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Original Research

Biomechanical Study of Extensor Tendon Lacerations Over the Finger Metacarpophalangeal Joints

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A R T I C L E I N F O

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Purpose: To assess the percentages of extensor tendon lacerations over the finger metacarpophalangeal (MCP) joints that may lead to an MCP joint extensor lag.
Methods: We obtained 8t fresh-frozen cadaveric hand specimens. The extensor and flexor tendons were isolated for simulated active extension and passive flexion. The specimens were secured to a testing jig. Sequential full-thickness, transverse cuts were made through the extensor tendons over each MCP joint. The fingers were cycled before and after each incremental tendon cut. Extensor tendon gaps were measured and inclinometer measurements of MCP joint rotation were used to determine MCP joint extensor lags.
Results: Incremental cuts of the extensor tendons caused sequential increases in subjacent MCP joint extensor lags in addition to interactive effects on other finger MCP joints. Extensor lags of the index and little finger MCP joints were statistically significant; lacerations extended across 75% or more of the combined widths of the extensor tendon slips. In comparison, extensor lags of the middle and ring finger MCP joints were statistically significant; lacerations involved 90% or more of the widths of the extensor tendons. A statistically significant MCP joint extensor lag in the index and little fingers was also observed when 1 of 2 extensor tendon slips in either finger was completely transected.
Conclusions: In this biomechanical study of extensor tendon lacerations over the finger MCP joints, we found that MCP joint extensor lags varied by both the finger involved and the percentage of tendon width damage. Additional work is needed to determine the clinical importance of MCP joint extensor lags of differing degrees.
Clinical relevance: Lacerations of extensor tendons overlying the finger MCP joints in clenched-fist to mouth injuries are typically repaired in a delayed fashion. An improved understanding of the relations between extensor tendon slip lacerations and MCP joint extensor lags may provide a basis for treatment algorithms that could potentially reduce the costs of care.

A laceration of one or more extensor tendon slips over the finger metacarpophalangeal (MCP) joints can occur during a clenched-fist altercation; the so-called fight bite. Previous studies showed that 75% to 96% of these injuries include tendon, joint capsule, and bone.[1,2] Because of deep inoculation with human oral pathogens and the potential for infection, the wounds are initially treated by irrigation and empiric antibiotics. Repair of extensor tendon tissue damage in this region of the hand (zone V) is typically delayed by 1 or more days.[3,4] However, many of these injuries occur in young adults who may fail to return for follow-up care after initial wound management.[5,6]

Indications to repair a partial extensor tendon slip injury over a finger MCP joint remain unclear. Historically, extensor tendon lacerations involving more than 50% of the tendon width in zone V have been treated surgically, whereas injuries involving less than

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50% of the tendon width have been treated either operatively or nonsurgically. Al-Qattan[7] reported that nonsurgical treatment of an extensor tendon laceration in zone V that involved more than 50% of the tendon substance (width) would lead to an MCP joint extensor lag. However, the percentages of tendon injury over 50% and the MCP joint extension deficits were not recorded.

The purpose of our biomechanical study was to determine the percentage of injury to extensor tendon slips over the finger MCP joints that would cause an MCP joint extensor lag as measured by MCP joint rotational loss and tendon gapping. The findings may provide clinicians with an improved understanding of MCP joint extension deficits with zone V extensor tendon lacerations and a foundation for designing treatment algorithms that may stimulate clinical studies.

Materials and Methods

Part I: Experiment preparation

Preparation of tendons

For this study, we obtained 8 fresh-frozen cadaveric hand specimens transected at the distal forearm level. The specimens included 4 males and 4 females, average donor age 55 years (range, 34–66 years). The index, middle, ring, and little fingers of each specimen were used for testing, for a total of 32 digits. Fluoroscopic images (GE OEC 9900 Elite; GE, Boston, MA) of each hand were completed to confirm the absence of motion limiting arthritic changes in the MCP and interphalangeal joints.

Each specimen was thawed at room temperature for approximately 24 hours before experimental manipulation. Flexor and extensor tendons were exposed proximal to the carpal tunnel and through the wrist extensor retinaculum, respectively. The individual flexor digitorum profundus (FDP), flexor digitorum superficialis (FDS), and extensor tendon slips were tagged proximally with number 2 FiberWire sutures (Arthrex, Inc, Naples, FL) using a Krackow suturing technique. When more than one extensor tendon slip to a finger was identified, tendon slips to this finger were combined proximally as a single tagged tendon unit.

Securing specimens to apparatus

Two smooth 2-mm Steinmann pins were drilled transversely through the second through fifth metacarpals, taking care not to entrap the finger extensor or flexor tendons by gently flattening the metacarpal arch. Two 8-mm metal rods were drilled transversely through the distal radius and ulna. We suspended the specimen vertically by clamping it to the testing apparatus with the wrist in neutral alignment (Fig. 1). Separate force equalization pulley systems were attached to the 4 FDP tendons and the 4 FDS tendons to allow a single 0.2-kg weight to produce equal force on all 4 tendons within each group (Fig. 2). The sutures affixed to the 4 finger extensor tendons, composed of single or combined tendon units, were passed through a third force equalization system and then attached to a linear actuator.

Testing apparatus and data acquisition

Custom 3-dimensional printed accelerometer brackets designed for this study were attached to each finger proximal phalanx using 2 small screws that were positioned through a longitudinal skin incision, taking care not to entrap the extensor apparatus or flexor tendons (Fig. 3). The brackets were affixed to the radial borders of the index and middle finger proximal phalanges and the ulnar borders of the ring and little finger proximal phalanges. Precalibrated gravity reference accelerometers (MMA7260; Freescale Semiconductor Inc, Austin, TX) were mounted to the custom brackets. All accelerometers were calibrated under static conditions

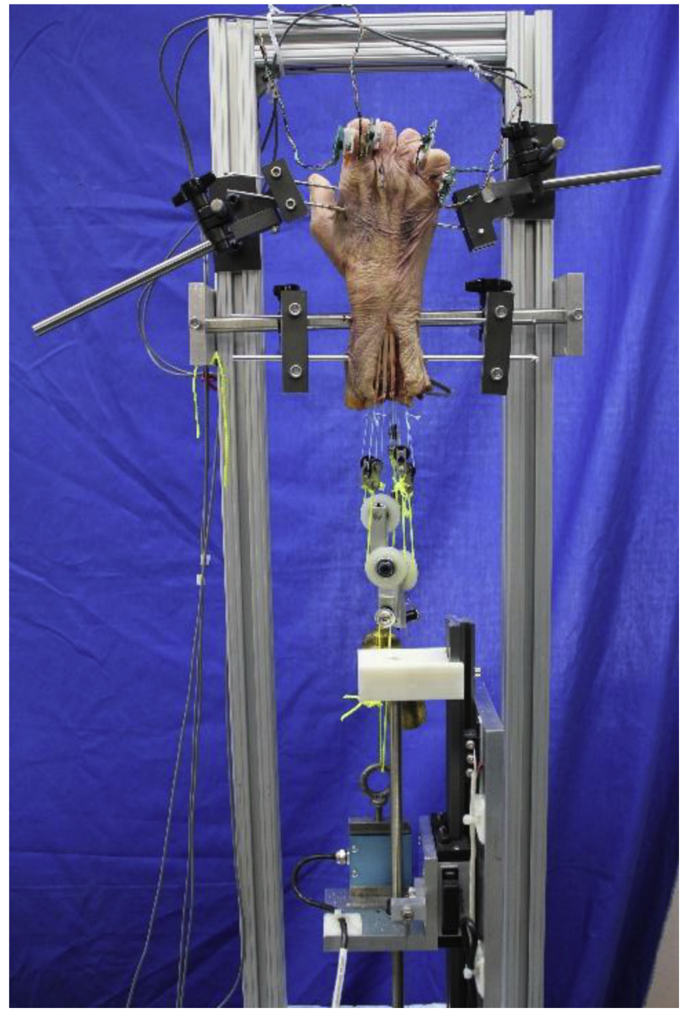

Figure 1. Mounted cadaveric hand specimen.

using the technique of Frosio et al.[8] The 3 accelerometer voltage outputs, which were proportional to the orientation of the accelerometer's coordinate system relative to the gravity field, were used to calculate the change in tilt angle of each accelerometer.[9] Changes in absolute tilt (resultant acceleration vector) during and between test runs were used to calculate finger MCP joint rotations.

Linear motions of the extensor tendons were produced using a stepper motor–driven linear actuator (MDrive 23; Schneider Electric, Rueil-Malmaison, France) and measured using a linear motion transducer (LX-PA-25; UniMeasure, Inc, Corvallis, OR). Custom software (Matlab; Mathworks, Inc, Natick, MA) was created to control the vertical translation stage attached to the load equalizers and extensor tendons. We also used the software to acquire data about the tensile force applied to the tendons, the accelerometer angles, and the displacement of the vertical translation stage.

Part II: Measuring MCP joint rotation and tendon cuts

Cyclic loading protocol

For each testing condition, the 4 fingers were cycled together 100 times approximating flexion and extension 10 times/h for a 10-hour day. Testing was initiated with the fingers fully extended. Finger flexion was aided by a 0.2-kg weight attached to each finger flexor tendon group and propagated by moving the vertical

Figure 2. Computer-generated drawing of a force equalization pulley system. The 4 top cables are attached to 4 FDP tendons, 4 FDS tendons, or 4 extensor tendons (or combined extensor tendon units). A single weight produces equal forces on the attached tendons.

translation stage toward the hand. Finger extension was assisted by moving the vertical translation stage away from the hand to pull on the extensor tendons and simulate full active MCP joint extension. The finger flexion-extension cycle had a linear motion amplitude of 15 mm over 5 seconds (0.2 Hz). Motorized excursion of the extensor tendons was limited to 15 mm, in accordance with available tendon motion data.[10–13]

Measuring extensor tendon widths, cuts, and gaps

While we applied static extensor and flexor forces to maintain the MCP joints in a resting cascade of flexion, we made a longitudinal skin incision over each finger MCP joint and in line with the extensor tendon slips. Single or combined widths of the extensor tendon slip(s) dorsal to each metacarpal head were measured using an electronic caliper (Mitutoyo Corporation, Kawasaki, Japan). Two 3-0 caliber marking sutures were placed in the tendon slip(s), one 5 mm proximal and the other 5 mm distal to the planned tendon cut (Fig. 4). The distance between these marking sutures was defined as the tendon gap.

The middle finger was approached first in each hand. Five sequential, transverse, perpendicular, full-thickness, and incrementally increasing cuts were made through each tendon slip(s) and joint capsule overlying the third metacarpal head, proximal to the sagittal bands and distal to the juncturae tendini. The cuts were performed radial to ulnar in half of the hands and ulnar to radial in the other half. The percentage cut through a single tendon slip over the MCP joint measured 25%, 50%, 75%, 90%, and 100% of the width of the tendon substance. In the case of more than one tendon slip over an MCP joint, the cut included 25%, 50%, 75%, 90%, and 100% of the combined width of the tendon slips. We measured the immediate tendon gap (ie, the distance between marking sutures). Fingers were cycled and measurements of tendon gapping were repeated.

After measurements were completed in the middle finger, the extensor tendons in the remaining 3 fingers were sectioned sequentially in a similar fashion. The order in which the remaining 3 fingers were tested proceeded from the index to the little finger. The immediate and post-cycling extensor tendon gaps were measured. The effects on MCP joint rotation in all fingers were then calculated from the accelerometer data.

After complete testing of all fingers, the skin over the dorsum of the hand was sharply reflected. The number of tendon slips projecting to each MCP joint and the gross appearance of the juncturae tendini interconnecting the tendon slips were recorded.

Statistical methods

We compared MCP joint rotation before and after each tendon cut to compute MCP joint extensor lag. The relations between extensor tendon cuts of incrementally increasing size and tendon gapping and those between extensor tendon cuts of incrementally increasing size and MCP joint rotational losses (ie, MCP joint extensor lags) were compared using paired 2-tailed *t* tests. $P < .05$ was determined to be significant.

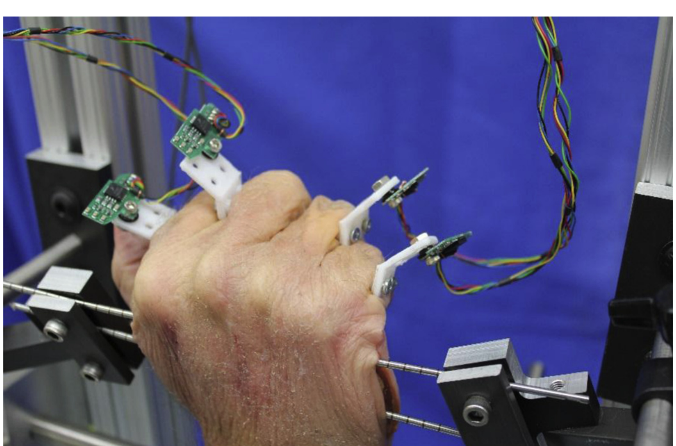

Figure 3. Accelerometers attached to each finger proximal phalanx.

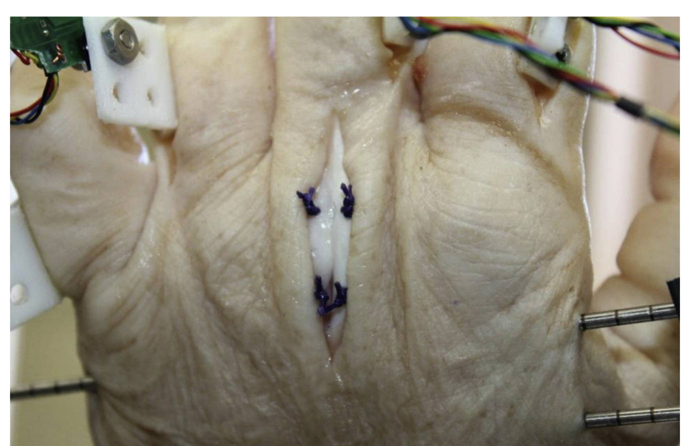

Figure 4. Suture marking references for measurements of tendon gapping.

Results

Anatomy

In all 8 hand specimens, there were 2 tendon slips to the little finger at the level of the fifth MCP joint. Seven of 8 specimens had 2 tendon slips to the index finger at the level of the second MCP joint. In one specimen there were 2 tendon slips to the middle finger, and in another specimen there were 2 tendon slips to the ring finger at the MCP joint level; the other 7 specimens had a single tendon slip to the middle and ring fingers at the MCP joint level. These tendon arrangements were compatible with previous reports.[14–17]

Mean widths of the individual or dual extensor tendon slips over each MCP joint were second MCP joint slip(s), 7.0 ± 1.7 mm; third MCP joint slip(s), 5.5 ± 2.3 mm; fourth MCP joint slip(s), 4.1 ± 0.6 mm; and fifth MCP joint slips, 8.3 ± 2.0 mm. Juncturae tendini interconnected the extensor tendon slips to each finger proximal to the MCP joints and exhibited macroscopic features of either tendon (one specimen) or fascia (7 specimens).

Extensor tendon gapping

In fingers with a 25% width laceration through the extensor tendon slip(s), the average gap between suture tags increased more than 0.5 mm after completing finger flexion-extension cycling. Further extending the cut through the width of the extensor tendon(s) over each MCP joint significantly increased tendon gapping compared with the intact extensor tendon condition in all but 2 experimental situations. The 2 experimental outliers were the 50% width laceration of the middle finger extensor tendon slip(s) and the 25% width laceration of the ring finger extensor tendon slip(s) (Fig. 5).

Changes in MCP joint rotation

Sequential cuts of the extensor tendon slip(s) caused reductions in range of motion (ROM) of the subjacent MCP joint after cyclic loading (Fig. 6). The decreased MCP ROM was observed by the naked eye as decreased MCP joint extension (ie, MCP joint extensor lag). Diminished ROM was significant in the second and fifth MCP joints after a laceration involving 75% or more of the width of the tendon slips ($P < .05$). Average ROM loss in the second MCP joint was 24° and average ROM loss in the fifth MCP joint was 18°. A significant decrease in ROM of the second and fifth MCP joints was also seen after complete disruption of one extensor tendon slip, leaving the other slip intact ($P < .05$). In the middle and ring fingers, decreased MCP joint ROM was significant when 90% or more of the tendon width was compromised ($P < .05$). Average ROM loss in the third MCP joint was 17° and average motion loss in the fourth MCP joint was 21°.

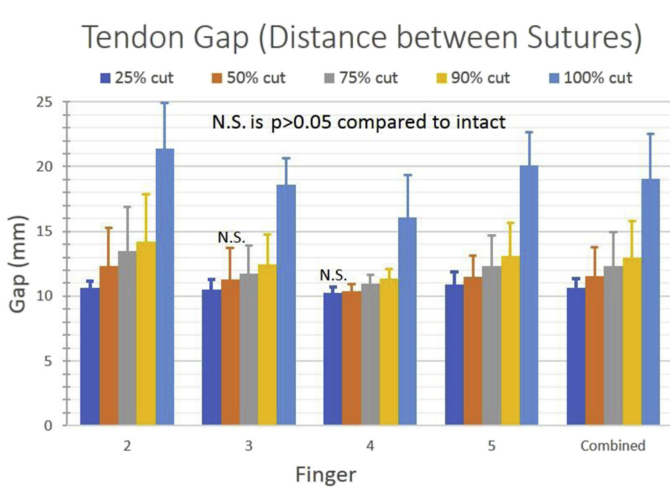

Figure 5. Extensor tendon gapping in each finger with incrementally increasing cuts. N.S., not significant.

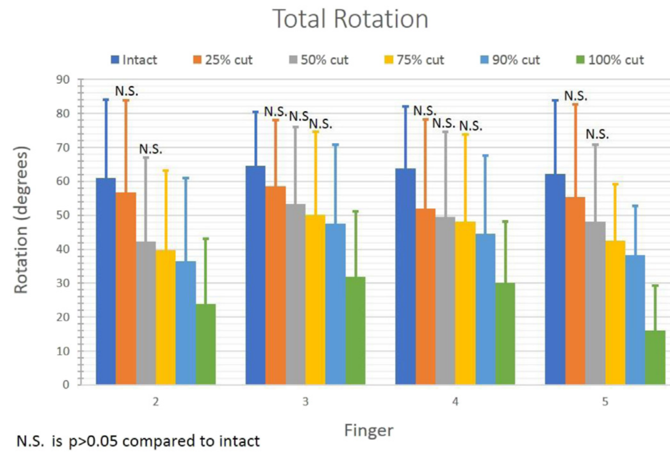

Figure 6. Total MCP joint rotation in each finger with incrementally increasing cuts. N.S., not significant.

The middle finger was the initial finger tested in each hand. The extensor tendon slips to the index, ring, and little fingers remained intact when we incrementally cut the middle finger extensor tendon substance and cycled this digit. A defect of 25% or more through the width of the extensor tendon substance overlying the third MCP joint resulted in significant reductions in MCP joint ROM in the surrounding fingers: the average loss of ROM in other MCP joints was 3° to 20° ($P < .05$). We also saw varying degrees of reductions in MCP joint ROM in all fingers after subsequent and incremental cutting of the extensor tendons in the other digits. For example, after complete laceration of the middle finger extensor tendon slip(s), incremental cuts through the extensor tendon slip(s) of the adjacent fingers caused further loss in third MCP joint ROM. Tables 1 to 5 show the calculated MCP joint extensor lags for the experimental conditions.

Discussion

A fight bite injury over a finger MCP joint (zone V) can be catastrophic to the finger extensor tendon apparatus and potentially cause joint sepsis and impairment of hand function.[3] However, to our knowledge, no clinical series have clearly defined a tolerable MCP joint extensor lag before a functional deficit is realized. Because fight bite injuries might occur in individuals who do not seek further care after initial wound management, it would seem prudent to counsel all individuals about the potential for loss of MCP joint extension without tendon repair.[5,6] A better understanding of the relationships between zone V extensor tendon slip lacerations and MCP joint extension deficits may provide a basis for treatment algorithms that could potentially lead to improved care recommendations and reduced costs.

Table 1
Metacarpophalangeal Joint Rotation Angles (in Degrees) With Intact Extensor Tendon Slips

Total Average Second MCP Joint	Total Average Third MCP Joint	Total Average Fourth MCP Joint	Total Average Fifth MCP Joint
61.0 ± 23.1	64.7 ± 15.7	63.8 ± 18.2	62.2 ± 21.6

Table 2
Average Degree of MCP Joint Extensor Lag or ROM Loss at MCP Joint in All Fingers During Sequential Cuts Through Middle Finger Extensor Tendon

Middle Finger Tendon Cut (%)	Average Loss per Finger of ROM or in Extension Lag (Degrees)			
	Index	Middle	Ring	Little
25	3.2 ± 6.1	5.9 ± 7.7	5.7 ± 7.7	4.2 ± 7.1
50	5.8 ± 6.4	11.1 ± 10.1	10.9 ± 9.9	8.5 ± 9.0
75	6.8 ± 7.2	14.1 ± 11.5	13.0 ± 11.2	10.3 ± 10.0
90	8.0 ± 6.9	17.7 ± 5.7	14.4 ± 10.4	11.4 ± 10.2
100	10.8 ± 8.6	27.4 ± 5.9	23.7 ± 11.0	19.5 ± 13.1

We measured the effects of incrementally increasing extensor tendon slip lacerations in zone V in 2 ways: extensor tendon gapping and MCP joint rotational losses. All lacerations (25% to 100% of the widths of the extensor tendon slips) caused a tendon gap, as evidenced by an increase in the distance between suture tags. The extensor tendon gaps were significant ($P < .05$) with the exceptions of the 50% lacerations in the middle finger (average tendon gap, 1.3 mm) and the 25% lacerations in the ring finger tendon slips (average tendon gap, 0.26 mm). We suspect that the insignificant gaps in these 2 conditions can be attributed to the thicker and cylindrical morphology of the middle and ring finger extensor tendon slips relative to the thinner shape of the index and little finger extensor tendon slips at the MCP joint level.[17]

The rotational changes in MCP joint motion after each tendon cut were compared with MCP joint motion before tendon cutting to compute the MCP joint extensor lags. The effects of incrementally increasing cuts in the extensor tendon slips on MCP joint extension loss were evident in all specimens. Increased extensor lags of the index and little finger MCP joints were significant; lacerations extended across 75% or more of the combined widths of the extensor tendon slips, whereas increased extensor lags of the middle and ring finger MCP joints were significant, with lacerations involving 90% or more of the widths of the single extensor tendons. Significant MCP joint extension deficits in the index and little fingers were also observed when 1 of 2 extensor tendon slips in either finger was completely transected.

Damage to the middle finger extensor tendon before experimental manipulation of the other fingers caused unexpected MCP joint extensor lags in the other fingers. The MCP joint extensor lags in the adjacent fingers were most pronounced with complete laceration of the middle finger extensor tendon slip(s). This was an unsuspected finding given the preservation of juncturae tendini interconnections between the middle finger extensor tendon and the adjacent finger extensor tendons slips proximal to the laceration. The juncturae tendini would conceivably augment extension of the adjacent finger MCP joints with proximal translation of the partially or completely cut middle finger extensor tendon slip(s).

Table 4
Average Degree of MCP Joint Extensor Lag or ROM Loss at MCP Joint in All Fingers During Sequential Cuts Through Ring Finger Extensor Tendon*

Ring Finger Tendon Cut (%)	Average Loss per Finger of ROM or in Extension Lag (Degrees)			
	Index	Middle	Ring	Little
25	34.3 ± 34.1	31.3 ± 22.0	13.5 ± 19.8	6.7 ± 12.1
50	34.3 ± 32.8	32.3 ± 21.3	15.8 ± 19.0	8.7 ± 12.8
75	34.5 ± 34.3	32.5 ± 23.0	17.4 ± 19.9	7.9 ± 15.6
90	36.9 ± 33.0	35.4 ± 21.0	21.0 ± 17.6	9.7 ± 13.2
100	39.8 ± 29.1	39.3 ± 15.5	35.3 ± 12.3	13.7 ± 14.8

* The middle and index finger extensor tendons already underwent testing and had a 100% cut tendon.

The same adverse effect on adjacent finger MCP joint extension was observed with subsequent transections of the other finger extensor tendon slips. The unrepaired extensor tendon slips in more than one finger may have contributed to the added MCP joint extensor lags. This might explain the loss of full active extension of the index and little finger MCP joints with complete transection of either the extensor indicis proprius or the extensor digiti minimi tendon. *In vivo*, when either of these tendon slips is released at the MCP joint level with preservation of adjacent finger extensor tendons (eg, tendon transfer operation to restore thumb extension using the extensor indicis proprius tendon), full active extension of the underlying MCP joint is typically preserved.

Several limitations to the study design might have affected the findings. We were unable to compute the number of experimental digits required with an a priori power analysis because of the paucity of literature on partial extensor tendon lacerations in the hand. The biological effects of injury edema and healing on tensile tendon forces were not evaluated. We positioned all hands vertically in the experimental jig to minimize the effects of gravity and pulley friction on observed hand kinematics. We realize that positioning and testing the hands horizontally might have produced different results.

The experimental loads placed on the extensor tendons conceivably differed from normal *in vivo* extensile forces with consequently accentuation or dampening of the extensor tendon gaps and MCP joint extensor lags. Similarly, the experimental loads placed on the flexor tendons might have exceeded the forces normally experienced by extensor tendons with active finger extension, in effect contributing to tendon gapping and the MCP joint extensor lags. The number of extensor tendon slips varied in a few fingers and also might have adversely affected MCP joint extension after tendon cutting.

We tested only the middle finger in each hand; the extensor tendons in the other fingers were left intact. We did not measure the effects of isolated extensor tendon lacerations in the index,

Table 3
Average Degree of MCP Joint Extensor Lag ROM Loss at MCP Joint in All Fingers During Sequential Cuts Through Index Finger Extensor Tendon*

Index Finger Tendon Cut (%)	Average Loss per Finger in ROM or in Extension Lag (Degrees)			
	Index	Middle	Ring	Little
25	5.7 ± 18.3	28.0 ± 20.9	17.2 ± 23.7	16.4 ± 19.4
50	21.8± 34.7	37.2 ± 22.8	30.6 ± 21.8	23.4 ± 18.1
75	24.2 ± 35.4	38.5 ± 20.2	31.4 ± 23.4	23.6 ± 19.0
90	27.8 ± 35.0	38.4 ± 19.2	31.5 ± 22.8	23.0 ± 19.5
100	40.4 ± 30.1	39.6 ± 12.3	32.7 ± 18.1	27.1 ± 18.0

* The middle finger extensor tendon had already undergone testing and had a 100% cut tendon.

Table 5
Average Degree of MCP Joint Extensor Lag or ROM Loss at MCP Joint in All Fingers During Sequential Cuts Through Little Finger Extensor Tendon*

Little Finger Tendon Cuts (%)	Average Loss per Finger of ROM or in Extension Lag (Degrees)			
	Index	Middle	Ring	Little
25	39.4 ± 34.1	39.1 ± 23.6	33.5 ± 20.7	5.4 ± 18.1
50	46.8 ± 27.2	47.2 ± 14.1	43.1 ± 12.7	13.8 ± 14.5
75	48.3 ± 26.0	49.2 ± 14.6	46.0 ± 14.6	18.3 ± 14.8
90	49.8 ± 25.9	51.6 ± 15.0	49.5 ± 14.3	22.6 ± 18.4
100	50.4 ± 25.9	52.1 ± 16.8	51.4 ± 16.5	45.2 ± 14.4

* The middle, index, and ring finger extensor tendons already underwent testing and had a 100% cut tendon.

ring, or little fingers. Furthermore, none of the extensor tendon slips were repaired between finger experimentation because of concerns regarding shortening of the extensor tendons and the effects that this might have had on MCP joint rotation. Randomizing the order of the first finger to undergo sequential extensor tendon cuts might have helped us to understand the interactive effects on adjacent finger MCP joints better. However, randomization in this manner would have required a larger number of hand specimens and exceeded the budget of the experiment.

The study results define extensor tendon slip cuts in zone V that may lead to statistically significant MCP joint extensor lags: complete laceration of one extensor tendon slip, laceration of the middle finger extensor tendon substance involving 25% or more of the tendon width, 75% laceration of the combined tendon slip widths in either the index or little finger, and 90% laceration of the ring finger extensor tendon slip(s) width. We acknowledge that this experiment did not determine clinically significant MCP joint extensor lags. Hand impairment will likely be different among different individuals and relate to age, health, occupation, and functional demands. Further studies are necessary to determine the clinical impact of zone V extensor tendon lacerations and resultant MCP joint extensor lags.

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