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Wrist salvage procedures alter moment arms of the primary wrist muscles

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ABSTRACT

Background: Proximal row carpectomy and scaphoid-excision four-corner fusion are salvage procedures that relieve pain by removing arthritic joint surfaces. While numerous studies have examined how these procedures affect joint motion, few have examined how they influence muscle mechanical actions. This study examines whether muscle moment arms change after these procedures.
Methods: Moment arms of primary wrist muscles were measured in 8 cadaveric specimens using the tendon excursion method. In each specimen, moment arms were measured for two degrees of freedom (flexion–extension and radial–ulnar deviation) and three conditions (nonimpaired, scaphoid-excision four-corner fusion, and proximal row carpectomy). For each muscle and degree of freedom, moment arm versus joint angle curves for the three conditions were statistically compared.
Findings: Wrist salvage procedures significantly alter moment arms of the primary wrist muscles. Proximal row carpectomy primarily alters flexion–extension moment arms, while scaphoid-excision four-corner fusion primarily alters radial–ulnar deviation moment arms. Both procedures also alter the balance between agonist and antagonist wrist muscles. Following proximal row carpectomy, wrist extensors have smaller moment arms in extended postures. Following scaphoid-excision four-corner fusion, radial deviators have larger moment arms throughout radial–ulnar deviation.
Interpretation: Different moment arms indicate that different forces are required to complete the same tasks in nonimpaired and surgically altered wrists. The altered muscle moment arms likely contribute to post-operative impairments. Understanding how salvage procedures alter muscle mechanical actions is a critical first step toward identifying the cause of post-operative impairments and is necessary to develop effective interventions to augment deficient muscles and improve overall function.

1. Introduction

During wrist salvage procedures, some aspects of wrist and hand function are sacrificed to relieve osteoarthritic pain. Which salvage procedure has the best outcome is unclear. In particular, numerous studies have compared proximal row carpectomy (PRC) and scaphoid-excision four-corner fusion (SE4CF) (Bisneto et al., 2011; Cohen and Kozin, 2001; Dacho et al., 2008; De Smet et al., 2006; Mulford et al., 2009; Vanhove et al., 2008; Wyrick et al., 1995). Although several of these studies conclude that PRC preserves wrist range of motion, while SE4CF preserves grip strength (Cohen and Kozin, 2001; Dacho et al., 2008; Mulford et al., 2009), studies of long-term outcomes report that grip strength and wrist range of motion remain similarly and permanently impaired following both procedures (Bain and Watts, 2010; DiDonna et al., 2004; Jebson et al., 2003; Richou et al., 2010).

Most scientific studies examining the mechanism responsible for impairments following PRC and SE4CF have focused on skeletal changes. For example, limits in wrist range of motion following SE4CF have been attributed to the fused position of the lunate; misaligning the lunate and capitate can bias the wrist toward either flexion or extension (De Carli et al., 2007; Dvinskikh et al., 2011). Alternatively, limits in wrist range of motion following PRC have been attributed to impingement between carpal bones and the radial styloid (Blankenhorn et al., 2007) as well as differences in curvature between the surfaces of the lunate, capitate, and radius (Hawkins-Rivers et al., 2008; Imbriglia et al., 1990).

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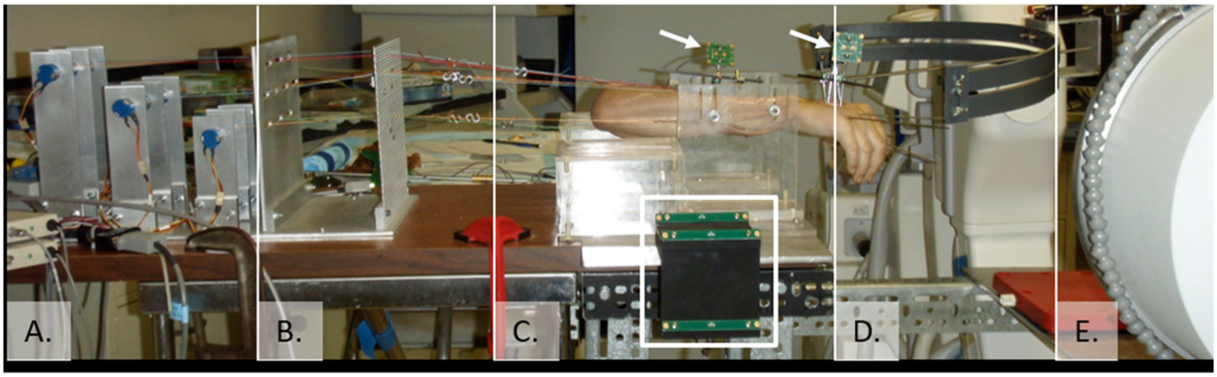

Fig. 1. The full experimental set-up included (A) potentiometers to measure tendon excursion, (B) suture lines extended by nylon line to connect exposed tendons and potentiometers, (C) custom, acrylic jig to secure the specimen during testing, (D) planar track to guide wrist motion, and (E) C-arm to capture fluoroscopy while performing surgeries in the jig. Wrist joint angles were measured using a motion capture system (not shown), which measured the position of the global reference frame (enclosed by white rectangle) and two infrared targets secured to the third metacarpal and radius (marked by white arrows).

How the geometric changes imposed by PRC and SE4CF influence muscle function is not fully understood. Because PRC shortens the carpus, it is assumed that muscles crossing the wrist operate at longer lengths following PRC, thereby reducing grip strength (Nagelvoort et al., 2002). Yet, SE4CF does not involve shortening the carpus, and reduced grip strength is still reported (Cohen and Kozin, 2001). To our knowledge, only one study has compared muscle actions following SE4CF and PRC (Debottis et al., 2013). This cadaver study demonstrated that to move nonimpaired, SE4CF, and PRC wrists through identical motions, different forces must be applied to the tendons of the primary wrist muscles. The fact that different tendon forces were required suggests that these procedures alter muscle moment arms. A muscle's moment arm is the geometric factor that transforms the force produced by a muscle into torque about the joint's axis of rotation, thereby determining how the joint moves. For example, when the extensor carpi radialis longus (ECRL) produces force, the wrist moves in extension and radial deviation; in contrast, the flexor carpi ulnaris (FCU) moves the wrist in the opposite directions (i.e., flexion and ulnar deviation). As demonstrated by Brand and Hollister (1999), the opposing mechanical actions of these muscles are reflected in their moment arms. While the data from Debottis et al. (2013) suggests that the wrist muscle moment arms change following salvage procedures, their study did not quantify moment arms. To our knowledge, no studies report moment arms following SE4CF and only one study reports moment arms following PRC (Sobczak et al., 2011). The significance of muscle moment arms at the wrist is well established by the works of Brand and Hollister (1999) and Zajac (1992), which describe the important role of moment arms in balancing antagonist muscle forces, dictating how muscles lenthen (or shorten) during joint movement, and determining how muscle oppose external loads at the hand. Thus, quantifying the differences in moment arms between nonimpaired and surgically altered wrists is critical for understanding why grip strength (i.e., the ability of muscles to produce external forces at the hand) is impaired following salvage procedures.

The purpose of this study was to measure and compare muscle moment arms in nonimpaired, SE4CF, and PRC wrists in a cadaveric model. We hypothesized that moment arms following salvage procedures would differ from the nonimpaired wrist. Additionally, because the geometric construction of the wrist joint is substantially different following PRC versus SE4CF, we expected that moment arms following each procedure would change in divergent ways.

2. Methods

The muscle moment arms of nonimpaired and surgically altered wrists were studied using eight unmatched, fresh-frozen cadaver upper extremities (four male; four female) amputated at the midhumeral level. The average age of donors at time of death was 62.3 (standard deviation, 8.9 years; range, 44 to 73). Radiographs were taken to exclude specimens with abnormalities.

Moment arms were estimated using the tendon excursion method (An et al., 1983), which defines moment arm as the derivative of tendon excursion with respect to joint angle. Tendon excursions were measured using rotary potentiometers (Model 3543s, Bourns Inc.); calibration of the devices within our experimental set-up indicates that, as implemented, they could resolve 0.08 mm excursions. Joint angles were calculated from the position of infrared targets, which were measured using a motion capture system (Optotrak Certus, Northern Digital Inc.) that has an accuracy of 0.1 mm.

2.1. Specimen preparation

Each specimen was thawed at room temperature and prepped twenty-four hours prior to testing. Preparation included: exposing the tendons of five primary wrist muscles and securing infrared targets. The wrist muscles were exposed via three incisions. One dorsal incision exposed the tendons of the extensor carpi radialis brevis (ECRB), extensor carpi radialis longus (ECRL), and extensor carpi ulnaris (ECU). Two separate volar incisions exposed the tendons of the flexor carpi radialis (FCR) and flexor carpi ulnaris (FCU). The extensor retinaculum was preserved. Infrared targets were secured to the radius and third metacarpal via external fixators (Fig. 1, white arrows). A third infrared target on the base established a global reference frame (Fig. 1, indicated by white, outlined box). Each custom-made target had six infrared that could be optically recorded and used to establish local coordinate frames. These targets were necessary for joint angle measurements.

2.2. Experimental testing

For a single specimen, all data were collected in a single day with the specimen at room temperature. During testing, each specimen was mounted in a custom, x-ray compatible acrylic jig by drilling two 4.76 mm threaded steel rods through the radius and ulna (Fig. 1C). The humerus was fixed to an acrylic support so that the elbow was at ninety degrees. The forearm was fixed in neutral pronation–supination. The wrist was not fixed. Wrist motions were guided by a single experimenter, who applied passive motion by moving a steel rod along a planar track (Fig. 1D); the steel rod was connected to the second metacarpal via an external fixators. This set-up is similar to previous wrist moment arm studies (Horii et al., 1993; LaRoque et al., 2008; Loren et al., 1996; Sobczak et al., 2011; Tang et al., 1997).