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Short communication

Moment arms of the human digital flexors

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ABSTRACT

For the extrinsic hand flexors (flexor digitorum profundus, FDP; flexor digitorum superficialis, FDS; flexor pollicis longus, FPL), moment arm corresponds to the tendon's distance from the center of the metacarpalphalangeal (MP), proximal interphalangeal (PIP), or distal interphalangeal (DIP) joint. The clinical value of establishing accurate moment arms has been highlighted for biomechanical modeling, the development of robotic hands, designing rehabilitation protocols, and repairing flexor tendon pulleys (Brand et al., 1975; An et al., 1983; Thompson and Giurintano, 1989; Deshpande et al., 2010; Wu et al., 2010). In this study, we define the moment arms for all of the extrinsic flexor tendons of the hand across all digital joints for all digits in cadaveric hands.

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1. Introduction

Muscle moment arm is the shortest distance between the force across a joint and its center of rotation (Zajac, 1992). For the hand flexors (flexor digitorum profundus, FDP; flexor digitorum superficialis, FDS; flexor pollicis longus, FPL), moment arm corresponds to the tendon's distance from the center of the metacarpalphalangeal (MP), proximal interphalangeal (PIP), or distal interphalangeal (DIP) joint due to tethering by the annular pulleys (Strickland, 1995). Thus, loss of flexion at a joint after a pulley injury occurs secondary to mechanical changes resulting from the increased moment arm (Lin et al., 1989; Tomaino et al., 1998; Mitsionis et al., 1999). The clinical value for establishing accurate moment arms has been highlighted for biomechanical modeling, the development of robotic hands, designing rehabilitation protocols, and repairing flexor tendon pulleys (Brand et al., 1975; An et al., 1983; Thompson and Giurintano, 1989; Deshpande et al., 2010; Wu et al., 2010). However, no study has reported the normal moment arms for finger flexors across all digits and joints (Brand et al., 1975; An et al., 1983; Brook et al., 1995; Smutz et al., 1998; Fowler et al., 2001; Buford et al., 2005; Wu et al., 2009; Deshpande et al., 2010; Wu et al., 2010).

Derivation of the instantaneous moment arm across a joint has been modeled by Landsmeer (1961) and has been used to calculate moment arms in a variety of studies with the following equation: $M=dE/d\theta$, where E is the tendon excursion and θ is the joint angle (An et al., 1983). This study provides experimentally derived values for moment arms of the digital flexors across all joints for all five digits.

2. Methods

2.1. Sample preparation

This experiment utilized fresh-frozen upper limbs amputated at the distal humerus ($n=6$) with all distal structures intact. Longitudinal forearm and palmar incisions were made proximal to the cardinal line (Vella et al., 2006) to avoid disturbing tendon architecture at the level of PA or A1 pulleys. The carpal tunnel was incised longitudinally and the flexor digitorum superficialis (FDS), flexor digitorum profundus (FDP), and flexor pollicus longus (FPL) tendons were released in the forearm and pulled through the palmar incision. FDP tendons were identified by flexion of the DIP joint. The median nerve was also identified and severed to avoid mechanical interference during testing. Hands or digits were excluded if any anatomical abnormality was observed.

Steinmann pins (1.6 mm diameter, 85 mm length) were drilled proximally from the distal phalanx tip down the phalangeal medullary canals until they were distal to the MP joint for all five digits, securing the PIP and DIP joints (IP joint for the thumb) in extension. A 40 g weight was secured at the end of each pin to provide a physiologic counter-force during tendon excursion, with a moment distance of 85 mm (Fig. 1).

2.2. Mechanical testing

Hands were mounted palmar side up on a grooved platform that allowed placement of a single axis goniometer sensor (Biometrics Limited, Ladysmith, VA; accuracy $\pm 2^\circ$ over 90° from neutral position). The two sensors of the goniometer were placed over the dorsal aspect of the bone just proximal and just distal to the tested joint with the assistance of benzoin tincture (James Alexander Corp., Blairstown, VA) and double-stick tape. Each tested digit was aligned longitudinally with the device, and the bone immediately proximal to the tested joint was secured with two Steinmann pins that penetrated two cortices and was then

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