INTRODUCTION
Excessive distraction during wrist external fixation has been demonstrated to lead to inferior clinical outcomes of distal radius fracture treatment. Previous studies have been unable to define the mechanism involved or the threshold at which distraction adversely affects the wrist. Neutral zone, a concept well-characterized in spine biomechanics, has been defined as the region of joint laxity. In the spine, changes in the neutral zone have been shown to be a sensitive marker for the increased motion that is seen following ligamentous injury.

Theorizing that overdistraction results in subclinical injury of extrinsic wrist ligaments, we chose neutral zone as a suitable biomechanical parameter to serve as a marker for excessive distraction. The purpose of this study was then to characterize distraction-induced changes in the neutral zone of the wrist joint and to determine an in vitro threshold of overdistraction based on these changes.

METHODS
Eight fresh-frozen human cadaveric above-elbow upper extremity specimens were dissected free of skin, muscles, and tendons. With elbows held in 90 degrees of flexion, the forearms were locked in full supination with two Steinmann pins. The distal 20 cm of the forearm-hand specimens were then saved and mounted for biomechanical testing.

To determine the neutral zone in the radial-ulnar plane, a flexibility protocol was employed. The protocol consisted of applying pure moments in the radial and ulnar directions to a specially designed wheel mounted on the third metacarpal. The maximum moment of 0.4 Nm was applied in four incremental equal steps. Two cycles were used to precondition the specimen. The specimen was allowed to creep for 30 s for each load and unload step within each cycle to reduce viscoelastic effects. The start of the third load cycle was recorded as the neutral zone in that direction.

The Optotrak system (Northern Digital Inc.; Waterloo, Ontario) was used to track 3-D motion of the third metacarpal relative to the radius. A Howmedica Hoffman II Compact external fixator was placed on the wrist in the standard fashion for a distal radius fracture. The external fixator was modified to measure load using strain gauges mounted on the rod surface. Using the load information from the fixator, the initial zero point for the distraction trials was defined to be when the carpus was first lifted off the radius. The distraction trials consisted of sequentially distracting the wrist 2, 4, 6, 8, and 10 mm. At each point of the distraction trial including the zero point, the fixator was removed and the specimen was left unloaded to allow for viscoelastic relaxation. With the external fixator removed, the flexibility protocol was utilized to determine the neutral zone in the radial and ulnar directions for each distraction point.

A one-factor repeated-measures ANOVA was used to determine statistical significance for the total neutral zone in the radial-ulnar plane. The factor was the amount of distraction. A post-hoc Tukey test was used to determine if subsequent distraction points were significantly higher than the zero point. The statistical significance was set at p < 0.05.

RESULTS
Prior to distraction, the mean (± SD) total neutral zone in the radial-ulnar plane was found to be 42.5 ± 13.9°. We found that the total neutral zone in the radial-ulnar plane to be significantly higher after 4 mm of distraction compared to the neutral zone prior to distraction (see Figure 1). The mean (± SD) force required to distract the wrists 4 mm was 15.8 ± 7.3 N.

DISCUSSION
In this study, we characterized the neutral zone of the wrist joint in the radial-ulnar plane. We found a threshold of 4 mm after which there are significant increases in the neutral zone. We believe that this increase in the neutral zone signifies subclinical ligament injury in this in vitro model. As such, it may serve as an estimate of the acceptable upper limit of distraction across a wrist when using an external fixator clinically.

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