REPDODUCING PHYSIOLOGIC MOMENT ARMS WITH AN ELBOW SIMULATOR

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INTRODUCTION

The elbow is critical to activities of daily living, for gross tasks such as lifting heavy objects and finer tasks such as grooming. Some treatments of elbow injury, including replacement and/or reconstruction, do not restore stability or complete function. Tools are lacking to evaluate kinematics and stability of surgical treatments *in vitro*. An elbow simulator described in the literature has actuated its muscles with open-loop force control [1] and lacked antagonist muscle control making accurate positioning difficult at best. A wrist simulator's success using force and position control illustrates that proportional-integral-derivative control can replicate physiologic motion in an upper extremity joint [2].

The purpose of the current work was to construct an apparatus to replicate realistic, accurate motion and neuromuscular control of a cadaver elbow while maintaining moment arms similar to the broad range of those reported in the literature. Fulfillment of these design requirements will permit the study of force and motion control strategies.

METHODS

The apparatus controls the dominant movements (flexion-extension (f/e) and pronation-supination (p/s)) via the *brachialis*, *biceps brachii*, *triceps*, *pronator teres*, and *brachioradialis*. A custom frame (Figure 1) supports five servoelectric cylinders (Exonic Systems, Pittsburgh, PA) coupled with Gemini servo drives (Parker Hannifin Corp., Cleveland, OH) to actuate the muscles. Each muscle is connected to its actuator via a cable that passes through a muscle-specific custom pulley system which maintains physiologic alignment (and thus accurate moment arms) throughout the motion. The cables to extend the *biceps brachii*, *brachialis*, and *triceps* do not undergo large alignment changes during elbow motion and require only stationary pulleys. However, the *brachioradialis* and *pronator teres* undergo marked alignment changes with elbow flexion and thus a more advanced pulley system is required to allow multiple rotations (Figure 1, inset) and to prevent cable dislocation with elbow motion.

To evaluate the apparatus, a mock elbow with realistic size and mass properties that could move in both f/e and p/s was constructed. The muscle origins were adjustable to encompass the range of values previously reported [3]. The moment arms of the mock elbow's five muscles in our apparatus during 140° of elbow f/e were calculated.

RESULTS AND DISCUSSION

A realistic elbow simulator has been constructed. The versatile design can accommodate both right and left arm specimens and can test elbows in both varus and valgus orientations. Custom pulleys (Figure 1) allow the muscles to maintain their physiologic lines of action and moment arms throughout the elbow's range of motion. Calculated moment arms agree closely with previously-published results [4] (Figure 2 shows one of the five outcomes).

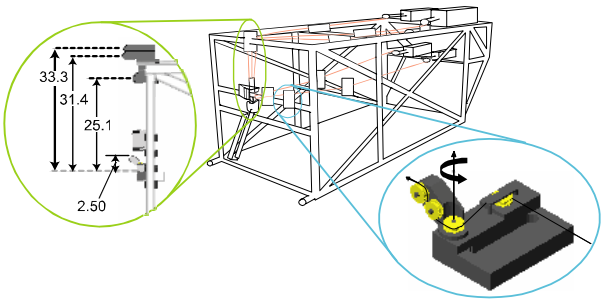

Figure 1: Schematic of frame and custom pulleys (insets), dimensions in cm.

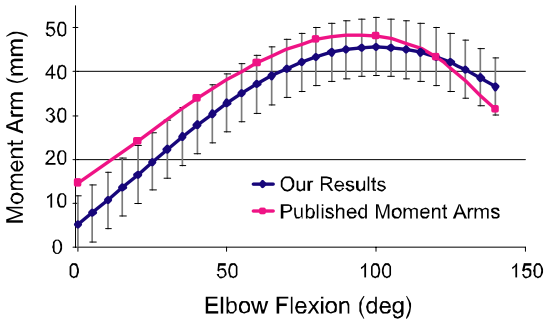

Figure 2: Moment arm results for *biceps brachii*. Error bars indicate the moment arms within the range of those reported in the literature.

As a validation, the apparatus successfully moved the mock elbow through complete f/e and p/s cycles. This design can flex and extend a cadaver elbow at 300°/s (a realistic movement speed) and lift a 7 kg weight in the hand.

REFERENCES

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