A New Device for Measuring Flexor Tendon Forces and Grip Force: A Cadaver Model

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INTRODUCTION

Failure to properly consider tendon forces in designing a tool and excessive use of hand tools can have harmful effects on users. These effects may range from minor discomfort and fatigue to work related disorders or cumulative trauma disorders (CTDs) of the finger, hand and forearm [1]. From the solutions of force / moment equili-brium equations of Kong (2001), for an external load of P, 9.05P and 2.83P were reported for the flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) in the gripping task, respectively [2]. The most reliable assessment of the effects of external loading conditions on tendon forces is obtained by directly measuring tendon forces. However, no method has solved the force rate between the tendon forces and the external forces in the power grip with hand tools, and simultaneously applied tension to tendons to study the muscle coordination necessary to produce two-dimensional gripping force. The objective of this study was to develop a hand motion simulator (HMS) as a method that is capable of simultaneously measuring both flexor tendon (internal) forces and a grip (external) force with simulating a power grip hand motion with different tendon force ratios in a cadaver arm.

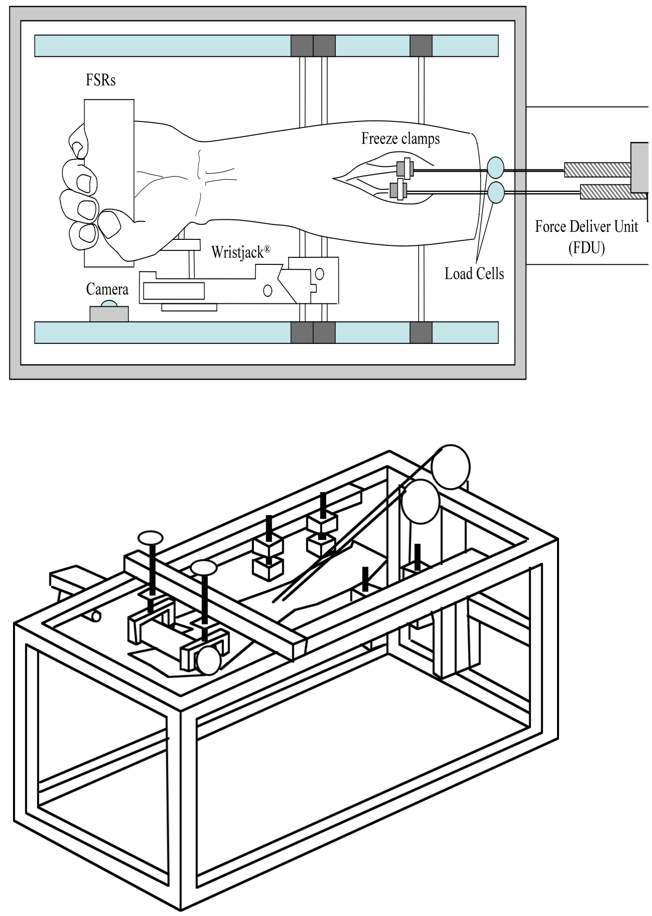

Figure 1: Schematic of the Hand Motion Simulator showing the muscle delivery unit and force transducers with a cadaver arm.

METHODS

The hand motion simulator was built to simulate a grasp motion of a cadaver hand with a grip force generated by pulling flexor tendons connected with linear actuators. This new device was composed with a testing frame, Force Delivery Unit (FDU), Data Acquisition (DAQ), and Vision system for motion capturing, and a custom developed software (Figure 1). The FDU consists of two stepper motors driven linear actuator in series with a force transducer for force feedback control. Each force transducer is attached to a cable connected to a freeze clamp in the line of force of each muscle [3]. The DAQ system was designed for measuring internal & external forces coupled with force feedback control system. External forces are defined as grip force measured from a force transducer in a handle, and internal forces are determined as tendon forces taken by force transducers in line with force delivery units. In addition, 16 ch. force sensitive resistors were attached on each phalange to measure finger force distributions for a power grip motion. For finger motion capturing, a CCD camera was attached on the side of the frame to capture finger joint angles in lateral view. Captured images represented static grip postures of each condition. As the post process, the custom Labview software analyzes captured images to measure finger joint angles. One human cadaver forearm was used to demonstrate the utility of the device for measuring tendon forces and a grip force. The entire forearm was mounted into the testing frame with Schanz screws to secure the specimen. The flexor digitorum profundus (FDP) and the flexor digitorum superficialis (FDS) were the main finger flexor muscles to control finger postures for grasping motion. The activities of the FDP and FDS were each demonstrated by a separate force delivery unit activated by a motion controller. To control muscle forces, the motion controller implemented a force-feedback control loop in order to keep the actual force, F_A, in each FDU cable measured by each load transducer equal to the target force, F_T, desired force to grasp a handle.

RESULTS

The hand motion simulator showed very stable motions and data acquisition with a cadaver forearm. In the validation test of the force feedback control system, the HMS generated 98.98±0.41 N for 100 N target forces. The error between F_A and F_T was 1.02±0.41N and it showed the reliability of the system (Figure 2). Figure 3 shows sample data plots of tendon forces (FDP and FDS) measured by force transducers in line with the force delivery units and grip forces recorded by a handle.

DISCUSSION

The new device presented in this study dose has some limitations. Intrinsic muscles were not considered in our research, because effects of these muscles on the finger flexion could be neglected. However, pulling the FDP and FDS muscles was limited to control metacarpophalangeal (MCP) joint regardless of the motion of proximal and distal interphalangeal joints. We believe that the strengths of this study outweigh the weakness. Although we cannot make firm conclusions based on only one specimen being tested, we believe that this new testing device will provide new and useful information on the source of direct measurement of tendon forces.

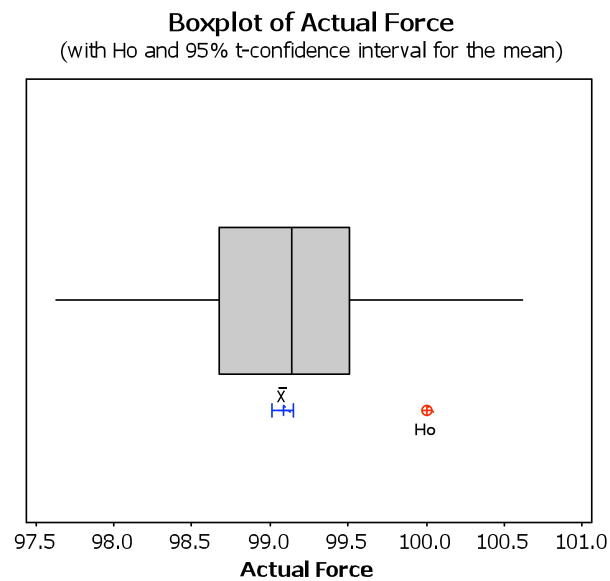

Figure 2: Average Actual force generated by the HMS for 100 N Target Force

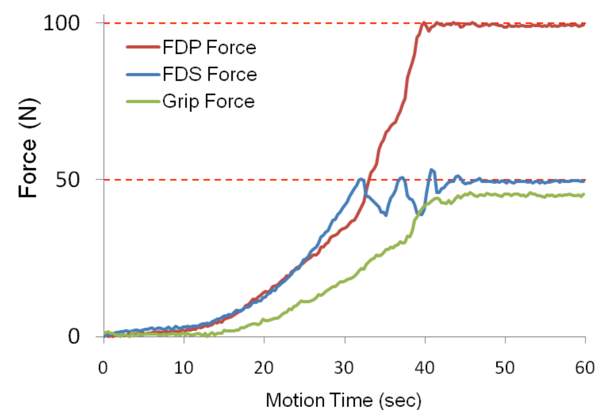

Figure 3: Sample data plots of tendon forces and a grip force measured by the HMS

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2. Kong, Y.K., Optimum Design of Handle Shape through Biomechanical Modeling of Hand Tendon Forces, *Ph.D. dissertation*, University Park, PA: Pennsylvania State University, 2001
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