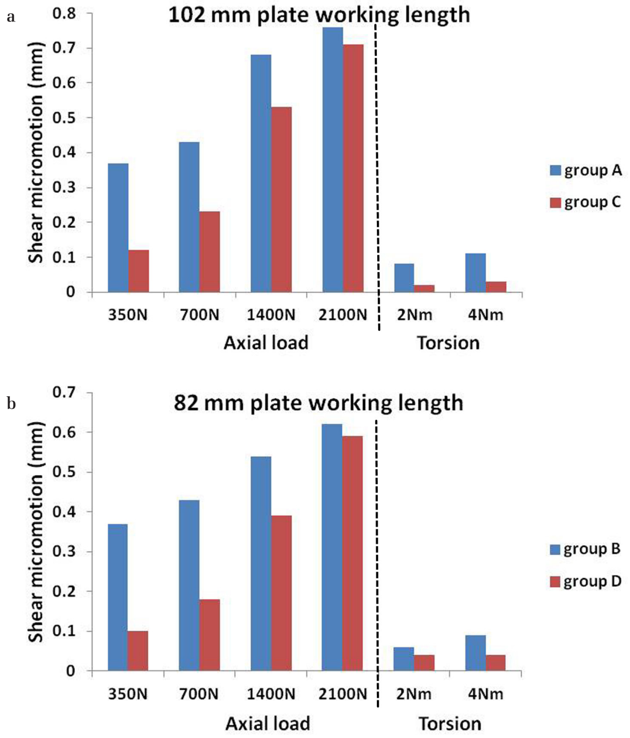


Figure 3. a, b. a) The shear micromotion with 102 mm plate working length for two loading tests (axial, torsion). b) The shear micromotion with 82 mm plate working length for two loading tests (axial, torsion)

Boundary and loading conditions

With regard to the boundary conditions, the degrees of freedom on the surface of the distal femur were fully constrained (26). The frictional interactions at all of the contact surfaces of the femur, except the fracture site, were assumed to be fully bonded; the screws were fully tied to the plate; the internal fixations were fully tied to the bone; the friction coefficient of 0.3 was used for bone-bone and bone-lag screw interaction (27). The angle of 15° between the axis of the femoral shaft and the body axis was selected for all models (25). The axial (350 N, 700 N, 1400 N and 2100 N) and torsional loads (2 Nm and 4 Nm) were applied to the center of the femoral head without considering the effects of various ligaments and muscles.

All of these analyses were performed by using the ANSYS Workbench 13 software. In this study, the strength of the materials was represented by construct stiffness, interfragmentary micromotion, and implant stress. The construct stiffness was defined as the ratio of the maximum vertical displacement of the femur to the applied 700 N axial load. The distances of 16 pairs of points at the midpoints and junctions along the fracture line of the proximal and distal fragments was analyzed, (28) and the interfragmentary micromotion (axial and shear; Figure 1b) was calculated according to the average distance change of points after load bearing. The peak VMS on the plate was also assessed.

Results

Model validation

To validate our FEA models, the shear interfragmentary micromotion of the 102-mm plate working length was compared with that in a cadaveric study (29). In their study, the fresh frozen femoral cadaveric specimens were fixed by the 9-hole locking plate and three proximal locking screws with or without a lag screw. The results of shear micromotion in our FEA model were agreeable with the cadaveric study. Both results showed that the shear micromotion was reduced with a lag screw, and the trends were similar (Figure 3a). The small disparities may be due to the variations of osteotomy and implant fixation.

Construct stiffness

Group D provided the highest axial stiffness (1347 N/mm), followed by group C (1035 N/mm) and group B (460 N/mm), and group A was the weakest (439 N/mm). The construct stiffness of group D was 66% higher than that of group B (82-mm working length), and group C was 58% better than group A (102-mm working length).

Shear micromotion

The shear micromotion remained generally low with a lag screw compared with without a lag screw for all axial and torsional load

Table 1. The interfragmentary micromotion (mm) for two plate working lengths with or without lag screw

Load		Group A	Group B	Group C	Group D
350 N	Shear micromotion	0.37	0.37	0.12	0.10
	Axial micromotion	0.69	0.69	0.17	0.13
700 N	Shear micromotion	0.43	0.43	0.23	0.18
	Axial micromotion	0.87	0.83	0.33	0.24
1400 N	Shear micromotion	0.68	0.54	0.53	0.39
	Axial micromotion	1.29	1.01	0.75	0.51
2100 N	Shear micromotion	0.76	0.62	0.71	0.59
	Axial micromotion	1.48	1.15	1.05	0.80
2 Nm	Shear micromotion	0.08	0.06	0.02	0.04
	Axial micromotion	0	0	0.02	0.03
4 Nm	Shear micromotion	0.11	0.09	0.03	0.04
	Axial micromotion	0	0	0.03	0.04

Group A, long working length (102 mm) without lag screw; Group B, short working length (82 mm) without lag screw; Group C, long working length (102 mm) with lag screw; Group D, short working length (82 mm) with lag screw

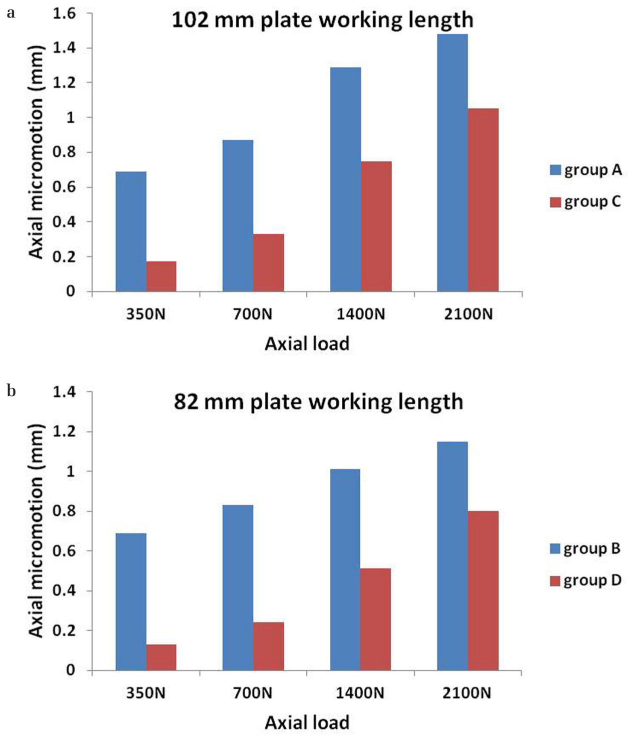


Figure 4. a, b. a) The axial micromotion with 102 mm plate working length for the axial loading. b) The axial micromotion with 82 mm plate working length for the axial loading

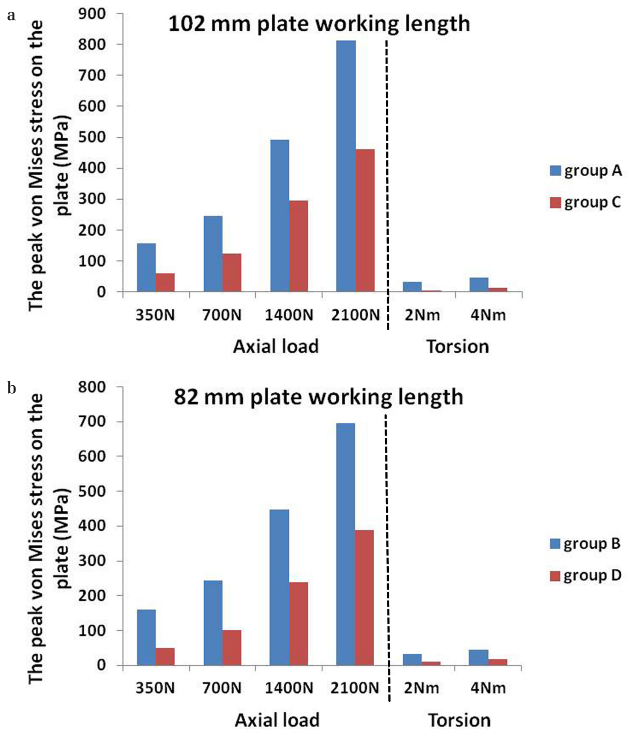


Figure 5. a, b. a) The peak von Mises stress (VMS) on the plate with 102 mm plate working length for two loading tests (axial, torsion). b) The peak VMS on the plate with 82 mm plate working length for two loading tests (axial, torsion)

Table 2. The peak Von Mises Stress (MPa) on the plate for two plate working lengths with or without lag screw

Load	Group A	Group B	Group C	Group D
350 N	157.04	160.27	59.27	48.14
700 N	244.39	243.30	124.26	100.43
1400 N	492.69	448.32	294.25	237.53
2100 N	811.86	695.26	461.24	389.22
2 Nm	32.58	31.42	5.53	9.16
4 Nm	45.40	44.08	13.97	17.24

Group A, long working length (102 mm) without lag screw; Group B, short working length (82 mm) without lag screw; Group C, long working length (102 mm) with lag screw; Group D, short working length (82 mm) with lag screw

levels, and for both plate working lengths (Figure 3. a, b; Table 1), i.e., 0.23 mm with a lag screw versus 0.43 mm without a lag screw (102 mm working length, 700 N). The percentage decreases of the shear micromotion under axial (350/700/1400 N) and torsional loads for the 102-mm plate working length (groups A and C) were >22% and 73%, respectively, while those for the 82-mm plate working length (groups B and D) were >28% and 33%, respectively. The percentage decrease of the shear micromotion under the 2100 N axial load was similar for both the plate working lengths.

Axial micromotion

With a lag screw, reduction of the axial micromotion was observed for all axial load levels compared to without screw, as well as for both plate working lengths (Figure 4; Table 1), i.e., 0.33 mm with a lag screw versus 0.87 mm without a lag screw (102 mm working length, 700 N). However, for the torsional loading, the lag screw plays a minor role in axial movement for both plate working lengths. The percentage decreases of the axial micromotion under axial loading (350/700/1400 N) for the 102-mm and 82-mm plate working lengths were >42% and 50%, respectively; the percentage decrease of the axial micromotion under the 2100 N axial load was similar for both the plate working lengths.

Implant stress

The peak VMS on the plate stayed generally low with a lag screw compared with without a lag screw throughout all tested load levels, as well as for both plate working lengths (Figure 5; Table 2). The peak VMS of the implant was concentrated on the plate around the fracture site in the group without the screw. Whereas in the group with the screw, the peak VMS occurred at the lag screw around the fracture site, and the stress on the plate was obviously reduced, i.e., 124.26 MPa with a lag screw versus 244.39 MPa without lag screw (102 mm working length, 700 N, Figure 6). With a lag screw, the percentage decreases of the peak VMS on the plate under axial (350/700/1400 N) and torsional loads for the 102-mm plate working length were >40% and 69%, respectively, while those for the 82-mm plate working length were >47% and 61% respectively; the percentage decrease of the peak VMS under the 2100 N axial load was similar for both the plate working lengths.

Discussion

Currently, locking plates together with MIPO techniques are the preferred implant options for internal fixation of distal femoral fractures with advantages of excellent fracture stability, improved biomechanical performance, and less damage to vascularity of the fracture site and soft tissue (8, 9, 30, 31). The concept of relatively stable fixation benefits from interfragmentary gap motion with increased callus formation is well accepted for almost all fracture patterns nowadays (32). However, many authors found that interfragmentary gaps in simple distal femoral fractures (i.e., AO/OTA 33A1-, 33A2-, 33C1-type fractures) using indirect reduction techniques are difficult to control, and eventually some gap remains resulting in a delay in fracture healing (17, 18, 33). Some trauma and biomechanical experts have questioned the strict separation of the philosophy of relatively and absolutely stable fixation for simple fractures, and an interfragmentary lag screw plus a locking plate is used for the treatment of simple

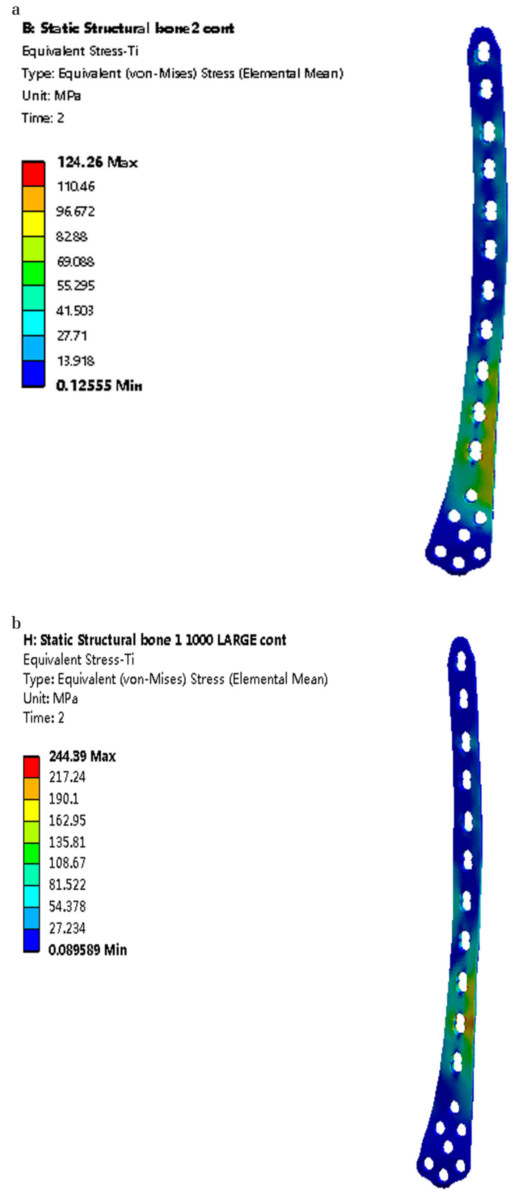


Figure 6. a, b. The stress nephogram of the plate with 102 mm plate working length under 700 N axial load. a) The peak VMS on the plate with lag screw was 124.26 MPa. b) The peak VMS on the plate without lag screw was 244.39 MPa

fracture patterns in clinical trials although being partially contradictory to the principle of secondary fracture healing (14-16, 29, 34-36). It is believed that if a fracture is fixed with a lag screw, anatomical reduction and absolutely stable fixation should be gained to enable primary fracture healing. However, Märdian et al. apparently demonstrated that a lag screw plus a locking plate did not decrease interfragmentary movement at the fracture zone to a level of absolutely stable fixation at the distal femur in simple fracture patterns, while shear movements were diminished to a level of allowing fracture healing (29). Furthermore, Horn et al. confirmed secondary fracture healing through the existence of callus formation when using an interfragmentary lag screw together with a locking plate in a clinical trial (15). Similarly, Plecko et al. observed the presence of callus formation as a sign of secondary bone healing while using a lag screw and a locking plate construct in a sheep model (16). Nevertheless, the amount of callus might be smaller and quicker remodeling might be found compared with a sole locking plate construct (15, 16). Therefore, an additional lag screw does not necessarily assure absolutely stable fixation, the existence of callus formation could be observed, although this might be regarded as contrary to established philosophies.

The results of our study clearly demonstrate that adding a lag screw to a locking plate construct could increase the strength of the materials in a simple fracture model. To decrease the risk of implant failure, the maximum stress on the plate should be as low as possible. The lag screw has a great effect on the peak value of VMS. With a lag screw, some stress was dispersed by the interfragmentary lag screw. As a result, the stress on the plate dramatically declined. Additionally, the lag screw reduced interfragmentary movement at the fracture zone, especially the harmful shear micromotion, which might aid in faster fracture healing. We observed that the percentage decreases of the shear micromotion and the peak stress on the plate were more obviously reduced when adding a lag screw to the 102-mm plate working length for the torsional loading, while the lag screw played a more important role in reducing fracture micromotion and implant stress for the 82-mm plate working length under axial loading (350/700/1400 N). Our results support the hypothesis that adding a lag screw to the 102-mm plate working length could have better stability for the torsional loading, but an additional screw to the 82-mm plate working length would be more stable for the axial loading.

There is agreement that an interfragmentary lag screw in a locking plate construct of simple fracture patterns can provide greater fixation stability. Our results are compatible with the biomechanical study of Märdian et al. who demonstrated that the insertion of a lag screw combined with a locking plate construct had biomechanical advantages compared with a bridging plate construct pertaining to axial and torsional stiffness at the distal femur in simple fracture patterns, thus increasing stability, leading to a faster union (34). A similar biomechanical study of Märdian et al. also showed that interfragmentary movement was decreased with a lag screw, especially for longer plate working lengths and concluded that an interfragmentary lag screw next to a locking plate diminished detrimental shear movements at the fracture site, while preserving micromotion which is necessary for secondary fracture healing (29). In a sheep osteotomy model, Epari et al. clearly proved that high shear stiffness together with axial stiffness provided excellent fracture healing, the results of which were in concordance with the data of Elkins et al. who demonstrated that shear was associated with lesser callus formation (37, 38). In another in vivo study in sheep, Plecko et al. compared five different osteosynthesis configurations with locking compression plates simulating simple fracture patterns, and the results suggested that an interfragmentary lag screw plus a locking compression plate did demonstrate the highest stiffness values in biomechanical testing and lower values for the bridging plate construct (16). Moreover, the most endosteal callus formation with the constant values of all tested groups was found in the interfragmentary lag screw group at week 6.

Recent studies have found that the combined use of an interfragmentary lag screw together with a locking plate might achieve faster fracture healing in simple fracture patterns. In a retrospective study, Horn et al. reported that in simple distal tibial fractures, the time to full weight bearing was significantly shorter in the interfragmentary lag screw group than that in the sole bridge plating group (11.38 vs. 14.9 weeks, p=0.044), although the callus index at full weight bearing was obviously lesser in patients with a screw compared with those without (15). Similar prospective data of Yang et al. also observed that in distal tibia fractures using the MIPO technique, the time for initial callus formation and radiologic union was significantly shorter with an additional screw compared with without a screw (58.0 vs. 76.8 days, p=0.044; 258.7 vs. 409 days, p=0.002, respectively) (35). Moreover, the rate of clinical union at 12 months was significantly higher in the screw group than in the group without the screw (p=0.0063). Consequently, four patients who had simple fractures (33-A1, A2) without an additional screw developed nonunion, while none of the patients in the screw group were diagnosed with delayed union or nonunion (p<0.001). The results were in concordance with the data of Chung et al. who conducted a retrospective analysis in simple distal femur fractures (AO/OTA 33A1-, 33A2-, 33C1-type fractures) and found that a faster radiologic union was achieved when an interfragmentary screw was used (25 vs. 30 weeks, p=0.006) (14). In addition, five developed malalignment (p=0.021), and the union rate at 12 months was dramatically slower in the conventional MIPO group (p=0.002). The adverse events as malalignment and malunion have been attributed to indirect reduction techniques (10, 32). Therefore using interfragmentary screws to reduce the fracture gap is considered to be helpful in achieving a more rapid union. Another study using absolute (lag screw and neutralization plate) or relative stability (bridge plate) in MIPO of simple tibia fractures was analyzed (36), and the authors found that the median time to radiological fracture union was significantly shorter when using a lag screw plus a locking plate (19 vs. 27 weeks, p=0.04), which led the authors to conclude that the usage of a lag screw in simple fractures promoted faster radiologic fracture healing without an increase in complications or number of revisions compared with bridge plating.

According to the strain theory of Perren (8), the amount of mobility allowed depends on the relation of the width of the fracture gap and displacement. According to this rule, biological internal fixation in simple fracture patterns seemed controversial since simple fractures must bear the full displacement. Thus, it is advisable to reduce the fracture gap in simple fracture patterns in order to maintain the strain under critical values, which is favorable for fracture healing. Many surgeons found that the fracture gap in simple fractures requires a relatively longer time for bone healing than that in multi-fragmental fractures (14, 15). Additionally, the findings of clinical practice have emphasized the importance of an interfragmentary lag screw in a locking plate construct for simple fracture patterns (14, 15, 35, 36). The lag screw can either be placed through the plate or outside the plate. Cottom et al. biomechanically compared a locking plate with an intraplate compression screw versus the same locking plate with a plantar interfragmentary screw in a cadaveric study and observed that the mean ultimate load was statistically greater in the free interfragmentary screw group than that in the intraplate screw group (383.2 vs. 205.5 N, p=0.027), and thus, the author came to the conclusion that the free interfragmentary compression screw apparently increased stability, and the construct might decrease the incidence of nonunion and allow patients to bear weight faster postoperatively in Lapidus arthrodesis (39).

In treating simple distal femoral fracture using MIPO techniques, it is well accepted that the fracture is reduced first using a reduction method and screw, then the plate is inserted and fixed. There are various reduction methods such as manual traction, skeletal traction using pins, external fixation technique, the joystick technique, and a reduction clamp technique. In a retrospective study, Chung et al. used a collinear reduction clamp to reduce fracture gaps, and the fracture gap reduction was sustained by a positional screw (14). Our reduction methods are in concordance with Wenger et al. who showed that the fracture was reduced by percutaneous or mini-open reduction using a pointed reduction clamp, then a percutaneous lag screw was inserted (36). There was no significant difference observed in the time to radiological union and the time to full weight bearing (17 vs. 19 weeks; 10 vs. 11 weeks, respectively) between the two methods, which lead the authors to conclude that if a percutaneous reduction is impracticable for the insertion of a lag screw, a mini-open approach does not lead to a delay in fracture healing.

One must keep in mind that in some elderly patients with osteoporotic bones, the lag screw could not achieve effective compression between the fragments and thus an additional lag screw would not be recommended in this situation. However, in most cases (14-16, 29, 34-36), biomechanical investigations and clinical data support the argument that an additional screw plus a locking plate is favorable for simple fractures and may lead to faster fracture healing.

Our study has several limitations. The FEA is based on the CT data of only one healthy volunteer; although this subject was carefully chosen and can be regarded as representative regarding age and bone quality, it is a clear limitation of this study. In addition, the forces and contributions of ligaments and muscles were ignored because of the difficulty in establishing and assessing the fracture model. In fact, it is a very simplified model. Finally, we adopted a static and simplified loading simulation, which is not the most advanced loading analysis; therefore, more complex loading and boundary conditions should be investigated. However, our model has proven to be effective in performing FEA between the two distal femoral fracture patterns.

In this study, locking plate constructs with or without an interfragmentary lag screw was applied in the AO/OTA 33A1-type fracture models using FEA. It was found that the combination of an interfragmentary lag screw and a locking plate can provide greater stability, demonstrate less stress distribution, and withstand lower deformation in the simple distal femoral fracture patterns. Our data also showed that adding a lag screw to the 102-mm plate working length could have better stability for torsional loading, but an additional screw to the 82-mm plate working length would be more stable for the axial loading. These findings of FEA might be a solution to improve fracture healing problems as delayed union or malunion when locking plates together with MIPO techniques are performed in simple fracture patterns.

In conclusion, the current FEA concludes that in a simple distal femur fracture adding a lag screw to a locking plate construct provides a better torsional stability with the 102-mm plate working length and a better axial stability with the 82-mm plate working length. Additionally, the strength of the materials is increased, and implant failure can be minimalized by using this technique.

Ethics Committee Approval: Ethics committee approval was received for this study from the Ethics Committee of Shanghai Pudong New Area Peoples' Hospital (No. 2019-17).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

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References

1. Court-Brown CM, Caesar B. Epidemiology of adult fracture: A review. Injury 2006; 37: 691-7. [Crossref]
2. Marsh JL, Slongo TF, Agel J, et al. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma 2007; 21: S1-S133. [Crossref]
3. Ehlinger M, Ducrot G, Adam P, Bonnomet F. Distal femur fractures. Surgical techniques and a review of the literature. Orthop Traumatol Surg Res 2013; 99: 353-60. [Crossref]
4. Egol KA, Kubiak EN, Fulkerson E, Kummer FJ, Koval KJ. Biomechanics of locked plates and screws. J Orthop Trauma 2004; 18: 488-93. [Crossref]

5. Claes L. Biomechanical principles and mechanobiologic aspects of flexible and locked plating. J Orthop Trauma 2011; 25: S4-S7. [Crossref]
6. Krettek C, Muller M, Miclau T. Evolution of minimally invasive plate osteosynthesis (MIPO) in the femur. Injury 2001; 32: SC14-SC23. [Crossref]
7. Tan SLE, Balogh ZJ. Indications and limitations of locked plating. Injury 2009; 40: 683-91. [Crossref]
8. Perren SM. Evolution of the internal fixation of long bone fractures. The scientific basis of biological internal fixation: choosing a new balance between stability and biology. J Bone Joint Surg Br 2002; 84: 1093-110. [Crossref]
9. Weight M, Collinge C. Early results of the less invasive stabilization system for mechanically unstable fractures of the distal femur (AO/OTA types A2, A3, C2 and C3). J Orthop Trauma 2004; 18: 503-08. [Crossref]
10. Ehlinger M, Adam P, Abane L, Arlettaz Y, Bonnomet F. Minimally-invasive internal fixation of extra-articular distal femur fractures using a locking plate: tricks of the trade. Orthop Traumatol Surg Res 2011; 97: 201-05. [Crossref]
11. 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: 156-62. [Crossref]
12. Gardner MJ, Nork SE, Huber P, Krieg JC. Stiffness modulation of locking plate constructs using near cortical slotted holes: a preliminary study. J Orthop Trauma 2009; 23: 281-7. [Crossref]
13. Linn MS, McAndrew CM, Prusaczyk B, Brimmo O, Ricci WM, Gardner MJ. Dynamic locked plating of distal femur fractures. J Orthop Trauma 2015; 29: 447-50. [Crossref]
14. Chung JY, Cho JH, Kweon HJ, Song HK. The use of interfragmentary positional screw in minimally invasive plate osteosynthesis for simple distal femur fractures in elderly patients: A retrospective, single-centre pilot study. Injury 2016; 47: 2795-9. [Crossref]
15. Horn C, Dobele S, Vester H, Schäffler A, Lucke M, Stöckle U. Combination of interfragmentary screws and locking plates in distal meta-diaphyseal fractures of the tibia: a retrospective, single-centre pilot study. Injury 2011; 42: 1031-7. [Crossref]
16. Plecko M, Lagerpusch N, Pegel B, et al. The influence of different osteosynthesis configurations with locking compression plates (LCP) on stability and fracture healing after an oblique 45 degrees angle osteotomy. Injury 2012; 43: 1041-51. [Crossref]
17. Strauss EJ, Schwarzkopf R, Kummer F, Egol KA. The current status of locked plating: the good, the bad, and the ugly. J Orthop Trauma 2008; 22: 479-86. [Crossref]
18. Henderson CE, Kuhl LL, Fitzpatrick DC, Marsh JL. Locking plates for distal femur fractures: is there a problem with fracture healing? J Orthop Trauma 2011; 25: S8-S14. [Crossref]
19. Cegonino J, Garcia Aznar JM, Doblare M, Palanca D, Seral B, Seral F. A comparative analysis of different treatments for distal femur fractures using the finite element method. Comput Methods Biomech Biomed Engin 2004; 7: 245-56. [Crossref]
20. Cheng HY, Lin CL, Lin YH, Chen ACY. Biomechanical evaluation of the modified double-plating fixation for the distal radius fracture. Clin Biomech (Bristol, Avon) 2007; 22: 510-7. [Crossref]
21. Kobayashi E, Wang TJ, Doi H, Yoneyama T, Hamanaka H. Mechanical properties and corrosion resistance of Ti-6Al-7Nb alloy dental castings. J Mater Sci Mater Med 1998; 9: 567-74. [Crossref]
22. Sitthiseripratip K, Van Oosterwyck H, Vander Sloten J, et al. Finite element study of Trochanteric gamma nail for trochanteric fracture. Med Eng Phys 2003; 25: 99-106. [Crossref]
23. Tang F, Zhou Y, Zhang W, et al. All-polyethylene tibial components in distal femur limb-salvage surgery: a finite element analysisbased on promising clinical outcomes. J Orthop Surg Res 2017; 12: 57. [Crossref]
24. Wieding J, Souffrant R, Fritsche A, Mittelmeier W, Bader R. Finite element analysis of osteosynthesis screw fixation in the bone stock: an appropriate method for automatic screw modeling. PLoS One 2012; 7: e33776. [Crossref]
25. Mei J, Liu S, Jia G, Cui X, Jiang C, Ou Y. Finite element analysis of the effect of cannulated screw placement and drilling frequency on femoral neck fracture fixation. Injury 2014; 45: 2045-50. [Crossref]
26. Shih KS, Hsu CC, Hsu TP. A biomechanical investigation of the effects of static fixation and dynamization after interlockingfemoral nailing: a finite element study. J Trauma Acute Care Surg 2012; 72: E46-E53. [Crossref]
27. Chen WP, Tai CL, Shih CH, Hsieh PH, Leou MC, Lee MS. Selection of fixation devices in proximal femur rotational osteotomy: clinical complications and finite element analysis. Clin Biomech (Bristol, Avon) 2004; 19: 255-62. [Crossref]
28. Chen SH, Chiang MC, Hung CH, Lin SC, Chang HW. Finite element comparison of retrograde intramedullary nailing and locking plate fixation with/without an intramedullary allograft for distal femur fracture following total knee arthroplasty. Knee 2014; 21: 224-31. [Crossref]
29. Märdian S, Schmölz W, Schaser KD, Duda GN, Heyland M. Locking plate constructs benefit from interfragmentary lag screw fixation with decreased shear movements and more predictable fracture gap motion in simple fracture patterns. Clin Biomech (Bristol, Avon) 2019; 70: 89-96. [Crossref]
30. Kubiak EN, Fulkerson E, Strauss E, Egol KA. The evolution of locked plates. J Bone Joint Surg Am 2006; 88: 189-200. [Crossref]
31. Wähnert D, Hoffmeier K, Fröber R, Hofmann GO, Mückley T. Distal femur fractures of the elderly--different treatment options in a biomechanical comparison. Injury 2011; 42: 655-9. [Crossref]
32. Döbele S, Gardner M, Schröter S, Höntzsch D, Stöckle U, Freude T. DLS 5.0--the biomechanical effects of dynamic locking screws. PLoS One 2014; 9: e91933. [Crossref]
33. Ehlinger M, Adam P, Arlettaz Y, et al. Minimally-invasive fixation of distal extra-articular f femur fractures with locking plates: limitations and failures. Orthop Traumatol Surg Res 2011; 97: 668-74. [Crossref]
34. Märdian S, Schmölz W, Schaser KD, Duda GN, Heyland M. Interfragmentary lag screw fixation in locking plate constructs increases stiffness in simple fracture patterns. Clin Biomech (Bristol, Avon) 2015; 30: 814-9. [Crossref]
35. Yang KH, Won Y, Kang DH, Oh JC, Kim SJ. Role of appositional screw fixation in minimally invasive plate osteosynthesis for distal tibial fracture. J Orthop Trauma 2015; 29: e331-5. [Crossref]
36. Wenger R, Oehme F, Winkler J, Perren SM, Babst R, Beeres FJP. Absolute or relative stability in minimal invasive plate osteosynthesis of simple distal meta or diaphyseal tibia fractures? Injury 2017; 48:1217-23. [Crossref]
37. Epari DR, Kassi JP, Schell H, Duda GN. Timely fracture-healing requires optimization of axial fixation stability. J Bone Joint Surg Am 2007; 89:1575-85. [Crossref]
38. Elkins J, Marsh JL, Lujan T, et al. Motion predicts clinical callus formation: construct-specific finite element analysis of supracondylar femoral fractures. J Bone Joint Surg Am 2016; 98: 276-84. [Crossref]
39. Cottom JM, Rigby RB. Biomechanical comparison of a locking plate with intraplate compression screw versus lockingplate with plantar interfragmentary screw for Lapidus arthrodesis: a cadaveric study. J Foot Ankle Surg 2013; 52: 339-42. [Crossref]