Sarcomere length varies with wrist ulnar deviation but not forearm pronation in the extensor carpi radialis brevis muscle

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Abstract

Extensor carpi radialis brevis (ECRB) sarcomere length was measured in seven patients using intraoperative laser diffraction. Sarcomere length was measured with the forearm in one of four positions: wrist in neutral with regard to radial-ulnar deviation and forearm in neutral rotation, wrist in ulnar deviation and forearm in neutral rotation, wrist in neutral and forearm in pronation, and wrist in ulnar deviation and forearm in pronation. Two-way ANOVA comparing sarcomere length between the four positions revealed a significant effect of ulnar deviation (p < 0.05), no significant effect of pronation (p > 0.7) and no significant interaction (p > 0.9). These results demonstrate that the axes of forearm rotation and wrist radial-ulnar deviation act independently, at least with regard to the ECRB and have implications regarding the etiology of tennis elbow.

Keywords: Lateral epicondylitis; Sarcomere length; Skeletal muscle; Repetitive strain injury; Laser diffraction

1. Introduction

Tennis elbow (lateral epicondylitis) is a relatively common syndrome associated with repetitive motion of the forearm and wrist (Cyriax, 1936). The most common types of motion that result in tennis elbow symptoms involve forced wrist extension with finger flexion such as is observed with golf, tennis, screwdriver use, and jack hammering (Werner, 1979). The extensor carpi radialis brevis (ECRB) muscle is considered to be the primary muscle involved in tennis elbow but the etiology of the syndrome is poorly understood. Mechanisms proposed include microrupture of the fibrous origin (Garden, 1961), inflammation of the ECRB origin (Hohmann, 1933), muscular circulatory compromise (Boyd and McLeod, 1973), excessive intramuscular pressure (Werner, 1979), and excessive muscle passive tension (Fridén and Lieber, 1994). It is understandable that, since the etiology of tennis elbow is not known, a range of treatments have been proposed ranging from conservative musculotendinous therapies to a variety of surgical interventions.

We recently provided evidence that the ECRB muscle displayed a biphasic sarcomere lengthening and shortening behavior with monotonic elbow joint flexion that may predispose it to chronic eccentric contraction and associated injury (Lieber et al., 1997b). Most investigators focus on wrist and forearm motion as causative in tennis elbow. While we measured the change in ECRB sarcomere length with wrist flexion and extension, the possibility exists that with supination/pronation and/or radial/ulnar deviation, unique forearm and wrist motions could occur that could predispose this muscle to injury. Thus, the purpose of this study was to measure the sarcomere length change in the ECRB muscle during ulnar deviation with the wrist in both the neutral and pronated position.

2. Material and methods

2.1. Subject population

In this study, 7 patients (4 women and 3 men) with an average age of 50 years (range = 38–63) were studied prior to surgical treatment of tennis elbow. The surgical procedure performed was lengthening of the distal...
tendon of the ECRB muscle, i.e., the Garden procedure (Garden, 1961). No qualitative difference in symptom severity was noted among patients.

2.2. Sarcomere length measurement method

ECRB sarcomere length was measured essentially as previously described (Fridén and Lieber, 1994; Lieber et al., 1994). Briefly, via a dorsoradial incision just proximal to the abductor pollicis longus, adequate exposure was created for both the distal tendon where the actual tendon lengthening was performed and the distal portion of ECRB’s muscle belly, where sarcomere length measurements were made. A small fiber bundle was isolated at the insertion site using delicate blunt dissection, being careful not to overstretched 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. All operations were performed under regional intravenous anesthesia, using prilocaine (5 mg ml⁻¹) with the patient lying supine, the elbow joint in ~10° of flexion and the wrist joint in the neutral position (i.e., 10° of extension representing the angle between longitudinal axis of the radius and the 3rd metacarpal).

ECRB sarcomere length was measured with the wrist in each of four positions: wrist in neutral with regard to radial-ulnar deviation and forearm in neutral rotation, wrist in ulnar deviation and forearm in neutral rotation, wrist in neutral and forearm in pronation, wrist in ulnar deviation and forearm in pronation. Positions including radial deviation and full supination were avoided in this study based on pilot experiments that revealed insignificant sarcomere length change in these positions because the ECRB muscle slackened (passive sarcomere length changed from 3.85 ± 0.07 to 3.83 ± 0.07 with forearm supination with the wrist in neutral radial-ulnar deviation, n = 10 different subjects). Thus, all sarcomere lengths reported were measured under conditions of slight-to-significant passive tension. The relationship between passive sarcomere lengths measured by laser diffraction and active sarcomere length expected during muscle contraction has been discussed previously in detail (cf Fig. 3B of Lieber et al., 1994). All procedures performed were approved by the Committees on the Use of Human Subjects at the Karolinska Institute, Stockholm and the University of California, San Diego, School of Medicine.

2.3. Sarcomere length measurements representative of entire muscle

To determine the extent to which intraoperative measurements from one region of a large muscle are representative of the entire muscle, we have performed a series of studies. First, in cadaveric specimens, sarcomere length and fiber length measurements were obtained from nine regions of the flexor carpi ulnaris (FCU) muscle and the pronator teres (PT) muscle from two different specimens. The FCU was chosen because of its relatively simple architectural design of short fibers arranged essentially in parallel along the muscle length (Lieber et al., 1990) and its relatively simple action of wrist flexion. The PT was chosen because of its obviously complex architecture that probably results from its multiple axes of action both in elbow flexion and forearm pronation (Lieber et al., 1992). Since the majority of our experience is with upper extremity muscles, we believed that these two muscles would represent the range of complexity observed among human muscles. Sarcomere length and fiber length were measured in nine regions of each muscle: the proximal, middle and distal region at each of three levels: superficial, middle and deep. In each location, two separate measurements were made (n = 72 – a total of nine locations × 2 measurements per location × 2 specimens per muscle × 2 muscles) and the data were analyzed by three-way analysis of variance (ANOVA) with repeated measures. Significant fiber length variation was observed between muscles (p < 0.0001, not surprising) and within the PT muscle (p < 0.01) but not with the FCU muscle (p > 0.4). However, in spite of this large fiber length variability, no significant sarcomere length difference was seen between muscles (p > 0.35) or between locations within either muscle (p > 0.4 for FCU, p > 0.6 for PT). These data reinforce the concept that skeletal muscle has a profound ability to regulate sarcomere number in response to various length changes in order to establish a certain sarcomere length. This means that sarcomere length itself represents a very stable variable throughout a muscle and supports its utility as the variable of choice intraoperatively.

2.4. Sarcomere length as a predictor of muscle function

Second, to determine whether sarcomere lengths measured by diffraction are good predictors of relative muscle force, we measured sarcomere length in the proximal forearm muscle mass of canine forelimbs (n = 4) within the flexor digitorum superficialis muscle (Lieber et al., 1996). The muscle was stimulated directly using intramuscular electrodes, and muscle force and sarcomere length measured during active contraction. We found an excellent linear relationship between active sarcomere length and active tension in these muscles, with correlation coefficients ranging from 0.81 to 0.94 demonstrating that, from 81 to 94% of the variation in muscle force is predictable using sarcomere length measurements by laser diffraction. Perhaps this is, in part, due to the fact that all of the illuminated sarcomeres
(thousands of sarcomeres) contribute to the pattern. This is clearly much more representative than sarcomere lengths measured using optical microscopy.

2.5. Statistical analysis

Average sarcomere length measured in the four experimental positions were compared by $2 \times 2$ two-way analysis of variance (ANOVA) using forearm rotation and radial-ulnar deviation as grouping variables. In addition, sarcomere length change relative to the wrist in neutral rotation and neutral radial-ulnar deviation (where minimum sarcomere length was observed) was compared to zero change using a one-sample $t$-test. Significance level was set to 0.05 for all tests. All data are presented as mean $\pm$ SEM ($n = 7$) unless otherwise noted.

3. Results

As expected, ECRB sarcomere length increased as the wrist was moved into ulnar deviation from either the neutral or pronated position (Fig. 1). Two-way ANOVA revealed a significant effect of ulnar deviation ($p < 0.05$), no significant effect of pronation ($p > 0.7$) and no significant interaction ($p > 0.9$). These results demonstrate that the axes of forearm rotation and wrist radial-ulnar deviation act independently, at least with regard to the ECRB.

Absolute sarcomere length increase, as the wrist was moved into ulnar deviation in neutral forearm rotation was $0.33 \pm 0.07 \, \mu m$ and $0.34 \pm 0.06 \, \mu m$ as the wrist was moved into ulnar deviation with the forearm pronated. Both of these values were significantly different from zero ($p < 0.005$; Fig. 2). No significant sarcomere length change was observed as the fore-arm was rotated from neutral to pronation ($p > 0.7$, Fig. 2). Based on the ulnar deviation magnitude of $30 \pm 2^\circ$, sarcomere length change per degree joint rotation, $dSL/d\phi$, was $11.0 \pm 2.3 \, \text{nm deg}^{-1}$.

4. Discussion

This study demonstrated that the radial-ulnar deviation and supination–pronation motions of the forearm are mechanically independent with regard to the ECRB muscle. This conclusion is based on the lack of significant statistical interaction between sarcomere lengths compared using two-way ANOVA ($p > 0.9$). These results have a number of implications with regard to the etiology of tennis elbow. While forearm rotation is viewed by some as a risk factor for developing tennis elbow, this is clearly not due to repetitive length changes imposed upon the ECRB with forearm rotation. Anatomically, this is because the ECRB apparently lies parallel to the axis of forearm rotation.

The effects of ulnar deviation were much more dramatic. The $dSL/d\phi$ of $11.0 \, \text{nm deg}^{-1}$ is greater than the $9.0 \, \text{nm deg}^{-1}$ measured for the flexion–extension movement and is a large number compared to similar values previously measured in the frog hindlimb that ranged from about 2 to 13 nm deg$^{-1}$ (Lieber and Brown, 1993). Thus, the ECRB acting in radial-ulnar deviation behaves like a “low gear” muscle and can produce high torque and relatively small excursion.

Prior biomechanical measurements of ECRB radial-ulnar deviation moment arm yielded a nearly constant relationship, described by the equation (Loren et al., 1996):

$$r_{ECRB} (\text{mm}) = -13 - 0.24\phi + 0.018\phi^2,$$

where $\phi$ is radial-deviation angle measured in degrees between the long axis of the radius and the third metacarpal and the negative sign refers to ulnar deviation.
Integrating this equation with respect to joint angle to yield muscle excursion and using the previously measured serial sarcomere number of 17,143 for ECRB fibers (Lieber et al., 1990), we calculate, for 30° of ulnar deviation, a muscle length change of 6.49 mm, a sarcomere length change of 0.38 μm, and a dSL/dθ of 12.6 nm deg⁻¹ all of which are close to the measured values reported here. This close agreement strongly supports the practice of combining muscle architectural measurements with joint kinematics to predict muscle properties during movement.

Given the monotonically changing sarcomere length measured with wrist flexion (Lieber et al., 1994, 1997a), ulnar deviation, and pronation, as well as the mechanical independence of the movement axes, the question arises as to why the ECRB is so uniquely associated with tennis elbow. We conjecture that the unique feature of the ECRB is not its wrist kinematics but rather its unique placement on the origin of the axis of elbow flexion. This placement results in cyclic lengthening and shortening of the muscle during monotonic elbow flexion (Lieber et al., 1997b). The resulting chronic eccentric contractions may cause this muscle to exhibit the soreness and damage associated with chronic tennis elbow. Thus, in our opinion, the wrist and forearm movements are simply associated with the types of actions that cause tennis elbow (e.g., screwdriver use, golf, tennis, jack hammering) but are not themselves causative.

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References