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Nail diameter significantly impacts stability in combined plate-nail constructs used for fixation of supracondylar distal femur fractures

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Abstract

Objectives: Plate-nail (PN) combinations have been described for fixation of supracondylar distal femur fractures. Small diameter retrograde intramedullary nails (rIMN) are commonly used. The purpose of this study was to investigate the effect of nail diameter on construct stability. We hypothesized that a larger diameter rIMN would not significantly change the stiffness of the PN construct when tested in torsional or axial loading.

Methods: Twelve synthetic osteoporotic femurs were used to compare nail diameters in an extraarticular supracondylar distal femur fracture model (Orthopaedic Trauma Association/Arbeitsgemeinschaft für Osteosynthesefragen type 33-A3). Constructs were fixed with a 12-hole 4.5 mm pre-contoured lateral distal femoral locking plate combined with either a 9 mm (n = 6) or an 11 mm (n = 6) retrograde intramedullary nail (rIMN). Specimens were cyclically loaded in torsion and axial compression. The primary outcome was construct stiffness, calculated using the average slope of the force-displacement curves.

Results: The 11 mm PN construct was approximately 1.6 times stiffer than the 9 mm PN construct averaged across all torsional loads (2.39 +/− 0.41 Nm/deg vs 1.44 +/− 0.17 Nm/deg) and approximately 1.3 times stiffer than the 9 mm PN construct averaged across all axial loads (506.84 +/− 44.50 N/mm vs 376.77 +/− 37.65 N/mm). There were no construct failures.

Conclusions: In this biomechanical model, nail diameter had a significant effect on both torsional and axial stiffness in PN constructs. While the use of smaller diameter rIMNs has been proposed to allow for easier placement of implants, the effect on overall construct stiffness should be considered in the context of the patient, their fracture and desired postoperative weight bearing recommendations.

Level of Evidence: N/A

Keywords: biomechanical, distal femur, nail, plate, supracondylar

1. Introduction

Supracondylar distal femur fractures remain a challenging clinical entity, especially when metaphyseal comminution, a short distal segment, or poor bone quality is present. Regardless of fracture pattern or host factors, goals include restoration of fracture length, alignment, and rotation and stable fixation that allows for immediate range of motion and early weight bearing, when appropriate. To this end, the use of combined plate-nail (PN) constructs for fixation of supracondylar distal femur fractures has been described in small cohort series.[1–3] In addition, the use of PN constructs has been the focus of recent multiple biomechanical studies.[4–6] The purported benefits of this technique include improved resistance to fixation failure and earlier return to full weight bearing.

The technique for PN fixation can occur with the retrograde intramedullary nail (rIMN) or lateral distal femoral locking plate (DFLP) placed first.[1] In an early publication describing the technique, authors suggested that "a smaller diameter nail is also preferred to accommodate bicortical screw plate fixation around the nail."[2] The importance of optimizing screw fixation from the DFLP, has been emphasized given the fact that many of these fractures occur in short distal segments above a total knee arthroplasty component or in osteoporotic bone. Distal screw fixation from the DFLP is commonly prioritized, as the rIMN does not contact the femoral cortical endosteum in the distal segment.

The purpose of this biomechanical study was to evaluate the effect of rIMN diameter on PN construct stability in an osteoporotic fracture-gap model. PN constructs with rIMN diameters of 9 and 11 mm were selected and tested in both torsion and axial loading. Our hypothesis was that increased nail diameter would improve but not significantly affect torsional or axial stiffness when distal screw and interlocking bolt remained consistent between the 2 groups.

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2. Materials and methods

The study was deemed exempt from Institutional Review Board and Animal Use Committee Review.

Twelve synthetic osteoporotic femurs (SKU 1130-130, Sawbones, Vashon, Washington) were used to compare 2 PN constructs in an extra-articular supracondylar distal femur fracture gap model (Orthopaedic Trauma Association/Arbeitsgemeinschaft für Osteosynthesefragen [OTA/AO] type 33-A3). Both constructs were fixed with a 12-hole pre-contoured titanium-alloy DFLP (Stryker AxSOS 3, Mahwah, New Jersey). In the first group (n = 6), a 9 × 280 mm titanium-alloy rIMN (Stryker T2 SCN, Mahwah, New Jersey) was used. In the second group (n = 6) an 11 × 280 mm rIMN was used. Screw configuration and fixation order was standardized between all specimens. First, the rIMN was placed into the intact specimen with 2 5.0 mm proximal interlocking bolts and a single medial-to-lateral 5.0 mm distal interlocking bolt to avoid initial implant interference during placement of the DFLP. Next, the DFLP was placed along the lateral aspect of the synthetic specimen. Three 4.5 mm cortical screws were placed proximally, anterior to the nail, in holes 1, 4, and 7. Distally, 3 5.0 mm locking screws were placed around the nail. An oscillating saw was then used to create a 2 cm gap osteotomy 6.5 cm proximal to the intercondylar notch to simulate an extra-articular comminuted supracondylar distal femur fracture (OTA/AO type 33-A3) following implant placement (Fig. 1). Creation of the osteotomy following implant placement ensured consistent alignment between all specimens. Implants were reused between specimens. The DFLP was changed every 3 specimens as the locking mechanism for this implant is FDA approved to lock a maximum of 3 times.

Specimen mounting and testing followed a previously published protocol.[5] Briefly, specimens were first loaded in torsion using a custom testing jig on an Instron testing machine (Instron Model 3365, Norwood, Massachusetts). Torque was applied along the femoral mechanical axis in internal rotation to mimic internal rotation of the tibia during normal knee flexion. Angular displacement was measured using two-dimensional WINanalyze video tracking software (Mikromak Service Brinkmann, Berlin, Germany). Tracking markers were secured to wires placed 5 mm proximal and 5 mm distal to the osteotomy. Two dots on each marker were used to define a vector on each segment that was used to calculate an initial angle theta (θ_i) between proximal and distal fragments. The change in theta ($\Delta\theta$) was measured throughout the loading cycle. Torques of 5 and 7.5 Nm were sequentially applied to each synthetic model at a rate of 70 deg/minute for 15 cycles/load (Fig. 2).

Following torsional testing, each specimen was subsequently tested in axial compression. Briefly, the femoral head was secured proximally using a custom acetabular cup that prevented translation in both sagittal and coronal planes. Distally, the femoral condyles were loaded onto a polyethylene tibial insert. A metal box was fixed around the distal articular block to prevent translation during loading. Specimens were loaded along the femoral mechanical axis resulting in both compressive and shear displacement of the proximal fragment relative to the distal fragment. Tracking markers were placed directly onto the anteromedial cortex of the bone 5 mm proximal and 5 mm distal to the osteotomy site. Two-dimensional WINanalyze software was used to measure the change in distance between these markers in both proximal-distal compression and medial-lateral shear in the coronal plane. The vector sum of the displacement in both planes was calculated. Stiffness was then calculated using the slope of the entire force-displacement curve. Specimens were subjected to sequential axial loads of 200, 500, and 800 N at a rate of 60 mm/minute for 15 cycles/load (Fig. 3).

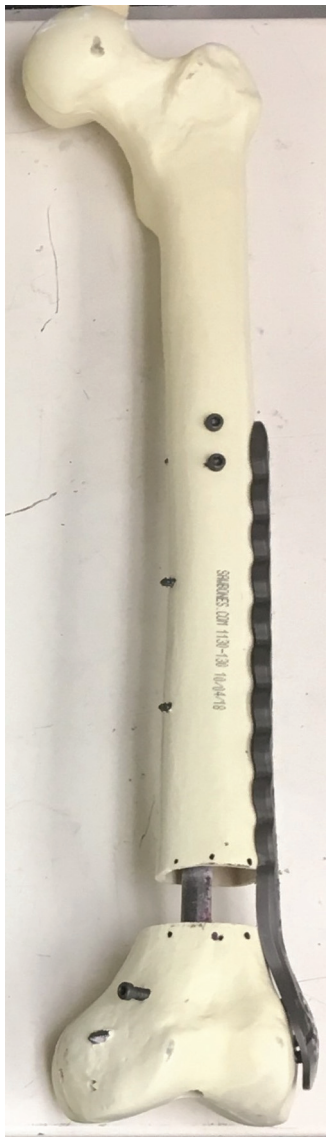

Figure 1. Plate-nail construct. Osteoporotic sawbones model with 11 mm plate-nail construct with 2 proximal interlocking bolts, 1 medial-to-lateral distal interlocking bolt, 3 proximal non-locking screws in holes 1, 4, and 7 as well as 3 distal locking screws placed around the nail.

The primary outcome measures were the load-dependent torsional stiffness and load-dependent axial stiffness for each construct. Load-dependent stiffness was determined by calculating the slope along the entire force-displacement curve for cycles 2 to 15 of each load.

3. Results

The 11 mm PN construct was approximately 1.6 times stiffer than the 9 mm PN construct averaged across all torsional loads (2.39 +/− 0.41 Nm/deg vs 1.44 +/− 0.17 Nm/deg, $P < .005$) and approximately 1.3 times stiffer than the 9 mm PN construct averaged across all axial loads (506.84 +/− 44.50 N/mm vs 376.77 +/− 37.65 N/mm, $P < .005$) (Figs. 4 and 5). Torsional

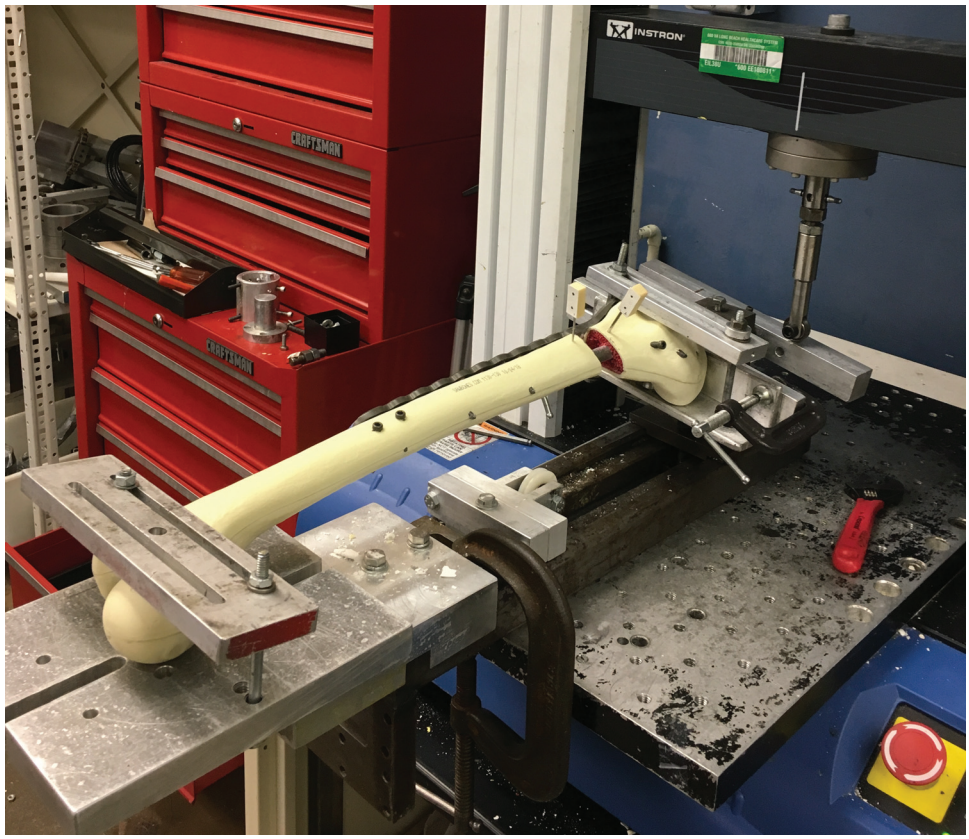

Figure 2. Torsional loading setup. The femur is secured between 2 proximal blocks to prevent rotation of the proximal femur and 2 distal blocks attached to a rotating bearing and lever-arm. An Instron is used to apply force to the lever arm at a distance of 5 cm from the center of rotation. The center of rotation is coaxial with the femoral mechanical axis.

stiffness remained significantly higher in the 11 mm construct compared to the 9 mm construct at individual torques of 5 Nm (2.44 +/− 0.50 Nm/deg vs 1.44 +/− 0.20 Nm/deg, $P = .001$), and 7.5 Nm (2.34 +/− 0.36 Nm/deg vs 1.43 +/− 0.16 Nm/deg, $P < .001$). Differences in load-dependent construct stiffness also remained significant at 200 N (582.75 +/− 52.87 N/mm vs 457.14 +/− 73.58 N/mm, $P = .007$), 500 N (513.56 +/− 54.99 N/mm vs 377.90 +/− 34.28 N/mm, $P < .005$), and 800 N axial loads (419.87 +/− 74.98 N/mm vs 295.28 +/− 38.58 N/mm, $P = .006$) for the 11 mm and 9 mm constructs, respectively. There were no construct failures.

4. Discussion

The use of endosteal substitution or intramedullary support to improve fixation of metaphyseal distal femur fractures was initially described before the development of locked plating technology.[7] Following their introduction, locking periarticular plates rapidly emerged as the preferred fixation method for treatment of distal femur fractures in both the native and periprosthetic setting. This subsequently resulted in decreased use of supplemental fixation including endosteal and intramedullary support in these fractures. However, complications including nonunion and implant failure remain, with reoperation rates as high as 20% in recent studies.[8,9] Concerns have been raised regarding the healing environment provided by locked plates, the challenges of short segment fixation, and fixation in poor-quality, metaphyseal bone.[10,11]

Retrograde intramedullary nailing of supracondylar distal femur fractures similarly evolved as a viable treatment option for fixation of native and periprosthetic supracondylar femur fractures. Comparative biomechanical and clinical studies have been performed to validate the use of retrograde nailing versus lateral locked plating for treatment of supracondylar distal femur fractures.[12–15] While small differences could be identified in biomechanical and clinical studies, pooled data suggests that there is no discernable difference between the 2 treatment types.[16]

Recently, several authors have supported the application of combined PN constructs for use in challenging supracondylar fractures such as those with poor-quality or osteoporotic bone, a short distal segment, nonunion, malunion, or peri-implant lesions.[1–3] In these situations, fixation strength and rigidity may help prevent loss of alignment and improve healing. In addition, the potential for early weight bearing has been highlighted by multiple authors.[17,18] The benefits of early weightbearing may be particularly advantageous in the geriatric population, where the mortality rate for distal femur fractures has been shown to be similar to that of hip fractures.[19] As a result, some have advocated for the use of distal femoral arthroplasty as an alternative to fracture fixation in the geriatric population.[20]

A recent series comparing immediate weight bearing as tolerated and partial touch-down weight bearing in patients over the age of 60 years who were treated for a distal femur fracture with a single implant (lateral locked plate or nail), reported an overall adverse event rate (requiring reoperation) of

Figure 3. Axial loading setup. The femur is secured proximally in a custom acetabular cup and distally on a polyethylene tibial insert. The specimen is loaded along the femoral mechanical axis. The distal fragment is set between 2 blocks, preventing coronal and sagittal translation of the distal segment during axial loading.

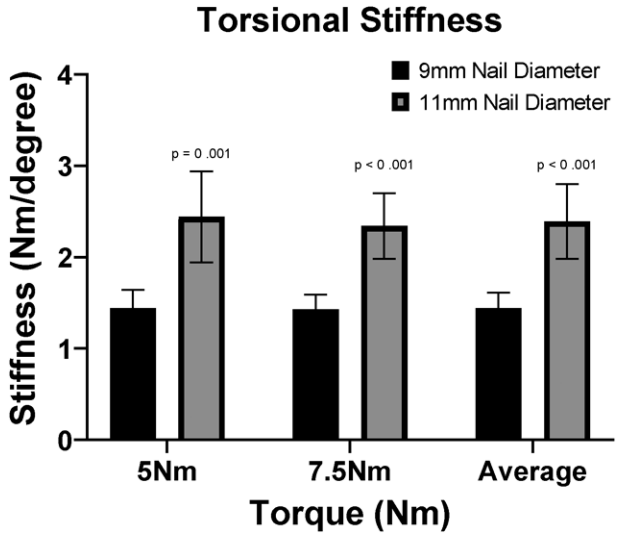

Figure 4. Torsional stiffness. Load-dependent and average torsional stiffness of 9 and 11 mm plate-nail constructs. Error bars represent standard deviation of the mean. Statistically significant differences as evaluated by independent samples *t* test are listed above each corresponding bar.

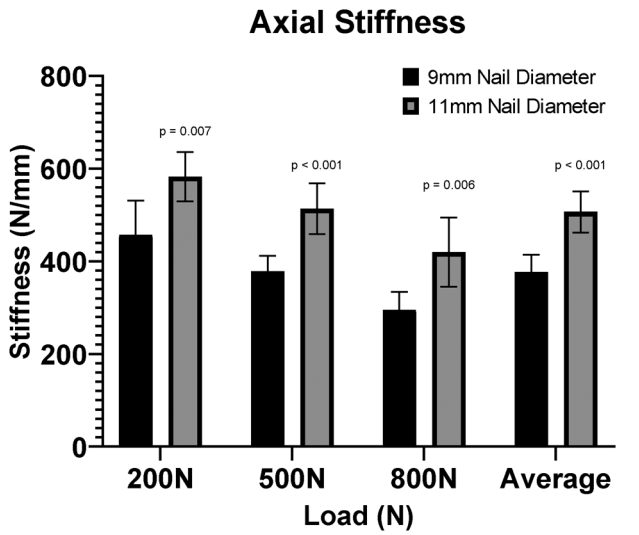

Figure 5. Axial stiffness. Load-dependent and average axial stiffness of 9 and 11 mm plate-nail constructs. Error bars represent standard deviation of the mean. Statistically significant differences as evaluated by independent samples *t* test are listed above each corresponding bar.

15%.[21] The use of combined PN constructs may offer an opportunity to more confidently allow immediate weight bearing as tolerated in these patients. In a recent small series of PN fixation in distal interprosthetic femur fractures, patients were allowed immediate weight bearing as tolerated with very favorable results.[22]

Multiple biomechanical studies have evaluated fixation of supracondylar distal femoral fractures with either a locked plate or retrograde nail.[6,23–27] Two recent biomechanical studies have looked at PN fixation of distal femur fractures.[4,5] Neither study evaluated the effect of nail diameter on construct stiffness. In the clinical setting, the effect of nail diameter has been evaluated in geriatric proximal intertrochanteric femur fractures.[28] To our knowledge a similar study has not been performed in geriatric distal femur fractures. Given the importance of overall construct strength providing both patients and surgeons the assurance that immediate weight bearing can be allowed following surgery, we sought to evaluate the effect of rIMN nail diameter on PN fixation. We hypothesized that given the stability provided by the DFLP and the lack of contact between the rIMN and cortical bone in the osteoporotic synthetic femurs, that a 2 mm diameter difference in the rIMN would show a difference in construct stiffness, but that this would not be statistically significant.

Contrary to our hypothesis, the larger diameter nail significantly outperformed the smaller diameter nail in both torsional and axial loading. In the context of nail biomechanics, it is worth noting that the moment of inertia of an IM nail be estimated as a function of the outer radius minus the inner radius to the fourth power. To simply the comparison for the purposes of discussion, a 9 mm nail has a radius of 4.5 mm while an 11 mm nail has a radius of 5.5 mm and, therefore, the torsional stiffness of an 11 mm nail compared to a 9 mm nail would be expected to be approximately 915/410 ~ 2.23 stiffer. This is reflected in our results which demonstrate that the torsional stiffness of the 11

mm construct approximately 1.6 times stiffer than the 9 mm nail construct.

The effect of nail diameter on construct stiffness also highlights the importance of contact between the nail and cortical bone or cortical substitute proximal to the fracture. Auston et al utilized a retrograde femoral nail in a geriatric supracondylar fracture model to compare the effect of cortical replacing screws in the proximal segment versus similar screws placed in the distal segment. In specimens where screws were placed proximal to the fracture, constructs showed significantly greater stiffness and less translation, eliminating what the authors termed the "bell clapper effect."[29]

Execution of the PN technique is technically easier with a small diameter rIMN within the medullary canal. This makes screw placement around the rIMN in the distal fracture segment and the proximal femoral shaft easier. Intraoperatively, opportunities for fixation will also be greater in patients with larger femora. In addition, different fixation configurations exist between various implant manufacturers. rIMN have different interlocking bolt positions and orientations. Different DFLPs also have dissimilar orientations for distal screw positions. Some even provide polyaxial locking technology which increases the ability for screws placed through the plate while avoiding interlocking bolt or nail interference. Preoperative planning is, therefore, essential to identify which implants can and will be used.

It is important to note that fixation failure was not seen with either PN construct in this biomechnical investigation. Implants were reused in this study, a potential weakness of the study. Initial pilot testing demonstrated no loss of implant integrity in this nondestructive testing protocol. In addition, we did not see sequential weakening of the constructs as implants were reused between specimens. For example, the absolute value of axial stiffness in specimen 3 was greater than the absolute value of axial stiffness in specimen 1. If reuse of implants resulted in failure, we would have expected absolute stiffness to consistently decrease between the first and third use. However, this was not the observed in this study, further confirming that our loading protocol was nondestructive. In the clinical setting, we, therefore, advocate for increased attention to the preoperative evaluation of radiographs and formal templating to anticipate what nail diameter can be placed and how screw and interlock positions may interfere. Intraoperatively, the surgeon obtains feedback during femoral medullary reaming and should weigh the benefits of placing a larger diameter nail with the difficulties that may occur with securing both implants. It should be noted that placement of a larger diameter nail does not necessarily improve or speed healing. Our findings show that increasing nail diameter is a means of improving overall construct stiffness, if desired. These results should not be interpreted to suggest that stiffer constructs are inherently better. An excessively stiff construct may delay healing in some scenarios. Consideration must be given to the biologic cost of an additional surgical approach and the effect of increasing construct stiffness on fracture biology and mode of healing when applying these constructs clinically. We do, however, suggest that surgeons do not reflexively place the smallest diameter nail when performing PN fixation and utilize this information in implant selection.

5. Conclusions

The use of smaller diameter rIMNs has been proposed to allow for easier implant placement in combined PN fixation of supracondylar distal femur fractures. In this biomechanical model, nail diameter had a significant effect on both torsional and axial construct stiffness. The effect on overall PN construct stiffness should be considered in the context of the patient, their fracture and desired postoperative weight bearing recommendations.

References

1. Spitler CA, Bergin PF, Russell GV, et al. Endosteal substitution with an intramedullary rod in fractures of the femur. J Orthop Trauma. 2018;32: S25–S29.
2. Liporace FA, Yoon RS. Nail plate combination technique for native and periprosthetic distal femur fractures. J Orthop Trauma. 2019;33: e64–e68.
3. Yoon RS, Patel JN, Liporace FA. Nail and plate combination fixation for periprosthetic and interprosthetic fractures. J Orthop Trauma. 2019;33 Suppl 6:S18–S20.
4. Fontenot PB, Diaz M, Stoops K, et al. Supplementation of lateral locked plating for distal femur fractures: a biomechanical study. J Orthop Trauma. 2019;33:642–648.
5. Wright DJ, Desanto DJ, Mcgarry MH, et al. Supplemental fixation of supracondylar distal femur fractures: a biomechanical comparison of dual-plate and plate-nail constructs. J Orthop Trauma. 2020;34: 434–440.
6. Başci O, Karakaşli A, Kumtepe E, et al. Combination of anatomical locking plate and retrograde intramedullary nail in distal femoral fractures: comparison of mechanical stability. Eklem Hastalik Cerrahisi. 2015;26:21–26.
7. Matelic TM, Monroe MT, Mast JW. The use of endosteal substitution in the treatment of recalcitrant nonunions of the femur: report of seven cases. J Orthop Trauma. 1996;10:1–6.
8. Hoffmann MF, Jones CB, Sietsema DL, et al. Clinical outcomes of locked plating of distal femoral fractures in a retrospective cohort. J Orthop Surg Res. 2013;8:43.
9. Ricci WM, Streubel PN, Morshed S, et al. Risk factors for failure of locked plate fixation of distal femur fractures: an analysis of 335 cases. J Orthop Trauma. 2014;28:83–89.
10. Stover M. Distal femoral fractures: current treatment, results and problems. Injury. 2001;32 Suppl 3:SC3–SC13.
11. Lujan TJ, Henderson CE, Madey SM, et al. Locked plating of distal femur fractures leads to inconsistent and asymmetric callus formation. J Orthop Trauma. 2010;24:156–162.
12. Firoozbakhsh K, Behzadi K, Decoster TA, et al. Mechanics of retrograde nail versus plate fixation for supracondylar femur fractures. J Orthop Trauma. 1995;9:152–157.
13. Meyer RW, Plaxton NA, Postak PD, et al. Mechanical comparison of a distal femoral side plate and a retrograde intramedullary nail. J Orthop Trauma. 2000;14:398–404.
14. Matlovich NF, Lanting BA, Vasarhelyi EM, et al. Outcomes of surgical management of supracondylar periprosthetic femur fractures. J Arthroplasty. 2017;32:189–192.
15. Park J, Lee JH. Comparison of retrograde nailing and minimally invasive plating for treatment of periprosthetic supracondylar femur fractures (OTA 33-A) above total knee arthroplasty. Arch Orthop Trauma Surg. 2016;136:331–338.
16. Magill H, Ponugoti N, Selim A, et al. Locked compression plating versus retrograde intramedullary nailing in the treatment of periprosthetic supracondylar knee fractures: a systematic review and meta-analysis. J Orthop Surg Res. 2021;16:78.
17. Kubiak EN, Beebe MJ, North K, et al. Early weight bearing after lower extremity fractures in adults. J Am Acad Orthop Surg. 2013;21:727–738.
18. Sanders R, Kellam J. To weight-bear or not to weight-bear? Is that really a question? J Orthop Trauma. 2016;30:375–376.
19. Streubel PN, Ricci WM, Wong A, et al. Mortality after distal femur fractures in elderly patients. Clin Orthop Relat Res. 2011;469:1188–1196.
20. Salazar BP, Babian AR, DeBaun MR, et al. Distal femur replacement versus surgical fixation for the treatment of geriatric distal femur fractures: a systematic review. J Orthop Trauma. 2021;35:2–9.
21. Lieder CM, Gaski GE, Virkus WW, et al. Is Immediate weight-bearing safe after single implant fixation of elderly distal femur fractures? J Orthop Trauma. 2021;35:49–55.
22. Hussain MS, Dailey SK, Avilucea FR. Stable fixation and immediate weight-bearing after combined retrograde intramedullary nailing

and open reduction internal fixation of noncomminuted distal interprosthetic femur fractures. J Orthop Trauma. 2018;32:e237–e240.
23. Wähnert D, Hoffmeier KL, von Oldenburg G, et al. Internal fixation of type-C distal femoral fractures in osteoporotic bone. J Bone Joint Surg Am. 2010;92:1442–1452.
24. Pekmezci M, McDonald E, Buckley J, et al. Retrograde intramedullary nails with distal screws locked to the nail have higher fatigue strength than locking plates in the treatment of supracondylar femoral fractures: a cadaver-based laboratory investigation. Bone Joint J. 2014;96-B: 114–121.
25. Heiney JP, Barnett MD, Vrabec GA, et al. Distal femoral fixation: a biomechanical comparison of trigen retrograde intramedullary (I.M.) nail, dynamic condylar screw (DCS), and locking compression plate (LCP) condylar plate. J Trauma. 2009;66:443–449.
26. Heiney JP, Battula S, O'Connor JA, et al. Distal femoral fixation: a biomechanical comparison of retrograde nail, retrograde intramedullary nail, and prototype locking retrograde nail. Clin Biomech (Bristol, Avon). 2012;27:692–696.
27. Bliemel C, Buecking B, Mueller T, et al. Distal femoral fractures in the elderly: biomechanical analysis of a polyaxial angle-stable locking plate versus a retrograde intramedullary nail in a human cadaveric bone model. Arch Orthop Trauma Surg. 2015;135:49–58.
28. Rinehart DB, O'Neill DE, Liu JW, et al. Does size matter for cephalomedullary nails in geriatric intertrochanteric fractures? J Orthop Trauma. 2021;35:329–332.
29. Auston D, Donohue D, Stoops K, et al. Long segment blocking screws increase the stability of retrograde nail fixation in geriatric supracondylar femur fractures: eliminating the "bell-clapper effect". J Orthop Trauma. 2018;32:559–564.