Physiologic Consequences of Surgical Lengthening of Extensor Carpi Radialis Brevis Muscle–Tendon Junction for Tennis Elbow

Jan Fridén, MD, PhD, Umeå, Sweden, Richard L. Lieber, PhD, San Diego, CA

Sarcomere length was measured intraoperatively using a laser diffraction method before and after surgical lengthening of the human extensor carpi radialis brevis muscle (ECRB) in five subjects treated for lateral epicondylitis. Based on measured sarcomere and filament lengths, we previously established the length-tension curve for this muscle and the normal sarcomere length range as a function of wrist joint angle. Preoperative measurements indicated that the ECRB developed near-maximal isometric force at full wrist extension, decreasing to 20% maximum at full wrist flexion. Stair-step surgical tendon lengthening of the ECRB by 9.1 mm resulted in mean ECRB sarcomere shortening of 0.30 μm. This 0.30 μm sarcomere shortening was predicted to have two primary biomechanical effects: (1) a 25% decrease in muscle passive tension that could lead to reduced insertional tension and decreased pain and (2) a 25% increase in active muscle force that opposes the notion that tendon lengthening necessarily results in muscle weakness. (J Hand Surg 1994; 19A:269–274.)

Several surgical procedures have been described for the treatment of lateral epicondylitis. These include surgical release or debridement of the tendinous origin at the epicondyle and extensor carpi radialis brevis (ECRB) lengthening at the muscle–tendon junction just proximal to the wrist. Yet, although frequently used, there is not general agreement as to the preference of one procedure over another nor is there information regarding the physiologic effects of tendon lengthening on skeletal muscle. Indeed, treatment of chronic lateral epicondylitis remains enigmatic. Numerous reports have appeared that propose specific surgical intervention based on a supposed underlying etiology. For example, Garden asserted that the lateral epicondylar pain resulted from periosteal tear at the origin of the ECRB resulting in high stress that could be relieved by an operation designed to lengthen the ECRB tendon at the distal muscle–tendon junction. Carroll and Jorgensen claimed, however, that it was not reasonable to assert that stress transmitted to the ECRB fibers of origin played a role in the pathogenesis of lateral epicondylitis. They thought it more likely that the force transmitted to the common wide fascial band of origin still produced pull after release, and thereby continued to produce pain. Other authors have proposed that debridement and/or release of the ECRB tendinous origin provides relief of lateral elbow pain, believing that pain resulted from...
from microrupture and subsequent chronic inflammation of the ECRB origin.

We have developed an intraoperative laser diffraction method that permits intraoperative measurement of ECRB sarcomere length. We investigated the specific effect of ECRB lengthening in patients with lateral epicondylitis to document the physiologic and biomechanic consequences of such a procedure. Using these data, we present a putative mechanism by which ECRB lengthening might relieve pain symptoms. We also refute the common belief that ECRB release is an undesirable procedure that results in overshortening and concomitant weakness.

Materials and Methods

Patient Description

Five patients who were undergoing surgical lengthening of the ECRB tendon for treatment of chronic lateral epicondylitis ("tennis elbow") were included in this study. Patients ranged in age from 35 to 50 years and included three men and two women. All procedures performed were approved by the Committee on the Use of Human Subjects at the University of Umeå and University of California, San Diego.

Intraoperative Laser Device

The device used was that described by Lieber et al., which is a modification of that originally described by Lieber and Baskin and Fleeter et al. Briefly, a helium-neon laser beam (Melles-Griot, Model LHR-007, Irvine, CA) was aligned with a specially designed prism, such that the beam projected normal to one prism face and was reflected 90° exiting the other prism face (Fig. 1). Great care was taken to maintain the prism in the normal plane of the muscle and not to stretch the muscle fiber bundle.

The device was calibrated using diffraction gratings of 2.50 μm and 3.33 μm grating spacing placed at the location of the muscle fiber bundle directly on the prism. Repeatability of sarcomere length measurements between observers was determined by sequential blinded measurement of diffraction patterns obtained from muscle biopsies. Average between-observer variability was 0.16 ± 0.29 μm.

Figure 1. Dorsal view on a right forearm of the device used for intraoperative sarcomere length measurement. The He-Ne laser is aligned to the transmitting face of the prism for optimal transmission of laser power into the muscle. Inset shows view of the illuminating prism placed beneath a muscle fiber bundle. From Lieber et al. with permission.
Experimental Protocol

Following insufflation of a pneumatic tourniquet and administration of intravenous regional anesthesia, an electromyograph (Penny and Giles Model Z110, Blackwood, Gwent, UK) was placed on the palmar surface of the subject's wrist and hand. The electromyograph was contained within a sterile plastic wrap and taped to the palmar skin using sterile tape. The wrist was allowed to assume its natural neutral position (typically a radiocarpal angle of about 10°), which was defined as 0°.

A 6–8 cm incision was made on the dorsilateral aspect of the forearm immediately proximal to the point where the extensor pollicis brevis and abductor pollicis longus obliquely cross the radius. The distal musculotendinous junction of the ECRB was exposed after incising the overlying fascia. A small fiber bundle was isolated at the insertion site using delicate blunt dissection, being careful not to over-stretch the muscle fibers.

The illuminating prism of the laser device was inserted beneath the fiber bundle and approximated into the normal plane of the muscle. We made every effort to measure sarcomere length in the in vivo position of the fibers and not to elongate them artificially by elevation of the fiber bundle. Pilot experiments revealed that small elevation of the fiber bundle increased sarcomere length by an average of 0.11 μm ± 0.10 μm, which would not alter the conclusions reached in the current study.

All sarcomere lengths were calculated using the +2 to −2 diffraction order spacing. Redundant measurements of +1 to −1 and +3 to −3 were also made to ensure calculation accuracy. Diffraction angle (θ) was calculated using the grating equation, nλ = dsinθ, where λ is the laser wavelength (0.632 μm), d is sarcomere length, and n is the diffraction order (2 in all cases) and assuming that the zeroth order bisected the orders on either side. Measurement resolution was 0.05 μm.

Sarcomere length was measured with the wrist placed in each of three positions: full flexion, neutral, and full extension. The actual angular value corresponding to each position was noted from the electromyograph's digital display. It was not technically possible to place the wrist in the same extreme angular positions for each subject due to variations in patient range of motion and, in one case, wrist arthrosis.

Biomechanical Model of ECRB Lengthening

To predict the effects of ECRB lengthening on joint strength, two pieces of information were required: the relationship between sarcomere length and tension in the ECRB and the moment arm of the ECRB at the wrist joint. The latter was recently presented by Jacobson et al.9 and can be used directly. In order to determine the effects of sarcomere length on tension, it is important to know the lengths of the actin and myosin filaments within the ECRB and the physiologic sarcomere lengths over which the ECRB operates. These data were recently presented by Lieber et al.6 in a study of in vivo ECRB sarcomere length. There we demonstrated that, physiologically, the ECRB operates in the range of 2.3–3.5 μm. Following ECRB tendon lengthening, sarcomere length decreased by 0.3 μm. Thus, the physiologic operating range of the ECRB after tendon lengthening is from 2.0 to 3.2 μm.

Surgical Lengthening of the ECRB Tendon

The distal ECRB musculotendinous junction was lengthened using a stair-step incision.4 On incision, the ECRB was allowed to retract and the tendon ends were resutured side to side. The actual muscle–tendon distance shortened was measured to the nearest 0.1 mm using calipers. Following ECRB release, sarcomere lengths were again measured at three wrist joint angles as described above.

Statistical Analysis

Comparison between wrist angles and sarcomere lengths in the different wrist configurations was made using one-way analysis of variance and multiple paired comparisons performed using Fisher’s least significant difference test (SuperANOVA, Abacus Concepts, Berkeley, CA). Significance level was set to α = .05. Based on the experimental coefficient of variation of 21%, statistical power (1 − β) was calculated as 81%.10

Results

Symptoms and Wrist Joint Range of Motion

Four of the five patients were completely cured by the procedure within 6 weeks postoperatively. One patient reported residual, although diminished, symptoms lasting for 3 months postoperatively. Average active postoperative ranges of motion after 6 weeks were 70° extension (80° to 55°) to 55° flexion (35° to 65°). No patients complained of inability to perform normal activities of daily living.

Laser Diffraction Pattern

Multiple diffraction orders were observed on either side of the zeroth order with approximately equal intensities in all cases. Typically, three diffrac-
tion orders were seen, but occasionally, up to five diffraction orders were observed, implying excellent preservation of the normal sarcomere lattice. It was easy to see that wrist flexion caused diffraction orders to move closer together and wrist extension caused diffraction orders to spread apart as expected.

Sarcomere Length Changes During Wrist Motion

Sarcomere lengths were measured over an approximately 100° range of wrist motion. With the wrist in full extension, passive sarcomere length was about 2.5 μm, which was significantly shorter than the 3.6 μm sarcomere length measured in the flexed position (p < .005). Sarcomere length with the joint in the neutral position was intermediate between these two values (3.2 μm) and significantly different than that observed in either the flexed or extended position (p < .05).

Sarcomere Length After Tendon Lengthening

The surgical procedure caused an average lengthening of the ECRB muscle-tendon unit by 9.1 ± .88 mm. This value corresponded to a shortening of 0.3 μm per sarcomere in the neutral position (Fig. 2). Thus, following ECRB shortening, the shortest sarcomere length of the ECRB was 2.2 μm, whereas preoperatively it was 2.5 μm. The length 2.2 μm corresponds to a slightly lower force than 2.5 μm because the sarcomere length is actually slightly on the ascending limb of the length-tension curve (Fig. 3A). However, this sarcomere shortening becomes advantageous at longer sarcomere lengths since the ECRB in full flexion will only be lengthened to a sarcomere length of 3.3 μm, as opposed to the pre-

Figure 2. Average sarcomere length change following surgical release of the ECRB tendon of about 9 mm. Two data points were obtained from each patient at two different joint angles. Since these joint angles did not always correspond to the preoperative joint angle, the difference is plotted on the abscissa and contributes to some of the scatter in the data. Note, that, on average, sarcomere length decreased by 0.3 μm for a 9 mm lengthening. Average sarcomere length change is shown by the standard deviation for five experimental subjects.

Figure 3. ECRB muscle force (A), wrist joint moment arm (B), and wrist joint torque before (open circles) and after (filled circles) ECRB shortening. Note that after ECRB shortening, sarcomere length range changed to shorter lengths resulting in higher muscle force at a given joint angle (vertical dotted line). Since moment arm does not change, resultant torque (C) increases throughout most of the range of motion (vertical dotted line), suggesting that the surgical procedure results in increased wrist joint torque due to decreased sarcomere length.
operative value of 3.6 μm (Fig. 3A). This 0.3 μm decrease in sarcomere length on the descending limb on the length-tension curve results in a 22% increase in muscle strength. Since the ECRB moment arm slowly increases throughout the joint range of motion (Fig. 3B), it is clear that by increasing skeletal muscle force due to the surgical procedure, the joint moment is actually predicted to increase (Fig. 3C). Since the moment arm is slowly increasing throughout the joint range of motion and since muscle force is higher throughout most of the range of motion, joint moment increases by approximately 22% from joint angles corresponding to 10° flexion up to 50° extension.

Discussion

Our 9 mm ECRB tendon lengthening caused a 10% passive shortening of the ECRB fibers. Given that a 0.3 μm sarcomere length change was measured during the surgical release of the ECRB, it is possible to determine the effects of such a length change on skeletal muscle active and passive properties. Using the active length-tension relationship (based on microscopic measurement of filament lengths from the same muscles6), a 0.3 μm sarcomere length change will increase the active tension associated with muscle contraction throughout the entire range of the descending limb of the sarcomere length-tension relationship (2.5–4.2 μm, Fig. 4A). On the plateau region of the sarcomere length-tension relationship, these small sarcomere length changes have no effect, and on the ascending limb of the sarcomere length tension relationship, they slightly decrease muscle force by about 5%. Thus, it is likely that the 0.3 μm sarcomere length change would increase the active tension generated by the ECRB, and it is clearly not necessarily the case that the lengthening procedure would result in muscle weakness.

To determine the effects of such a length change on passive tension, it is important to know the passive stress strain properties of the skeletal muscle. We have determined these properties experimentally for the ECRB and, using the observation that in mammalian skeletal muscle passive tension is approximately 0 at optimal length,10 the passive tension sarcomere length relationship can be superimposed on the active length tension relationship as shown in Fig. 4B. Note that the passive length-tension relationship is extremely steep at higher sarcomere lengths and, for example, shortening from a sarcomere length of 3.6 μm to 3.3 μm results in about a 25% decrease in the muscle passive tension. At shorter sarcomere lengths where passive tension is almost negligible, such a length change has a very small effect. Thus, it is likely that the ECRB lengthening procedure results in a decrease in muscle passive tension with a concomitant increase in muscle active tension. The precise magnitude of these changes are variable but are approximately 25% in both cases.

Since the relationship between sarcomere length and tension is linear throughout the descending limb of the length-tension relationship,11 it is evident that, in this case, ECRB shortening results in muscle strengthening over most of the physiologic range of motion. It is easy to demonstrate that since tension is maximum in the ECRB at a sarcomere length of 2.8 μm and zero at a sarcomere length of 4.25 μm, tension in the descending limb of this curve decreases in active tension at a rate of 77% P0/μm.

Figure 4. Active (A) and passive (B) sarcomere length tension curves of ECRB. Vertical dashed lines indicate the effect of 0.3 μm sarcomere length change. These effects are a 25% increase in active muscle force as shown in (A) and a 25% decrease in muscle passive tension as shown in (B).
Stated in the opposite manner, 0.3 μm of sarcomere shortening corresponds to a 22% increase in muscle force (Fig. 3A). Since the strength of active muscle force represents the multiplication of muscle force times the wrist joint moment arm,12 wrist extensor strength is predicted to increase as a product of muscle force and wrist moment arm (Fig. 3C).

Direct in vivo measurement of sarcomere length and an understanding of the mechanism of muscle force generation has predicted that the ECRB tendon lengthening procedure that results in ECRB muscle shortening produces a 22% increase in muscle force throughout most of the range of motion. This indicates that previous objections to the ECRB tendon lengthening procedure that suggest it might result in loss of muscle force are not consistent with the physiologic and anatomic data. If anything, such a muscle shortening would be predicted to increase strength. However, what is not clear is the extent to which the ECRB muscle itself would remodel following the procedure. Exactly which factors determine resting sarcomere lengths in skeletal muscle is unknown. While previous studies have demonstrated that muscles have a great ability to adapt to chronic length changes by altering the number of sarcomeres in series along the length of the muscle,13 the extent to which these findings are applicable to all muscles is not clear. Further studies of joint mechanical properties during rehabilitation are necessary in order to understand the adaptive phenomenon completely.

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References