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Does the Lateral Plate need to Overlap the Stem to Mitigate Stress Concentration When Treating Vancouver C Periprosthetic Supracondylar Femur Fracture?

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ABSTRACT

The effect of construct length on cortical strain and load to failure between locked compression plating and cemented femoral stem in a fall model was analyzed. Eight Sawbone femurs with cemented stems were instrumented with increasing fixation lengths starting 8 cm distal to stem tip and progressing proximally to overlapping constructs. Uniaxial strain gauges measured cortical strain. Load to failure was performed with 8 cm gap between implants, 2 cm gap, and proximally overlapping configurations. Strain was significantly reduced as the 8 cm gap transitioned to an overlapped construct with most comparisons. Load to failure in the overlapped construct was 273% greater compared to 2 cm gap construct. Overlapping the stem with a locking compression plate resulted in reduced strain and increased load to failure.

Postoperative periprosthetic femur fractures occur in 0.1–6% of all total hip arthroplasties [1–4]. Approximately 10% of these fractures are distal to a fixed proximal stem (Vancouver type-C fractures) [5–7]. Many of these Vancouver C periprosthetic fractures are essentially supracondylar femur fractures ipsilateral to the proximal femoral arthroplasty component. The mechanism of injury is typically from a ground level fall in elderly, osteopenic females [4,7–10]. Complication rates up to 55% have been reported after operative fixation of Vancouver type-C femoral fractures for non-union, malunion, and hardware failure [6,9,11]. While many of these authors were using conventional compression plating, the current preferred treatment is to use locking plates as these provide better fixation in osteoporotic bone and better purchase of the distal femur [12–18].

One of the controversies in treating Vancouver type-C fractures is how far proximal the plate construct should extend while avoiding a stress riser between the end of the femoral stem and plate 1 [9], Some authors have recommended using a proximal, transitional unicortical locked screw while others simply overlap the plate with the intramedullary implant [18,19]. There is no specific literature to guide surgeons as to where these plates must end relative to the well-fixed femoral stem. In the last 5 years we have treated three cases of interprosthetic fracture occurring between a well-fixed femoral stem and a distal femoral supracondylar plate. All three of these cases occurred after the Vancouver C periprosthetic femur fracture had healed and the patient had returned to ambulating. All periprosthetic fractures occurred proximal to the plate and were treated with revision open reduction, internal fixation with a plate overlapping the femoral arthroplasty stem proximally.

This study was designed to answer several questions regarding fixation of Vancouver type-C femoral fractures. First, is there an optimal location for a lateral locking plate in relationship to a femoral intramedullary stem that minimizes strain and decreases secondary fracture? Second, does the use of a transitional, unicortical locked screw in proximity to the femoral stem tip decrease the strain profile compared to a bicortical locked screw? Last, does overlapping the proximal stem with a lateral locking plate decrease load to failure in the zone between the plate and the prosthesis? We hypothesized that strains below a well-fixed stem would increase as the distance between implants decreased and that strain would decrease in the diaphysis as overlapping of implants occurred. We also hypothesized that an overlapped construct would require greater loads for failure with mechanical testing.

Materials and Methods

We chose to use a healed fracture model to recreate the worst-case scenario wherein there is no potential for strain dissipation at the

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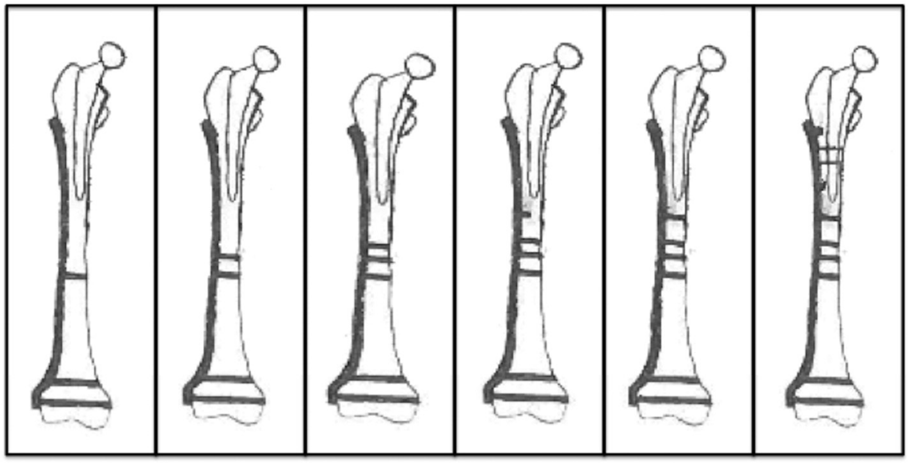

Fig. 1. Schematic of fixation constructs undergoing strain testing.

persistent fracture gap and all strain is potentially concentrated over the zone between the plate and the prosthesis. This model reproduces the clinical situation we have observed where the intra-prosthetic fracture occurs after the distal femoral Vancouver C fracture has healed.

Strain Measurements

Eight fourth-generation Sawbone femurs (model: #3406; Sawbones Worldwide/Pacific Research Laboratories Inc., Vashon Island, WA) were prepared for implantation with a 12 mm cemented hip arthroplasty stem (Zimmer Inc., Warsaw, IN) using Simplex bone cement (Zimmer Inc., Warsaw, IN). Femurs were solid cancellous composite with a density of 8–20mpcf and 16 mm intramedullary canal. The femoral neck cut was made 10 mm proximal to the lesser trochanter in all specimens. A cement restrictor was placed 1 cm distal to the stem and confirmed on fluoroscopy. A femoral head component was impacted onto the stem for purposes of loading. The composite femurs were instrumented with a pre-contoured 18-hole 4.5 mm periprosthetic locking compression plate (LCP) (Synthes USA, Paoli, PA), and they were positioned so that the center of the most proximal locked screw sat 8 cm below the tip of the stem. The proximal aspect of the plate extended to the level of the lesser trochanter, but it was initially un-instrumented. The plate was secured to the distal femur using three locked bicortical screws (Fig. 1A).

Uniaxial strain gauges (model L2A-06-125LW-120; Vishay, Shelton, CT) were affixed to simulated cortical bone with M-Bond 200 adhesive (Measurements Group Inc, Raleigh, NC) along the tension side of the femur. The strain gauges were placed 2 cm proximal to the hip stem, 1–2 cm distal to the stem and 3–4 cm distal to the stem. The specimens were potted distally using Cerrobend (CS Alloys, Gastonia, NC), a low melting-point metal potting compound. Load was applied to the prosthetic femoral head in a fall loading configuration to simulate a fall onto the greater trochanter from a standing height [20–23]. The femur was positioned with 15° adduction and the femoral neck in 15° anteversion. An Instron 1331 servo-hydraulic testing machine (Instron, Canton, MA) delivered an axial load of 500 N onto the femoral head at a rate of 0.5 Hz and cycled at least 5 times for reproducibility (Fig. 2). The load cell had a 50 kN capacity, 0.25% accuracy, and 0.1 mm resolution. This loading pattern is established and known to be below the threshold necessary for fracture in a fall loading configuration [20–23]. No preload was used for strain testing. The strain gauge measurements were processed using National Instruments (NI) hardware (National Instruments Corp., Austin, TX): SCXI-1000 chassis with a SCXI-1520 8-channel universal strain gauge input module and SCXI 1314 terminal block. NI Measurement and Automation Explorer (DMAX) version 3.02.3005 was used to calibrate the strain gauges in quarter bridge mode. NI Labview VI programming was written to monitor position, load, and strain in real time at 1 kHz. Following testing of the 8 cm group, we placed a bicortical locked screw at 6 cm distal to the stem (Fig. 1B). Next, the testing and data collection protocol was repeated. A bicortical locked screw was then placed at 5 cm and testing repeated (Fig. 1C). A transitional unicortical locked screw (22 mm) was then placed 2 cm from the tip of the stem and 1 cm distal to the cement mantle and testing was performed (Fig. 1D). The unicortical screw was exchanged for a bicortical locked screw after drilling the far cortex and testing repeated (Fig. 1E). The overlapping configuration placed one periprosthetic blunted unicortical screw (14 mm) 1 cm proximal to the tip of the stem and one near the top of the plate adjacent to the base of the greater trochanter (Fig. 1F). Two spaced cerclage cables were dispersed between the unicortical screws and uniformly tensioned using a calibrated device (Synthes USA, Paoli, PA). This overlapping construct was then tested. In summary, at each of the three gauges (2 cm proximal, 1–2 cm distal and 3–4 cm distal) a total of six screw configurations were tested (8 cm distal, 6 cm distal, 5 cm distal, 2 cm/uni, 2 cm/bi and overlapped). For each scenario tested, all specimens maintained an average linearity coefficient of $R^2 > 0.95$, thus remaining in the linear elastic region and avoiding permanent deformation.

Load to Failure

Three screw configurations were selected to test load to failure: (1) 8 cm gap (2) 2 cm gap and use of a bicortical locked screw at the

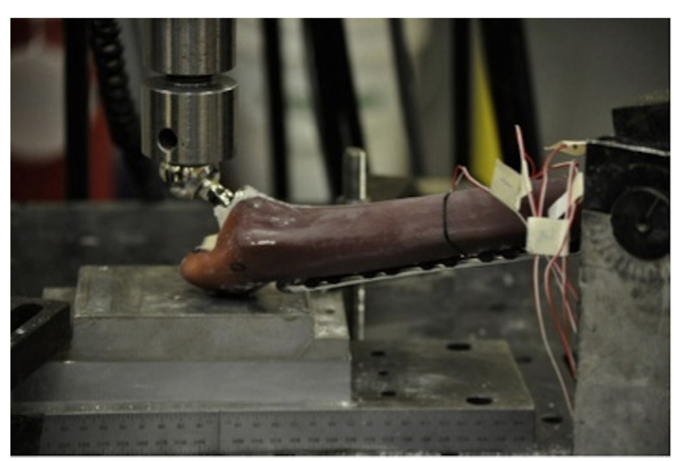

Fig. 2. Photograph of typical testing set-up for a fall loading configuration.