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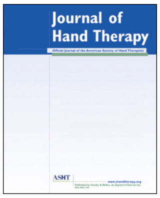

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Special Issue: Wrist

Role of muscles in the stabilization of ligament-deficient wrists

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ABSTRACT

This article reviews the results of a series of cadaver investigations aimed at clarifying the role of muscles in the stabilization of ligament-deficient wrists. According to these studies, isometric contraction of some forearm muscles induces midcarpal (MC) supination (ie, the abductor pollicis longus, extensor carpi radialis longus, and flexor carpi ulnaris), whereas other muscles induce MC pronation (ie, the extensor carpi ulnaris). Because MC supination implies tightening of the volar scaphoid-distal row ligaments, the MC supination muscles are likely to prevent scaphoid collapse of wrists with scapholunate ligament insufficiency. MC pronator muscles, by contrast, would be beneficial in stabilizing wrists with ulnar-sided ligament deficiencies owing to their ability to tighten the triquetrum-distal row ligaments. Should these laboratory findings be validated by additional clinical research, proprioceptive reeducation of selected muscles could become an important tool for the treatment of dynamic carpal instabilities.

Introduction

From a kinetic standpoint, a wrist is considered stable when it is capable of maintaining normal carpal relationships, under physiological loads, throughout the entire ranges of motion.[1,2] The mechanism by which this is achieved is complex and multifactorial. In theory, 4 prerequisites are necessary for the wrist to be stable under physiological loads: (1) all carpal joints must have normally tilted, reciprocally matching, smooth, and congruous articular surfaces, (2) both capsule and ligaments (static stabilizers) need to be intact and properly innervated, (3) the sensorimotor system (SMS), a collection of neural structures controlling the mechanisms of neuromuscular stabilization of the joints, must be functioning, and (4) the neighboring muscles (dynamic stabilizers) need to be permanently active and ready to effectively neutralize any attempt to destabilize the wrist.[3-5]

Fortunately, the wrist does not become unstable with the onset of torn ligaments. For the wrist to lose stability and collapse, the intricate mechanisms of neuromuscular stabilization must also fail. This may occur in the form of (1) an interruption of the pathways bringing information from the wrist to the central nervous system, (2) a disabling neurologic alteration of the SMS preventing proper assessment of the incoming proprioceptive information, or (3) a dysfunction of the muscles that enhance stability of ligament-deficient wrists.[3-5] Undeniably, ligaments and muscles are important contributors to wrist stabilization. The fact that the mechanisms of ligament stabilization are better understood than the methods of neuromuscular stabilization does not make the latter less important. The purpose of this article is to review the results of a series of cadaver investigations aimed at clarifying the role of muscles in the stabilization of ligament-deficient wrists.

John Kauer, in 1988,[6] was the first to speculate about muscular contributions in enhancing wrist stability. He described the extensor pollicis brevis, abductor pollicis longus (APL), and extensor carpi ulnaris (ECU) as an adjustable collateral system that compensates for the lack of true collateral ligaments. In 2002, Linscheid and Dobyns[7] suggested that the bowstringing force exerted by the flexor carpi radialis (FCR) tendon on the scaphoid tuberosity could help prevent carpal collapse of the wrists with dynamic instability.

The existence of mechanoreceptors within the substance of the palmar wrist ligaments was first documented by Petrie et al in

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1997.[8] Since then, several research teams have investigated the essential features of these mechanoreceptors, including their density, distribution, and function.[9-14] These studies concluded that muscles require a finely tuned SMS to adequately stabilize the carpus. Certainly, additional basic science related to the neuromuscular mechanisms of wrist stabilization will enhance efforts to identify optimal clinical interventions for the early stages of carpal instability. To better understand the role of these neurologic mechanisms in wrist stabilization, the authors performed a series of cadaver investigations. These studies documented changes in carpal alignment induced by either axial or muscle isometric loading, before and after sectioning specific carpal ligaments.[15-21] The following section summarizes the findings of those investigations.

Normal wrist joint

Axial loading affects carpal alignment

Forces applied along the axis of the third metacarpal to a normal and neutral positioned wrist result in distal carpal row pronation and proximal migration.[2,15,19] These biomechanical changes generate increasing amounts of compressive and shear forces across the midcarpal (MC) joint. At the scaphotrapeziotrapezoidal (STT) level, these forces push the scaphoid into flexion and pronation, whereas at the triquetrohamate level, the dorsally subluxing hamate induces triquetral extension via the palmar triquetrohamate ligament. If the different components of both the scapholunate (SL) and lunotriquetral (LTq) interosseous ligaments are intact, the extension moment of the triquetrum counteracts the scaphoid flexion moment, resulting in a stable equilibrium within the proximal row.[2,15]

As expected, the kinetic response to an axial load was similar but not identical in the vast majority of specimens. Minor differences in the magnitude and direction of rotation could have been attributable to anatomic variations in the shape of the MC joint; however, the overall pattern of carpal kinetics was the same. One notable exception was the distal carpal row supinated and the scaphoid flexed in less than 10% of the total specimens under axial load. The presence of variable degrees of cartilage degeneration at the STT joint could explain these anomalous kinetics.[15,21]

Axial loading and muscle loading are not equivalent in kinetic terms

Distal to the extensor retinaculum, tendons from the APL and extensor carpi radialis longus (ECRL) muscles change direction toward the lateral corner of the wrist, whereas the tendon from the ECU muscle courses toward the medial aspect of the ulnar side of the carpus.[15-17,19,20] All these tendons run from a dorsal position at the level of the distal radius to a volar/lateral or volar/medial position at the level of the hand (Fig. 1). When these muscles were isometrically loaded, variable amounts of MC pronation or supination were observed and measured. In fact, greater oblique tendon angulation was associated with increased rotation. Loading of the APL or the ECRL consistently induced MC supination, whereas the ECU always generated MC pronation.[15-17]

Similarly, on the volar side, the muscles with a tendon pulling from the radial corner of the distal row are MC pronators (FCR), whereas the flexor carpi ulnaris (FCU) is an MC supinator.

Based on these observations, the forearm muscles were classified into 2 categories: MC pronation muscles and MC supination muscles.[3,19-21]

The FCR is a peculiar muscle that uses the scaphoid tuberosity as a lever to pull the base of the metacarpal palmarly, generating a pronation moment to the distal row. The contact between the tendon and the scaphoid occurs at the medial corner of the scaphoid tuberosity. Because of this, when loaded, the tendon generates a dorsolateral-directed vector to the scaphoid, forcing it into supination. Indeed, the FCR is the only MC pronator muscle that supinates the scaphoid.[16]

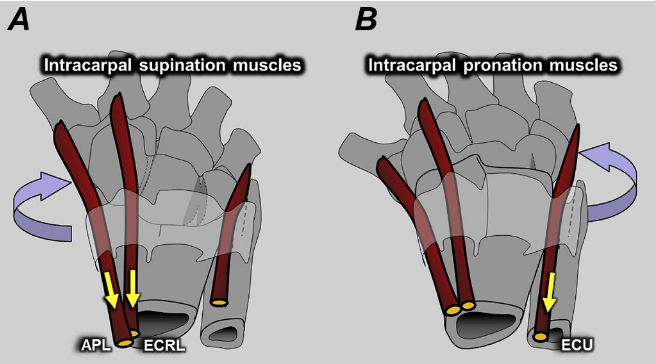

Fig. 1. Across the wrist, most tendons have an oblique disposition. (**A**) The ECU inserts onto the ulnar corner of the fifth metacarpal base. (**B**) Some other tendons (ECRL and APL) have an opposite obliquity, inserting onto the lateral corner of the first metacarpal. When the ECU contracts, it generates a pronation moment to the distal carpal row, whereas when the second muscles contract, the distal carpal row rotates into supination. ECU = extensor carpi ulnaris; ECRL = extensor carpi radialis longus; APL = abductor pollicis longus.

Previous investigations demonstrated that simultaneous isometric loading of all 5 wrist motor tendons (APL, ECRL, FCR, FCU, and ECU) generates a supination moment to the distal carpal row.[22] The studies reviewed in this article demonstrated a similar supination behavior when all muscles were simultaneously loaded.[17] When the same wrists were loaded not through their tendons but by applying an axial load to their third metacarpal, the distal row always rotated into pronation.

In other words, isometric muscle loading and axial loading are not equivalent forms of evaluating carpal kinetics; each one has its own distinct effects.[19,20]

The kinetic effects of muscle loading change with forearm rotation

The obliquity of the different tendons across the wrist joint varies with the degree of forearm rotation. That variation is particularly important for the ECU.[23] When the forearm is pronated, the portion of ECU distal to the ECU subsheath is mostly collinear with the main axis of the muscle, whereas it angles up to 30° when the forearm is in full supination (Fig. 2). Several cadaver studies evaluated the hypothesis that the larger this angulation, the greater the pronator effect of the ECU. Distal row kinetics, when all muscles were simultaneously loaded, was documented in 3 different forearm positions: maximal pronation, neutral supination, and maximal supination. The results were very consistent: in all forearm positions, except in full forearm pronation, the MC supinator muscles (APL, ECRL, and FCU) could hardly counteract the MC pronation effect induced by the ECU and FCR. That effect was maximized with the forearm in full supination, that is, when the ECU tendon was positioned in maximal obliquity.

Therefore, forearm rotation is an important factor to consider when planning muscle strengthening programs to stabilize the wrist. Indeed, forearm supination increases the mechanical advantage of the ECU muscle as an MC pronator.[23]

Kinetic classification of carpal ligaments

When the distal carpal row is positioned into extreme supination, by an external torque or by isometrically contracting