Additional fixation of medial plate over the unstable lateral locked plating of distal femur fractures: A biomechanical study

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A B S T R A C T

Introduction: Lateral locked plating is a standard treatment option for distal femur fractures. However, the unstable conditions after lateral locked plating are increasing. The objective of this study was to investigate the biomechanical strength of additional medial plate fixation over the unstable lateral locked plating of distal femur fractures.
Materials and methods: A distal femur fracture model (AO/OTA 33-A3) was created with osteotomies in the composite femur. Three study groups consisting of 6 specimens each were created for single-side lateral locked plating with 6 distal locking screws (LP-6), single-side lateral locked plating with 4 distal locking screws (LP-4), and additional medial locked plating on LP-4 construct (DP-4). A compressive axial load (10 mm/min) was applied in the failure test. Mode of failure, load to failure, and ultimate displacement were documented.
Results: All single-side lateral locked plating (LP-4 and LP-6) showed plate bending at the fracture gap, while none of the DP-4 showed plate bending at the fracture gap. Load to failure of DP-4 (mean 5522 N) was 17.1% greater than that of LP-6 (mean 4713.3 N, $p < 0.05$) and 29.2% greater than that of LP-4 (mean 4273.2 N, $p < 0.05$). Ultimate displacement of DP-4 (mean 5.6 mm) was significantly lower than that of LP-6 (mean 8.8 mm, $p < 0.05$) and LP-4 (mean 9.1 mm, $p < 0.05$).
Conclusions: Additional fixation of medial plate significantly increased the fracture stability in distal femur fractures fixed with the lateral locked plating. Especially in the clinical situations where sufficient stability cannot be provided at the distal segment, the medial plate may be considered as a useful biomechanical solution to obtain adequate stability for fracture healing.

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1 Introduction

Distal femur fractures represent 6% of all femur fractures, [1,2] which commonly require surgical procedures to gain optimal functional outcome. Lateral plating has been the standard operation procedure for distal femur fractures, which permits the stable fixation construct and fracture healing. With the advancement of technology, the locked plate improved the biomechanical stiffness of angle stable construct compared to conventional implants [3,4], allowing for early knee motion as well as mobilization of patient. Furthermore, as it is usually performed with minimally invasive plate osteosynthesis (MIPO), fracture healing has been further optimized [5,6]. From these new improvements, nonunion of the distal femur fractures are not common [3].

However, there are several types of fractures that may be deprive the biomechanical stability after lateral locked plating, and may eventually result in nonunion of distal femur fractures. In young patients, these fractures usually result from high-energy injuries, and they frequently associate with severe comminution of the metaphyseal area, extended fracture into the articular surface, and substantial soft tissue injury. In complex articular fractures of coronal and sagittal extensions, the stable fixation may not be achieved with only the lateral locked plating, because the pre-inserted screws to fix the articular fractures hinder subsequent screws from the main implant of the lateral plate. Furthermore, in extremely comminuted fractures of the metaphyseal area, the increased fracture gap may result in an unstable fixation construct. Although fractures in older patients are mainly from low-energy injuries, the poor bone quality from osteoporosis may obstruct the sufficient stability at the distal segment even with

locking screws. [2] Recently, peri-prosthetic fractures around the knee have been reported more in elderly patients, especially on the femoral side [7]. As the fracture continues around the prosthetic implant, the remaining small bone stock extremely limits the fixation of screws at the condylar area, and may result in subsequent instability, which is worsened by the poor bone quality of cancellous condyles. Therefore, the fracture pattern, osteoporosis, and associated knee arthroplasty may result in unexpected and insufficient stability in the single-side lateral fixation of the locked plate. Therefore, these fractures may result in nonunion, mal-union, and implant failures, which require revision surgery and resultant inferiority of knee function [8,9].

As the unfavorable conditions with instability after lateral locked plating are increasing, a solution is needed to increase the stiffness of the fixation construct as well as optimal fracture healing. Recently, double plating of distal femur fractures has been used with good radiological and functional outcomes, which consists of the current lateral plating technique with an additional fixation of the medial plate. [8,10,11] However, various types of medial plates have been clinically used, including different sizes of screw diameter and plate length, which are not sufficient for evaluating the effect of biomechanical stability. There have been several biomechanical evaluation studies in the fixation of distal femur fractures to identify an optimal stable construct after fixation. However, most of the studies were performed by considering the fixation stability between locked plate and retrograde nail. Furthermore, studies on the biomechanical difference between the constructs with double plating and single-side lateral plating are lacking, although it has been assumed that the medial plate may add the stiffness. Moreover, the specific conditions of insufficient stability in the segment of distal femur have yet to be considered through biomechanical experiments.

Therefore, this biomechanical study was performed to investigate whether additional fixation of the medial plate may increase the biomechanical stability under circumstances of insufficient stability, which are fractures fixed with limited screw numbers at distal parts of the lateral plate.

2 Materials and methods

Eighteen left-sided composite femurs (Pacific Research Laboratories, Inc, WA, USA) were used and randomized into 3 groups. The femur was 455 mm in length, the intramedullary (IM) canal was 13 mm in diameter, and the neck shaft angle was 135°. The composite bone model was chosen to minimize the difference and to maintain uniformity and similarities between specimens. In every model, the plates were first fixed with screws at the same locations, and then the fracture gap was generated using an electric saw to produce a consistent model of the fixation construct. To simulate the metaphyseal comminution of the distal femur (AO/OTA type 33-A3), an osteotomy was performed to create a fracture gap of 2.5 cm, at 6 cm proximal from the distal articular surface of the femur model.

2.1 Specimens and instrumentation

The specimens were classified to three groups according to the fixation methods and consideration of stability after fixation. In each group, six specimens were generated with the following consistent methods: 1) single-side lateral locked plating with 6 distal locking screws (LP-6 group), which represented the current standard fixation of distal femur fractures with sufficient screw numbers; 2) single-side lateral locked plating with 4 distal locking screws (LP-4 group), which represented insufficient stability with limited screw numbers; and 3) additional medial plating on the LP-4 construct (double plating; DP-4 group), which represented the improved construct of stability over insufficiently stabilized fractures.

2.2 Single-side lateral locked plating with 6 distal locking screws (LP-6 group)

The specimen was laterally fixed with a 11-hole locking compression plate-distal femur (LCP-DF®, DePuy-Synthes, Zuchwil, Switzerland) by using the currently used method for achieving relative stability. [12] At the distal part of the locked plate, six screws (length, 70–75 mm) were fixed, except for the most proximal hole among the 7 holes. At the proximal segment above the fracture gap, four screws (length, 38–40 mm) were bicortically fixed at hole numbers 1, 4, 7, and 9 from the proximal end. Then, an osteotomy was performed as previously described (Fig. 1a).

2.3 Single-side lateral locked plating with 4 distal locking screws (LP-4 group)

Similar to the LP-6 mode, the specimen was laterally fixed with LCP-DF. However, at the distal part of the locked plate, 4 screws (length, 70–75 mm) were fixed except at 3 proximal holes. This
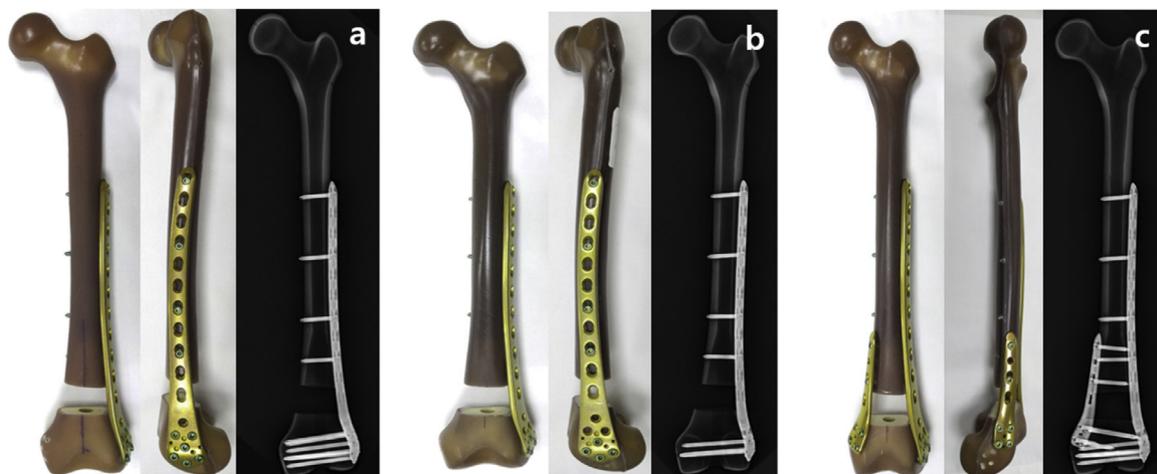

Fig. 1. Three different constructs of the distal femur fracture model with a 2.5 cm gap osteotomy and the radiographs; (a) Single-side lateral locked plating with 6 distal locking screws (LP-6); (b) Single-side lateral locked plating with 4 distal locking screws (LP-4); (c) Additional medial locked plating on LP-4 construct (DP-4).

limited number of screws was used to simulate the insufficient stability at the distal segment. Fixation of the proximal segment and osteotomy procedure were performed in the same manner (Fig. 1b).

2.4 Additional medial locked plating on LP-4 construct (DP-4 group)

A model of the double plating group (DP-4 group) was achieved by adding a medial plate over the medial side of the LP-4 model. A 4-hole Tomofix-medial distal femur (Tomofix-MDF®, DePuy-Synthes, Zuchwil, Switzerland) was used as the medial plate. All four screws were fixed at the distal part of the medial plate (locking screw; length, 28–65 mm), while 2 screws were bicortically fixed at hole numbers 1 and 3 from the proximal end (locking screw; length, 38 mm) (Fig. 1c).

To achieve a constant model for the biomechanical study, a single orthopedic surgeon performed all procedures under the guidance of fluoroscopy. Proper implantation was confirmed by using radiographs after instrumentation (Fig. 1).

2.5 Mechanical testing

Each femur model was mounted reversely in a servo-hydraulic testing machine (MTS Bionix 810, Eden Prairie, MN, USA). The femoral head and condylar of the femur was placed by a custom-made zig. The proximal femur was firmly held in a pre-shaped auto-polymerized acrylic resin (Vertex Dental, Zeist, Netherlands) embedding. Each construct was tested under axial loading. The set-up of the construct was positioned with 6° valgus angulation to simulate anatomic positioning with the weight bearing.

For the cyclic load test, one construct of each group was used. An axial load of 100 N was applied to stabilize the construct. The axial compressive cyclic load was applied from 100 to 1000 N for 100,000 cycles at 3 Hz.

The remained five constructs of each group were tested in the load to failure test. After applying an axial preload of 100 N to stabilize the construct before testing, an axial compressive load of 1000 N was applied at a rate of 10 mm/min in the load to failure test. The maximum displacements were recorded continuously using an MTS crosshead motion sensor from the initial position to maximum load. The axial load continued until a failure of the bone-implant construct occurred, as evidenced by a marked decrease of the load-displacement curve. The failure was defined as any breakage of implant or bone, or complete collapse of the osteotomy gap. The maximum axial load was recorded for all specimens before failure.

Statistical analysis was performed with the SPSS software package (V.20, IBM, Armonk, NY, USA). Any significant differences between the three groups of constructs were evaluated with the Kruskal-Wallis test. Post-hoc correction was checked with the Bonferroni method and Mann-Whitney test for multiple comparisons.

3 Results

All 3 specimens for the cyclic loading test were able to withstand cyclic loading up to 1000 N for 100,000 cycles. There were no gross failures of any construct during and after the cyclic test.

3.1 Mode of failures

In three of the LP-6 constructs, bone cracks occurred at the bone-locking screw interface of the distal segment, with plate bending at the fracture gap. The other two showed plate bending at the fracture gap without cracks. In two of the LP-4 constructs, bony cracks occurred at the bone-locking screw interface of the distal segment with plate bending at the fracture gap, whereas the other three showed plate bending at the fracture gap. However, none of the DP-4 constructs showed plate bending at the fracture gap, while only bone cracks at the bone-locking screw interface of the distal segment were observed in all of DP-4 (Fig. 2).

3.2 Load to failure and displacement

Load to failure was significantly different between the three fixation constructs, with the greatest value detected with DP-4 construct (mean 5522 N; standard deviation [SD], 262.6; $p = 0.008$,
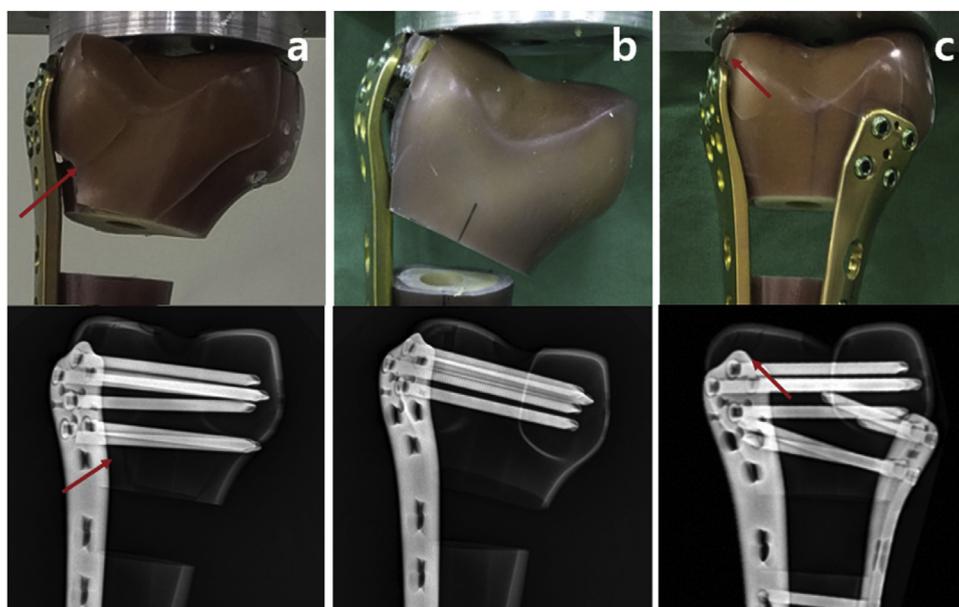

Fig. 2. Failure modes after axial loads with resultant radiographs. Both (a) LP-6 and (b) LP-4 constructs show bone cracks at the bone-distal locking screw interface or plate bending at the fracture gap. None of the (c) DP-4 constructs show plate bending at the osteotomy gap. However, all fracture models showed cracks at the bone-distal screw interface. The red arrow indicates the bone cracks between the bone and locking screw (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Mann-Whitney with Bonferroni's method), followed by the LP-6 (mean 4713.3 N; SD, 143.2) and LP-4 constructs (mean 4273.2 N; SD, 75.9). Load to failure of the DP-4 construct was 17.1% greater in the axial loading than that of the LP-6 construct and 29.2% greater than that of the LP-4 construct. Load to failure of the LP-4 construct was 9.4% smaller in axial loading than that of the LP-6 construct (Fig. 3).

In the evaluation of ultimate displacement, DP-4 showed significantly lower values (mean 5.6 mm; SD, 0.7; p = 0.008, Mann-Whitney with Bonferroni's method) than LP-6 (mean 8.8 mm; SD, 1.9) and LP-4 (mean 9.1 mm; SD, 2.0). However, any significant difference was not found between LP-6 and LP-4 (P = 0.841, Table 1).

4 Discussion

Distal femur fractures have been successfully salvaged with improved locked plating technology and minimally invasive procedures, which helped to increase the stability of fixation and promote fracture healing, thereby allowing for early gain of knee motion, early weight bearing, and excellent return to the daily life. However, complications after operative treatment of distal femur fractures are not uncommon in certain fracture pattern, populations, and associated morbidity. Nonunion, mal-union, and implant failures have been frequently shown when these fractures were not fixed with sufficient stability. Commonly seen in high energy trauma, fractures into the articular surface may obstruct the adequate fixation of screws from the lateral locked plate, as this injury necessarily needs the firm and accurate fixation of articular fractures before the lateral plating. Furthermore, when the metaphyseal comminution is large in high energy fractures, lateral locked plates cannot guarantee the stable fixation construct and the successful healing of the fracture gap. As the patient's life span is expansively increasing, the resultant fractures with osteoporosis have also been increasing in distal femur fractures. Unfortunately, the poor bone quality from the osteoporotic fracture may frustrate the fixation stability even with the locked plate, which is the standard implant. Moreover, the demands of knee arthroplasty have also been increasing in active old-aged people, while the peri-prosthetic fractures of femoral implants also increase consequently. In this biomechanical study, specimen for the test was created to have a comminuted fracture, having a significant gap at the level of the metaphysis. Furthermore, in order to simulate the weak stiffness after lateral locked plating, four of six screws were fixed at the distal part, as clinically required in the complex intra-articular fractures or peri-prosthetic fractures with knee arthroplasty. Unstable fixation with an insufficient number of distal screws cannot prevent acute or chronic complications such as reduction loss, resul-

tant mal-alignment, malunion, nonunion, or implant failures. The modelling of an unstable fixation construct with single side lateral plating is essential. As the load to failure of the LP-4 group was significantly lower (9.4%) than that of the LP-6 group, the limited number of screw fixations at the distal part of the lateral plate could achieve a successful model that can be commonly met in clinical situations as mentioned. Furthermore, this simulated model may be applied, since the lateral locked plate can be used to fix osteoporotic fractures of the distal femur.

After lateral locked plating of distal femoral fractures, the nonunion rate has been reported between 5–9%, [4,13–16] and failures of implants have also been reported up to 7%. Although locking screws can improve the stiffness of the fixation construct, the sufficient stability at the distal segment of the fracture often may not be obtained from the current technique of single-side lateral locked plating. Furthermore, the unstable fixation subsequently produces a harmful environment unsuitable for achieving adequate fracture healing. Streubel et al. [17] demonstrated that it would be desirable to obtain fixation with at least five screws distally in order to achieve an optimal outcome in extremely distal fractures of the femur [17]. Since it cannot be performed in many cases clinically, additional plating at the medial side of the distal femur is promising [18]. Many studies have reported that double plating resulted in good clinical outcomes for unstable distal femoral fractures [8,19,20]. However, there has been no biomechanical studies with double plating in the unstable, complex fractures of the distal femur. Therefore, this study has novel values in the experimental technique as well as clinical simulations. In this study, the strength of the fixation construct after additional medial plating (DP-4) was significantly higher (29%) than that of the unstable construct with single-side lateral plating (LP-4). The medial plate may sufficiently add stability when a limited number of screw fixations are inevitable at the distal segment, such as in complex distal femur fractures with unilateral or bilateral Hoffa fractures, or very low peri-prosthetic fractures of the distal femur. Furthermore, this double plating construct was also significantly higher in fixation strength (17%) than the stable traditional lateral plating (LP-6) construct. This finding suggests that the additional medial plate can also be useful in the highly comminuted fracture at the metaphyseal area, which is not uncommon in high-energy injuries of the distal femur.

In this study, a 2.5 cm transverse osteotomy gap was set 6 cm proximally to the distal articular femur surface to simulate an extra-articular comminution in the metaphyseal region AO/OTA 33-A3. This osteotomy gap also represents the typical site of peri-prosthetic fracture proximal to a total knee arthroplasty. [21] The osteotomy gap can be varied from 1 to 2.5 cm depending on the previous study [22–24].

In the mode of failure with biomechanical testing, the double plating model did not show plate bending, while all the other single-side lateral plate models (LP-6 and LP-4 constructs) showed plate bending at the fracture gap. This may also imply that an additional medial plate was sufficiently firm to resist the axial loading stress, even in highly comminuted fractures of the distal femur. When configuring the double plate, several clinical studies have reported that two plates were located with the orthogonal orientation, fixing the additional plate on the anterior side of the femur rather than the medial side. [18–20,25] However, there has been also several reports of double plating using the parallel fixation with medial and lateral plates, which achieved a successful rate of fracture healing [10,20,26,27]. Therefore, one disadvantage of this study was that anterior plating was not performed as an additional plate in this study. However, the fixation of the anterior plate may not effectively allow for screws into the distal articular area. Furthermore, the position of the plate on the anterior knee area may disturb the knee motion. Although the medial approach
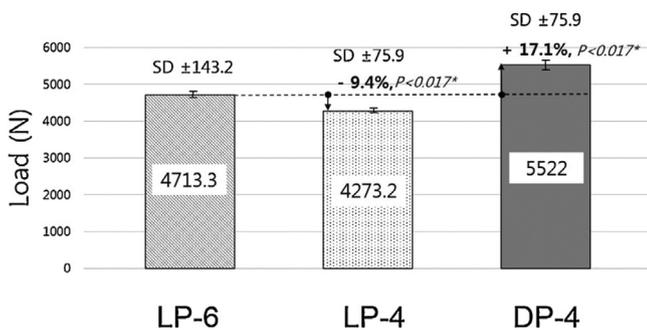

Fig. 3. Comparison of axial load to failures of three construct groups. The DP-4 group was most strong among the three constructs. The average loads to failure of the LP-4 and DP-4 group constructs were 90.6% and 117.1%, respectively, in terms of axial loading compared to that of the MP-6 group construct.
*Significance at *p-value*<0.017, Mann-Whitney with Bonferroni's method.

Table 1
Displacement and maximum load to failure data for specimens fitted with the LP-6, LP-4, and DP-4 groups.

Test	Ultimate displacement (mm)			Load to failure (N)		
	LP-6 group	LP-4 group	DP-4 group	LP-6 group	LP-4 group	DP-4 group
1	10.4	8.6	5.2	4587	4301	5430
2	6.4	10.3	5.8	4634	4329	5199
3	10.2	11.7	5.9	4955	4320	5555
4	7.2	6.5	4.6	4677	4143	5924
5	10	8.3	6.3	4713	4273	5502
Average	8.8	9.1	5.6	4713.3	4273.2	5522
SD	1.9	2.0	0.7	143.2	75.9	262.6
p-value	0.002*			0.009*		

* Significance at *p-value* < 0.05, Kruskal-Wallis.

may endanger the femoral artery near the adductor hiatus, careful dissection with the subvastus approach may promise the safety of the medial plating.

Various kinds of plates have been used as an additional medial plate, including the reconstruction plate, dynamic compression plate, and locking compression plate. [24,26] However, these plates need to be manually contoured as the medial condyle of femur is curved, which may be difficult for surgeons and require a longer time in operation. In this study, we chose the specially designed, pre-shaped implant for the osteotomy of the medial distal femur, which does not require custom-made bends during an operation. Currently, it is the only implant that fits the medial distal femoral condyle. From the results of this study, it seems that this plate improved the fixation stability significantly via advantages of the locked plate mechanism, even though the length of the medial plate was relatively short.

This experimental study has several limitations. First, a composite bone model was used, which is not made using the same material as the human bone. However, the composite bone provides several advantages over cadaveric bone, which has been approved for biomechanical studies. [28,29] These bones may provide standard sizes and properties between specimens, which will guarantee reproducibility of the implantation techniques. Furthermore, the varying dimensions, ages, and bone densities of cadaveric specimens were also avoided. Moreover, it has been reported that the composite femur has a modulus of elasticity similar to that of native bone [29,30]. It should be noted that the bone model in the present study was not an osteoporotic model, and therefore this data has limitations to applications in osteoporotic fractures. Secondly, screw fixation at the distal part of the lateral plate could be clinically different, depending on the fracture pattern or pre-existing prosthesis. Although it may not represent all clinical cases, reproducible results were achieved to create the weak model of fixation construct with single side lateral plating.

5 Conclusions

Additional fixation of the medial plate significantly increased the fracture stability under axial loading in distal femur fractures fixed with the lateral locked plating. Especially in cases where sufficient stability cannot be provided at the distal segment, the medial plate may be considered as a useful biomechanical solution to obtain adequate stability for fracture healing.

Declaration of Competing Interest

All authors have certified that they have no commercial associations (*e.g.,* consultancies, stock ownership, equity interest, or patent/licensing arrangements, *etc.*) that might pose a conflict of interest in connection with this article.

References

[1] Marsh JL, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA, et al. Fracture and dislocation classification compendium - 2007: orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma 2007;21(10 Suppl):S1–133.

[2] Martinet O, Cordey J, Harder Y, Maier A, Buhler M, Barraud GE. The epidemiology of fractures of the distal femur. Injury 2000;3(31 Suppl):C62–3.

[3] Cui S, Bledsoe JG, Israel H, Watson JT, Cannada LK. Locked plating of comminuted distal femur fractures: does unlocked screw placement affect stability and failure? J Orthop Trauma 2014;28(February 2):90–6.

[4] Ricci WM, Streubel PN, Morshed S, Collinge CA, Nork SE, Gardner MJ. Risk factors for failure of locked plate fixation of distal femur fractures: an analysis of 335 cases. J Orthop Trauma 2014;28(February 2):83–9.

[5] Gwathmey FW Jr, Jones-Quaidoo SM, Kahler D, Hurwitz S, Cui Q. Distal femoral fractures: current concepts. J Am Acad Orthop Surg 2010;18(October 10):597–607.

[6] Tan SL, Balogh ZJ. Indications and limitations of locked plating. Injury 2009;40(July 7):683–91.

[7] Gavaskar AS, Tummala NC, Subramanian M. The outcome and complications of the locked plating management for the periprosthetic distal femur fractures after a total knee arthroplasty. Clin Orthop Surg 2013;5(2):124–8.

[8] Sanders R, Swiontkowski M, Rosen H, Helfet D. Double-plating of comminuted, unstable fractures of the distal part of the femur. J Bone Joint Surg Am 1991;73(3):341–6.

[9] Su ET, DeWal H, Di Cesare PE. Periprosthetic femoral fractures above total knee replacements. J Am Acad Orthop Surg 2004;12(1):12–20.

[10] Peng Y, Ji X, Zhang L, Tang P. Double locking plate fixation for femoral shaft nonunion. Eur J Orthop Surg Traumatol 2016;26(5):501–7.

[11] Maimaitiyiming A, Amat A, Rehei A, Tusongjiang M, Li C. Treatment of the femoral shaft nonunion with double plate fixation and bone grafting: a case series of 14 patients. Injury 2015;46(6):1102–7.

[12] Anglen JO, Weinstein JN. American Board of Orthopaedic Surgery Research C. Nail or plate fixation of intertrochanteric hip fractures: changing pattern of practice. A review of the American board of orthopaedic surgery database. J Bone Joint Surg Am 2008;90(4):700–7.

[13] Meneghini RM, Keyes BJ, Reddy KK, Maar DC. Modern retrograde intramedullary nails versus periarticular locked plates for supracondylar femur fractures after total knee arthroplasty. J Arthroplasty 2014;29(7):1478–81.

[14] Kregor PJ, Stannard J, Zlowodzki M, Cole PA, Alonso J. Distal femoral fracture fixation utilizing the Less Invasive Stabilization System (L.I.S.S.): the technique and early results. Injury 2001;32(Suppl. 3):SC32–47.

[15] Large TM, Kellam JF, Bosse MJ, Sims SH, Althausen P, Masonis JL. Locked plating of supracondylar periprosthetic femur fractures. J Arthroplasty 2008;23(6 Suppl. 1):115–20.

[16] 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.

[17] Streubel PN, Gardner MJ, Morshed S, Collinge CA, Gallagher B, Ricci WM. Are extreme distal periprosthetic supracondylar fractures of the femur too distal to fix using a lateral locked plate? J Bone Joint Surg Br 2010;92(4):527–34.

[18] Imam MA, Torieh A, Matthana A. Double plating of intra-articular multifragmentary C3-type distal femoral fractures through the anterior approach. Eur J Orthop Surg Traumatol 2018;28(1):121–30.

[19] Ziran BH, Rohde RH, Wharton AR. Lateral and anterior plating of intra-articular distal femoral fractures treated via an anterior approach. Int Orthop 2002;26(6):370–3.

[20] Khalil Ael S, Ayoub MA. Highly unstable complex C3-type distal femur fracture: can double plating via a modified Olerud extensile approach be a standby solution? J Orthop Trauma 2012;13(4):179–88.

[21] Alexander J, Morris RP, Kaimrajh D, Milne E, Latta L, Flink A, et al. Biomechanical evaluation of periprosthetic refractures following distal femur locking plate fixation. Injury 2015;46(12):2368–73.

[22] Higgins TF, Pittman G, Hines J, Bachus KN. Biomechanical analysis of distal femur fracture fixation: fixed-angle screw-plate construct versus condylar blade plate. J Orthop Trauma 2007;21(1):43–6.

[23] Wahnert D, Lange JH, Schulze M, Lenschow S, Stange R, Raschke MJ. The po-
     tential of implant augmentation in the treatment of osteoporotic distal femur
     fractures: a biomechanical study. Injury 2013;44(6):808–12.
[24] Todorov D, Zderic I, Richards RG, Lenz M, Knobe M, Enchev D, et al. Is
     augmented LISS plating biomechanically advantageous over conventional
     LISS plating in unstable osteoporotic distal femoral fractures? J Orthop Res
     2018;36(10):2604–11.
[25] Wahnert D, Gruneweller N, Gehweiler D, Brunn B, Raschke MJ, Stange R. Dou-
     ble plating in Vancouver type B1 periprosthetic proximal femur fractures: a
     biomechanical study. J Orthop Res 2017;35(2):234–9.
[26] Steinberg EL, Elis J, Steinberg Y, Salai M, Ben-Tov T. A double-plating approach
     to distal femur fracture: a clinical study. Injury 2017;48(10):2260–5.

[27] Holzman MA, Hanus BD, Munz JW, O'Connor DP, Brinker MR. Addition of a
     medial locking plate to an in situ lateral locking plate results in healing of
     distal femoral nonunions. Clin Orthop Relat R. 2016;474(6):1498–505.
[28] Kim JW, Oh CW, Byun YS, Oh JK, Kim HJ, Min WK, et al. A biomechanical
     analysis of locking plate fixation with minimally invasive plate osteosynthesis
     in a subtrochanteric fracture model. J Trauma 2011;70(1):E19–23.
[29] Lee SM, Oh CW, Oh JK, Kim JW, Lee HJ, Chon CS, et al. Biomechanical anal-
     ysis of operative methods in the treatment of extra-articular fracture of the
     proximal tibia. Clin Orthop Surg 2014;6(3):312–17.
[30] Szivek JA, Gealer RL. Comparison of the deformation response of synthetic
     and cadaveric femora during simulated one-legged stance. J Appl Biomater
     1991;2(4):277–80 Winter.