Immediate Weight Bearing of Comminuted Supracondylar Femur Fractures Using Locked Plate Fixation

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Abstract

Full article available online at Healio.com/Orthopedics. Search: 20120725-21

Comminuted supracondylar femur fractures (AO-OTA 33A3) are commonly treated with locked plates. Weight bearing is generally restricted for 6 to 12 weeks until radiologic evidence exists of sufficient callous to support weight bearing. Recent clinical studies have reported high nonunion rates with distal femur locked plates. In an attempt to induce beneficial motion across the fracture site, some studies have recommended earlier weight bearing. The purpose of the current study was to determine the biomechanical feasibility of an immediate weight-bearing rehabilitation protocol to encourage healing of distal femur fractures treated with lateral locked plate fixation.

Sixteen fresh-frozen cadaveric femora were used for this study. A 2.5-cm supracondylar gap osteotomy was made. Ten-hole, 4.5-mm distal femur locking plates were used with a standardized screw configuration that maximized the working length. The specimens were placed in a servohydraulic testing machine and axially loaded (unidirectional) at 1 Hz for up to 200,000 cycles. Failure was defined as 1 cm of deformation of the construct. The staircase method was used to determine the fatigue limit of the construct. The fatigue limit was calculated to be 1329 ± 106 N. No specimen failed through the non-locking diaphyseal screws. Plastic deformation, when present, occurred at the metaphyseal flare of the plate. The fatigue limit of the locked plate constructs equaled 1.9 times body weight for an average 70-kg patient over a simulated 10-week postoperative course. Given that distal femoral loads during gait have been estimated to be more than 2 times body weight, the data from this study do not support immediate full weight bearing.

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Drs Granata, Litsky, Lustenberger, Probe, and Ellis have no relevant financial relationships to disclose.

Funding was obtained through a research grant from the Orthopedic Trauma Association. The Musculoskeletal Transplant Foundation donated all cadaveric specimens. The implants were provided through a materials grant from Smith & Nephew. The research was conducted independently without input from the funding sources.

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doi: 10.3928/01477447-20120725-21
Comminuted supracondylar femur fractures (AO-OTA 33A3) are commonly treated with locked plates. Weight bearing is generally restricted for 6 to 12 weeks until radiologic evidence exists of sufficient callous to support weight bearing. Restricted weight bearing is primarily due to concerns about implant failure or screw cutout. However, recommendations for postoperative weight bearing vary widely, without compelling mechanical evidence to support these recommendations.

The ease of use and biomechanical stability of locked plate fixation for supracondylar femur fractures has led to their widespread use over the past decade. Biomechanical studies of distal femur locked plates have shown superior performance relative to previous plate constructs. The feasibility of immediate weight bearing with lateral locked plate fixation has not been firmly established in the literature, and no universally accepted postoperative rehabilitation protocol currently exists for locked plate fixation of distal femur fractures.

The hypothesis of this study was that immediate full weight bearing of non-osteoporotic extra-articular supracondylar femur fractures would be possible with modern locked plated designs. This study model focused on high-energy fractures in younger patients with good bone quality and specifically excluded geriatric and periprosthetic fractures.

**Materials and Methods**

**Specimen Characteristics and Preparation**

Twenty-two fresh-frozen cadaveric femurs were procured for this study. Average donor age was 36 years. The donor demographics were selected to optimize the bone quality, and no bone density testing was performed. All specimens were visually examined and radiographed for defects; 6 specimens were discarded due to osseous abnormalities. The cadaveric femora were stored at −20°C until the day before testing and allowed to thaw under refrigeration for 24 hours prior to fixation.

A standardized construct was applied to all specimens. A 4.5-mm precontoured distal femur locking plate (#7182-0010; Smith & Nephew, Memphis, Tennessee) was used. Five 5.7-mm stainless steel cannulated locking screws were used for distal fixation, and 4 nonlocking 4.5-mm stainless steel cortical screws were used for proximal diaphyseal fixation. Due to the good bone quality, nonlocking cortical screws were used in the diaphysis. To increase flexibility of the construct, the diaphyseal screws were placed proximally in the plate to maximize the working length.

A 2.5-cm gap was arbitrarily created to simulate an unstable supracondylar femur fracture (AO type 33A3) (Figure 1). The osteotomy was created using parallel saw cuts at 6 and 8.5 cm proximal to the distal femoral articular surface.

**Testing Protocol**

Each specimen was placed in a customized fixture on the materials test frame (Bionix 858; MTS Systems Corporation, Eden Prairie, Minnesota) and loaded in axial compression for 200,000 cycles or until failure (Figure 2). The initial load was 1000 N, approximately 50% of the ultimate load to failure. The subsequent load level was determined by the performance of the previous specimen. If 200,000 cycles was tolerated (run-out), the load on the subsequent specimen was increased by 200 N. If the specimen failed prior to the full 200,000 cycles, the load on the subsequent specimen was decreased by 200 N. This was repeated for 16 consecutive specimens, allowing for calculation of the endurance (fatigue) limit according to the staircase method.

The ratio of peak-to-minimum loading for all cyclic testing in the study was 10:1. Failure was arbitrarily defined as 1 cm of deflection measured through the actuator of the materials test frame. The loading frequency (1 Hz), the peak-to-minimum loading ratio (10:1), the run-out limit (200,000 cycles), and the step size (ΔL=200 N, 10% σ_yield) were constant for all specimens tested.

**Statistical Analysis**

The staircase method is used to calculate the endurance (fatigue) limit with a limited number of specimens. A minimum of 15 specimens is required. This testing process effectively brackets the mean endurance limit of the implant. The protocol and equations for calculating the endurance limit are shown in Table 1.

**Results**

The fatigue data are summarized in Table 2. Of the 16 specimens tested, 9 toler-
erated the applied load for 200,000 cycles. The fatigue strength was calculated to be 1329 ± 60 N. No specimen failed through the nonlocking diaphyseal screws. Plastic deformation, when present, occurred at the metaphyseal flare of the plate.

**Discussion**

Despite the widespread use and popularity of lateral locked plate fixation of distal femur fractures, concern exists regarding the clinical outcomes achieved with these constructs. Recent clinical and basic science evidence suggest that the increased stiffness provided by the distal femur locked plates may lead to delayed or nonunions, with up to 32% of patients having difficulty healing their fracture.10

Numerous options are available to modify the mechanical performance of locked plate constructs. Increasing the working length, using titanium instead of stainless steel implants, and using locking diaphyseal screws that only lock in the distal cortex have all been suggested to decrease the stiffness and encourage interfragmentary motion.14 Increasing the applied load through weight bearing is another method to increase motion and stimulate callous formation in secondary bone healing, but this is dependent on the fatigue limit of the fixation construct.

The results of the current study do not support immediate full weight bearing for an average 70-kg patient. Peak forces in the distal femur during ambulation have been estimated to be 2 times body weight, exceeding the calculated fatigue strength of 1329 N.15 The nonlocking cortical diaphyseal screws used in the current study resisted cyclical loads up to 200,000 cycles without failure, despite a maximized working length to increased flexibility and overall motion. This suggests that locking diaphyseal screws are not necessary in younger patients with good bone quality and can result in a substantial (10%-20%) reduction in the overall implant cost.

This biomechanical study followed a similar protocol to an intramedullary nail fixation study of the femur by Brumback et al.9 In that study, the implants were cyclically loaded for 500,000 cycles using

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**Table 1**

| Protocol for the Staircase Method of Calculating Endurance Limit

1. Create a 5-column table to calculate the mean and SD:
   - Column 1: order all the peak load levels that resulted in the less frequent result (run-out vs. number of cycles).
   - Column 2: place a “0” for the lowest stress level in column 1, a “1” for the next load level, etc.
   - Column 3: record the number of “less frequent events” that occurred at each load level.
   - Column 4: record the product of value in column 2 and the value in column 3.
   - Column 5: record the product of value in column 2 squared times the value in column 3.

2. Calculate the estimated endurance limit, S:
   
   \[ S = L_o + \Delta L \left[ A/N \pm \frac{1}{2} \right] \]

   Where:
   
   - \( L_o \): lowest load level at which the less frequent event occurred
   - \( \Delta L \): step size
   - \( N \): total number of less frequent events (sum of column 3)
   - \( A \): sum of column 4 as defined in steps 7 and 8

   The plus (+) sign is used in the above formula if the less frequent event is run-out; the minus (−) sign is used if the less frequent event is failure.

3. Calculate the SD:
   
   \[ SD = 1.62 \Delta L \left( \frac{NB_A^2}{N^2} + 0.029 \right) \text{ if } (NB - A^2)/N^2 \geq 0.3 \]
   
   Or:
   
   \[ SD = 0.53 \Delta L \text{ if } (NB - A^2)/N^2 < 0.3 \]

   Where:
   
   - \( \Delta L \): step size
   - \( N \): total number of less frequent events (sum of column 3)
   - \( A \): sum of column 4 as defined in steps 7 and 8
   - \( B \): sum of column 5 as defined in steps 7 and 8

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**Table 2**

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<th>Fatigue Limit Data</th>
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the staircase method. The biomechanical results supported immediate full weight bearing of comminuted femoral shaft fractures with antegrade intramedullary implants. This data were then used to support a full weight-bearing rehabilitation protocol in a clinical series of 28 comminuted femoral shaft fractures, all of which healed with no implant failure.9 The study led many surgeons to change their practice by accelerating their postoperative rehabilitation protocols in select patients with appropriate fixation.

The current study had limitations. The biomechanical testing protocol was pure axial loading. This may be more appropriate for diaphyseal fracture patterns. In the distal femur, torsion and multiaxis loading conditions may play a significant role in understanding implant performance.16,17 Failure was arbitrarily defined as 1 cm of displacement, and this was measured through the actuator, which may not be reflective of the actual motion across the simulated fracture site. Distal femur fractures occur in a bimodal distribution, with high-energy traumatic injuries in younger patients and low-energy mechanisms in older patients with poor bone quality. This study focused on the biomechanics of fracture fixation in younger patients with good bone quality, and it is important not to extrapolate the results to older patients with osteoporotic bone.

Conclusion

Distal femur locked plates are capable of withstanding substantial axial loads over a sustained cyclical loading scenario. Although immediate full weight bearing is not recommended, this model suggests that a partial weight-bearing rehabilitation protocol could be tolerated, depending on the patient’s body habitus and compliance. To standardize the amount of partial weight bearing, rehabilitation could be accomplished safely in a pool, where apparent body weight can be reduced to one-half or one-third with the water level at the waist and chest, respectively.18 Early aquatic therapy starting on postoperative day 6 has been shown to improve functional outcomes in total knee replacement patients.19 Aqua therapy is generally initiated approximately 2 weeks postoperatively when the incisional wound has healed. Further clinical studies are needed to determine the indications and results of early partial weight bearing and maximized working length on nonunion rates in locked plate fixation of distal femur fractures.

References