Biomechanical Effects of a NiTiNOL Staple and Buttress Plating in Pauwels III Femoral Neck Fractures: A Cadaveric Comparison with Cannulated Screws

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INTRODUCTION: The incidence of femoral neck fractures is expected to be 1-2 million in 2025[1,2] and may rise to 7.3 million by 2050[3]. Of these, vertically oriented (Pauwels III) fractures, which commonly occur due to high energy trauma in non-geriatric patients are associated with some of the highest complication rates. Avascular necrosis, implant failure, and nonunions occur in up to 28% of cases, and the choice in reconstruction approach is controversial.[3,4] One of the most standard treatments is applying three screws oriented colinearly to the neck axis to reduce and stabilize the fracture. However, this construct may not prevent shear motion during loading.[5] The addition of an inferomedial plate, acting as a buttress, has recently gained popularity to resist shear motion but may result in asymmetric stabilization during loading, maintaining inferior reduction and resisting shear but allowing superior gapping.[6,7] The addition of a NiTiNOL staple on the superior-anterior aspect of the fracture may provide compression and stabilization at this site, allowing for early post-operative weightbearing. The purpose of this study was to evaluate the displacements at each aspect of the fracture gap and compare the strengths of four constructs: (1) three screws (3S), (2) three screws + buttress plate (3S+P), (3) three screws + a NiTiNOL staple (3S+St), and (4) three screws + buttress plate + NiTiNOL staple (3S+P+St).

METHODS: Fifteen matched pairs of fresh-frozen cadaveric lower limb specimens were assigned based weight and age to three comparison groups: (1) 3S vs. 3S+P, (2) 3S vs. 3S+St, or (3) 3S vs. 3S+P+St, with 5 matched pairs per comparison. With soft-tissue intact, fracture creation, instrumentation and fixation were applied to each specimen under fluoroscopic guidance. Simulated vertically oriented fractures were created using an oscillating surgical saw with an inferomedial buttress plate maintaining an idealized reduction. Then, three partially threaded cannulated screws were placed in all specimens in standard fashion.[5] In specimens receiving plates, the plate used for reduction remained in position, and longer screws were added. In specimens receiving a NiTiNOL staple (DynaNite, Arthrex, Naples, FL, USA), the staple was placed on the anterosuperior aspect of the fracture line. Specimens were then dissected, removing all soft-tissue and keeping the acetabulum and part of the pelvis intact. Post-fixation CT scans were obtained, and all specimens were manually segmented for virtual planned fixture alignment (Fig. A). Custom 3D printed fixtures were created for all distal femurs that had a negative volume for insertion (Fig. B). Femurs were aligned in the stance phase of gait using a previously described coordinate system.[8,9] Loads were applied to the potted anatomic hip joint (Fig. C) using an electric actuator. First, a linear ramped compression to 500 N was applied at 15 N/s. Then cyclic at 2 Hz was applied, increasing the peak compressive force by 100 N every 100 cycles until failure. Motion tracking of each side of the fracture was conducted using a point-based system (ARAMIS 2 M System, GOM GmbH, Germany) (Fig. C). Using the accompanying software, 3D model overlays (Fig. D) were performed to define points on the most anterior, posterior, superior, and inferior aspects of the fracture gap on each side of the fracture (assuming 0.25 mm gap). Failure was defined as 10 mm of 3D displacement between point pairs across the fracture gap.

RESULTS: The mean load to failure was the highest in the 3S+P+St group, occurring at loads 43% higher than its respective matched pair 3S group (Fig. H). Most failures (60%) in the 3S+P+St group occurred simultaneously at multiple point pairs. The second highest failure loads were observed for the 3S+P group, occurring at loads that were 32% higher than its respective 3S group. The majority (60%) of failures in the 3S+P group occurred at the superior point pair. The addition of the staple alone in the 3S+St group had slightly larger failure loads than its respective control, and the majority (60%) failed simultaneously at all point pairs. Across all control (3S) specimens, 48% failed simultaneously at all point pairs. No significant differences for failure load were detected between groups.

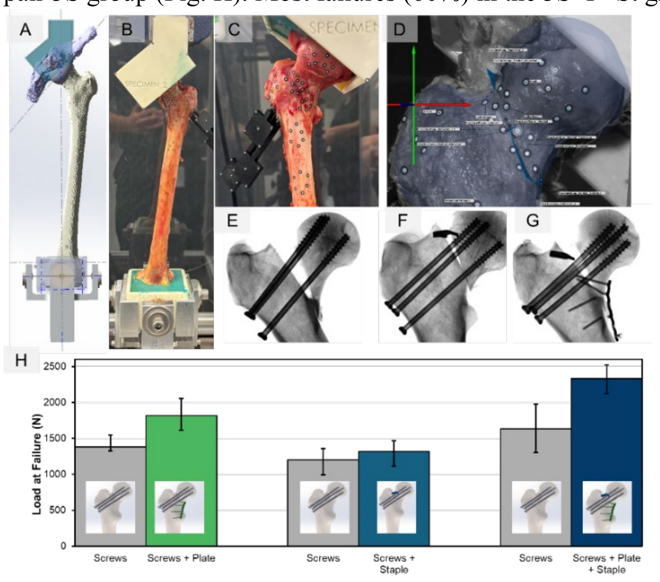

Figure: Biomechanical setup and stance phase alignment for the (A) virtual model generated from CT scan and (B) the physical setup with specimen-specific fixtures. (C) The motion capture markers were placed on each side of the fracture gap. (D) The 3D virtual model was overlayed to determine the fracture gap plane and the four point pairs (anterior, superior, posterior, and inferior) used for analysis. (E,F) Shear failure was common in the 3S and 3S+St group, (G) while superior gapping was most common in specimens with plates. (H) The mean failure loads (± SD) for each matched pair comparison, where failure was defined as 10 mm of displacement between at least one point pair.

DISCUSSION: Shear failure, indicated by simultaneous failure across multiple point pairs, was most apparent in constructs that did not contain a plate (Fig. E,F). The addition of a plate appears to provide a relatively large increase in load to failure (Fig. H). However, the constructs with plates all experienced screw breakage (Fig. G) and the superior gapping may be mitigated by the addition of a staple, which also resulted in the highest failure loads. The matched pair design of the study was prioritized, but the small sample size is a limitation. Additional tests are in process, and the analysis of screw motion, including cut-out and backout will be added.

SIGNIFICANCE/CLINICAL RELEVANCE: This study is the first to incorporate NiTiNOL staples for vertically oriented femoral neck fractures and aimed to understand the biomechanical effects of each construct across four anatomic aspects of the fracture gap.

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