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GENERAL REVIEW

Currents of plate osteosynthesis in osteoporotic bone

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Abstract Osteoporotic fractures are becoming more prevalent with ageing of populations worldwide. Inadequate fixation or prolonged immobilization after non-surgical care leads to serious life-threatening events, poor functional results and lifelong disability. Thus, a stable internal fixation and rapid initiation of rehabilitation are required for faster return of function. Conventional internal fixation attempts to achieve the exact anatomy, often with extended soft-tissue stripping and compression of the periosteum, causing disturbance of the metaphyseal and comminuted fracture's bone blood supply. This technique relies on frictional forces between bone and plate. Osteoporotic bone might not be able to generate enough torque with the screw to securely fix the plate to bone. Thus, this surgical management have resulted in increased incidence of poor results in elderly, osteoporotic patients. The newly developed locked internal fixators, locking compression plates and less invasive stabilization system, consist of plate and screw systems where the screws are locked in the plate, minimizing the compressive forces exerted between plate and bone. Thus, the plate does not need to compress the bone nor requires precise anatomical contouring of a plate disturbing the periosteal blood supply. These fixators allowed the development of the minimal invasive percutaneous osteosynthesis. Nowadays, locking plates are the fixation method of choice for osteoporotic, diaphyseal or metaphyseal, severely comminuted fractures.

Keywords Osteoporosis · Fracture · Internal fixation · Plate osteosynthesis

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Introduction

Osteoporotic fractures are becoming more prevalent with ageing of populations worldwide [1]. In 2005, more than 2 million osteoporosis-related fractures were responsible for an estimated $19 billion in costs, and by 2025, experts predict to rise to approximately 3 million fractures with costs of $25.3 billion in the USA [2]. Inadequate fixation or prolonged immobilization after non-surgical care might results in atrophy of soft tissues, osteoporosis, thinning of articular cartilage, severe joint stiffness, causalgic pain and decubitus ulceration, as well as serious life-threatening events such as thromboembolisms, pulmonary complications and generalized musculoskeletal deterioration resulting in poor functional results and lifelong disability [3]. Thus, a stable internal fixation and rapid initiation of rehabilitation are required for faster return of function, and therefore, techniques for fracture fixation in osteoporotic bone are becoming more and more important.

Evolution of plate osteosynthesis

The first plate osteosynthesis reported in 1886 by the surgeon Hansmann [4]. In 1958, when the treatment of fractures included prolonged immobilization and its consequences, a group of Swiss general and orthopaedic surgeons established the "Arbeitsgemeinschaft für Osteosynthesefragen" (AO) or the "Association for the Study of Internal Fixation" (ASIF). The AO/ASIF standardized the use of plating systems to achieve anatomical reduction and stable fixation for early initiation of mobilization [5]. Later, they developed a new method involving application of a dynamic compression plate (DCP) and the concept of a lag screw to achieve stable internal fixation with axial compression of fracture that is useful in periarticular fractures which demand anatomical and stable reduction and in simple diaphyseal fractures [6]. This system leads to primary bone healing with no visible callus formation. With this surgical technique, they attempted to achieve the exact anatomy, often at the expense of bone and soft-tissue vitality. Such a wide exposure leads to delayed healing, non-union and an increased tendency to infection, especially in osteoporotic or severely comminuted diaphyseal and metaphyseal fractures [7].

During 1980s, a greater understanding of the above complications forced AO/ASIF to alter the principles of absolute stability and anatomical reconstruction. Therefore, the concept of limited-contact dynamic compression plate (LC-DCP) and later that of point contact fixator (PC-Fix) were developed reducing the contact surface by more than 50 % compared with the conventional DCP [8–11]. To minimize the risk of additional devascularization of the bone fragments, the lag screw was no longer used. Callus healing was not an undesirable side effect, but represented the aim of the treatment with secure fracture consolidation [7].

Osteoporotic fracture

Osteoporosis is a systemic disease characterized by decreased bone mass and degraded bone microarchitecture, leading to bone fragility and an increased susceptibility to fractures. Approximately, 1 in 2 women and up to 1 in 4 men over 50 years old will have an osteoporosis-related fracture in their remaining lifetime [2].

Osteoporotic alterations initiate from cancellous bone due to the underlying pathophysiology. Consequently, metaphyses are at a higher risk of osteoporotic fracture than diaphysis [12]. Also, changes in the diameter of inner and outer cortices affect the bending and torsional characteristics of entire bone and predispose to low-energy fractures, which are often severely comminuted. At a tissue level, there is a decrease in cancellous and cortical bone mineral density and an increase in porosity of cortical bone, which can affect the holding capacity of screws [13–15]. Experimental studies have shown that although the fracture healing and union of osteoporotic bones is normal, the healing process is prolonged [16]. Clinically, such delay in fracture healing is reflected in an increased rate of implant fixation failure [17].

The bone failure, and not the implant breakage, is the primary mode of internal fixation failure in osteoporotic bone. The poor quality of trabecular network would therefore requires adequate fixation elements. However, the number and size of implants that can be placed, especially in articular fragments, are often limited [18].

Limitations of conventional internal fixation techniques are still remaining. The implant-related limitations are that conventional fixation relies on frictional forces between the bone and plate and requires absolutely anatomical reduction for stability. Osteoporotic bone may not be able to generate enough torque with the screw to securely fix the plate to bone [19]. The technical limitations of conventional technique are the extended soft-tissue stripping and the compression of the periosteum, which cause disturbance of bone blood supply adding a biological insult to the poor bone quality of metaphyseal and comminuted fractures [7, 20]. Thus, this surgical management has resulted in increased incidence of poor results in elderly, osteoporotic patients and must be modified to achieve satisfactory results in osteoporotic bone [19, 21, 22].

General principles and biomechanics of conventional plating technique

Direct anatomical reduction and stable internal fixation of fracture are required for internal fixation using a conventional non-locked plate and screw system, for example. DCP. Wide exposure of bone is necessary to allow exact anatomical reduction and stable plate fixation. This procedure requires precontouring of plate to match the bone anatomy. The screws are tightened to fix the plate onto bone, which then compresses plate and bone. The actual stability results from the friction between plate and bone and depends on the quality of the underline bone [23].

Stability determines the amount of strain at the fracture site, and strain determines the type of healing that can occur at the fracture site. Strain is defined as the relative change in fracture gap divided by the fracture gap. Primary bone healing (endosteal healing) occurs when there is absolute stability (rigid fixation), and strain is less than 2 %. Compression plating provides an example of a rigid fixation, minimizing strain by decreasing gap motion and prohibiting increase in gap length. Secondary bone healing (endochondral ossification) occurs when there is relative stability, and strain is ranging between 2 and 10 %. Locked plates and external fixators can provide such relative stability (Fig. 1). Secondary bone healing is characterized by

Fig. 1 Anteroposterior radiograph shows the callus formation due to secondary bone healing using LCP plate for a severely comminuted femoral diaphysis fracture, 2 (**a**) and 9 months (**b**) post-operatively

callus formation. Unlikely, there is no bone healing when strain is greater than 10 % [24].

Conventional plates have the ability to resist axial, torsional and bending loads when applied properly. There is no fracture gap, and the plate is placed on the tension side of fracture [20]. They load axially in tension and/or compression and convert the force applied to shear stress at plate–bone interface. The axial forces are countering by frictional force between the plate and bone, which is a product of the frictional coefficient. Frictional coefficient exits between the bone–implant interface and the force normal to the plate. The force normal to the plate is equal to the axial force generated by the torque applied to screws fixing plate to bone [25]. The screw with the greatest torque contributes the greatest amount of force normal to the plate and therefore bears the greatest load [24].

The resistance to pullout a screw depends on screw's length purchase and thread diameter, as well as the bone quality. Screws should have the largest thread diameter compatible with the scale of fracture being repaired and should be placed to secure fixation into cortical bone. Greater resistance to screw pullout has the cortical bone compared with trabecular because it has greater mineral density. Thus, in osteoporotic bone, a smaller diameter cortical screw may be better than a larger diameter cancellous screw that does not secure cortical purchase [26]. Also, screws placed parallel to the trabecular pattern have greater pullout strength than those placed across trabeculae. The variable of bone quality is crucial in screw holding power. When bone mineral content falls below 0.4 gm/cm^2, the effect of varying thread diameter is lost [26, 27].

Osteoporotic or comminuted bone cannot develop sufficient screw torque to generate sufficient normal force to prevent plate and fracture motion. Osteoporotic bone allows for generation of approximately 3 Nm, or lower, of screw torque. The ideal torque is between 3 and 5 Nm for 3.5 mm screws [24, 25]. Furthermore, approximately 1,200 N is the largest load that can be resisted by a conventional plate fixed with 3.5 mm cortical screws when motion has occurred at plate–bone interface [25]. The lack of axial screw control by the plate demands that bone cortex nearest plate provides the axial screw control. High shear stresses that exceed the strength of cortical bone lead to bone failure in compression or bone absorption and subsequent screw loosening.

Conventional plating techniques may continue to be the fixation method of choice for periarticular fractures which demand anatomical and stable reduction, simple diaphyseal fractures such as forearm fractures and certain types of non-union where anatomical reduction is necessary.

General principles and biomechanics of locking plates

Certain complications using conventional non-locked plates included delayed union, non-union, re-fracture after device removal and infection [28–30]. Subsequently, an effort has been made to reduce the above complications utilizing an improved understanding of the roles of gap strain and tissue vascularity.

Locking plates seem to have biomechanical advantages over traditional plate–screw constructs in osteoporotic bone [19, 21, 22]. They consist of plate and screw systems where screws are locked in the plate minimizing compressive forces exerted between the plate and bone. These plates achieve stability through a threaded interface between the screw head and plate. Thus, locking plates do not rely on frictional forces of bone-implant interface, to secure the plate to bone [20, 31]. These fixators allowed the development of minimal invasive percutaneous osteosynthesis (MIPO) [32]. The locking plates do not need to compress bone nor requires precise anatomical contouring of a plate disturbing the periosteal blood supply. The basic locked internal fixation technique aims at flexible elastic fixation to initiate spontaneous healing and induce of callus formation [23].

An improved locked plating system is the less invasive stabilization system (LISS), which is indicated for stabilization of fractures of the distal femur and the proximal

Fig. 2 Clinical application of LCP in an 83-year-old osteoporotic woman who sustained an extra-articular distal femoral fracture (type 33-A2). Preoperatively (**a**), 3 months (**b**), and 1 year post-operatively (**c**)

tibia, and is applied via a minimally invasive surgical procedure. The plate lies beneath the deep fascia and muscle, but outside the periosteum and is anatomically preshaped. It preserves blood circulation because it is inserted through a small incision at the epiphyseal level and is not needed excessive soft-tissue dissection. It cannot be used as a reduction tool, and the fracture must be reduced and held in traction prior application of the plate [18].

The recent development in the field of variable angle locked plating is the locking compression plate (LCP), which can combine the above mentioned properties (Fig. 2). This system improves fixation using locked compression and gives the option to use the fixator as a reduction tool. The LCP hole can be filled with a conventional cortex screw or a locking head screw [33]. Also, the head of screw has a spherical form, which allows the screw to be fixed at various angles. In synthetic models, the LCP was found to be mechanically better to the DCP when used as a bridging plate and tested in axial compression [34]. However, this system requires further mechanical and clinical studies to evidence its potential advantages over osteoporotic fractures, as well as it demands teaching due to the application complexity.

Locking plates provide angular and axial, relative stability, which leads to secondary bone healing and decreases or eliminates the need for exact plate contouring. These plates are single-beam constructs. A single-beam construct is characterized by the absence of motion between components of the beam and is 4 times stronger than load-sharing beam construct, where motion occurs between individual components of the beam construct [35]. In contrast, conventional non-locked plates can function as single-beam constructs only in ideal circumstances of good bone quality that permits screw torques between 3 and 5 Nm, sufficient coefficient of friction between plate and bone and physiological loads lower than 1,200 N [24].

Functioning as a fixed-angle device can preserve fracture fixation in circumstances where fracture configuration or bone quality does not provide sufficient screw purchase. Locking plates convert shear stress to compressive stress at the screw–bone interface, and fixation is improved because bone has much higher resistance to compressive stress than shear stress [24]. The strength of fixation of locking plates equals the sum of all screw–bone interfaces rather than that of a single screw's axial stiffness or pullout resistance as seen in unlocked plates.

Locked plates act as "internal external fixators" [25]. A long plate and adequate spacing between locking screws must be used. In multifragmentary shaft fractures, it is important to perform indirect closed reduction and attend the axis, length and rotation of the limb [23].

Failure to achieve sufficient medial stability, especially in significant medial bone disruption, pathological fractures and non-union cases [36], has lead to the introduction of the medial endosteal plating. The main advantage of this technique is the ability to achieve bicolumnar support through one incision in comminuted fractures of the distal femur. This technique is not broadly used maybe because it presents a challenge; if the endosteal plate needs to be removed, such as in cases of revision surgery, infection, conversion to intramedullary devices and subsequent joint arthroplasty [37]. Lateral plating alone indirectly supports the medial column. Failure of fixation, through screw pullout or plate breakage, and varus collapse are potential complications, especially when extensive comminution, poor bone quality or a delay in union is present. Bilateral plating supports the medial column, but at the expense of an additional surgical incision or further soft-tissue stripping through a single incision. Biomechanically lateral plating with endosteal substitution showed a decreased gap motion in torsional and axial loading compared with isolated lateral plating [38].

The last decade has been generated plates which allow multiple angle stable screw fixation and aim locking screws in a fracture-specific direction that enables the fixation of many fractures, which are not treatable with standard types of devices. It is particularly crucial when minimal distal bone stock exists or in the setting of periprosthetic fracture. Comparison of stability between polyaxial locking and conventional locking plating showed that the polyaxial plate is stiffer in axial and torsional loading and exhibit less irreversible deformation and higher loads to failure [39]. Although the clinical applicability of polyaxial plates is undisputed, discrepancy exists on the advantages of biomechanical properties over fixed-angle devices [40]. Thus, additional testing is needed to determine their clinical importance.

Novel technique is the utilization of both non-locking and locking screws within a single plate construct termed "hybrid plating". During hybrid plating, the principles of fracture reduction and fixation are the same with the other presented techniques. After reduction of the fracture, non-locking screws are used to compress the plate to bone and help to provide interfragmentary compression (Fig. 3). Then, locking screws are placed altering the overall stiffness of the construct. Studies showed that hybrid technique is mechanically similar to locked constructs, and both are significantly more stable than unlocked constructs under torsional loading [41, 42]. In recent studies, hybrid plating has better vertical subsidence (irreversible deformation) and deflection (reversible deformation) [43], similar bending strength, higher torsional strength and mild decrease in axial strength than an all-locked bridge plating construct [44]. However, the hybrid technique is not recommended by many authors, maybe because sometimes it is performed incorrectly (Fig. 4). A preclinical study in animal tibia found radiologically, biomechanically and histologically less good results of hybrid technique compared with conventional compression and locking compression osteosynthesis [45]. Despite biomechanical and preclinical evidence, there is no clinical data in the literature to study the clinical results of hybrid fixation of osteoporotic fractures and to compare this technique with the others.

Little or no callus formation and paucity of callus on the lateral side of the femur, near the locked plate, where interfragmentary motion is most inhibited, generated the concept of far cortical locking (FCL) [46]. FCL screws reduce the stiffness of a locked-plate construct and provide parallel interfragmentary motion while retaining construct strength and promoting the symmetrical callus formation. The performance of these constructs relies on a particular FCL screw design that supports screw flexion while providing a controlled motion envelope in the near cortex to prevent flexion of screw shafts beyond their elastic limit. In a biomechanical study, these screws retained at least 84 % of the axial strength of the locked-plate constructs, were up to 54 % stronger in torsion and were up to 21 % stronger in bending than the locked-plate constructs [47].

The question of how many screws are needed proximal and distal to the fracture still remains. Following of assessment of radiolucencies, there have been recommended at least 3 cortices on either side of fracture [48], which seems dangerous. Other researchers have proposed, for simple fractures, at least 2 screws per main fragment with purchase of at least 3 cortices and, for comminuted fractures, at least 2 screws per main fragment with purchase of at least 4 cortices [49]. Generally, in good quality bones, the use of monocortical locking head screws is sufficient, however, at least 3 screws should be inserted on either side of the fracture in each main fragment. In osteoporotic bones, the use of locking head screws is recommended with at least 3 screws in each main fragment, on either side of the fracture, of which at least 1 must be inserted bicortically. It is important to avoid stress concentration at the fracture site, while 2- or 3-plate holes in fracture zone without screws lead to stress distribution [23].

Locking plates are the fixation method of choice, for osteoporotic diaphyseal and metaphyseal fractures, for bridging of severely comminuted fractures to minimize soft-tissue damage and for the plating of fractures where a compression plate may not be placed on the tension side of fracture.

Conclusions

Appropriate treatment of osteoporotic fractures requires the understanding of the effect of disease on bone material and structural properties, as well as any effect on the fracture healing. The internal fixation of an osteoporotic fracture should be relatively stable, allowing the secondary bone healing with callus formation. The principles of biological fracture repair should be applied, especially when it is a comminuted fracture. Careful handling of the surrounding soft tissues and avoidance of unnecessary stripping of

Fig. 3 78-year-old woman, with total hip arthroplasty performed 20 years ago and a periprosthetic fracture fixed with a DCP plate 4 years ago at her left limb, sustained an intra-articular distal femoral fracture and a transverse patella fracture (**a**). The old DCP plate was removed, and a new longer LCP plate was introduced with hybrid technique for the fixation of the distal femoral fracture. As for the patella fracture, it was fixed with tension band wiring. Four months after surgery, there is bone healing (**b**)

Fig. 4 80-year-old woman with previous total hip and total knee arthroplasty sustained a periprosthetic fracture which was fixed with LCP. The wrong application of hybrid osteosynthesis, that is, the rigid osteosynthesis without achieving adequate compression, led to plate breakage 6 months later

fracture fragments preserve blood supply to the fracture site. The above principles will reduce the complication rate which is presented by using conventional non-locked plates, including delayed union, non-union, re-fracture after device removal and infection.

Conflict of interest None.

References

1. Reginster JY, Burlet N (2006) Osteoporosis: a still increasing prevalence. Bone 38(2 Suppl 1):S4–S9
2. National Osteoporosis Foundation (2008) Fast Facts on Osteoporosis. Washington. http://www.nof.org
3. Chechik O, Amar E, Khashan M, Kadar A, Rosenblatt Y, Maman E (2012) In support of early surgery for hip fractures sustained by elderly patients taking clopidogrel: a retrospective study. Drugs Aging 29(1):63–68
4. Hansmann C (1886) Eine neue methode der fixierung der fragmente bei complicierten frakturen. Verh Dtsch Ges Chir 158
5. Helfet DL, Haas NP, Schatzker J, Matter P, Moser R, Hanson B (2003) AO philosophy and principles of fracture management-its evolution and evaluation. J Bone Joint Surg Am 85-A(6): 1156–1160
6. Perren SM, Russenberger M, Steinemann S, Muller ME, Allgower M (1969) A dynamic compression plate. Acta Orthop Scand Suppl 125:31–41
7. Schutz M, Sudkamp NP (2003) Revolution in plate osteosynthesis: new internal fixator systems. J Orthop Sci 8(2):252–258
8. Perren SM (1991) The concept of biological plating using the limited contact-dynamic compression plate (LC-DCP). Scientific background, design and application. Injury 22(Suppl 1):1–41
9. Blatter G, Weber BG (1990) Wave plate osteosynthesis as a salvage procedure. Arch Orthop Trauma Surg 109(6):330–333
10. Perren SM, Klaue K, Gautier E (1993) Die limited-contact-DC-platte (LC-DCP), konzept und wissenschaftliche Grundlage. Hefte zu der Unfallchirurg 230:813–815

11. Tepic S, Perren SM (1995) The biomechanics of the PC-fix internal fixator. Injury 26(Suppl):5–10
12. Prestwood KM, Raisz LG (2000) Consequences of alterations in bone remodeling. In: Henderson JE, Goltzman D (eds) The osteoporosis primer. Cambridge University Press, Cambridge, pp 199–211
13. Stromsoe K, Kok WL, Hoiseth A, Alho A (1993) Holding power of the 4.5 mm AO/ASIF cortex screw in cortical bone in relation to bone mineral. Injury 24(10):656–659
14. Seebeck J, Goldhahn J, Morlock MM, Schneider E (2005) Mechanical behavior of screws in normal and osteoporotic bone. Osteoporos Int 16(Suppl 2):S107–S111
15. Seebeck J, Goldhahn J, Stadele H, Messmer P, Morlock MM, Schneider E (2004) Effect of cortical thickness and cancellous bone density on the holding strength of internal fixator screws. J Orthop Res 22(6):1237–1242
16. Namkung-Matthai H, Appleyard R, Jansen J, Hao Lin J, Maastricht S, Swain M, Mason RS, Murrell GA, Diwan AD, Diamond T (2001) Osteoporosis influences the early period of fracture healing in a rat osteoporotic model. Bone 28(1):80–86
17. Stromsoe K (2004) Fracture fixation problems in osteoporosis. Injury 35(2):107–113
18. Curtis R, Goldhahn J, Schwyn R, Regazzoni P, Suhm N (2005) Fixation principles in metaphyseal bone–a patent based review. Osteoporos Int 16(Suppl 2):S54–S64
19. Davis C, Stall A, Knutsen E, Whitney A, Becker E, Hsieh AH, O'Toole RV (2012) Locking plates in osteoporosis: a biomechanical cadaveric study of diaphyseal humerus fractures. J Orthop Trauma 26(4):216–221
20. Perren SM (2002) 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 84(8):1093–1110
21. Smith WR, Ziran BH, Anglen JO, Stahel PF (2007) Locking plates: tips and tricks. J Bone Joint Surg Am 89(10):2298–2307
22. Greiwe RM, Archdeacon MT (2007) Locking plate technology: current concepts. J Knee Surg 20(1):50–55
23. Wagner M (2003) General principles for the clinical use of the LCP. Injury 34(Suppl 2):B31–B42
24. Egol KA, Kubiak EN, Fulkerson E, Kummer FJ, Koval KJ (2004) Biomechanics of locked plates and screws. J Orthop Trauma 18(8):488–493
25. Cordey J, Borgeaud M, Perren SM (2000) Force transfer between the plate and the bone: relative importance of the bending stiffness of the screws friction between plate and bone. Injury 31(Suppl 3):C21–C28
26. Cornell CN (2003) Internal fracture fixation in patients with osteoporosis. J Am Acad Orthop Surg 11(2):109–119
27. Turner IG, Rice GN (1992) Comparison of bone screw holding strength in healthy bovine and osteoporotic human cancellous bone. Clin Mater 9(2):105–107
28. Stover M (2001) Distal femoral fractures: current treatment, results and problems. Injury 32(Suppl 3):SC3–SC13
29. Syed AA, Agarwal M, Giannoudis PV, Matthews SJ, Smith RM (2004) Distal femoral fractures: long-term outcome following stabilisation with the LISS. Injury 35(6):599–607
30. Bolhofner BR, Carmen B, Clifford P (1996) The results of open reduction and Internal fixation of distal femur fractures using a biologic (indirect) reduction technique. J Orthop Trauma 10(6):372–377
31. Perren SM (2001) Evolution and rationale of locked internal fixator technology. Introductory remarks. Injury 32(Suppl 2):B3–B9
32. Nayak RM, Koichade MR, Umre AN, Ingle MV (2011) Minimally invasive plate osteosynthesis using a locking compression plate for distal femoral fractures. J Orthop Surg (Hong Kong) 19(2):185–190
33. Frigg R (2001) Locking compression plate (LCP). An osteosynthesis plate based on the dynamic compression plate and the point contact fixator (PC-Fix). Injury 32(Suppl 2):63–66
34. Snow M, Thompson G, Turner PG (2008) A mechanical comparison of the locking compression plate (LCP) and the low contact-dynamic compression plate (DCP) in an osteoporotic bone model. J Orthop Trauma 22(2):121–125
35. Gautier E, Perren SM, Cordey J (2000) Effect of plate position relative to bending direction on the rigidity of a plate osteosynthesis. A theoretical analysis. Injury 31(Suppl 3):C14–C20
36. Matelic TM, Monroe MT, Mast JW (1996) The use of endosteal substitution in the treatment of recalcitrant non-unions of the femur: report of seven cases. J Orthop Trauma 10(1):1–6
37. Jones CB (2012) Augmentation of implant fixation in osteoporotic bone. Curr Osteoporos Rep 10(4):328–336
38. Prayson MJ, Datta DK, Marshall MP (2001) Mechanical comparison of endosteal substitution and lateral plate fixation in supracondylar fractures of the femur. J Orthop Trauma 15(2):96–100
39. Wilkens KJ, Curtiss S, Lee MA (2008) Polyaxial locking plate fixation in distal femur fractures: a biomechanical comparison. J Orthop Trauma 22(9):624–628
40. Otto RJ, Moed BR, Bledsoe JG (2009) Biomechanical comparison of polyaxial-type locking plates and a fixed-angle locking plate for internal fixation of distal femur fractures. J Orthop Trauma 23(9):645–652
41. Gardner MJ, Griffith MH, Demetrakopoulos D, Brophy RH, Grose A, Helfet DL, Lorich DG (2006) Hybrid locked plating of osteoporotic fractures of the humerus. J Bone Joint Surg Am 88(9):1962–1967
42. Stoffel K, Lorenz KU, Kuster MS (2007) Biomechanical considerations in plate osteosynthesis: the effect of plate-to-bone compression with and without angular screw stability. J Orthop Trauma 21(6):362–368
43. Estes C, Rhee P, Shrader MW, Csavina K, Jacofsky MC, Jacofsky DJ (2008) Biomechanical strength of the peri-loc proximal tibial plate: a comparison of all-locked versus hybrid locked/nonlocked screw configurations. J Orthop Trauma 22(5):312–316
44. Doornink J, Fitzpatrick DC, Boldhaus S, Madey SM, Bottlang M (2010) Effects of hybrid plating with locked and nonlocked screws on the strength of locked plating constructs in the osteoporotic diaphysis. J Trauma 69(2):411–417
45. Plecko M, Lagerpusch N, Pegel B, Andermatt D, Frigg R, Koch R, Sidler M, Kronen P, Klein K, Nuss K, Gedet P, Burki A, Ferguson SJ, Stoeckle U, Auer JA, von Rechenberg B (2012) The influence of different osteosynthesis configurations with locking compression plates (LCP) on stability and fracture healing after an oblique 45 degrees angle osteotomy. Injury 43(7):1041–1051
46. Lujan TJ, Henderson CE, Madey SM, Fitzpatrick DC, Marsh JL, Bottlang M (2010) Locked plating of distal femur fractures leads to inconsistent and asymmetric callus formation. J Orthop Trauma 24(3):156–162
47. Bottlang M, Doornink J, Lujan TJ, Fitzpatrick DC, Marsh JL, Augat P, von Rechenberg B, Lesser M, Madey SM (2010) Effects of construct stiffness on healing of fractures stabilized with locking plates. J Bone Joint Surg Am 92(Suppl 2):12–22
48. Hertel R, Eijer H, Meisser A, Hauke C, Perren SM (2001) Biomechanical and biological considerations relating to the clinical use of the point contact-fixator–evaluation of the device handling test in the treatment of diaphyseal fractures of the radius and/or ulna. Injury 32(Suppl 2):B10–B14
49. Gautier E, Sommer C (2003) Guidelines for the clinical application of the LCP. Injury 34(Suppl 2):B63–B76