Inductive Powering Profile of an Instrumented Trapezium for Measuring *In Vivo* Loads at the Base of the Thumb

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INTRODUCTION: We are developing an instrumented replacement trapezium implant (iTrapz, Fig. 1) capable of measuring loads at the base of the thumb *in vivo*. The implant will be used in patients whose trapeziums have been resected as part of their treatment for advanced trapeziometacarpal arthritis. Our long-term goal is to directly record the loads at the base of the thumb during normal hand function, with the goal of informing clinical treatment, advancing arthroplasty design, and refining the inputs for musculoskeletal modeling. The iTrapz will be powered inductively, via a transmitting coil embedded in a tight-fitting glove with mating receiving electronics installed in the trapezium-shaped housing. Inductive power transmission is most efficient when the transmitting and receiving coils are co-axial, parallel, and in close proximity. In this study, we sought to determine the envelope of coil separation and alignment that would yield adequate inductive power transmission.

METHODS: The external housing of the iTrapz was designed using a statistical shape model generated from healthy CT segmented trapezia (N=46), scaled to the 95th percentile bone volume (male volunteer, approx. 17x15x25mm^3). Made of laser sintered Ti6Al4V, the housing included a circular, dorsally directed boss to fixture the ferrite-encased receiving coil. The location of the receiving coil was approximated by its exterior circular receiving "window" (Fig. 2 green disk). Our prototype inductive power transmission system included a pair of stacked 4-layer, 20 mm X 2.7 mm wireless charging coils (TDK WT202080-28F2-G) and a pair of concentric receiving coils (Wurth 760308101217 and 760308101221) in an uncoated PC200 ferrite core (TDK B65803J0000R608). The transmitting coil was powered at 3V with up to 3A of current. Induced current in the receiving coil was rectified with a matching capacitor bridge rectifier consisting of 4 low-forward-voltage-drop Schottky didoes, and a 3.3V Zener protection diode. Output voltage was measured with a Fluke 189 True RMS Multimeter. Transmitting coil and receiving window positions were quantified using a four-camera Qualisys optical motion capture (OMC) system (Oqus 500, 200Hz) and two custom 3D marker appliances: 1) a wand designed to facilitate moving of the transmitting coil and 2) a rigid mount for the iTrapz prototype (negative impression of the iTrapz volar surface, window facing up) (Fig. 2). The transmitting coil wand was manually elevated, rotated, and translated while marker positions were captured and synchronized with the receiving voltage. OMC and voltage data were acquired at 200Hz (Measurement Computing, integrated into Qualisys). The position of the transmitting coil relative to the receiving coil window was quantified by calculating a) Separation: the vertical distance from the transmitting coil center to the window center, and b) Alignment: the distance from window center to the projection of the coil vertical axis on the window plane. Successful power transmission was defined as ≥1.8V output from the receiving coil.

RESULTS: For positions where the receiving voltage was ≥1.8V (Fig. 3 dashed outline), the vertical transmitting coil height from the iTrapz receiver window (Separation) averaged less than 9.0±3.6mm and ranged from 5.5mm to 16.7mm. Average Alignment during the motion trials was 5.9±4.8 mm, ranging from 0.01mm to 14.2mm. However, within this coil position envelope (<16mm Separation and <14mm Alignment offset), where there was generally successful power transmission, there were also recordings where the output voltage was below 1.8V (Fig 3. dark blue). Additional measures of coil position are needed to fully describe the voltage distance-coupling relationship.

DISCUSSION: We present progress on the development of a trapezium replacement designed to measure *in vivo* loads across the thumb carpometacarpal joint. Here, we provide evidence that our design can be powered inductively, with a small (~20mm dia.) transmitting coil placed adjacent to dorsal surface of the base of the thumb. Additional design and testing iterations will be performed to optimize the envelope of threshold-level power transmission, and coil sizing. Once this is complete, and benchtop testing has been performed for structural and electrical integrity, the electrical components will be miniaturized, and fully functional prototypes will be produced for mechanical fatigue and hermetic seal testing.

SIGNIFICANCE/CLINICAL RELEVANCE: An instrumented trapezium capable of measuring kinetics at the base of the thumb will be immensely valuable to clinicians, researchers, and implant designers who need accurate joint loading data to understand the role of joint loading in thumb CMC joint pathophysiology, to refine musculoskeletal models, to standardize pre-clinical testing, and to develop more effective and cost-effective surgical treatments.

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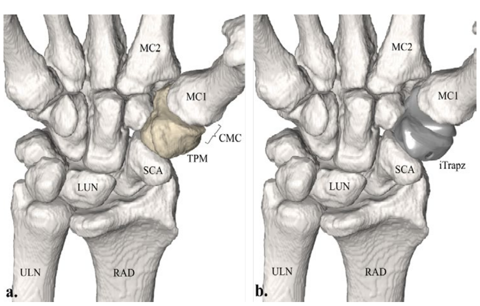

Fig. 1. Palmar view of the skeletal hand (a) segmented from a CT volume. The trapezium carpal bone (TPM) will be replaced with the load sensing iTrapz (b) in patients undergoing trapeziectomy for severe osteoarthritis.

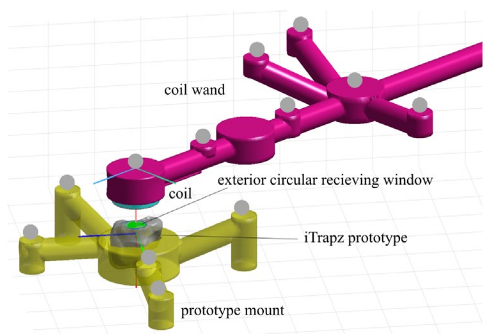

Fig. 2. 3D marker cluster appliances outfitted with optical motion capture markers (grey spheres). Optimally aligned (maximal transmission voltage = 4.9 V) reference position shown.

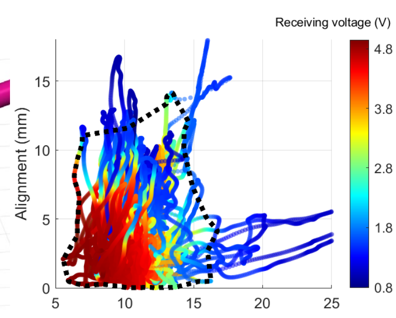

Fig. 3. Coil position during all motion trials quantified by Separation and Alignment, and colored by receiving voltage (color bar, V). Dashed black boundary depicts position envelope ≥1.8V.