SCIENTIFIC ARTICLE

Biomechanics and Pinch Force of the Index Finger Under Simulated Proximal Interphalangeal Arthrodesis

Paul Arauz, PhD,* Karen DeChello, MS,† Alexander Dagum, MD,‡ Sue Ann Sisto, PhD,† Imin Kao, PhD*

Purpose To analyze the effect of simulated proximal interphalangeal (PIP) joint arthrodesis on distal interphalangeal (DIP) joint free flexion-extension (FE) and maximal voluntary pinch forces.

Methods Five healthy subjects were tested with the PIP joint unconstrained and constrained to selected angles to produce (1) free FE movements of the DIP joint at 2 selected angles of the metacarpophalangeal joint, and (2) maximal voluntary tip (thumb and index finger) and chuck (thumb, index, and middle fingers) pinch forces. Kinematic data from a motion analysis system, pinch force data from a mechanical pinch meter, and electromyography (EMG) data recorded from 2 flexor and extensor muscles of the index finger were collected during free FE movements of the DIP joint and pinch tests for distinct PIP joint constraint angles.

Results The EMG root mean square (RMS) values of the flexor digitorum profundus (FDP) and extensor digitorum (ED) did not change during free FE of the DIP joint. The extension angle of the range of motion of the DIP joint changed during free FE. It increased as the PIP constraint angle increased. The EMG RMS value of FDP and ED showed maximum values when the PIP joint was unconstrained and constrained at 0° to 20° of flexion during tip and chuck pinch. Neither the index finger metacarpophalangeal and DIP joint positions nor pinch force measurements differed with imposed PIP joint arthrodesis.

Conclusions The PIP joint arthrodesis angle affects DIP joint extension. A minimal overall impact from simulated PIP arthrodesis in muscle activity and pinch force of the index finger was observed. The EMG RMS values of the FDP and ED revealed that a PIP arthrodesis at 0° to 20° of flexion leads to a more natural finger posture during tip and chuck pinch.

Clinical relevance This study provided a quantitative comparison of free FE motion of the DIP joint, as well as FDP and ED forces during pinch, under simulated index finger PIP arthrodesis angles. *(J Hand Surg Am. 2017;■(■):1.e1-e7. Copyright © 2017 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Proximal interphalangeal joint fusion, finger biomechanics, electromyography, finger tendon forces, hand.

Online Exclusive

ARTHRODESIS OF FINGER INTERPHALANGEAL joints, a surgical treatment for joint degeneration of any etiology, provides a pain-free stable joint; however, it sacrifices motion. In addition, the biomechanical function in the digit is altered by an arthrodesis of either the distal interphalangeal (DIP) or the proximal interphalangeal (PIP) joint.[1–8] Although the impact of arthrodesis on hand and

From the *Department of Mechanical Engineering; †School of Health Technology and Management; and ‡Department of Surgery, School of Medicine, Stony Brook University, Stony Brook, NY.

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Corresponding author: Paul Arauz, PhD, Department of Mechanical Engineering, 106 Heavy Engineering Building, Stony Brook University, Stony Brook, NY 11790; e-mail: paulusgon@gmail.com.

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finger function remains a matter of debate among surgeons, preoperative planning has to include a decision regarding the appropriate angle for arthrodesis.[1–3,8–12] Whereas several studies have contributed to an understanding of finger and hand movement capabilities and function under imposed joint constraints, limited information is available regarding how finger muscle activation and strength during pinch as well as free DIP motion are affected under finger joint arthrodesis. The human finger contains tendinous mechanisms that are essential for proper control.[13] One such mechanism couples the DIP and PIP joints in the unloaded finger when flexed or extended.[14] However, this mechanism no longer couples the motion of the DIP and PIP joints when the PIP joint is constrained because the DIP joint can flex and extend independently.[2] Typically, a subject is unable to move the DIP joint separately because the tendon of the flexor digitorum profundus (FDP) acts on the DIP and PIP joints simultaneously.[15] In addition, the strength of the finger depends on the anatomical structure and the maximum effort of each individual muscle involved.

The purpose of this study was to investigate the effect of simulated PIP arthrodesis on the range of motion (ROM) and muscle activation of the DIP joint during index finger free flexion-extension (FE), index finger muscle activity during maximal voluntary pinch, and pinch forces and postures. The finger biomechanical properties and strength involved in movement and force application must be analyzed to understand better the impairment associated with fusion of an individual joint. In this study, a biomechanical and strength evaluation was conducted on the index finger to determine the PIP joint arthrodesis angle allowing for optimal free DIP joint FE activation and maximum voluntary pinch forces.

PARTICIPANTS AND METHODS

Participants

Five male right-handed subjects aged 24 to 35 years volunteered for this study. All participants had no history of upper-extremity disorders. Before data collection, subjects signed an informed consent document approved by the institutional review board.

Instrumentation

A 7-camera motion capture system (Vicon MX, Oxford, UK) at a sample frequency of 100 Hz was arranged in a 2 × 2-m^2 region for data collection. Three-dimensional coordinate measurement was determined to be well within 0.5 mm.[14] We attached 13 × 4-mm hemispherical markers to the dorsal aspects of the thumb, index, and middle fingers and hand with double-sided tape (Fig. 1). Markers were placed proximal to the joint on the distal head of the proximal bone.[16] Custom-made thermoplastic orthoses were used to constrain the PIP joint at distinct angles (Fig. 1). One experimenter customized each PIP orthosis based on individual finger length. Manual goniometers were used to verify the constraint angles and adjust the orthoses accordingly.[2,3] Kinematic data were reviewed immediately after testing to ensure proper data collection with minimal marker dropout. We used a mechanical pinch meter to collect index finger pinch strength data for each participant who performed tip and chuck pinch (Fig. 1). Index finger muscle activities were documented with 2 wireless surface electromyography (EMG) sensors placed on the volar and dorsal sides of the forearm to sense the FDP and the extensor digitorum (ED), respectively (Fig. 1).[17] These muscles were selected for their role in index finger flexion and extension. The FDP and ED data were collected at a sample frequency of 1,000 Hz.

During measurements, subjects were seated in a height-adjustable chair with the right shoulder in a neutral position, the elbow at approximately 90° flexion, and the forearm in pronation. All fingers were flexed and relaxed with exception of the fingers that performed the movements instructed. Subjects were instructed to: (1) keep the wrist at a steady neutral position and with the index finger metacarpophalangeal (MCP) joint extended at approximately 0°, and perform full FE movements of the DIP joint continuously; (2) keep the wrist at a steady neutral position with the index finger MCP joint flexed at approximately 45° and perform full FE movements of the DIP joint continuously; (3) maintain the wrist extended at approximately 30° and pinch on a mechanical pinch meter, held by one experimenter, using the thumb and index finger; and (4) maintain the wrist extended at approximately 30° and pinch on a mechanical pinch meter, held by one experimenter, using the thumb, index, and middle fingers (Fig. 1).

Participants performed 3 trials (5 seconds each) under 2 conditions: (1) unconstrained (UC) finger, and (2) with the index finger PIP joint constrained to 0°, 20°, 30°, 40°, and 60° flexion. Each subject performed a practice trial with the UC and constrained finger before data were recorded. Participants performed the instructed motions relatively slowly (approximately one DIP flexion-extension cycle per second) and positions of the MCP joint at 0° and 45° were well controlled while performing a task.