INTRODUCTION:
The biomechanical properties of the carpal tunnel are fundamentally relevant to carpal tunnel syndrome (CTS). Elevated tunnel pressure is one of the underlying mechanisms associated with CTS in patients [1]. This pressure increase can result from volume expansion of the contents in the restricted carpal tunnel. The carpal tunnel is a relatively rigid structure defined by the transverse carpal ligament (TCL) volarly and the carpal bones in the radial, ulnar, and dorsal aspects. Carpal tunnel release relieves carpal tunnel pressure by reducing the constraint of the TCL [2] and increasing carpal tunnel volume [3]. Biomechanics of the carpal tunnel have been investigated in several studies [4, 5], however, it remains unknown how carpal tunnel cross-sectional area (CSA) changes in response to pressure variation in a carpal tunnel with an intact TCL. Therefore, the purpose of this study was to investigate the relationship between carpal tunnel pressure and tunnel CSA using cadaveric hands.

METHODS:
Fresh-frozen cadaveric hand specimens were used (N=3 completed, 5 additional in progress). Each specimen was dissected to expose the TCL. The contents of the carpal tunnel, including the nine flexor tendons and median nerve were identified proximally, transected and removed distally, evacuating the carpal tunnel. The proximal and distal carpal tunnel boundaries were identified as the proximal and distal extents of the TCL using visual inspection and anatomical landmarks. Following identification, a thin catheter tube filled with a MRI contrast agent was affixed to the TCL using sutures to serve as an alignment tool for MRI slice localization. A positioning device was used to place the specimen palmar side up in the anatomically neutral position.

A custom pressure device was designed that consisted of pneumatic and liquid sides (Figure 1). The liquid side of the system included a medical balloon filled with a MRI contrast agent to clearly identify the tunnel boundaries. The balloon was inserted into the evacuated carpal tunnel and inflated to exert a specified pressure in the range of 0 to 200 mmHg. An inflation device was used to increase the pressure on the pneumatic side and this pressure was transmitted to the liquid side through a diaphragm. The following 12 pressures were tested: 0, 10, 20, 30, 40, 50, 75, 100, 125, 150, 175, and 200 mmHg. At each tested pressure, axial MR images perpendicular to the dorsal carpal tunnel surface were taken. Prior to initiating each MRI sequence, the specimen was given 2 minutes to adjust to the new pressure. At the conclusion of each MRI scan, the pressure was reduced to 0mmHg and the specimen was imaged after 10 minutes to address possible creep behavior.

The cross-sectional images were analyzed using ImageJ software to calculate the tunnel CSA at four levels: proximal, middle, distal, and hook of hamate. Regression analyses were performed for the pressure-tunnel area relationship.

RESULTS:
The CSA of the carpal tunnel increased with increasing carpal tunnel pressure (Figure 2). On average, the initial CSA of the tunnel was 217.2 ± 180.2, 179.0, and 177.2 mm² for the proximal, middle, distal, and hook of hamate levels, respectively, and increased 22.6 ± 8.4%, 16.7 ± 3.8%, 15.5 ± 3.3%, and 13.1 ± 1.9% at each respective level at 200 mmHg (Figure 3). Regression analyses showed a linear relationship between tunnel pressure and CSA, with slopes of 0.251, 0.148, 0.126, and 0.109 mm²/mmHg for the proximal, middle, distal, and hook of hamate levels, respectively.

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