Primary bone grafting with locked plating for comminuted distal femoral fractures: can it improve the results?

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Background

Distal femoral fractures are challenging injuries. The thin cortex, wide medulla, extensive comminution, and articular extension make fixation difficult, with high rates of nonunion and implant failure. Fixation of such fractures with bridging plates relies on secondary healing with callus formation. Although locked plating has improved the fixation strength, recent studies substantiate the concern that the high stiffness of these constructs suppresses callus formation, contributing to a nonunion rate of up to 19% seen with periarticular fractures. The absence or delay of osseous union maintains the construct loaded with the possibility of implant failure or loss of fixation.

Aim of the work

To highlight the importance of primary bone grafting with distal femoral locked plates in fixation of comminuted distal femoral fractures in adults as a biological enhancer of early callus formation; adding a protective mechanical support – once integrated – to the construct against stresses that can cause non-union and/or implant failure due to the reported callus suppression with such constructs with high stiffness.

Patients and methods

This prospective study included 11 patients with closed, comminuted distal femoral fractures. Clinical and radiological evaluation was performed. Fractures were classified according to the AO-OTA system. Radiological results were evaluated according to the ASAMI radiological scoring system, whereas functional results were assessed according to Schatzker and Lambert criteria and the ASAMI functional scoring system. All fractures were fixed through the open lateral approach using locked plates with primary autogenous bone grafting in the comminuted area all around.

Results

All fractures united with a mean union time of 16.2 weeks. The functional outcome according to the used scoring systems was excellent in nine patients (81.8%) and good in two patients (18.2%). Thus, satisfactory results (excellent and good) were obtained in all cases of the studied group, with no cases developing nonunion or implant failure.

Conclusion

Adding primary autogenous bone grafting to the locked bridging construct can overcome the problem of deficient callus formation. It does not only induce rapid callus formation biologically, but also mechanically protects the construct – once integrated – against repetitive stresses that can cause varus collapse, nonunion, and implant failure.

Keywords:

comminuted distal femoral fractures, locked plates, primary bone graft

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Introduction

Treatment of comminuted distal femoral fractures remains a significant surgical challenge with high complication rates [1–4]. Locked plates were developed for adequate stabilization of fractures where there was poor bone quality or comminution. Periarticular locking plates have been rapidly adopted as an alternative to intramedullary nails, blade plates, and nonlocking condylar plates [5].

The introduction of locked plates with fixed-angle screws has improved the fixation strength of plate constructs and they are frequently indicated for bridge plating of periarticular fractures and comminuted metaphyseal or diaphyseal fractures [6–8].

Interfragmentary compression is not obtained when these locked plates are used to bridge comminuted distal femur fractures; thus, healing must occur by secondary bone healing with callus formation between the fragments [9]. Secondary bone healing is mediated by interfragmentary motion in the millimeter range [10–13]. Although construct rigidity offers benefits from mechanical strength, it may also lead to delayed bone healing due to suppression of interfragmentary micromotion essential for callus formation [14].

What is the problem?

Many cases with distal femoral fractures presented to our department with delayed union or nonunion after

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fixation by distal femoral locked compression plating and sometimes with different modes of implant failure (Fig. 1). All these cases were high-energy trauma, with closed fractures fixed either by classic open reduction or by MIPO using LISS. These cases were infection-free (no clinical or laboratory signs of infection) and were managed without primary bone graft at the time of initial fixation. Most of the cases were highly comminuted, whereas others were simple fractures. Some cases needed a second intervention in the form of delayed open bone grafting after a few months, once recognized as delayed union.

This problematic situation raised two important questions; why does a mechanically superior plate inserted in a biological manner fail biologically (deficient callus formation) and mechanically (implant failure)? The second is, what to be done in the future to avoid this problem?

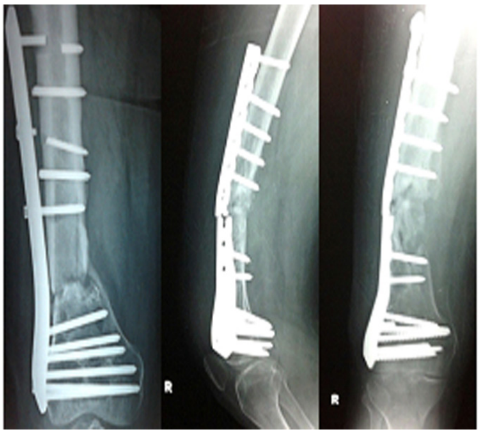
Why this occurred?

Reviewing the literature, recent data suggest that up to 20% of fractures fixed with locking plates may encounter suboptimal fracture healing with nonunion [15]. Recent clinical studies substantiate the concern that the inherently high stiffness of locked-plate constructs suppresses callus formation with deficient healing and may also contribute to late hardware failures seen with locking plates [16–18].

The 20% of the femoral fractures that became nonunions exhibited less callus formation while stable implant alignment was maintained. This suggests that callus inhibition, rather than implant failure, is the primary cause of these nonunions [15].

Another study documented that callus inhibition was readily apparent 6 months after surgery, as 37% of all fractures had no or very little callus. Callus formation was most inhibited closer to the plate, where the asymmetric gap closure characteristic of bridge-plate constructs causes the least interfragmentary motion [19].

Figure 1



Two cases of nonunion with different modes of implant failure.

In another six studies, the authors reported an incidence of 52% of implant failures in which the timing of these failures occurred more than 6 months after fixation [17,18,20–23], indicating that the failure was the result of implant fatigue in the presence of an established nonunion. Proper identification of late implant failures as nonunions in studies of locked plates should further raise the concern that locked-plate constructs may be too stiff to promote reliable healing.

Because bones are more flexible than metal plates, fixing a metallic plate to bone makes it stiff and produces ‘stress riser’ at each end of the plate. In the absence of union, even the strongest metal plates and screws will eventually break or pull out of the bone [24]. Fatigue arising from cyclic loading can cause fracture of an implant [25], which effectively leads to failure of the fixation device. Implant failure from fatigue fracture is more common with plates than with intramedullary nails [26]. Vallier *et al.* [27] reported medial comminution as a major cause of implant failure with the use of locked compression plating.

Many modifications were made to improve the mechanical properties of locked plating constructs. Bottlang *et al.* [28,29] introduced the concept of far cortical locking in 2009 as a method of providing flexible fixation with parallel interfragmentary motion and callus formation.

In another study presented in 2010 by Bottlang *et al.* [19] about the effect of construct stiffness on healing of fractures stabilized with locking plates, far cortical locking as a stiffness-reduced locked-plate technique to improve fracture healing and protect against implant failure was presented and documented.

Doebele *et al.* [30] introduced the new concept of dynamic locking screws as a new generation of locking screws that reduces construct stiffness. The dynamic locking screws is a relatively new concept with emerging evidence to display its benefits. Although the screws are relatively expensive, they offer the operator the option of using them in compression mode, thereby reducing the fracture gap and promoting improved healing by reducing strain across the fracture.

From the previous data; we can conclude that the problem was mechanical (construct rigidity and increased stiffness) but the result was biological (suppression of callus formation with deficient fracture healing) with a mechanical sequel (implant failure). Thus, augmentation of the mechanically improved construct using a simple procedure by adding primary autogenous bone graft as a biological enhancer of early callus formation is supposed to give a protecting role to the construct, once integrated, against repetitive stresses that will induce implant failure and nonunion.

Patients and methods

Eleven adult, male patients with isolated closed distal femoral shaft fractures were included in this prospective case series study carried out in the Orthopaedics department of Benha University Hospital from March 2012 to September 2014. Their ages ranged from 23 to 62 years (mean 32 years). Fractures were classified according to the AO/OTA classification; all cases were complex multifragmentary, comminuted fractures (10 cases of A3 type and one case of C2 type).

The injury/surgery interval varied from 2 to 18 days with a mean of 4 days. Distal femoral locked plates were used in all cases (titanium plates in eight cases and stainless steel plates in three cases) through the standard open lateral approach with the construct augmented mainly on the medial comminuted area of the femur and between the plate and the lateral cortex of the bone with bone grafts taken from the iliac crests of the patients. Cases were followed up for a mean of 13 months postoperatively, and results were evaluated according to ASAMI and Schatzker and Lambert criteria. Cases with open fractures, pediatric fractures, pathological fractures, and cases with other associated ipsilateral or contralateral long bone fractures were excluded from this study.

Preoperative evaluation of the patients

Complete history of the injury with careful evaluation for other associated injuries was taken in the emergency room with stress on the affected side. Examination for ecchymosis, blisters, superficial abrasions, deep contusions, open fractures, or neurovascular insults that can occur in such injuries was done. Initial reduction and splinting on a Thomas frame or above the knee slab was applied to relieve pain and swelling until surgery. Radiological evaluation included the standard trauma survey for high-energy injured patients, and anteroposterior (AP) and lateral views of the affected limb were taken to evaluate the fracture pattern. CT was performed to assess intra-articular extensions and comminution and for classification of injury and planning of the intervention (Fig. 2).

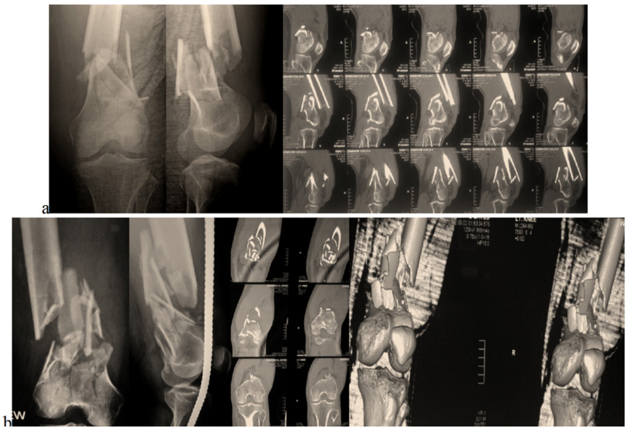
Operative procedure

Under complete aseptic conditions, patients in the supine position were operated upon under spinal anesthesia on a standard radiolucent table to allow access to the image intensifier once needed. The knee is slightly flexed 30° by supporting it with padding; this will relax the neurovascular structures posteriorly away from the operative field and will help reduction by releasing traction of the gastrocnemius muscle preventing extension of the distal fragment. Free draping of both legs allows for intraoperative comparison of length, axes, and rotation in relation to the unaffected leg by indirect reduction through manual traction.

The lateral approach to the distal femur allows for visualization, reduction, and fixation of most of the fractures not involving the articular surface (type A) as well as simple articular fractures of the distal femur (type C1–2). The most important step is to gently address the comminuted fragments and avoid stripping their periosteal sleeve. The approach relies on an atraumatic elevation of the vastus lateralis from the lateral aspect of the distal femur, and a lateral arthrotomy for joint access (if needed). Anatomical articular reduction (Fig. 3) and application of a lateral plate – of variable length (10–15 shaft holes), made of stainless steel or Titanium alloy – were achieved through the same approach. The approach may be extended proximally to display the entire length of the femoral shaft according to the fracture extent.

Bone grafting was planned preoperatively, so that the graft was harvested before approaching the femur to decrease the time of fracture exposure and the potential risk for infection. After fixation, the harvested graft was inserted in the comminuted area.

Figure 2

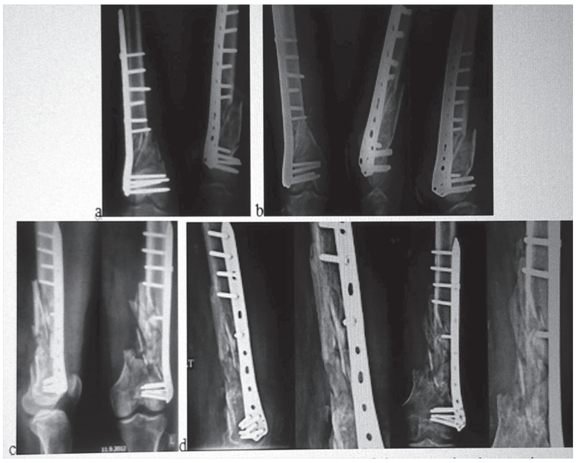


(a) X-ray and CT of case 1 with a comminuted lower-third femoral shaft fracture (A3). (b) X-ray and CT of case 2 with a comminuted lower-third femoral shaft fracture (A3).

Figure 3

Preoperative and postoperative radiograph of a case of distal femoral fracture (C2) with simple articular and comminuted metaphyseal fracture fixed by locked plate and augmented with a primary bone graft.

Figure 4



(a, b) Progression of healing with graft incorporation in case 1. (c, d) Progression of healing with graft incorporation in case 2.

The graft was taken from the anterior part of the iliac crest. The first harvested bone segment was a tricortical bone of the desired length; thereafter, multiple slices of corticocancellous bone chips and finally a cancellous core graft from the crest were taken. The tricortical strong segment was used as a strut medially after fully impacting the graft in the comminuted area (medially and laterally under the plate); thereafter, the wound was closed in layers after proper hemostasis, and a suction drain was put in place.

Postoperative regimen

AP and lateral views of the affected side were taken to assess the adequacy of reduction and fixation regarding alignment in both planes, restoration of length, and adequacy of grafting in the comminuted area. Active, active assisted, and passive knee motion was started on day 1 postoperatively. Wound inspection was done on the second postoperative day with drain removal before discharge. Third-generation intravenous cephalosporins, DVT prophylaxis, and analgesics were given for 7 days, followed by oral antibiotics for another 7 days until removal of sutures. A walker frame was used to help ambulation without weight-bearing on the affected side. Non-weight-bearing continued for 6 weeks until early radiological signs of graft taking and incorporation were seen.

Gradual progressive weight-bearing – as tolerated by the patient – was encouraged once early radiographic evidence of healing was present (Fig. 4); thereafter, safe, nonprotected, full weight-bearing was allowed. Regular follow-up at 4-week intervals was done to assess progression until complete union and then every 3 months with evaluation of the clinical and radiological outcomes.

Results

Patients were followed up for a mean period of 13 months postoperatively (ranging from 7 to 28 months). Union was defined as the presence of bridging callus of three of the four cortices and disappearance of the fracture line on the plain radiographs for a patient who was able to bear full weight, with the area of comminution-bone graft completely incorporated, amalgamated, and remodelled with the proximal and distal ends of the comminuted fractures. Radiological results in this study were evaluated according to the ASAMI radiological scoring system [31]. Functionally, results were assessed according to the criteria of the ASAMI functional scoring system and the Schatzker and Lambert functional criteria [32]. Radiological and functional results of the studied cases are presented in Tables 1–3.

All fractures united with acceptable alignment in AP, oblique, and lateral views (Fig. 5), with a mean union time of 16.2 weeks (ranging from 13 to 28 weeks). Radiologically, excellent results were obtained in 11 cases (representing 100% of the studied cases) (Table 1). Functionally (Fig. 6a and b), excellent results were obtained in nine cases (representing 81.8% of the studied cases). Good results were obtained in two cases (representing 18.2% of the studied cases). No cases had fair or poor results (Tables 2 and 3). Thus, satisfactory results (excellent and good results) were obtained in all cases of the studied group.

In the two cases rated functionally good, there was persistent limping due to limb length discrepancy with shortening of about 1 cm due to inadequate restoration of length and incomplete restoration of the knee ROM with limited flexion range to about 90°. In the other

Table 1 Radiological results of cases in this study according to the ASAMI scoring system

Bone results	Criteria	Number of patients
Excellent	UnionNo infectionDeformity <7°Limb length discrepancy (LLD) <2.5 cm	11
Good	Union+any two of the following: Absence of infectionDeformity <7°LLD<2.5 cm	0
Fair	Union + any one of the following: Absence of infectionDeformity<7°LLD<2.5 cm	0
Poor	Nonunion/refracture/union + infection +Deformity>7° + LLD >2.5 cm	0

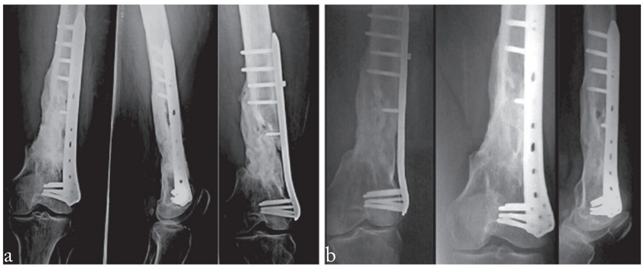
Table 2 Functional results of cases in this study according to the ASAMI scoring system

Functional results	Criteria	Number of patients
Excellent	ActiveNo limpMinimum stiffness (loss of <15°, knee extension/ <15° ankle dorsiflexion) No reflex sympathetic dystrophy (RSD) Insignificant pain	9
Good	Active with one or two of the following: Limp Stiffness RSD Significant pain	2
Fair	Active with three or all of the following: Limp Stiffness RSD Significant pain	0
Poor	Inactive (unemployment or inability to return to daily activities because of injury)	0

Table 3 Functional outcomes classified according to the Schatzker and Lambert criteria

Functional results	Criteria	Numner of patients
Excellent	Full extensionFlexion loss of <10° No varus, valgus, or rotary deformityNo painPerfect joint congruency	9
Good	Not more than one of the following:Length loss of not >1.2 cmVarus or valgus deformity of <10° Flexion loss of not >20°Minimal pain	2
Fair	Any 2 of the criteria in the good category	0
Poor	Any of the following: Varus or valgus deformity exceeding 15° Joint incongruence Disabling pain	0

Figure 5



(a) X-ray after 7 months showing complete union with graft amalgamation in the area of marked comminution (case-2 presented in this study) with proper alignment in antero-posterior, lateral and oblique views. (b) Final X-ray showing complete healing and remodeling after 18 months.

case there was also incomplete restoration of the knee ROM with loss of more than 15° of knee extension and slight varus deformity of less than 7°.

No cases had iatrogenic neurovascular complications or deep wound infection; no cases were complicated by DVT or compartment syndrome; no cases developed reflex sympathetic dystrophy; no cases had implant failure until the last follow-up; and no cases required a second major open intervention to induce union. No complaints or morbidities related to graft harvesting were reported.

Discussion

Distal femoral fractures are difficult injuries irrespective of the improvements of fixation mechanics, techniques of application, and plate designs. With the advent of locking plates, this fixed angle construct has been used to span an area of comminution with improved security at the screw–bone interface.

Despite the widespread use and popularity of lateral locked-plate fixation of distal femur fractures, concern exists regarding the clinical outcomes achieved with these constructs. Recent clinical and basic science evidence suggests that the increased stiffness provided by the distal femur locked plates may lead to delayed union or nonunion, with up to 32% of patients having difficulty to achieve healing of their fracture [5].

Zlowodzki *et al.* [33] analyzed the outcome of many studies as part of a systematic literature review and concluded that average nonunion, fixation failure, deep infection, and secondary surgery rates were 5.5, 4.9, 2.1, and 16.2%, respectively.

In this study, the fixation of these comminuted fractures with distal femoral locking plates through the standard open approach and indirect reduction using manual

Figure 6

(a) Complete restoration of the knee ROM with good quadriceps power, proper alignment, restoration of length with no LLD and completely healed scar in a 46 years old patient (Case-2). (b) Incomplete restoration of the knee ROM with good quadriceps power, proper alignment, LLD about 1cm and completely healed scar in a 62 years old diabetic patient (Case-1).

traction with preservation of the periosteal attachment of the comminuted fragments has the advantage of decreasing the incidence of malunion, with only one case (representing 9.1% of the studied cases) that had varus deformity of less than 7°.

Papakostidis *et al.* [34] reported a malunion rate of 0–29% for femur fractures treated with plate and screws using the biological fixation technique. They found that the cause of malunion was generally inadequate intraoperative reduction in some cases with displaced comminuted fractures fixed by LISS or MIPO. According to Schütz *et al.* [18] closed reduction of comminuted fractures may be difficult, and this could be the cause of malunion. They believed that the malunion rate correlates with inadequate intraoperative reduction rather than the selected fixation method of intramedullary nail or plate and screws [18,34].

Regarding the added role of primary grafting in fracture union, all cases united in a relatively short period of time (the mean union time was 16.2 weeks, ranging from 13 to 28 weeks) despite the high-energy nature of trauma and the fracture comminution compared with other studies. The addition of primary bone grafting to the area of comminution was the cornerstone for rapid and secure healing with no need for second open intervention, which is usually delayed grafting in many studies. The role of delayed bone grafting as a secondary procedure for treatment of cases with delayed union or nonunion was documented in a study presented by Philip *et al.* [35]. They documented that 7% of all fractures eventually failed to heal with secondary procedures including bone grafting. Another study attributed nonunion to the severity of comminution and bone loss and documented that it is better in these cases to perform primary grafting [36].

Zlowodzki *et al.* [33] declared that one of the technical errors that have been reported for fixation failure was waiting too long to bone graft the defects. Pascarella *et al.* [37] reported two patients in their study with nonunion who were treated with cancellous autograft 32 weeks after the first surgery and documented that both cases healed at about 3.5 months after the second surgery.

The race between implant failure and bone healing is a standard rule in internal fixation. Whatever the strength and material modifications, implants will fail if healing is hindered by deficient callus formation. For a lateral distal femoral plate, plate bending induces more stresses medially leading to increased chances for implant failure. Thus, an intact or restored medial cortex of the femur is an important protector against implant failure. Numerous studies have shown that the mechanical conditions at the fracture site, principally the fixation stability, influences callus formation during fracture healing [38].

In comminuted fractures, locked plates function in a bridge plate mode that provides relative stability. Fracture healing in this situation will occur with callus formation through secondary or indirect fracture healing. When the fracture gap is too great or the amount of interfragmentary motion is too little, adequate callus formation cannot occur with high incidence of nonunion and implant failure [39].

Using the recommendations of Hak *et al.* [39] about the effect of large fracture gap and its role in decreasing callus formation, primary bone grafting can abolish these gaps and promote healing depending on the biological properties of bone grafting (osteogenesis, osteoinduction and osteoconduction). This can mechanically protect the construct with decreased incidence of implant failure.

Even with the use of titanium plates with decreased number of screws to decrease the stiffness of locked plating constructs, asymmetric callus formation with the largest periosteal callus was observed at the medial cortex with deficient callus formation laterally under the plate [35]. This also contributed to implant failure. By using primary bone grafting in the comminuted area medially and between the plate and lateral comminuted cortex of the femur also we can also overcome this problem.

The limitations of this study are the small number of patients included and the absence of a control group, which did not enable us to draw sound conclusions. However, these limitations do not undermine the results achieved by this study and by other presented studies [33,35–37]. It is clear that primary bone grafting at the time of initial fixation of such comminuted fractures by locking plates will fasten the healing process with early added protection of the construct leading to shorter union time and good functional outcome.

Conclusion

Locking-plate constructs could be too stiff to reliably promote fracture healing. So, only improved mechanics can't guarantee fracture healing.

Primary bone grafting can overcome the reported drawbacks of high stiffness of the locked constructs that hinders inter-fragmentary motion at the fracture site leading to deficient callus formation with subsequent high rates of non-union and failure.

Whatever the strength of the construct, biological failure will inevitably lead to a mechanical failure.

Adding primary autogenous bone grafting to the locked bridging constructs not only improves the biological environment with rapid callus formation, but also mechanically protects the construct – once integrated – against repetitive stresses that can cause varus collapse with loss of reduction, non-union and implant failure.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

References

1 Olerud S, Olerud S, Olerud S. Operative treatment of supracondylar – condylar fractures of the femur. Technique and results in fifteen cases. J Bone Joint Surg Am 1972; 54:1015–1032.

2 Schmit-Neuerburg KP, Hanke J, Assenmacher S. Osteosynthesis of distal femoral fractures. Chirurg. 1989; 60:711–722.

3 Siliski JM, Mahring M, Hofer HP. Supracondylar-intercondylar fractures of the femur. Treatment by internal fixation. J Bone Joint Surg Am 1989; 71:95–104.

4 Schatzker J. Fractures of the distal femur revisited. Clin Orthop Relat Res 1998; 347:43–56.

5 Kubiak EN, Fulkerson E, Strauss E, Egol KA. The evolution of locked plates. J Bone Joint Surg Am 2006; Suppl 4: :189–200.

6 Kolodziej P, Lee FS, Patel A, Kassab SS, Shen KL, Yang KH, Mast JW. Biomechanical evaluation of the schuhli nut. Clin Orthop Relat Res. 1998; 347:79–85.

7 Ramotowski W, Granowski R. Zespol. An original method of stable osteosynthesis. Clin Orthop Relat Res 1991; 272:67–75.

8 Ring D, Kloen P, Kadzielski J, Helfet D, Jupiter JB. Locking compression plates for osteoporotic nonunions of the diaphyseal humerus. Clin Orthop Relat Res 2004; 425:50–54.

9 Egol KA, Kubiak EN, Fulkerson E, Kummer FJ, Koval KJ. Biomechanics of locked plates and screws. J Orthop Trauma 2004; 18:488–493.

10 Claes LE, Heigele CA, Neidlinger-Wilke C, Kaspar D, Seidl W, Margevicius KJ, Augat P. Effects of mechanical factors on the fracture healing process. Clin Orthop Relat Res 1998; 355:S132–S147.

11 Duda GN, Sollmann M, Sporrer S, Hoffmann JE, Kassi JP, Khodadadyan C, Raschke M. Interfragmentary motion in tibial osteotomies stabilized with ring fixators. Clin Orthop Relat Res 2002; 396:163–172.

12 Goodship AE, Kenwright J. The influence of induced micromovement upon the healing of experimental tibial fractures. J Bone Joint Surg Br 1985; 67:650–655.

13 Augat P, Penzkofer R, Nolte A, Maier M, Panzer S, v Oldenburg G, *et al*. Interfragmentary movement in diaphyseal tibia fractures fixed with locked intramedullary nails. J Orthop Trauma 2008; 22:30–36.

14 Nikhil N, Marcus W. Current concepts to reduce mechanical stiffness in locked plating systems: a review article. Orthop Res Rev 2014; 6:91–95.

15 Henderson CE, Bottlang M, Marsh JL, Fitzpatrick DC, Madey SM. Does locked plating of periprosthetic supracondylar femur fractures promote bone healing by callus formation? Two cases with opposite outcomes. Iowa Orthop J 2008; 28:73–76.

16 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; 24:156–162.

17 Kregor PJ, Stannard JA, Zlowodzki M, Cole PA. Treatment of distal femur fractures using the less invasive stabilization system: surgical experience and early clinical results in 103 fractures. J Orthop Trauma 2004; 18:509–520.

18 Schütz M, Müller M, Krettek C, Höntzsch D, Regazzoni P, Ganz R, Haas N. Minimally invasive fracture stabilization of distal femoral fractures with the LISS: a prospective multicenter study. Results of a clinical study with special emphasis on difficult cases. Injury 2001; Suppl 3: SC48–SC54.

19 Bottlang M, Doornink J, Lujan TJ, Fitzpatrick DC, Marsh JL, Augat P, *et al*. Effects of construct stiffness on healing of fractures stabilized with locking plates. J Bone Joint Surg Am 2010; Suppl 2: 12–22.

20 Schandelmaier P, Partenheimer A, Koenemann B, Grün O, Krettek C. Distal femoral fractures and LISS stabilization. Injury 2001; 32:SC55–SC63.

21 Raab GE, Davis CM III. Early healing with locked condylar plating of periprosthetic fractures around the knee. J Arthroplasty 2005; 20:984–989.

22 Ricci WM, Loftus T, Cox C, Borrelli J. Locked plates combined with minimally invasive insertion technique for the treatment of periprosthetic supracondylar femur fractures above a total knee arthroplasty. J Orthop Trauma 2006; 20:190–196.

23 Kayali C, Agus H, Turgut A. Successful results of minimally invasive surgery for comminuted supracondylar femoral fractures with LISS: comparative study of multiply injured and isolated femoral fractures. J Orthop Sci 2007; 12:458–465.

24 David JD, Edwards DJ. Essential orthopaedics and trauma. 5th ed. Edinburgh: Churchill Livingstone; 2009.

25 Clarke H, Green M, Nokes L. *Engineering theory in orthopaedics: an introduction*. Chichester: Ellis Horwood; 1988. 24–25.

26 Sharma K, Kumar A, Joshi G, John T. Retrospective study of implant failure in orthopaedic surgery. MJAFI 2006; 62:70–72.

27 Vallier HA, Hennessey TA, Sontich JK, Patterson BM. Failure of LCP condylar plate fixation in the distal part of the femur. A report of six cases. J Bone Joint Surg Am 2006; 88:846–853.

28 Bottlang M, Doornink J, Fitzpatrick DC, Madey SM. Far cortical locking can reduce stiffness of locked plating constructs while retaining construct strength. J Bone Joint Surg Am 2009; 91:1985–1994.

29 Bottlang M, Lesser M, Koerber J, Doornink J, von Rechenberg B, Augat P, *et al*. Far cortical locking can improve healing of fractures stabilized with locking plates. J Bone Joint Surg Am 2010; 92:1652–1660.

30 Doebele S, Horn C, Eichhorn S, Lucke M, Koch R, Stöckle U. Dynamic locking screws (DLS) – biomechanical testing of a new screw system. J Bone Joint Surg [Br] 2011; 93:100.

31 Chaddha M, Gulati D, Singh AP, Singh AP, Maini L. Management of massive posttraumatic bone defects in the lower limb with the Ilizarov technique. Acta Orthop Belg 2010; 76:811–820.

32 Schatzker J, Lambert DC. Supracondylar fractures of the femur. Clin Orthop Relat Res 1979; 138:77–83.

33 Zlowodzki M, Bhandari M, Marek DJ, Cole PA, Kregor PJ. Operative treatment of acute distal femur fractures: systematic review of 2 comparative studies and 45 case series (1989 to 2005). J Orthop Trauma 2006; 20:366–371.

34 Papakostidis C, Grotz MR, Papadokostakis G, Dimitriou R, Giannoudis PV. Femoral biologic plate fixation. Clin Orthop Relat Res 2006; 450: 193–202.

35 Philip JK, James AS, Michael Z, Peter AC. Treatment of distal femur fractures using the less invasive stabilization system surgical experience and early clinical results in 103 fractures. J Ortop Trauma 2004; 18:50–59.

36 Ahmed Mohamed MA. Biological fixation of closed comminuted distal femur fractures using the less invasive stabilization system (LISS). El-Minia Med Bull 2008; 19:33–39

37 Pascarella R, Bettuzzi C, Bosco G, Leonetti D, Dessı S, Forte P, Amendola L. Results in treatment of distal femur fractures using polyaxial locking plate. Strategies Trauma Limb Reconstr 2014; 9:13–18.

38 Klein P, Schell H, Streitparth F, Heller M, Kassi JP, Kandziora F, *et al*. The initial phase of fracture healing is specifically sensitive to mechanical conditions. J Orthop Res 2003; 21:662–669.

39 Hak DJ, Toker S, Yi C, Toreson J. The influence of fracture fixation biomechanics on fracture healing. Orthopedics 2010; 33:752–755.