INTRODUCTION
Carpal tunnel syndrome (CTS) is the most common peripheral nerve entrapment syndrome, afflicting as much as 3.7% of the general population in the United States with a wide range of disabling hand symptoms [1]. Symptoms arise from compression of the median nerve and generally follow a progression from primarily sensory symptoms to increasing motor disturbances. Sensory symptoms include pain and paresthesias that become more constant as the disease progresses. Motor manifestations include weakened grip strength, loss of hand coordination, and thenar muscle atrophy. The motor disturbances are caused primarily by impaired median nerve conduction to the thenar muscles: the flexor pollicis brevis, opponens pollicis, and abductor pollicis brevis.

The thumb is an integral part of complex hand tasks, allowing for the grasping and manipulating of objects, and a slight disturbance in motor function can be disabling. Previous studies have attempted to quantify thumb motion in tasks such as opposition and circumduction in healthy subjects, but data about the pathological hand is limited [2, 3]. Clinical evaluation of motor symptoms in CTS has been limited to linear measurements of impairment in opposition, joint range of motion (ROM) in a single plane, and grip strength. The purpose of this study was to evaluate the ROM of individual thumb joints in all planes during circumduction and opposition for individuals with CTS. We hypothesized that people with CTS would have decreased ROM in pronation and abdution at the carpometacarpal joint.

METHODS
Five CTS patients and five gender- and age-matched controls participated in this study. The inclusion criteria for CTS subjects were (1) a positive response to Tinel’s test, Phalen’s test, or carpal compression test; (2) a history of pain or paresthesia in the region of median nerve innervation; and (3) a prolonged sensory latency (>3.7 ms) or prolonged motor latency (>4.2 ms) of the median nerve. CTS subjects were also required to be right hand dominant, right hand affected, have no previous hand trauma or surgery, not pregnant, and have no systemic disease. Control subjects were screened to ensure that they did not have any systemic diseases, neuromusculoskeletal disorders, or trauma to the right hand or wrist. The Institutional Review Board approved the protocol of this study and informed consents were received from all subjects.

A motion capture system (Vicon 460, Oxford, UK) was used to record three-dimensional thumb motion. Six markers of 5 mm diameter were affixed to the thumb. These markers established coordinate systems for the thumb segments. Three additional markers were placed on the immobilization device to provide a reference coordinate system for the forearm. Euler angles were calculated to quantify the flexion, abduction, and pronation angles of the carpometacarpal (CMC) and metacarpophalangeal (MCP) joints, and the flexion angle at the interphalangeal (IP) joint.

RESULTS
CTS subjects and controls were compared using a one-way ANOVA. Comparisons were made between CTS and control subjects for opposition, circumduction, and grip strength.

- **Opposition**: The CTS subjects had a significant decrease in opposition (right) compared to control subjects.
- **Circumduction**: The CTS subjects had decreases in pronation (right) and abduction (right) during circumduction.
- **Grip Strength**: CTS subjects had decreased grip strength compared to control subjects.

DISCUSSION
In studying the motor manifestations of CTS, we expected to find a decreased ROM at the CMC joint due to impaired function of the thenar muscles with a compensatory increase at the MCP and IP joints. We also observed compensation patterns at the MCP and IP joints. For example, the IP joint in CTS subjects showed increased, although highly variable, flexion to compensate for the lack of abduction and pronation.

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REFERENCES