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ORIGINAL ARTICLE

Does the type of medial plate fixation matter for supplemental fixation of distal femur fractures manage with a lateral pre-contoured locked plate? A Biomechanical study

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Abstract

Introduction Fixation of distal femur fractures with a lateral pre-contoured locking plate provides stable fixation and is the standard treatment in most cases, allowing early range of motion with a high rate of union. However, in situations, the stability achieved with the lateral plate alone may be insufficient, predisposing to fixation failure. The objective of the study was to compare, in synthetic bone models, the biomechanical behaviour of the fixation with a distal femur lateral pre-contoured locking plate solely and associated with a 3.5 mm proximal humeral locking plate applied upside down or a 4.5 mm helical locking compression plate on the medial side.

Material and methods A total of 15 solid synthetic left femur samples were used. A metaphysical defect at the level of the medial cortex was simulated. The samples were randomly distributed into three groups equally. All groups received a 4.5/5.0 mm single lateral 9-hole distal femur lateral pre-contoured locking plate. Group 1 had no supplementary plate. Group 2 received a supplementary 6-hole 3.5 mm proximal humeral locking plate and Group 3 received a supplementary 4.5/5.0 mm helical 14-hole narrow locking compression plate.

Results Both supplementary plate types used in groups 2 and 3 contributed to increase the apparent stiffness of the construct, but pairwise comparison showed statically significant difference only between group 1 and 3. No significant difference was observed between groups 2 and 3.

Conclusion Both supplementary plates might be considered for improving the fixation in distal femur fracture in selected cases.

Keywords Distal femur fracture · Dual plating · Helical plate

Introduction

Distal femur fractures account for 6% of all femoral fractures [1]. Internal fixation with a lateral pre-contoured locking plate provides stable fixation, and it is the standard treatment nowadays, allowing an early range of motion with a high rate of union [2, 3]. However, in situations with extensive metaphyseal bone defect, medial metaphyseal comminution and/or instability, and small epiphyseal fragment on stable periprosthetic knee fractures, the stability achieved with the lateral plate alone may be insufficient, predisposing to fixation failure [4, 5]. For these situations, different strategies to increase stability have been described [5–12]. The supplementation with a retrograde intramedullary nail (nail-plate combination) provides a more balanced fixation, especially when there is the possibility of using the "closing the box" concept, linking both proximal and distal screws between the plate and the nail. This construct enhances the rigidity of the construction, allowing early weight bearing in most cases [8]. Another strategy is the augmentation with a medial plate, which may be a helpful alternative due to the certain anatomic characteristics of the fracture, which preclude nail placement, or the presence of a previous implant, such as a closed-box femoral knee prosthesis [13].

Dual plate fixation of the femur was first described in the clinical setting by Ruoff and Biddulph in 1972 to manage challenging distal femur fractures [6]. Although recent biomechanical studies have shown that supplementation with a medial plate increases fixation rigidity [14–18], there is

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some debate about which plate construction provides the best mechanical environment. Ultimately, this is crucial as the appropriate stiffness and fracture motion for distal femur fracture healing is unknown, and the fixation construct can lead to a nonunion, either because it is too stiff or too flexible [3, 19].

We hypothesize that the apparent stiffness of the helical locking compression plate is superior to that obtained with the proximal humerus plate. In the herein study, we aim to compare the biomechanical behaviour of two different locking plates in association with a distal femur lateral pre-contoured locking plate (DFLP) in an experimental model of a distal femur fracture with medial defect.

Material and methods

Sample description

Fifteen manufactured solid synthetic left femur samples from the same batch (Nacional Ossos, Jaú, Brazil) were used. The models were made of polyurethane, with high-density cortical bone and soft cancellous bone, measuring 460 mm in length, 80 mm in condylar width and 9.5 mm in canal diameter. The mechanical characteristics and mechanical behaviour of the tested models were previously validated in other studies [20, 21].

A transverse cut was made from lateral to medial with an oscillating saw 6 cm from the distal part of the lateral condyle of the femur. A second cut was made in the medial cortical bone at a 45° inclination, 3 cm proximal to the site of the first osteotomy and directed towards the external cortical bone. All cuts were standardized by the authors and performed by the manufacturer.

The samples were randomly distributed into three groups equally. All groups received a 4.5/5.0-mm single lateral 9-hole distal femur lateral pre-contoured locking plate (Zimmer® Periarticular Locking Plate (ZPLP), Zimmer-Biomet, Warsaw, USA). At the distal part, the plate was fixed with five 5.0-mm locking screws (70- to 80-mm length). At the proximal segment the plate was fixed with three 4.5mm bicortical non-locking screws at hole numbers 4, 7 and 9. We chose to use non-locking screws in the proximal part of the plate because the model used reproduced normal cortical bone density. As the objective was to evaluate the mechanical role and behaviour of the medial plates, the choice of non-locking screws was a constant variable in the 3 experimental groups. In the distal part of the fixation, we chose to use 5 locked screws, which mimics what is done in the clinical scenario, increasing the fixation power in the shorter fragment, and leaving space for the placement of the screws used in the 2 experimental groups using a medial plate.

Group 1 (DFLP) received no supplementary plate; Group 2 (DFLP + PHLP) received a supplementary 6-hole 3.5-mm proximal humeral locking plate fixed with three distal locking screws and two proximal non-locking screws (Zimmer® Periarticular Proximal Humeral Locking Plate System, Zimmer-Biomet Warsaw, USA) (Fig. 1); and Group 3 (DFLP + hLCP) received a supplementary 4.5/5.0-mm helical 14-hole narrow locking compression plate (LCP®, DePuy-Synthes – J&J Company, Warsaw, USA) fixed with two locking screws distally and two non-locking screws proximally. All plates and screws were made of stainless steel. Both supplementary plates were placed in the distal segment to avoid conflict with screws from the DFLP.

Biomechanical testing

The experiment was held on the Mechanical Testing Laboratory, Department of Manufacturing and Materials Engineering, Faculty of Mechanical Engineering – UNICAMP (Campinas, Brazil). The tests were performed in a universal

Fig. 1 AP view of a Group 2 sample (DFLP + PHLP). Note the orthogonal arrangement of the plates. The model was mounted upside down on the testing machine, with an adduction angle of 10 degrees to reproduce physiological load transmission, and the load was applied to the condyle through a polymeric component of a knee prosthesis

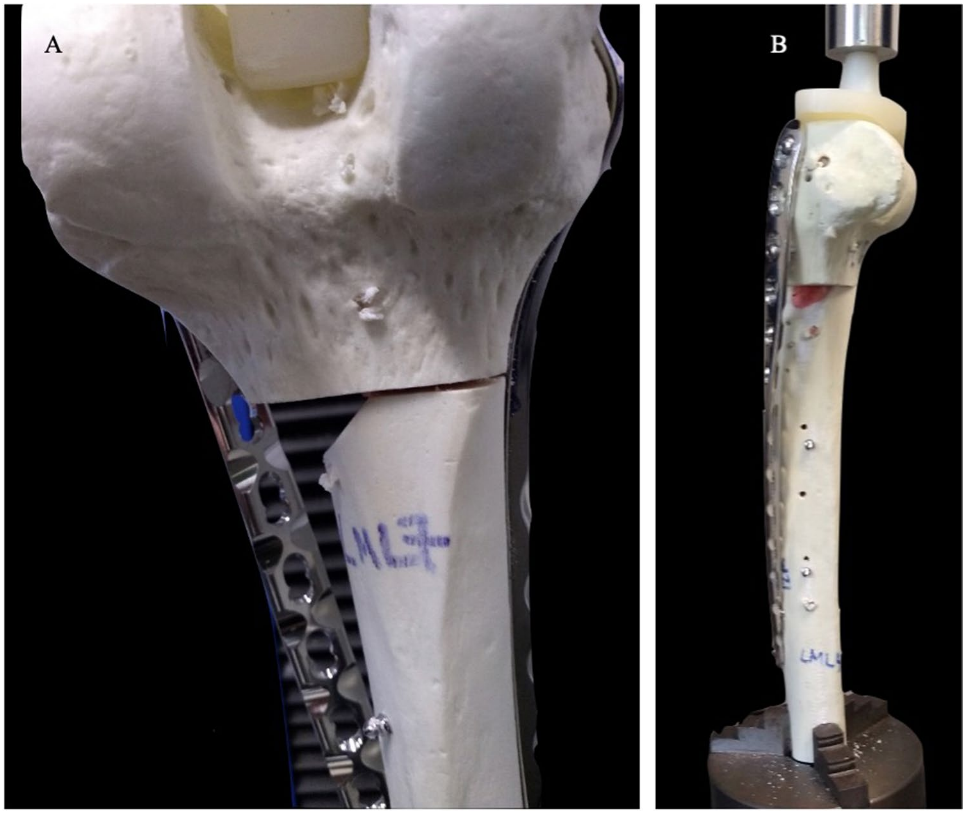

Fig. 2 Test details on a Group 3 model (DFLP + hLCP). **A**, AP view of the distal defect with the orthogonal construct. **B**, Positioning the model on the universal testing machine for mechanical testing – lateral view of the sample

testing machine (EMIC DL3000) using a load cell with a capacity of 5000 N. The femoral head was removed for better fixation, and the load was applied to the condyle through a polymeric component of a knee prosthesis. The femurs were assembled upside down with a 10° adduction angle to reproduce physiological load transmission. The proximal part of the femur was clamped on the bottom side of the material testing machine (Fig. 2). A preload of 150 N was initially applied to stabilize the sample. An increasing load was then applied to the sample by moving the machine's movable crosshead downwards at a 10 mm/min speed. The maximum load was set at 2000 N. The tests were interrupted automatically when the maximum load was reached or manually if the sample showed signs of permanent deformation. The data were recorded by a computer connected to the machine. The software generated in real time and recorded a load (N) curve vs. displacement (mm). From the data recorded in the computer, the linear region of the curve was identified, and from its slope, the sample's apparent stiffness in N/mm was obtained.

Statistical analysis

Outcome of interest was the apparent stiffness (N/mm). Data were compared across all groups. Due to the no normal distribution of the parameters, we used the nonparametric Kruskal–Wallis test. The Dwass-Steel-Critchlow-Fligner test was used for post hoc multiple comparisons. Data were analysed with the open statistical software Jamovi, version 2.3.

Results

Table 1 shows the mean, standard deviation, median, maximum, minimum, and interquartile range of the apparent stiffness for each experimental group. In the biomechanical model employed, the medial plate supplementation of a distal femur fracture treated with a DFLP significantly influenced the apparent stiffness ($p = 0.014$). Both supplementary plates used in groups 2 (DFLP + PHLP) and 3 (DFLP + hLCP) contributed to an increase in the apparent stiffness of the constructs, but pairwise comparison showed a statistically significant difference only between DFLP and DFLP + hLCP ($p = 0.024$). Although the assembly DFLP + PHLP also exhibited increased apparent stiffness than the DFLP, it did not raise statistical significance ($p = 0.72$). No significant difference was observed between DFLP + hLCP and DFLP + PHLP ($p = 0.615$). Figure 3 shows the results in the box-plot form.

Table 1 Statistical data of the apparent stiffness according to the experimental model *Source* Mechanical Testing Laboratory, Department of Manufacturing and Materials Engineering, Faculty of Mechanical Engineering – UNICAMP (Campinas, Brazil)

Experimental model	Mean	Standard deviation	Median	Maximum	Minimum	Inter-quartile range
DFLP	180.8	25.2	178.5	214.5	155.3	38.1
DFLP + PHLP	240.4	59.0	224.9	340.3	183.3	8.6
DFLP + hLCP	252.5	23.6	257.8	279.4	221.1	31.1

Values in N/mm

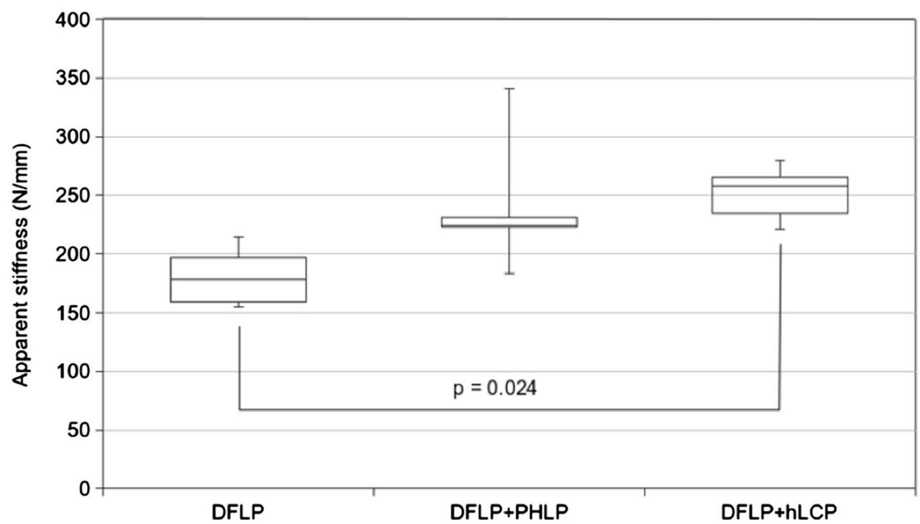

Fig. 3 Box-plot chart of the apparent stiffness values according to the experimental group, highlighting statistically significant differences between DFLP and DFLP-hLCP

Discussion

Our biomechanical study demonstrates that the apparent stiffness of an experimentally produced unstable fracture of the distal femur fixed with a distal lateral locking plate is significantly increased using a supplemental medial plate, either a 3.5-mm proximal humerus locking plate or a 4.5-mm helical LCP. Although no statistically significant difference was observed between the DFLP + hLCP and DFLP + PHLP groups, in the pairwise comparison, it was observed a statistically significant difference only between the DFLP and DFLP + hLCP groups. Even the DFLP + PHLP group showing greater apparent rigidity than the DFLP group, this was not statistically significant. Our findings are intriguing, as there was no difference between the groups that used the medial plate. A possible explanation could be the small sample size used in our study, although the p value for the DFLP + PHLP group did not tend towards statistical significance. Another possible explanation can be attributed to the length of the plates, since for more comminuted fracture patterns, a long plate has been shown to provides better axial and torsion stability than a short plate [19].

Since there is no plate specifically designed for the anatomy of the medial aspect of the distal femur, in our study, a proximal humerus locking plate and a helically twisted locked straight plate were tested. These implants are among the most used in these situations in clinical series due to specific characteristics that make both highly versatile in adapting to this anatomic region [13, 22–25]. The proximal humerus locked plate has a low profile and a design that perfectly adapts to the medial aspect of the distal femur without needing pre-moulding in most patients, thus avoiding irritation of the medial soft tissues. In addition, it offers multiple screw options in different directions, which is advantageous not only to avoid the screw traffic present in these situations but also to increase the pull-out force required for mechanical failure [26]. Anatomical studies have shown that using this implant in the distal femur from a medial approach is a safe technique concerning the pre-bent helical, straight-locked plate. Hohenberger et al. [22] demonstrated that the most proximal perforating artery was located at a mean distance of 20.15 mm starting from the proximal plate margin and the mean interval between the medial border of the plate at the level of its proximal tip and the femoral artery was 51.9 mm. Moreover, the average distance between the femoral nerve, and the medial border of the proximal part of the plate was 42.3 mm and the interval between the medial border of the plate and the femoral artery was at a mean of 40.5 mm at the level of the proximal margin of the vasto-adductor membrane [22]. In another anatomical study with CT angiography, Pastor et al. [24] showed that inserting 90° and 180° helical plates with minimally invasive plate osteosynthesis is a safe technique. These authors drew attention to the medial neurovascular structures using 90° helical plates and the proximal perforating vessels using 180° helical plates.

Several studies have supported the biomechanical advantages of medial plate augmentation for severely unstable and/or comminuted distal femur fractures, either native or periprosthetic [12–18]. Torodov et al. [16] evaluated the competence of two different methods for supplementation of the Less Invasive Stabilization System (LISS) in synthetic bones. They found that the dual plating achieved the greatest fracture stability compared to intramedullary graft augmentation or LISS alone. Fontenot et al. [17] assessed the biomechanical properties of a lateral locked plate alone or in combination with a supplemental medial plate or retrograde nail in synthetic femurs. They found that the low-profile 3.5-mm medial distal tibia plate did not add significant stiffness to the construct. However, the 3.5-mm reconstruction plate and retrograde nail supplementation were significantly superior to the lateral plate alone. Park et al. [15] evaluated the biomechanical performance of medial plate supplementation in unstable lateral distal femur plating using only four distal locking screws. They found that construct stiffness was greater with medial plate supplementation compared with an isolated stable lateral distal femur plating using six distal locking screws.

On the one hand and in line with what has been previously reported, the results of our study show that the medial supplementation increases the apparent fixation stiffness achieved by a single lateral plate in the setting of an unstable distal femur fracture. On the other hand, to the best of our knowledge regarding distal femur fractures and different from previous biomechanical studies, our study was the first to compare pre-contoured locked plates used for other regions and adapted to the distal medial anatomy, such as the lateral proximal tibia or the proximal humerus locked plates, with a locked straight plate used as a twisted helical implant. Lenz et al. [27] in a biomechanical study comparing stiffness and plate surface strain of different constructs in a transverse contact and gap femoral shaft fracture model, showed that additional helical plating increases axial and torsional construct stiffness in synthetic bone and provides well-balanced load sharing. These authors concluded that supplemental medial plating should be considered in demanding situations for gap or defect fractures, where single-plate osteosynthesis provides inadequate stiffness for fracture healing and induces nonunion. Moreover, in another study by the same group, Lenz et al. [9] demonstrated that the mediolateral bending and torsional stiffness achieved with orthogonal plate osteosynthesis is increased compared to a single lateral plate fixed with two locking attachment plates in a model using fresh frozen human femurs with cemented Charnley hip prosthesis, where a transverse osteotomy was placed distally to the tip of the prosthesis, simulating a Vancouver type B1 fracture.

Regarding the surgical technique, using a long helical plate allows a minimally invasive technique, which could potentially benefit the healing process [28]. A 4-cm long subvastus approach over the medial distal femur is sufficient to apply and fix the helical plate without further exposure to the fracture site [29]. Proximal fixation is accomplished through the proximal anterior approach, or preferably, the lateral approach used for the lateral plate fixation. In situations where there is a loss of medial cortical support, avoiding a formal double-incision approach potentially avoids additional soft tissue damage and prevents any devascularisation of bone fragments [30].

The main strength of our study is to be one of the first to investigate the mechanical behaviour of a helical plate used on the medial surface of the distal femur using an experimental model with a medial cortical defect. Although clinically has been demonstrated the benefits of using a helical implant as an augmentation implant in unstable fractures of the distal femur managed with a lateral pre-contoured distal femur plate [31], only the study by Gueorguiev et al. [32] has biomechanically investigated this technique. A second strength is using an experimental reproducible model that perfectly resembles a situation of distal femur instability due to medial cortex bone loss [33]. The medial cortical defect simulated in our models was tested and validated in previous studies [17, 34]. At the same time, all implants and screws configuration used were previously well validated in biomechanical studies for distal femur fixation. [14–19, 32–37]. Distal fixation of the lateral plate with at least five locking screws has been founded sufficient to fix distal femur fractures [16, 35] while facilitating additional screws placement in the medial supplementary plate models. In all models, we used locking screws for metaphyseal fixation and non-locking bicortical screws for diaphyseal fixation as has been well documented in biomechanical settings for non-osteoporotic bone fracture fixation [36, 37].

This study has some limitations. Firstly, the tests were carried out on synthetic models with inherent limitations when translating biomechanical findings to clinical scenarios. The role of soft tissues in fixation stability cannot be overlooked. However, Cristofolini et al. [38] have previously validated biomechanical studies in bone composite femur models and pointed out the variability of cadaveric specimens, requiring a huge sample size to obtain statistically significant results. Furthermore, the inter-femur strain variability for cadaveric specimens is extremely significant. Another limitation lies in the absence of a cutting guide to allow the femoral cuts to be the same. Although we tried to perform a quite similar cut on all femurs, it is important to recognize that slight differences may have occurred—the same situation for implants placement. Locking screws were placed through the locking holes, but unlocking screws not. An external guide should minimize this potential bias of screws in slightly different trajectories. A radiograph to confirm the correct placement of the implants was not performed to confirm implant positioning. The same plates may present different mechanical behaviour depending on the implant size and screw configuration. We can only confirm the role of the medial plate using these plate sizes and screw configurations. Extrapolating the results for all medial plates is impossible with this study design. It is also important to highlight that only axial compression forces were tested. Other acting forces, such as torsion, were not tested and could have shown a difference in stiffness, probably in favour of a plate. Finally, fatigue analysis and failure mode were not tested. Clinical studies will be necessary to evaluate if the potential less surgical aggression generated by the minimally invasive application of the helical plate is reflected in better clinical results.

In conclusion, in line with our hypothesis, this study shows that adding a medial supplementary plate with the described configurations increases the stability provided by an isolated lateral plate in a distal femur fracture. Both supplementary plates might be considered for improving the fixation in distal femur fracture in selected cases. However, a supplementary 4.5/5.0-mm helical 14-hole narrow locking compression plate (fixed with two locking screws distally and two non-locking screws proximally) significantly increases the apparent stiffness of the construct.

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Author contributions All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Sebastian Pereira, Ricardo Mariolani and William Belangero. Sebastian Pereira wrote the first draft of the manuscript and all authors commented on previous version of the manuscript. Vincenzo Giordano and Sebastian Pereira wrote the revision of the manuscript. All authors read and approved the final manuscript.

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Availability of data and material All data generated and analysed during this study are included in this published article and are available from the corresponding author on reasonable request.

Declarations

Conflict of interest All authors have certified that they have no conflict of interest to declare that are relevant to the content of this article.

Ethics approval N/A.

Consent data N/A.

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