How Does Capitate Bone Morphology Relate to Screw Toggle Characteristics?

CP Lynch[1], MA Miller[1], FW Werner[1], KA Mann[1], ME Oest[1], A Rodriguez[1], JN Dowthwaite[1], KM Albanese[1]
[1]SUNY Upstate Medical University, Syracuse, New York

DISCLOSURES: Lynch(N), Miller (N), Werner (4-Moximed), Mann (N), Oest (N), Rodriguez(N), Dowthwaite(N), Albanese (N**)**

INTRODUCTION: Characterization of bone morphology/density may be of clinical importance for patients undergoing carpal bone hardware fixation. A recent study from our lab found that ultradistal radius areal bone mineral density and capitate morphology/density correlated positively with force required to cause capitate screw pullout[1]. Literature regarding pedicle screw fixation has suggested that screw toggling due to transverse loading of the screw may be an important mechanism to consider in understanding orthopedic hardware failure. Further, studies that explore the effect of screw toggling on pullout force are equivocal and likely depend on the specifics of screw placement and the quality of bone into which the screw is implanted. The purposes of this study were 1) to assess the relationship between bone morphology/density and capitate screw toggle in response to transverse loading, and 2) whether prior screw toggling affects the force required to cause screw pullout. We hypothesized that screw toggle would be greater for cases in which the capitate had low bone density and that toggle loading would reduce the effective pullout force of the screw.

METHODS: Dual-energy x-ray absorptiometry scans of the ultradistal radius were performed for fourteen individual donors, as fresh-frozen cadaveric right-left arm pairs to document clinical measures of regional cortico-cancellous bone quality (Ultradistal radius bone mineral density (UDBMD) T-scores: normal >-1.0 vs. osteopenic -2.5 to -1.0 or osteoporotic <-2.5) associated with matching capitate specimens. To assess regional cortical bone quality using planar X-ray of the hand, 2nd metacarpal cortical percentage (2MCP) was measured[2]. Following bilateral capitate dissection, micro-CT imaging was used to quantify detailed bone morphology of each capitate in terms of bone volume fraction as bone volume / total volume (BV/TV). BV/TV was calculated separately for trabecular bone of the entire capitate (trabecular BV/TV) and for an annular shell of cortical bone around the screw insertion point (cortical shell BV/TV). Half of the capitates were subjected to our screw pullout protocol without toggle-loading (see below). For the remaining contralateral capitates, a 3.0 mm headless compression screw was implanted and a potting fixture secured the capitate to a transverse loading device in a Qtest mechanical test frame (**Fig 1A)**. Fully reversible volar/dorsal toggle forces were applied perpendicular to the screw long axis using progressive loading steps (1 cycle at 5N, 20 cycles at 10N and 20N, 100 cycles at 40N, and 1 final "post-loading" cycle at 5N). The post-toggle screw-capitate constructs were then reoriented in the test fixture and loaded using a progressive tensile load to determine pullout force. The local screw-bone relative motion due to toggling and pullout were captured in still frame image sequences and quantified using digital image correlation (**Fig 1B**). Toggling was defined as the screw-bone relative motion due to a 5N volar/dorsal load during each loading step. Linear regression analysis was used to assess association between measures of bone quality and screw-bone toggle testing at a 5N load during the final cycle of the 20N load step. Paired t-tests were used to compare donor capitate pairs for non-toggle vs. post-toggle screw pullout force; subgroup analyses were performed within normal capitate pairs and osteopenic/osteoporotic capitate pairs.

RESULTS: All specimens completed the 20N load step, but 6 of 14 did not complete all 100 cycles at 40N due to excessive screw displacement (>2.5 mm). Screw toggle increased with load magnitude and cycle count. 2MCP (R^2=0.38, p=0.020), trabecular BV/TV (R^2=0.35, p=0.027), and cortical shell BV/TV (R^2=0.69, p<0.001) were significantly associated with screw toggling, but ultradistal BMD was not (**Fig 2**). Pullout force was 16% lower (p=0.095) for toggled specimens compared with paired, non-toggled contralateral counterparts (**Fig 3A**). For donors with osteopenic/osteoporotic bone (n=8), the reduction in pullout force after toggle loading was 32% (p=0.002, **Fig 3B**), while there was no significant difference in pullout force for "normal" bone (n=6, p=0.74).

DISCUSSION: BV/TV and 2MCP may be valuable measures for understanding quality of carpal bone screw fixation. Cortical shell BV/TV appears to be especially pertinent to screw toggling behavior which is consistent with previous findings in the spine literature.[3] Screw toggling may play an important role in carpal bone screw pullout, particularly for osteoporotic or osteopenic patients.

CLINICAL SIGNIFICANCE: Carpal bone quality may be an important factor to consider when indicating patients and planning strategies for carpal bone fixation. In particular, patients with poorer bone quality may be particularly prone to hardware failure subsequent to transverse loading of intraosseous screws. Resistance to transverse loading may be an important factor to consider when selecting fixation constructs for this population.

References: 1. Benoit, ORS 2025. 2. Schreiber, J Hand Surg 2017. 3. Pelletier, J Spine Surg 2017

Acknowledgement: Funded by the Department of Orthopedic Surgery, SUNY Upstate Medical University.

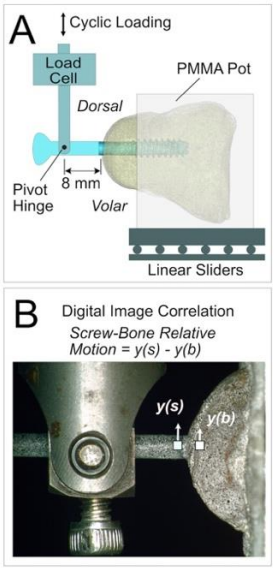

Figure 1

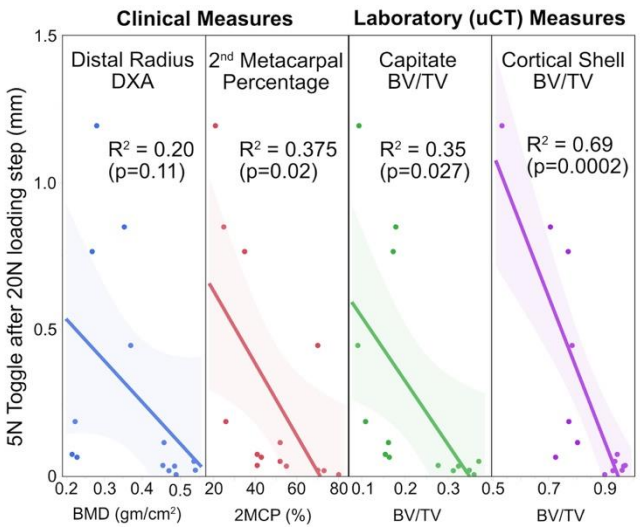

Figure 2

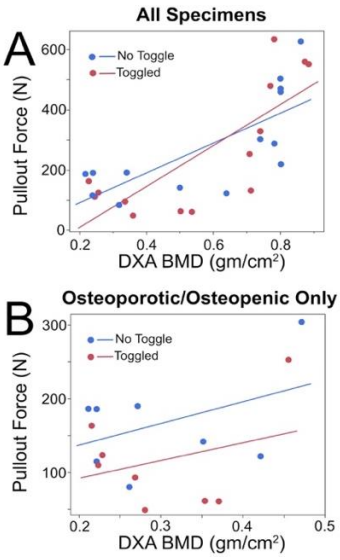

Figure 3