Ligamentomuscular Protective Reflex in the Elbow

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A reflex are from the medial elbow ligaments to the forearm pronator muscles was shown to exist in the feline model. A single articular branch emerging from the median nerve and converging on the medial collateral ligament was identified and stimulated with supramaximal pulses of 100 μs duration at a rate of 10 pulses/s. Stimulation of the articular nerve elicited myoelectric activity in the flexor digitorum superficialis, flexor digitorum profundus, flexor carpi radialis, flexor carpi ulnaris, and pronator teres. Transection of the articular nerve between the electrodes and the median nerve resulted in the disappearance of any myoelectric activity in the muscles, thus confirming the afferent nature of the articular nerve. The mean time delay from the application of the stimulus to the corresponding myoelectric discharge ranged from 3.2 to 5.8 ms for the 5 muscles. The existence of a fast-acting reflex arc from the medial elbow ligaments to the forearm muscles both confirms the concept of ligamentomuscular protective synergy (shown to exist in the knee, shoulder, and ankle joints) and extends it to the elbow. This reflex arc has significant implications for both the planning of elbow surgery while preserving the neural supply of the ligaments and for the planning of postsurgical or conservative therapeutic rehabilitation modalities. (J Hand Surg 1997; 22A:473–478.)

The concept that synergistic relationships between muscles and ligaments help to maintain active and passive joint stability is well established for the knee[1] and was recently confirmed for the shoulder[2,3] and the ankle.[4] The functional properties of such a ligamentomuscular protective mechanism are manifested by the interaction of several types of mechanoreceptors that are embedded in the ligaments.[5–7] These mechanoreceptors communicate signals indicating their stress/strain status to spinal motor neurons via articular nerves. The spinal motor neurons, in turn, initiate muscular activity of appropriate level that contributes to the preservation of joint stability.[8–11] It is also well established that conditioning the musculature as a nonoperative treatment of knee ligamentous defects is, by itself, effective as a rehabilitation modality for the unstable knee.[12–14]

While the ligamentomuscular protective reflex was demonstrated in the knee, shoulder, and ankle, two major questions remain: does this reflex exist in all other major joints, and what are the specific nerves, muscles, and ligaments associated with the reflex in a given joint? In the knee joint, for example, mechanoreceptors in the anterior cruciate ligament are neurologically linked to motor units that control the hamstrings muscle.[1] Similarly, several muscles crossing the shoulder become active when different bands of the glenohumeral capsule are stimulated.[2,3,6] In the ankle joint, however, stress in the medial (del-

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toid) ligament elicits contraction of the intrinsic foot muscles, none of which cross the joint.[4] The contraction of the quadratus, flexor digitorum brevis, and the abductors digiti minimi and hallucis increases the arch of the foot and opposes any eversion that may cause undue strain in the deltoid ligament, thereby preventing instability and loss of balance.

Therefore, it is clear that although the ligamentomuscular reflex is conceptually similar in function (eg, maintaining joint stability), its architecture and innervation may vary greatly from joint to joint.

The objective of this report was to determine if a ligamentomuscular protective reflex arc exists from the elbow ligaments to the associated muscles. Such information may be valuable in both the planning of surgical repairs while preserving joint innervation and the design of optimal postsurgical or conservative treatment modalities.

Materials and Methods

Preparation

Six adult cats were anesthetized with a single intraperitoneal injection of chloralose (60 mg/kg), as this anesthetic does not inhibit reflex motor activity.[15–17] Dissection of each hindlimb was initiated after the preparation settled into anesthesia. A circumferential incision was made in the skin in the midhumerus level, and the skin was reflected to the wrist. Nerves descending the limb in that region were exposed above the elbow and followed distally. Loupe magnification was used to trace articular nerve branches leaving a main nerve trunk and terminating on the medial or lateral elbow ligaments. Articular nerve branches found to terminate in the ligaments were gently freed from their surrounding connective tissue for later placement over the stimulating probe electrode. Articular nerves not terminating on the ligaments were excluded. A dissecting microscope was used to confirm the trajectory of any articular nerve branch that was considered in the study.

Instrumentation

A bipolar stimulating stainless-steel electrode probe was used to apply 100 μs supramaximal pulses at a rate of 10 pulses/s to the articular nerve branches. Supramaximal pulses were used to ensure that all nerve axons, including the finest axons corresponding to the bare ending–type mechanoreceptors, were excited by the stimulus. The electrodes were bent into hooks and spaced 1.5 mm apart. To assess reflex activation of any muscles around the elbow joint, fine-wire electrodes were inserted into the muscle bellies. The wires were multistrand stainless steel and were covered with insulating polytetrafluoroethylene. The wires were first inserted into hypodermic needles. A 2-mm tip was stripped of insulation and bent backward over the needle tip to form a hook. Two wires, spaced 3–4 mm apart, were inserted into each muscle to form the input to a differential electromyographic (EMG) amplifier. The amplifier had a 110-dB common mode rejection ratio, a gain of up to 200,000, and a bandpass filter for frequencies from 6 to 2,500 Hz. A ground electrode was placed elsewhere on the preparation.

The M-wave, known as the EMG response to each pulse, is the synchronous discharge of all active motor units in the muscle. The response was monitored by an oscilloscope and a Brush 260 6-channel recorder (Gould Inc., Cleveland, OH). The M-wave discharge of each muscle was recorded and stored in an IBM computer (IBM, Armonk, NY) at a sampling rate of 5,000 Hz.

The conduction time, from application of the stimulus to the nerve to the appearance of the reflexive M-wave, was calculated from time expanded scaling on the computer. The conduction time calculated for each M-wave in the 3 10-second recordings of each of the 12 specimens of the same muscle were pooled and the mean ± SD was calculated.

Protocol

After an articular nerve terminating in the ligaments was identified and freed from its surrounding connective tissue, the bipolar stimulating probe was applied to the nerve, and a pulse train (10 pulses/s) was applied for 10 seconds while the resulting M-wave train was recorded and stored in the computer. Three sets of 10-second recordings were made to ensure repeatability of data. A ligature was then applied around the articular nerve, between the electrodes and the main nerve trunk. The articular nerve was transected, proximal to the ligature, and a second pulse train was applied. Absence of M-wave activity indicated that the articular nerve was an afferent nerve conducting information from mechanoreceptors within the ligament to the spinal cord, eliciting the reflex in the muscles from which EMG activity was recorded. The muscles monitored included the biceps, triceps, brachioradialis, flexor digitorum superficialis (FDS), flexor digitorum profundus (FDP), flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), and pronator teres.

Results

A single articular nerve emerging from the main trunk of the median nerve just above the elbow joint was identified. The articular nerve traveled medially and terminated with several diffused branches entering the three different components of the medial ligaments of the elbow, as shown in Figure 1. The projection of the articular nerve was consistent in the 6 preparations tested, bilaterally, without presenting any variability in the number of branches or termination location. Articular nerve branches to the lateral ligaments of the elbow were not found in any of the 6 preparations.

Stimulation of the articular nerve resulted in EMG discharge in the FDS, FDP, FCR, FCU, and pronator teres. The EMG discharge was present in the same 5 muscles, bilaterally, in all 6 preparations. Figure 2 shows a typical M-wave discharge from the 5 muscles, elicited by stimulation of the articular nerve.

Stimulating the articular nerve after application of the ligature and transection of the articular nerve at its emergence from the main trunk of the median nerve resulted in the disappearance of all EMG discharge in the 5 muscles. This confirmed that the articular nerve was afferent, conducting sensory information from mechanoreceptors in the ligaments to the spinal cord.

The mean ± SD time delay, from application of the stimulus to the nerve to the peak of the resulting M-wave, was 3.26 ± 0.98 ms for the FDS, 5.8 ± 0.84 ms for the FDP, 3.52 ± 0.69 ms for the FCR, 3.56 ± 0.56 ms for the FCU, and 3.19 ± 0.80 ms for the pronator teres.

Discussion

This investigation documents that a fast-acting reflex arc exists from sensory elements in the medial ligaments of the elbow to the flexor–pronator muscles of the forearm and that this reflex is mediated by the median nerve and its articular branch.

In the feline, as well as in the human, the pronator teres, FCR, FCU, and FDS cross the elbow joint medially. As these muscles contract, the resulting force vector generates compressive forces on the medial aspects of the joint, resisting or relieving valgus stresses that may exist in the medial collateral ligament (MCL). The FDP, however, is a wrist flexor. In the feline, which bears load on the forelimb, contraction of the profundus muscle and the resulting wrist flexion can realign the elbow joint with respect to forces transmitted through it, and thereby have an indirect impact on relieving stress on the MCL. Such indirect control of ligamentous stress by distal muscles was previously observed in the ankle joint,[1] also a load-bearing joint.

It is well established that the medial elbow ligaments, and especially the anterior bundle, bear the major function of maintaining stability in the presence of valgus loads resulting from routine daily activities and from certain sports activities involving upper-extremity functions. Slocum[18] was among the first to describe the concurrent increase in tension on the medial elbow and compression in the lateral elbow during activities such as throwing sports. Schwab et al.[19] documented cases in which MCL injuries occurred under valgus stress due to falls with outstretched arms, throwing sports, heavy use of a hammer, pitching a baseball, and throwing a javelin. Ruptures of the MCL resulting from valgus stress are often associated with damage to the forearm pronators and wrist flexor muscles/tendons.[20–22] The overload on the medial aspects of the elbow during throwing sports occurs to a mild extent during the cocking phase but primarily in the acceleration, deceleration, and follow-through phases, during which a large amount of valgus stress is compounded with hyperextension overload.[21]

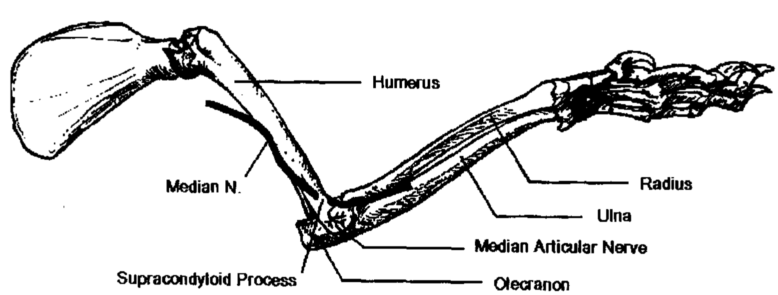

Figure 1. Schematic of the medial aspect of the elbow showing the median nerve, the articular branch, and the terminus on the medial elbow ligaments.

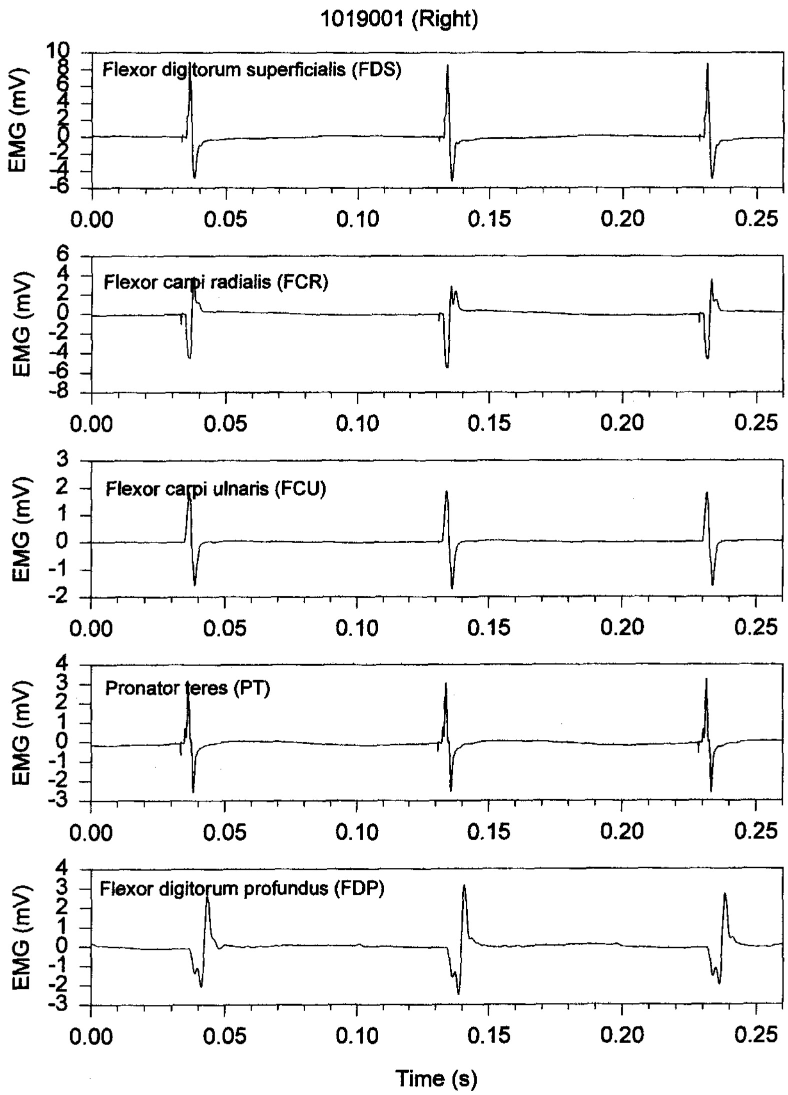

Figure 2. Typical myoelectric (M-wave) discharge of the flexors digitorum superficialis and profundus, flexors carpi radialis and ulnaris, and the pronator teres in response to stimulation of the median articular nerve to the medial ligaments of the elbow.

Interestingly, Bennet and Tullos[23] reported from clinical observation that the flexor–pronator muscle group is providing additional support against valgus instability, as it is common to see symptoms of overuse of these muscles in athletes engaged in throwing sports. Indeed, Parkes[24] designated the wrist flexors–forearm pronators (FCR, FCU, pronator teres, etc.) as the first line of defense in decreasing stress in the medial elbow ligaments and consequently in decreasing symptoms of their overuse in throwing athletes and tennis players. In essence, overload of the medial elbow ligaments causes an increase in activity of the flexor–pronator muscle group, which in turn is subjected to overuse symptoms upon repeated use over time.

Thus, it is established that the medial ligaments, especially the anterior bundle, are highly stressed in circumstances that elicit valgus loads on the elbow and further that the wrist flexor–forearm pronator muscles are capable of protecting the ligaments from damage by providing additional resistance to valgus stress through contracting with sufficient force at the appropriate time. The reflex arc described in this study, therefore, explains the interaction of symptoms in deficient elbows, as observed by Parkes,[24] by the reflexive neurologic linkage between the medial ligaments and the flexor–pronator muscles of the wrist and forearm, respectively.

The time delay from onset of stimulus in the articular nerve at the ligament to the activation of the flexor–pronator muscles was 3.0–3.5 ms, with the exception of the FDP, which exhibited a 5.8-ms delay. The average length of the median nerve from the spine to the elbow was 12 cm. Assuming a conduction velocity of action potentials of 120 m/s and a 0.5-ms delay in the neuromuscular junction, one can assert that only a monosynaptic delay in the spinal cord was present. This underscores the importance of the reflex function in providing a fast response to stress in the medial elbow ligament and in dynamically participating in protecting joint stability.

The FDP required nearly twice as much time to respond to the stimulus. This could be due to slower conduction velocity in the nerve axons, polysynaptic transmission in the spinal cord, or slower contractile coupling in the muscle itself. At present, it is not possible to pinpoint the exact reason for the longer delay in activation in this muscle; additional work is required to clarify this issue. From the data of the other 4 muscles, it is clear that the reflex is spinal in nature and provides automatic activation of the muscles to prevent undue stress in the medial elbow ligaments without requiring conscious decisions or effort from the higher nervous system structures.

The reflex was delineated in the feline, a small model in comparison to the human. It is necessary, therefore, to account for the size difference and its implication on the time delay. Considering that action potentials will need to travel a distance 5 times longer in the human than in the cat (from the elbow to the spine), a time delay of 15–20 ms could be estimated. This still provides a fast reaction to stresses in the medial elbow, allowing for prompt dynamic stabilization of the joint in various activities.

While this study clearly demonstrates the presence of a ligamentomuscular protective reflex in the medial elbow, it provokes several interesting questions yet to be answered. Specifically, it is of interest to define if mechanoreceptors within the MCL provide ongoing discharges to the muscles during routine daily activities such that continuous increases and decreases in muscle activity accompany respective increases or decreases in MCL tension. Alternatively, the MCL may signal the muscles to contract only upon stresses that may threaten its integrity.

Furthermore, although not measured, the observed muscle contraction upon stimulation of the articular nerve from the MCL was relatively strong and sufficient to assist in relieving valgus stress. It is of interest, however, to determine the magnitude of the forces and their effectiveness over the full range of motion of the human elbow. Additional research is required to delineate the overall mechanism of the ligamentomuscular protective reflex in the elbow.

The surgical implications of these findings advocate elbow repair procedures that preserve the neural supply of the ligaments and elbow capsule in order to allow as normal as possible dynamic stabilization of the joint. Also, these implications advocate the deployment of the muscles in postsurgical rehabilitation or in conservative treatment of elbow deficiencies.

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