Basci et al.
Journal of Orthopaedic Surgery and Research (2025) 20:312
https://doi.org/10.1186/s13018-025-05686-3

Journal of Orthopaedic Surgery and Research

RESEARCH

Open Access

The effect of screw hole inserts for the unused screw holes on the strength of a plate

Onur Basci[1], Selahaddin Aydemir[1*], Ahmet Emrah Acan[2], Onur Gursan[1], Bora Uzun[3] and Mehmet Erduran[1]

Abstract

Introduction The purpose of this study was to determine if the use of specially designed screw hole inserts in empty locking screw holes improves the strength and failure characteristics of locking plates.

Methods Forty-two 7-hole locking LC/DCP plates were mounted on cylindric UHMW Polyethylene blocks with a 1-cm gap between blocks, simulating a fracture with comminution and bone loss. 21 plates had a screw hole insert placed in the center hole (centered over the simulated fracture), while 21 of the plates remained empty in the center hole. The plate–block constructs were placed in a mechanical testing machine and subjected to loading conditions. The axial, bending, and torsional stiffness and displacements needed for the failure of each plate–block construct were calculated. The statistical analysis was performed using the Mann–Whitney U test for independent variables.

Results All plates were then loaded to failure. There were significant differences in the axial load to failure ($p=0.017$), bending load to failure ($p<0.01$), and bending displacements ($p<0.01$) of the test groups favoring the screw hole insert group as higher mechanical strength.

Discussion/conclusion In conclusion, the study demonstrates that the addition of the specially designed locking screw hole insert does significantly change the strength of the locking LC/DCP plates and might be suggested in the clinical application.

Keywords Screw hole inserts, Biomechanical stability, Locking compression plates (LC/DCP), Fracture treatment, Plate fatigue

Introduction

Achieving success in fracture treatment relies on ensuring both biological and biomechanical stability [1–3]. Traditionally, fixation principles require rigid fixation of the bone to the plate, but this approach often disrupts periosteal blood flow, leading to ischemia and necrosis [4, 5]. This situation may be further complicated by systemic conditions such as inadequate vascular nutrition, infection, soft tissue loss, and diabetes, which delay fracture healing [3, 6, 7]. As a result, the mechanical load on the implants increases, which can lead to fatigue failure [8, 9].

In recent years, locking compression plates (LC/DCP) have become an important option, especially in treating diaphyseal complex fractures and comminuted fractures [9–11]. These plates offer the advantage of providing biomechanical stability and promoting biological healing

*Correspondence:
Selahaddin Aydemir
selahaddinaydemir@gmail.com
[1] Department of Orthopaedics and Traumatology, Dokuz Eylul University, Izmir, Turkey
[2] Department of Orthopaedics and Traumatology, Balıkesir University, Balıkesir, Turkey
[3] Department of Biomechanics, Dokuz Eylul University, Izmir, Turkey

while overcoming the limitations of conventional plates [1, 12, 13]. While locking plate technology has been extensively studied, the use of grooved inserts to address stress concentrations in empty screw holes remains underexplored. Also, there is limited research on the specific topic of filling empty screw holes and its impact on the mechanical strength of the plate. Empty screw holes act as stress foci, which can lead to crack initiation and fatigue failure of the plate under mechanical loads [14, 15]. The grooved design redistributes these stress concentrations more evenly, reducing the likelihood of crack formation and increasing the overall structural integrity of the plate [3, 10, 16, 17]. However, there is still a lack of studies examining the effects of screw hole inserts under multiaxial physiological loading conditions and different plate geometries. By improving the biomechanical stability and fatigue life of the implant, the grooved screw hole inserts may provide a practical solution to one of the key challenges in fracture fixation, particularly in cases where maintaining both biological and mechanical stability is critical.

Although the effects of this approach are promising, further research is required under different plate geometries and multiaxial physiological loading conditions.

The purpose of this study was to determine whether the use of specially designed screw hole inserts in unfilled locking and compression screw holes improves the durability and failure characteristics of locking plates. We hypothesize that filling unfilled screw holes with specially designed screw hole inserts will improve the fatigue life and stability of fixation in the treatment of fractures.

Fig. 1 The left panel shows details of the threaded screw hole insert compatible with the LC/DCP system. The center panel shows the placement of the screw hole inserts on the plate. The right panel shows the configuration of the LC/DCP plate and screw hole inserts mounted on a synthetic UHMW block to simulate fracture fixation

Fig. 2 Displays a threaded screw hole insert aimed at enhancing the biomechanical stability of dynamic locking compression plates (LC/DCP). The left panel illustrates a side view of the threaded design, while the right panel presents a top view of its circular shape

Material method

In this study, the effects of adding screw hole inserts to unused screw holes in locking plates on the durability and mechanical properties of the plates were investigated. In this study, 42 LC/DCP locking plates with 7 holes were mounted on cylindrical UHMW (Ultra High Molecular Weight) polyethylene blocks. Plate is made of Cr–Ni–Mo Stainless Steel (ISO 5832-1) and dimensions are 135 mm × 12 mm × 4 mm.The screw hole inserts have diameter of 4.5 mm and pitch of 1 mm. These dimensions were optimized so that it can be placed on the plate like a locking screw head and screwed together. A model simulating comminuted fracture and bone loss was created by leaving a 1 cm gap between these blocks (Fig. 1). The 10 mm gap was designed to leave sufficient bone for the removal of screws adjacent to the defect, while also providing enough space to allow flexion of the plates without contact between the opposing cortices. Also, by leaving a gap of 1 cm, a fracture with fragmentation and bone loss was simulated [3, 16, 21]. In 21 of the mounted plates, threaded (grooved) screw hole inserts were added to the center holes, while the center holes were left empty in the other 21 plates. Based on the screw cap design of Firoozabadi et al. [10], a threaded structure was added to the cap for better adaptation and tight fit of the screw heads to the plate holes (Fig. 2). These threads aim to optimize the load distribution by increasing the mechanical stability of the screws and prevent the screw hole inserts to pop out due to mechanical stress.

The plate–block constructions were placed in a mechanical analyzer (AG-IS 10 kN, Shimadzu, Kyoto, Japan) and subjected to various loading conditions. These loading conditions were applied as follows:

1. *Axial loading tests*: Each plate–block model was tested to measure durability by applying axial loads.

Loading speed was set as 100 mm/min, and the tests continued until the plates failure without any duration. The load and the displacement values were recorded at failure.

2. *Bending tests*: Bending tests were performed to measure the elasticity and deformation properties of the plates (Fig. 3). Load was applied at a rate of 100 mm/min until failure without any duration and maximum load and displacement values were recorded.
3. *Torsion tests*: Torsion loads were applied to evaluate the torsional stiffness and durability of the plates until failure at same speed and condition as other tests. (Fig. 4). In torsion tests, the maximum loads and deformation levels were measured.

The mechanical properties of each plate–block construction were calculated using axial stiffness and displacement values, bending stiffness and deformation properties, and torsional stiffness and deformation parameters. These mechanical parameters were recorded to understand how the plates perform under various loading conditions and quantify the effects of design changes.

For statistical analysis, the Mann–Whitney U test was used to compare between independent variables. All analyses were performed using a 95% confidence interval to assess whether the results were statistically significant. This is a Level III biomechanical study.

Results

Axial loading tests

A comparison was conducted to evaluate the axial load performance of interlocking plates with unfilled screw holes versus those with filled screw holes. In tests on the interlocked plates with open screw holes, the average fracture axial load was recorded at 1325 N. Meanwhile, the average fracture axial load for the plates with filled screw holes was 1457 N. Statistical analyses indicated a significant difference between the two groups ($p = 0.017$) (Fig. 5). We observed that using the screw hole insert provided 10% more strength under axial loading (1325–1457 N). This result demonstrates that plates with filled screw holes can support significantly higher axial loads before fracturing compared to those with open screw holes. Therefore, filling the screw holes enhances the mechanical stability and load-bearing capacity of the

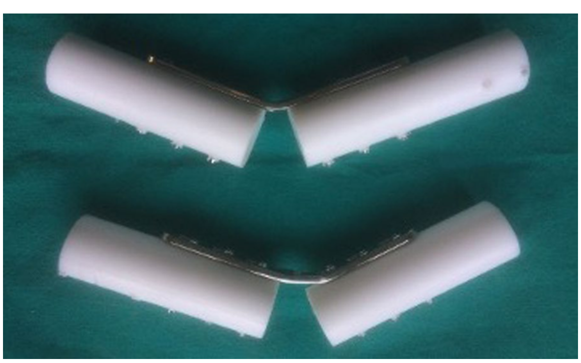

Fig. 3 The top panel shows that the plate without the screw hole inserts is bent at a sharper angle, while the bottom panel shows that the plate with the screw hole inserts is bent less sharply, effectively distributing stress proximally and distally with a lower angle

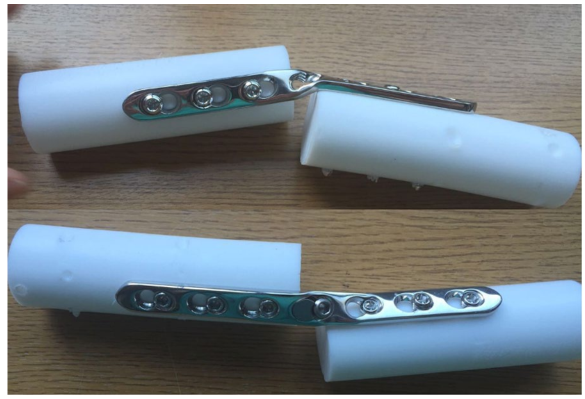

Fig. 4 Top panel: LC/DCP plate without screw hole inserts with torsional torsion at the screw hole. Bottom panel: In the LC/DCP plate with screw hole inserts, rotational fracture was observed between two screw holes rather than a single hole with a lower rotational deformation

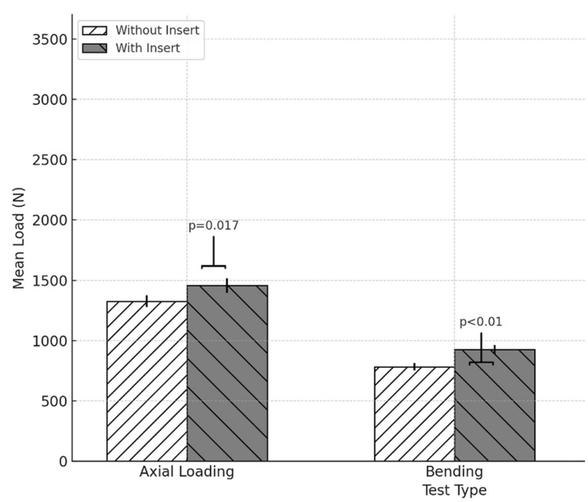

Fig. 5 Comparison of mean axial load and bending load between locking plates with and without screw hole inserts. The plates with inserts showed significantly higher mean axial load ($p = 0.017$), bending load ($p < 0.01$) compared to plates without inserts, indicating improved mechanical strength

locked plates. These findings suggest that screw hole inserts have the potential to improve the biomechanical properties of locking plates, representing a valuable option for clinical applications.

Bending tests

When comparing the lateral bending of plates with hollow screw holes to those with solid screw holes, it was observed that plates with solid screw holes exhibited superior mechanical strength and flexibility. The average failure bending load for solid plates was 925.31 N, compared to 782.08 N for hollow plates (approximately 15% more strength). Likewise, solid plates demonstrated greater deformation tolerance with a displacement of 26.78 mm, while hollow plates reached only 16.17 mm (about 39% more flexibility). This prevents the plate from breaking where the empty hole is, causing the parts of the plate that are farther away from the hole filled with the insert to bend, without breaking. Statistical analysis confirmed that both parameters indicated solid screw holes enhance the load-carrying capacity and structural stability of the plates ($p < 0.01$) (Figs. 5 and 6). These results suggest that inserts for screw holes improve the lateral bending biomechanical performance of locking plates.

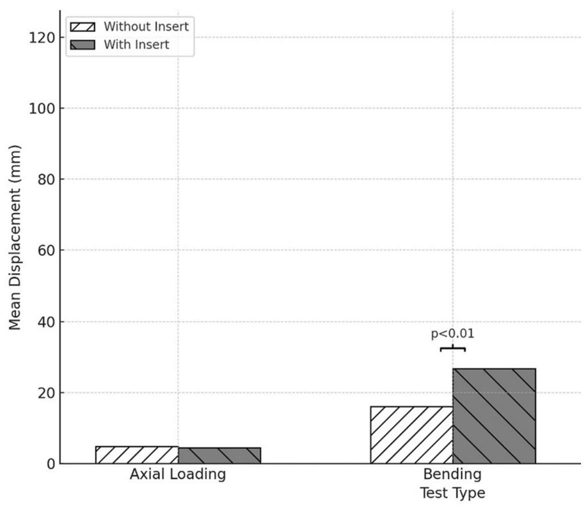

Fig. 6 Comparison of mean axial and bending between locking plates with and without screw hole inserts. Plates with inserts demonstrated significantly higher displacement during bending tests ($p < 0.01$), indicating enhanced deformation tolerance

Torsion tests

Plates with screw holes filled and plates with screw holes left open were compared to evaluate the torsional load and displacement performances. The average failure torsional load of the plates with filled screw holes was measured as 32.43 Nm, and the average displacement value was measured as 116.47 mm. The average failure torsion load was 29.81 Nm, and the average displacement was 122.68 mm for plates with screw holes left open. This means 10% more torsional improvement. Despite the improvement in torsional load, no difference was seen in torsional displacement. This is because the inserts primarily enhance load distribution rather than altering the overall deformation characteristics of the plate. Statistical analysis showed a significant difference between the two groups ($p < 0.01$) (Fig. 7). The plates with filled screw holes withstood significantly higher torsion

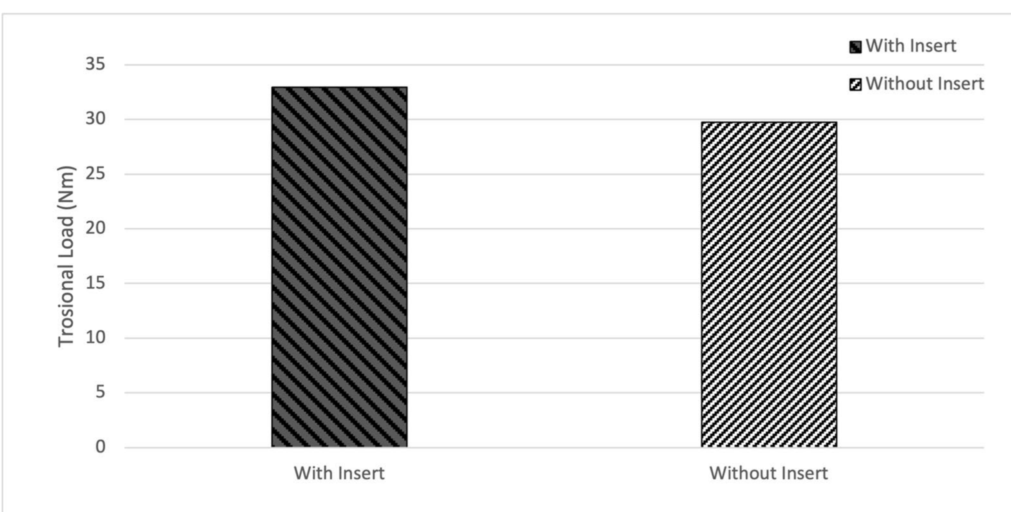

Fig. 7 Comparison of torsional loads between between locking plates with and without screw hole inserts

loads before failure compared to the plates with open holes.

Discussion

Locking compression plates (LC/DCP) have significantly improved the treatment of comminuted fractures, yet some aspects still require optimization. Stress concentrations caused by empty screw holes are a major factor that shortens implant fatigue life and leads to mechanical failures. Hardware failure, such as plate fractures or screw breakages, has been reported in approximately 7% of plate fixations [18].

Stress analyses by Nassiri et al. identified screw heads as critical points of fatigue failure due to high stress concentrations [19]. Similarly, Stoffel et al. observed that plate failures often occur at DCP holes, where stress is most concentrated [20]. Our findings align with this literature, showing that the new threaded inserts provide an effective solution to these stress-related issues.

Empty screw holes create stress concentrations that can increase internal stresses up to threefold, often initiating fatigue failure [3]. Filling these holes with threaded screw heads or metal plugs has been shown to improve implant fatigue life [3, 10, 16, 17]. Bellapianta et al. reported that filling screw holes quadrupled the fatigue life of locking plates without significantly affecting bending stiffness [3]. Tompkins et al. found similar results but noted that eccentric and non-threaded plugs in combination holes did not provide effective reinforcement [16]. These findings suggest that screw plugs enhance fatigue strength by slowing crack growth, though they do not significantly alter the plate's elastic properties.

Conflicting results have also been reported. Eichinger et al. found that screw hole inserts had no significant effect on the mechanical properties of 1/3 tubular locking plates, likely due to factors such as plate size and limited tooth support as well as the lack of evaluation of the 'cold weld' effect that may occur between the plate and screws. These were stated as important limitations [21]. The type and dimensions of the plates they use are different from the ones we use. In addition, in their study, only an insert consisting of a hollow screw head was used. In our study, a grooved insert that we developed and a structure in the shape of a screw head that would also fill the other hole were used. In this way, all the gaps were filled and the insert was prevented from coming out of its place thanks to the grooved structure. Viitanen et al. reported that filling the empty plate holes with locking plugs in bridging osteosynthesis did not increase the stiffness or strength of the plate-bone structure under the conditions tested in their study by creating a 25 mm defect [17]. Despite these mixed findings, our study demonstrated significant improvements in the mechanical properties of LC/DCP plates, especially under high-stress conditions, highlighting the potential of these inserts in optimizing implant performance.

Studies have shown that the design and configuration of locking plates—such as the number and position of screws, plate length, and working length—significantly affect biomechanical performance in plate osteosynthesis [19, 20, 22]. Zhang et al. demonstrated how locking compression plate (LCP) systems with asymmetric holes and polyaxial screws fail, highlighting that the narrow side is especially prone to stress concentrations and requires reinforcement. They emphasized that screws should be positioned at a $-10°$ angle and avoided at the fracture site [22]. While the fixed-angle structure is key to the success of locking plates, polyaxial screws maintain this feature only up to a 10° angle. At extreme angles like 15°, mechanical stability is compromised [23]. Our study supports these findings by showing that specially designed grooved inserts can significantly enhance the mechanical properties of LC/DCP plates. In multipart fractures where working distance cannot be adjusted, placing screw hole inserts at fracture sites could further improve mechanical stability.

We hypothesized that a threaded insert design would improve stabilization by enhancing the adaptation of screw heads to plate holes. Our results confirmed that these inserts significantly improved axial loading, bending, and torsional strength while reducing the risk of fatigue due to stress concentrations. This design optimizes stress distribution and enhances implant durability, making it a promising option for clinical use. Our study demonstrates that newly designed threaded screw hole inserts may offer notable potential clinical benefits.

Our design consists of two main components: a grooved screw hole insert and a grooved screw head. The grooved hole insert is placed into the empty screw hole of the locking plate, while the grooved screw head secures the insert in place and simultaneously fills the adjacent hole. This dual-component system ensures that both the insert and the screw head are firmly locked, preventing any risk of pull-out from the plate. Additionally, this design allows both holes of the locking plate to be filled, addressing the issue of stress concentration around empty screw holes.

In contrast to previous studies, where filling materials were often used for only one hole, our design provides a more robust solution. Earlier approaches have faced limitations, such as insufficient mechanical reinforcement and the risk of the filling material dislodging due to inadequate fixation. Our innovative design not only enhances the mechanical stability of the plate but also eliminates the risk of component migration, offering a significant improvement over existing methods.

Despite these encouraging findings, our study has limitations. Mechanical tests were conducted on synthetic bone models, which may not fully reflect the variability of human bone. Additionally, in vitro conditions do not account for the effects of soft tissue or dynamic loading found in vivo. Future studies should validate these findings under more clinically relevant conditions, including in vivo experiments with dynamic loading and soft tissue interaction. Further research on different plate geometries, lengths, and working lengths could provide a broader understanding of the biomechanical benefits of screw hole inserts. In addition to implant material variability, biological variability can affect real-world performance, such as differences in bone density, age, gender, and other patient-specific factors. However, these factors will generally not have a significantly different effect than traditional plating methods. Advanced computational modeling, such as finite element analysis, could also help optimize their design and placement to reduce stress concentrations and prevent implant fatigue. These steps will help translate the promising results of this study into more comprehensive clinical applications.

Conclusions

This study demonstrates that the addition of threaded screw hole inserts significantly improves the mechanical performance of LC/DCP plates, particularly enhancing axial, bending, and torsional strength. The use of these inserts provides an effective method to reduce stress concentrations and mitigate the risk of fatigue fractures, especially under high-stress conditions. Considering their affordability, simplicity in application and ability to extend the life of implant, screw hole inserts offer a very useful option for use in clinical settings. Future studies should focus on validating these findings in different plate geometries and in vivo conditions to further enhance their effectiveness in clinical practice.

Abbreviations

LC/DCP	Limited contact dynamic compression plate
UHMW	Ultra high molecular weight
DCP	Dynamic compression plate
LCP	Locking compression plate

Acknowledgements

Not applicable.

Author contributions

All authors contributed to study design. O.B., A.E.A. and M.E.: study design. O.B., A,E,A., B.U.: conducted the biomechanical experiments and collected the data. S.A., O.B., M.E.: data analysis and statistical analysis. S.A, O.B.: preparation of manuscript, tables and figures. O.B., S.A., O.G.: contributed to the interpretation of the results and provided critical revisions to the manuscript. O.B., A.E.A, S.A.: revision of the manuscript, tables and figures. The final version was approved by all authors.

Funding

This study did not receive financial support.

Availability of data and materials

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

No human or animal subjects were involved in this biomechanical study. Therefore, ethical approval was not required.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 20 January 2025 Accepted: 6 March 2025
Published online: 25 March 2025

References

1. Miller DL, Goswami T. A review of locking compression plate biomechanics and their advantages as internal fixators in fracture healing. Clin Biomech (Bristol, Avon). 2007;22(10):1049–62. https://doi.org/10.1016/j.clinbiomech.2007.08.004.
2. Augat P, von Rüden C. Evolution of fracture treatment with bone plates. Injury. 2018;49(Suppl 1):S2–7. https://doi.org/10.1016/S0020-1383(18)30294-8.
3. Bellapianta J, Dow K, Pallotta NA, Hospodar PP, Uhl RL, Ledet EH. Threaded screw head inserts improve locking plate biomechanical properties. J Orthop Trauma. 2011;25(2):65–71. https://doi.org/10.1097/BOT.0b013e3181dc56b1.
4. Strauss EJ, Schwarzkopf R, Kummer F, Egol KA. The current status of locked plating: the good, the bad, and the ugly. J Orthop Trauma. 2008;22(7):479–86. https://doi.org/10.1097/BOT.0b013e31817996d6.
5. Kubiak EN, Fulkerson E, Strauss E, Egol KA. The evolution of locked plates. J Bone Jt Surg. 2006;88(Suppl 4):189–200. https://doi.org/10.2106/JBJS.F.00703.
6. Nandra R, Grover L, Porter K. Fracture non-union epidemiology and treatment. Trauma. 2016;18(1):3–11. https://doi.org/10.1177/1460408615591625.
7. Perumal V, Roberts CS. (ii) Factors contributing to non-union of fractures. Curr Orthop. 2007;21(4):258–61.
8. Fulkerson E, Egol KA, Kubiak EN, Liporace F, Kummer FJ, Koval KJ. Fixation of diaphyseal fractures with a segmental defect: a biomechanical comparison of locked and conventional plating techniques. J Trauma. 2006;60(4):830–5. https://doi.org/10.1097/01.ta.0000195462.53525.0c.
9. Gardner MJ, Brophy RH, Campbell D, Mahajan A, Wright TM, Helfet DL, Lorich DG. The mechanical behavior of locking compression plates compared with dynamic compression plates in a cadaver radius model. J Orthop Trauma. 2005;19(9):597–603. https://doi.org/10.1097/01.bot.0000174033.30054.5f.
10. Firoozabadi R, McDonald E, Nguyen TQ, Buckley JM, Kandemir U. Does plugging unused combination screw holes improve the fatigue life of fixation with locking plates in comminuted supracondylar fractures of the femur? J Bone Jt Surg Br. 2012;94(2):241–8.
11. Grau L, Collon K, Alhandi A, Kaimrajh D, Varon M, Latta L, Vilella F. Filling open screw holes in the area of metaphyseal comminution does not affect fatigue life of the synthes variable angle distal femoral locking plate in the AO/OTA 33–A3 fracture model. Surg Technol Int. 2018;32:293–7.

12. Egol KA, Kubiak EN, Fulkerson E, Kummer FJ, Koval KJ. Biomechanics of locked plates and screws. J Orthop Trauma. 2004;18(8):488–93. https://doi.org/10.1097/00005131-200409000-00003.
13. Wagner M. General principles for the clinical use of the LCP. Injury. 2003;34(Suppl 2):B31–42. https://doi.org/10.1016/j.injury.2003.09.023.
14. Sommer C, Babst R, Müller M, Hanson B. Locking compression plate loosening and plate breakage: a report of four cases. J Orthop Trauma. 2004;18(8):571–7. https://doi.org/10.1097/00005131-200409000-00016.
15. Yukata K, Doi K, Hattori Y, Sakamoto S. Early breakage of a titanium volar locking plate for fixation of a distal radius fracture: case report. J Hand Surg. 2009;34(5):907–9. https://doi.org/10.1016/j.jhsa.2009.01.004.
16. Tompkins M, Paller DJ, Moore DC, Crisco JJ, Terek RM. Locking buttons increase fatigue life of locking plates in a segmental bone defect model. Clin Orthop Relat Res. 2013;471(3):1039–44. https://doi.org/10.1007/s11999-012-2664-1.
17. Viitanen J, Quinn R, Allen M, Broeckx BJG, Bartkowiak T, Haimel G. Do locking plugs improve implant strength? Biomechanical comparison of polyaxial locking constructs with and without locking plugs in a fracture gap model. BMC Vet Res. 2023;19(1):104. https://doi.org/10.1186/s12917-023-03660-x.
18. Ramotowski W, Granowski R. Zespol. An original method of stable osteosynthesis. Clin Orthop Relat Res. 1991;272:67–75.
19. Nassiri M, Macdonald B, O'Byrne JM. Computational modelling of long bone fractures fixed with locking plates: How can the risk of implant failure be reduced? J Orthop. 2013;10(1):29–37. https://doi.org/10.1016/j.jor.2013.01.001.PMID:24403745;PMCID:PMC3768240.
20. Stoffel K, Dieter U, Stachowiak G, Gächter A, Kuster MS. Biomechanical testing of the LCP: How can stability in locked internal fixators be controlled? Injury. 2003;34(Suppl 2):B11–9.
21. Eichinger JK, Herzog JP, Arrington ED. Analysis of the mechanical properties of locking plates with and without screw hole inserts. Orthopedics. 2011;34(1):19.
22. Zhang NZ, Liu BL, Luan YC, Zhang M, Cheng CK. Failure analysis of a locking compression plate with asymmetric holes and polyaxial screws. J Mech Behav Biomed Mater. 2023;138:105645. https://doi.org/10.1016/j.jmbbm.2022.105645.
23. Hebert-Davies J, Laflamme GY, Rouleau D, Canet F, Sandman E, Li A, Petit Y. A biomechanical study comparing polyaxial locking screw mechanisms. Injury. 2013;44(10):1358–62. https://doi.org/10.1016/j.injury.2013.06.013.

Publisher's Note