Wrist Range of Motion Depends on Elbow Position after the Br-ECRB Tendon Transfer

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Introduction

The ability to extend and flex the wrist is required if functional use of the hand is to be restored to persons with tetraplegia. Due to the passive forces developed by the muscles of the fingers and thumb, wrist extension passively closes the hand and wrist flexion passively opens the hand, providing a means to grasp and release light objects (Wilson, 1956). Individuals with a spinal cord injury at the fifth cervical segment have severely weakened or paralyzed wrist extensors and paralyzed wrist flexors. Surgically attaching the distal tendon of the brachioradialis (Br), a non-paralyzed elbow flexor, to the distal tendon of the extensor carpi radialis brevis (ECRB), a paralyzed wrist extensor, restores active wrist extension (Freehafer and Mast, 1967). Once voluntary wrist extension is restored, gravity provides passive wrist flexion.

It is important to be able to extend and flex the wrist over a broad range of elbow postures because many self-care activities (e.g., eating, grooming) involve acquiring an object at a distance from the body and then bringing the object close to the body. Anecdotally, we have observed that some individuals have difficulty maintaining wrist extension when the hand is close to the body (i.e., when the elbow is flexed). The brachioradialis has a large elbow flexion moment arm and changes length substantially during elbow flexion, which implies the force brachioradialis produces depends on elbow position (Murray et al., 2000). We hypothesize that the wrist’s active range of motion depends on elbow position after the Br-ECRB tendon transfer because of the changes in brachioradialis’ force-generating capacity that occur with elbow flexion. The objectives of this study are: (i) to quantify active range of motion of the wrist at different elbow positions in individuals with Br-ECRB transfers, and (ii) to simulate how force-length properties and surgical tensioning of the Br-ECRB transfer influence the relationship between elbow posture and wrist range of motion using a biomechanical model.

Methods

Active range of motion of the wrist was evaluated in six individuals (eight wrists) with Br-ECRB tendon transfers. The Br-ECRB procedure was often performed in conjunction with other surgical procedures that were not studied in this project. Surgical tensioning of the transfer was not objectively quantified intraoperatively. All patients underwent three weeks of casting post-operatively, followed by one to two weeks of inpatient rehabilitation and training to learn to use the transfer. The rest position and the most extended position of the wrist against gravity were measured at full elbow extension (range = 0°-30° elbow flexion across subjects) and 120° elbow flexion. These data were collected by an occupational therapist using a handheld goniometer. The human subjects protocol was approved by the Institutional Review Board of MetroHealth Medical Center (Cleveland, OH). All subjects provided informed consent.

Using a biomechanical model of the upper extremity, we simulated the active range of motion of the wrist after the Br-ECRB tendon transfer in different elbow positions. The model allows the calculation of muscle lengths, forces, moment arms, and joint moments as a function of both elbow and wrist position (Murray et al., 1995; Gonzalez et al., 1997; Delp and Loan, 1995). We compared the active and passive moment-generating capacities of a slack transfer and a tight transfer to passive properties of the wrist. The
slack transfer assumes the brachioradialis muscle fibers operate on the ascending limb and plateau of the isometric force-length curve between full elbow extension (0°) and 130° elbow flexion. The tight transfer assumes the fibers operate at longer lengths (the plateau and descending limb of the force-length curve) for this range of elbow motion. Passive wrist joint properties were estimated by combining the gravitational wrist flexion moment imposed by the weight of the hand, estimated for a 50th percentile male from regression equations (McConville et al., 1980), with the passive moment generated at the wrist by joint structures and muscles, measured from a subject with C5 level tetraplegia (Lemay and Crago, 1997).

Wrist range of motion was simulated in an arm posture where gravity opposes wrist extension. For each elbow position, active range of motion of the wrist was defined as the range of wrist postures where two conditions were met. First, at each wrist position, the Br-ECRB transfer must be capable of producing a moment that is large enough to maintain that position. Thus, the total isometric moment-generating capacity of the Br-ECRB transfer (active and passive) must be greater than or equal to the total passive flexion moment at the wrist. Second, it must be possible to reach each wrist position when the Br-ECRB transfer is not activated. In this case, the passive extension moment produced by the Br-ECRB transfer must be less than or equal to the total passive flexion moment at the wrist. In each simulation, we assumed maximal muscle activation and we assumed that elbow extension strength was sufficient to balance the elbow flexion moment that is produced by the Br-ECRB transfer when it is activated to extend the wrist.

Results & Discussion

Active range of motion of the wrist depends on elbow position after the Br-ECRB tendon transfer. The maximum position of wrist extension that could be maintained against gravity decreased substantially in four wrists when the elbow was flexed (Fig. 1; wrists A, E, D right, and C, compare top values of filled and open bars). In seven of eight wrists evaluated, the wrist rested in a more flexed posture at 120° elbow flexion compared to full elbow extension (Fig. 1; all wrists, compare bottom values of filled and open bars).

![Figure 1. Active range of motion of the wrist measured in six subjects (eight wrists) with the elbow fully extended (filled bars) and flexed 120° (open bars). Positive numbers are wrist extension, negative numbers are wrist flexion. Each bar indicates the rest position (bottom) and most extended position (top) of the wrist against gravity.](image)

The biomechanical model indicates that surgical tensioning influences both active wrist extension and the rest position of the wrist against gravity. Elbow flexion compromised active wrist extension after the slack transfer (Fig. 2). The tight transfer provided more wrist extension than the slack transfer at 120° elbow flexion but severely limited passive wrist flexion at full extension.

After cervical spinal cord injury, the inability to maintain a given wrist posture in different elbow positions could influence grasp strength and could limit an individual’s ability to acquire, hold, or release objects over the full range of elbow motion. Our clinical data and computer simulations support the
hypothesis that active range of motion of the wrist depends on elbow position after the Br-ECRB tendon transfer. In addition, the biomechanical model suggests that surgical tensioning of the transfer can be optimized to maximize active wrist extension (and hand grasp) over the full range of elbow motion. However, optimizing wrist extension may sacrifice passive wrist flexion (and hand opening) when the elbow is fully extended.

Figure 2. Computer simulation of the active range of motion of the wrist against gravity for the slack and tight transfers in two elbow postures. Bottom arc of the shaded region corresponds to the rest position of the wrist against gravity; top arc to the most extended position that can be maintained against gravity.

This study suggests that both the active and passive force-generating properties of the Br-ECRB tendon transfer have important effects on post-operative wrist function. We believe that biomechanical modeling studies can lead to objective criteria for surgical tensioning of tendon transfers. Integration of these criteria with quantitative assessments of muscle strength and passive joint properties, as well as intraoperative measurements of muscle sarcomere lengths (e.g., Fridén and Lieber, 1998), could greatly improve restored function in individuals with tetraplegia.

References

McConville, J. et al., Anthropometric relationships of body and body segment moments of inertia, Wright-Patterson Air Force Base, 1980.

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