Locking Buttons Optimize Fatigue Life of Locking Plates in Allograft Nonunion Model

Tompkins M; Paller D; Moore DC; Crisco JJ; Terek RM

Department of Orthopaedics, The Warren Alpert Medical School of Brown University and Rhode Island Hospital, Providence, RI

Richard_Terek@brown.edu

Introduction:
The locking plate has improved the internal fixation of osteoporotic bone and comminuted fractures. The applicability of locked plating for allograft reconstruction after tumor resection is not entirely clear. The rigidity and fatigue life of the construct are affected by the total number of screws used, the number of locking and conventional compression screws, and their position in the plate. In bulk allograft reconstruction and in comminuted fractures, particularly in smokers and diabetics, healing times can be prolonged, at times greater than one year. The nonunion rate for allografts, defined as lack of healing at 1 year, is 10%. With nonunion, there is oftentimes graft resorption of several millimeters, adding additional strain to the plate. Under such conditions, the fatigue life of the internal fixation becomes increasingly important. It is not intuitively obvious which type of plate will have the longest durability. In allograft reconstruction, there is also concern about placing a screw immediately adjacent to the allograft-host junction for fear of introducing a stress riser in the allograft and potentially in the plate. On the other hand, locked screws may reinforce the plate and increase fatigue life. Alternatively, a nonlocking screw may cause less of a stress riser than a locking screw and an open hole would increase the working length of the plate and potentially have the least detrimental effect on fatigue life. A locking button (the screw head alone) may be the best option by avoiding the plate without causing a stress riser in either the plate or the allograft. Therefore, the objective of this project was to evaluate the dynamic fatigue properties of various plate/screw configurations in a simulated allograft nonunion model.

Methods:
An allograft nonunion model was simulated in Sawbones fourth generation composite femurs (Pacific Research Laboratories, Vashon, WA). A 10 mm osteotomy was created to simulate a worst case load bearing scenario on the screw and plate construct and to eliminate the effect of the fatigue life of the bone. The osteotomy site spans the portion of the plate between the two centermost holes leaving only solid plate exposed. Prior to instrumentation, the intramedullary canal was filled with PMMA bone cement to maximize pull out strength of the screws. Internal fixation was performed with 4.5 x 157 mm locking plates in four different configurations: Group 1: fixed with all locking screws (Locked), Group 2: all compression screws (Unlocked), Group 3: 6 compression screws with 2 locking buttons in the holes on either side of the osteotomy (Button), Group 4: 6 compression screws with 2 open holes on either side of the osteotomy (Open), (Table 1, Fig. 2) (Smith and Nephew). Five or six specimens were tested for each group. Both locking and compression 4.5 mm screws have the same thread, therefore the only variable is the type of screw head. Buttons are locking screw heads without the shank. All holes were drilled, tapped, and screws and buttons tightened with a torque screw driver to 35 in-lb.

Fatigue testing was performed according to ASTM fatigue testing guidelines (Standard Specification and Test Method for Metallic Bone Plates, Designation: F382-99 (Reapproved 2003)) in a servo-hydraulic fatigue testing system (810, MTS Corp, Eden Prairie, MN). A custom mounting jig for testing of specimens was made such that an unconstrained bending moment was applied to the specimens (Fig. 1). Mean yield load was determined by monotonic testing of a locked screw and plate construct in compression at a rate of 25.4 mm/min in a servo hydraulic test frame for the type of plate used. Each construct (with a new plate) was loaded in dynamic fatigue with a load equal to 65% of the yield load at a rate of 5 Hz up to 1,000,000 cycles. In the event of a run out, the load was increased to 75% of the static yield load with resumption of testing. Load and displacement data were collected logarithmically at 200 Hz. The total number of cycles until failure was recorded for each specimen.

One-way ANOVA was used to detect significant effects of fixation configuration on dynamic fatigue duration (cycle count). Tukey HSD post-hoc tests were performed to evaluate significance between groups. The level of statistical significance was set to 0.05 a priori.

Results:
The static yield load was 1060 N for the 4.5 x 157 mm plate with locked screws. The compressive load for the 65% and 75% dynamic tests was 689 N and 795 N respectively. Fatigue life was different amongst the different constructs (ANOVA, p < 0.006). Post hoc testing showed group 3 with compression screws and locking buttons (Button) to have longer fatigue life than all locked (Locked) or all compression screws (Unlocked) (p < 0.019, p < 0.008) (Fig. 2). The number of specimens in each group requiring testing at 75% yield strength (i.e. more than 1 million cycles) was 1 of 5 in the Locked group, 0/5 in Unlocked, 5/6 in Button, and 3/6 in Open. In all specimens, a screw hole adjacent to the osteotomy was the failure site (Fig. 3). There were no broken screws, screw pull outs, or Sawbones fractures.

Conclusion:
These results show that the highest concentration of stress is at a screw hole adjacent to the osteotomy or fracture site. Insertion of a screw, regardless of design, creates a stress riser and fulcrum for motion, thereby decreasing fatigue life, whereas a locking button reinforces the plate, increases fatigue life, and would avoid a stress riser in the allograft close to the allograft-host junction.

Acknowledgement:
Supported by the RIH Orthopaedic Foundation, Providence, RI.