# Predicted Effects of Metacarpal Shortening on Interosseous Muscle Function

**Matthew J. Meunier, MD, Eric Hentzen, MD, PhD,**
**Michael Ryan,** ***San Diego, CA*****, Alexander Y. Shin, MD,** ***Rochester, MN*****,**
**Richard L. Lieber, PhD,** ***San Diego, CA***

**Purpose:** Metacarpal fractures are common in hand surgery. Metacarpal shortening ranging from 2 mm to as much as 10 mm has been deemed acceptable in the literature. We examined the effect of metacarpal shortening on interosseous muscle architecture and predicted force production capacity based on the standard muscle length-tension curve (commonly known as the *Blix curve*).

**Methods:** The dorsal interosseous muscles between the middle and ring finger metacarpals from 9 adult human cadaver hands were exposed and studied. The ring finger metacarpal was translated proximally in 2-mm increments in relation to a stationary middle finger metacarpal. Digital images were obtained and analyzed to define the length and orientation of individual muscle fibers with each incremental change in position.

**Results:** Interosseous muscle fiber length increased and pennation angle decreased uniformly with increasing proximal translation of the ring finger metacarpal. At 10 mm of shortening the fiber length had increased to 20.8 ± 1.8 mm, or to approximately 125% of optimum fiber length, and the pennation angle had decreased to 6.7° ± 2.2° or by approximately 50%.

**Conclusions:** The interosseous muscles have been shown to have a high fiber-to-muscle length ratio. This ratio indicates that these muscles function optimally over a short range of lengths, leaving them vulnerable to derangement in function owing to alteration in the surrounding bony architecture. Based on the standard muscle length–-tension relationship we had predicted a steady linear decrease in interosseous power with proximal translation of the metacarpal. The results indicate an initial linear progression with a plateau at approximately 8 mm of shortening. At 2 mm of shortening there is an approximately 8% loss of power generation, at 10 mm of metacarpal shortening we predict the interosseous muscle to be capable of only approximately 55% of its optimum power compared with the resting position. (J Hand Surg 2004;29A:689–693. Copyright © 2004 by the American Society for Surgery of the Hand.)

**Key words:** Biomechanics, muscle architecture, fracture fixation.

---

From the Departments of Orthopedic Surgery and Bioengineering, University of California, San Diego and Veterans Administration Medical Centers, San Diego, CA; and the Department of Orthopedic Surgery, Division of Hand Surgery, Mayo Clinic, Rochester, MN.

Received for publication June 9, 2003; accepted in revised form March 4, 2004.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

Reprint requests: Matthew Meunier, MD, Department of Orthopaedics, University of California, San Diego, 350 W. Dickinson Ave, Suite 121, San Diego, CA 92103-8894.

0363-5023/04/29A04-0021$30.00/0
doi:10.1016/j.jhsa.2004.03.002

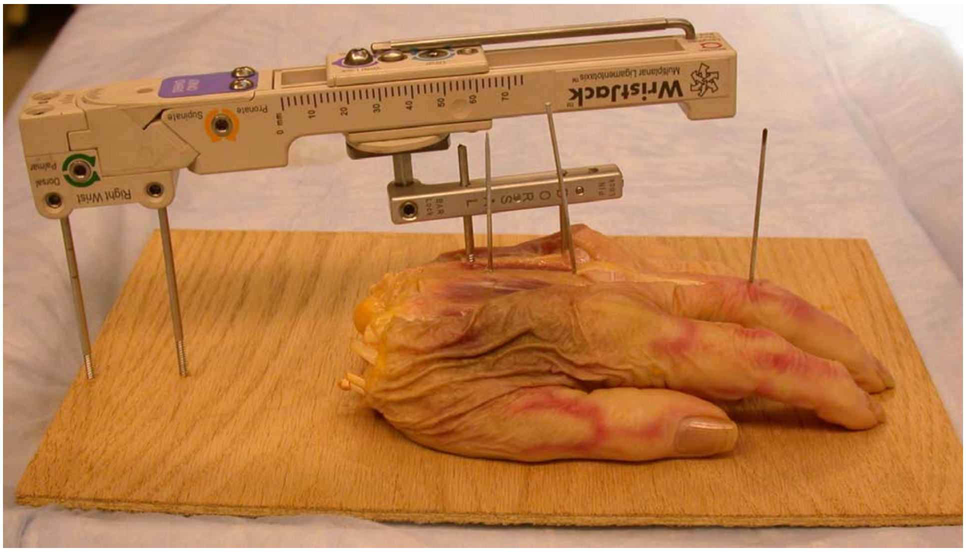

**Figure 1.** Experimental setup. The middle finger metacarpal and proximal phalanx have been transfixed to the board. The frame is affixed to the board independent of the specimen. Proximal translation of the metacarpal is to the left of the image.

Metacarpal fractures are seen commonly in hand surgery. Although the clinical guidelines for metacarpal rotation and angulation after reduction are well described,[1,2] published guidelines for the acceptable degree of metacarpal shortening after fracture ranges from 2 to 10 mm.[3–5] Anecdotal experience suggests that as little as 2 mm of shortening may affect grip strength and, ultimately, hand function. We hypothesize that the basis for the change in strength observed with metacarpal shortening is an alteration in the properties of the dorsal and palmar interosseous muscles. Because these muscles are highly pennated with relatively short fibers and a high pennation angle,[6] it is possible that even small amounts of metacarpal shortening can cause enough interosseous fiber length and pennation angle change to affect function. There are no anatomic data available, however, to simulate such a shortening; we have therefore simulated this situation in cadaver specimens. We hypothesize that metacarpal shortening has a functional effect on muscle fibers, specifically via extrapolation,[7] on the sarcomere lengths in the dorsal and palmar interosseous muscles, which can significantly alter the power generated during grip activities.

## Materials and Methods

Power analysis was performed and indicated 8 hands would be required. Ten hands were initially selected, allowing for errors in technique. One hand showed ulnar neuropathy, leaving 9 fresh-frozen adult human cadaver specimens without notable musculoskeletal defect or deformity and intact from the midhumeral level. The hand was amputated at the level of the radiocarpal joint. The dorsal skin was incised from the wrist to the middle finger proximal interphalangeal joint and reflected to the radial and ulnar sides. Extrinsic extensor tendons then were exposed and resected to expose the third dorsal interosseous muscle (DI#3) between the middle and ring finger metacarpal. Remaining subcutaneous tissue was removed so that the DI#3 and its central tendon were exposed from the metacarpal base to the level of the metacarpal head. Care was taken not to injure the muscle fibers, tendon, or surrounding structures.

The specimen was fixed to a plywood board with smooth K-wires placed through the head and base of the middle finger metacarpal and through the middle finger proximal phalanx to maintain it in neutral abduction. Two Steinmann pins were driven into the base and head of the ring finger metacarpal and then clamped (Agee WristJack; Hand Biomechanics, Sacramento, CA) to the board. The apparatus used contains a worm gear that allows incremental, controlled, longitudinal translation of the clamp in relation to the stationary body. After the specimen was fixed to the board and clamped with the metacarpal maintained in their normal anatomic alignment the carpals were removed *en bloc* to allow proximal translation of the ring finger metacarpal in relation to the middle finger metacarpal. The dorsal and volar ligaments linking the metacarpal bases and the volar ligament linking the metacarpal heads also were released (Fig. 1).

By using the protocol of Lieber et al[7,8] the individual muscle fiber bundles within the DI#3 were

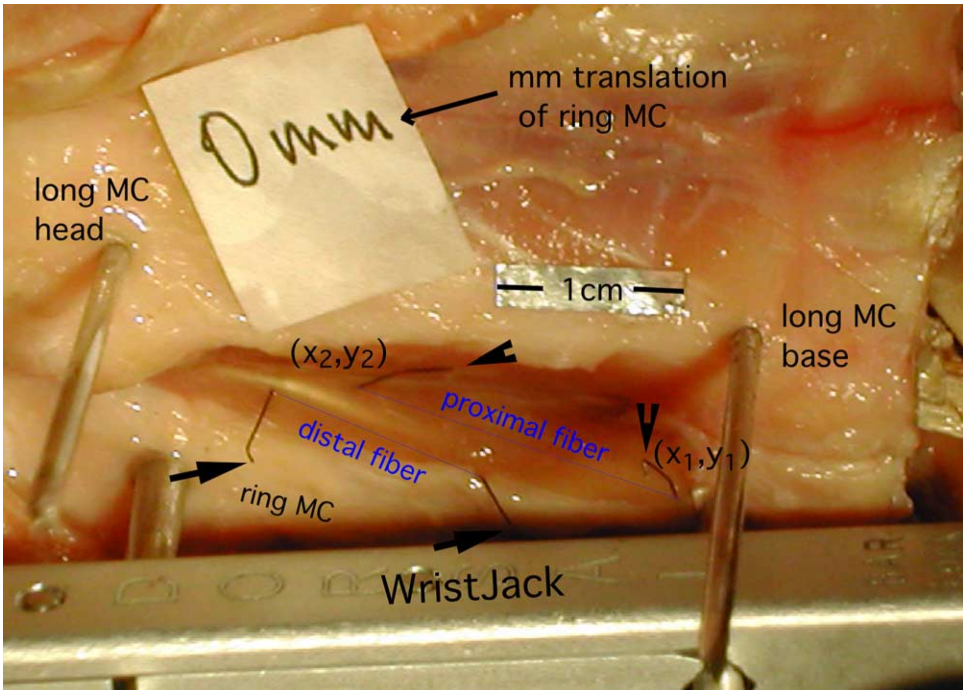

**Figure 2.** Experimental setup. Proximal and distal fibers are marked with insect pins (arrowheads). The frame is at the bottom of the picture. The carpus is to the right of the image. Translation of the metacarpal is to the right of the image.

differentiated under loupe dissection and their origins on the ring finger metacarpal and insertions at the central tendon were demarcated with insect pins. This was performed for a fiber bundle originating near the ring finger metacarpal base and for another fiber that was more distal but still allowed observation of the insertion site where the tendon coursed between the metacarpal heads. Once fibers were labeled the ring finger metacarpal was translated proximally in 2-mm increments in relation to the middle finger metacarpal.

To record changes in configuration of the dorsal interosseous muscle, digital photographs (Nikon 995 camera; Nikon, Melville, NY; uncompressed .tiff format) were obtained in the initial configuration and at each translation increment. The camera was oriented perpendicular to the major plane of the interosseous muscle and care was taken to ensure that the insertion sites of each insect pin were visible. A calibrated scale and a label indicating translation distance were placed into the field at the level of the dorsal interosseous muscle. Photographs were obtained at translation distances of 0, 2, 4, 6, 8, and 10 mm, as well as at the distance at which the muscle failed by tearing either in midsubstance or near its attachment to metacarpal periosteum. This failure distance was consistently 18.00 ± 1.07 mm (mean ± SD, n = 9) of proximal translation of the metacarpal.

Dorsal interosseous muscle fiber lengths and fiber to middle finger metacarpal angles were quantified from digital images (National Institute of Health Image Version 1.62; a public domain image analysis program available at http://rsb.info.nih.gov/ij/index.html). Images were calibrated relative to the standard scale present in each image. The positions of proximal and distal dorsal interosseous muscle fiber origin and insertion loci, as indicated by the embedded ends of the insect pins, then were digitized in a Cartesian coordinate system. Likewise, the coordinates of the centers of the middle finger head and base were determined (marked by Steinmann pin sites). The slope of the axis of the middle finger metacarpal in the Cartesian plane was determined mathematically (see equation 1, Appendix A; this appendix can be viewed at the *Journal*'s Web site, www.jhandsurg.org). In a similar manner, equation 1 then was used to calculate the slope of each muscle fiber in this plane (see equation 2, Appendix A).

Fiber length of the muscles was determined from the coordinates of their origins and insertions from the calibrated digital photographs (see equation 3, Appendix A). Data are presented in the text and figures as mean ± standard error of the mean unless otherwise noted.

## Results

Interosseous muscle fiber length increased and pennation angle decreased monotonically with increas-

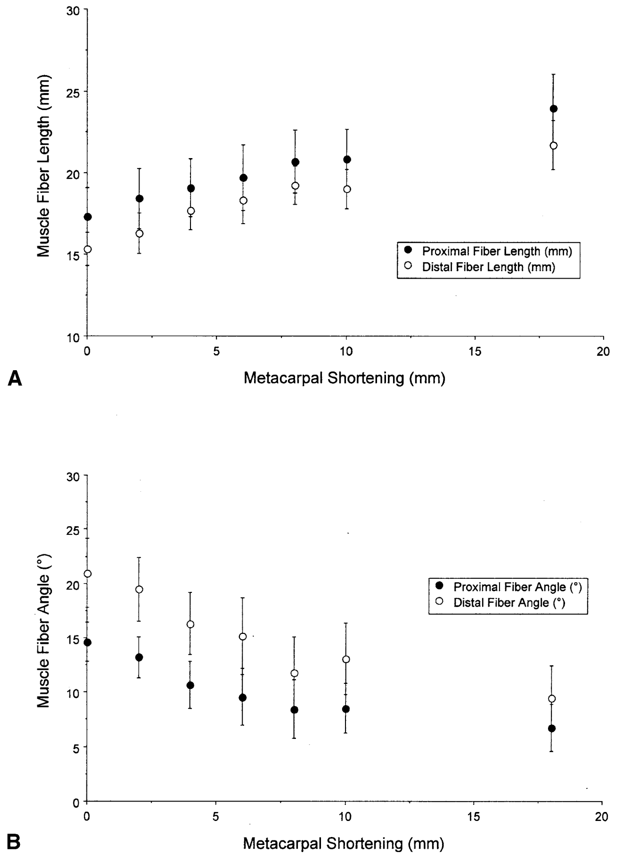

**Figure 3.** (A) Change in fiber length at each increment of shortening. ●, Proximal fiber length (mm); ○, distal fiber length (mm). (B) Change in pennation angle at each increment of shortening. The far right point represents failure of the interosseous muscle. ●, Proximal fiber angle (°); ○, distal fiber angle (°).

ing proximal translation of the ring finger metacarpal (Figs. 2, 3). Both linear and second-order polynomial regression revealed that fiber length and pennation angle changed significantly with metacarpal translation ($p < .01$). There was no significant difference in the behavior of the proximal muscle fibers compared with the distal muscle fibers (Fig. 3) based on the lack of significant difference in regression coefficients from these regions ($p > .4$). This result indicates that the interosseous muscles act as a single unit—that is, as if both the ring and small finger origins were translating proximally in response to this fracture simulation model. At 10 mm of metacarpal shortening the interosseous muscle fiber length increased to 20.8 ± 1.8 mm, or to approximately 125% of optimum fiber length, and pennation angle had decreased to 6.7° ± 2.2°, or by approximately 50%. Based on previously published data indicating that the interosseous muscles are at a sarcomere length of approximately 2.5 $\mu$m with the middle finger in neutral adduction-abduction, these data permit calculations that indicate a 0.73 ± 0.12 $\mu$m sarcomere length change, which would correspond to a force decrease of approximately 50%.[7,8]

## Discussion

Skeletal muscle function is related quantitatively to skeletal muscle architecture.[9] In general, muscles with long fibers appear to be adapted for excursion whereas muscles with short fibers function better for force generation. The palmar and dorsal interossei are architecturally similar and have short fiber lengths suggesting adaptation for force generation in the hand.[6] Loss of intrinsic muscle function owing to low ulnar nerve palsy has been shown to lead to a loss of grip strength of between approximately 60%[10] and 90% and results in a flexion force in individual fingers approximately 12% of normal.[11] Injection studies in which the ulnar nerve is paralyzed temporarily have shown a loss of grip strength of approximately 38%.[12] In the extrinsic muscles, metacarpal shortening of greater than 3 mm decreases flexion and extension force ratios.[1] Clinical guidelines suggest that shortening of up to 10 mm may be accepted without major compromise in function[4,5]; however, other investigators have reported functional compromise with less than 5 mm of metacarpal shortening.[3]

Metacarpal fractures are seen commonly in the practice of hand surgery.[13] It is well established that alterations from normal anatomy can affect the final outcome of these injuries.[14] Rotational malalignment of more than approximately 5° in the metacarpal usually is not well tolerated.[2] Alterations in force

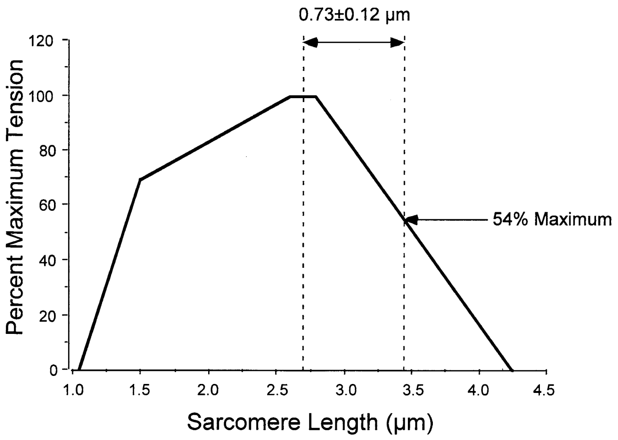

**Figure 4.** Shift along a standardized length-tension curve of the sarcomere length of the interosseous muscle associated with metacarpal shortening. The normal resting position of the interosseous muscle is indicated by the left-hand line and normal contraction of the interosseous muscle would be to the left of the curve. Fiber length is correlated to sarcomere length as described by Jacobson et al.[6]

generation of the extrinsic muscles have been shown with angular deformities of approximately 30°.[1] Clinically accepted guidelines for metacarpal shortening, however, encompass a range of 2 mm[3] to 10 mm.[15]

Strauch et al[16] showed an average of 7° of extension lag for every 2 mm of metacarpal shortening but provided no clinical guidelines for treatment. Based on previous reports[6] it is known that the interosseous muscles in the resting position, with the metacarpo-phalangeal joints extended, are at the maximal point on the force generation curve. Contraction of the interosseous muscles in the normal state will shorten the fibers and force generation capacity will start to decrease (Fig. 4). Initially normal flexion of the metacarpal joint shortens interosseous muscle fibers, whereas force generation is predicted to increase until the maximal force generation position is achieved, at which point force generation decreases. Our data indicate that fractures of the metacarpal that cause proximal translation of the metacarpal will lengthen the fibers of the interosseous muscles distal to the level of the fracture. This in turn moves these fibers further along the x-axis of the slope of the length-tension generation curve, resulting in a loss of force production. A proximal translation of the entire bone of 2 mm will cause an approximately 8% decrease in force capacity, and a 10-mm proximal translation leads to an almost 45% loss of interosseous power in the resting position.

We chose the middle–ring finger interspace because the small finger can accommodate significant alterations in normal anatomy with reasonable success and the carpometacarpal joint moves in opposition to the flexion-extension arc. The situation described in this study involves translation of the entire metacarpal. Clinical fractures, however, are less likely to involve the entire bone, so a less pronounced effect would be expected. In addition, clinical fractures distal to the termination of the musculotendinous unit will have the opposite effect, functionally slackening the muscle tension rather than stretching it. We decided to examine only the dorsal interosseous muscle because of the destructive dissection required to examine the palmar interosseous muscle. Based on earlier work the relationships discussed are assumed to hold true in the palmar interosseous muscle.[7,8] Stability of the system after sectioning of the transverse–metacarpal ligament could be questioned; however, an initial trial run was performed without sectioning of the transverse–metacarpal ligament. The frame and worm gear were unable to overcome the ligament, so with an intact ligament only approximately 5 mm of proximal translation was obtained.

The contribution of all of the interosseous muscles to grip strength is estimated at approximately 40% to 90%.[11,12] The potential impact of the loss of nearly half of the force from a given interosseous muscle is substantial. Although clinical restoration of metacarpal length and the appropriate length of the interosseous muscles is no guarantee of normal hand function after a metacarpal fracture, our data support the idea that even a minimal alteration in the bony architecture of the hand will affect the architecture of the interosseous muscles. This could have a considerable impact on hand function and shows that restoration of normal anatomy should be a goal of treatment.

## References

1. Low CK, Wong HC, Low YP, Wong HP. A cadaver study of the effects of dorsal angulation and shortening of the metacarpal shaft on the extension and flexion force ratios of the index and little fingers. J Hand Surg 1995;20B:609–613.
2. Opgrande JD, Westphal SA. Fractures of the hand. Orthop Clin North Am 1983;14:779–792.
3. Gropper PT, Bowen V. Cerclage wiring of metacarpal fractures. Clin Orthop 1984;188:203–207.
4. Bloem JJ. The treatment and prognosis of uncomplicated dislocated fractures of the metacarpals and phalanges. Arch Chir Neerl 1971;23:55–65.
5. Butt WD. Fractures in the hand. I. Description. CMAJ 1962;86:731–735.
6. Jacobson MD, Raab R, Fazeli BM, Abrams RA, Botte MJ, Lieber RL. Architectural design of the human intrinsic hand muscles. J Hand Surg 1992;17A:804–809.
7. Lieber RL, Jacobson MD, Fazeli BM, Abrams RA, Botte MJ. Architecture of selected muscles of the arm and forearm: anatomy and implications for tendon transfer. J Hand Surg 1992;17A:787–798.
8. Lieber RL, Fazeli BM, Botte MJ. Architecture of selected wrist flexor and extensor muscles. J Hand Surg 1990;15A:244–250.
9. Lieber RL, Friden J. Functional and clinical significance of skeletal muscle architecture. Muscle Nerve 2000;23:1647–1666.
10. Smith RJ. Tendon Transfers of the Hand and Forearm. Boston: Little, Brown and Company, 1987:110.
11. Schreuders TA, Stam HJ. Strength measurements of the lumbrical muscles. J Hand Ther 1996;9:303–305.
12. Kozin SH, Porter S, Clark P, Thoder JJ. The contribution of the intrinsic muscles to grip and pinch strength. J Hand Surg 1999;24A:64–72.
13. Hove LM. Fractures of the hand. Distribution and relative incidence. Scand J Plast Reconstr Surg Hand Surg 1993;27:317–319.
14. Seitz WH Jr, Froimson AI. Management of malunited fractures of the metacarpal and phalangeal shafts. Hand Clin 1988;4:529–536.
15. Eglseder WA Jr, Juliano PJ, Roure R. Fractures of the fourth metacarpal. J Orthop Trauma 1997;11:441–445.
16. Strauch RJ, Rosenwasser MP, Lunt JG. Metacarpal shaft fractures: the effect of shortening on the extensor tendon mechanism. J Hand Surg 1998;23A:519–523.