The Quantification of the Origin Area of the Deep Forearm Musculature on the Interosseous Ligament

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Abstract
The diagnosis and treatment of injuries involving rupture of the interosseous ligament remain challenging. Few studies have considered the effects of rupture of the interosseous ligament on deep forearm muscle function. The objective of this study was to quantify the attachment areas of the deep forearm muscles on the interosseous ligament. The origins of the extensor indicis, extensor pollicis longus, extensor pollicis brevis, abductor pollicis longus, flexor pollicis longus, and flexor digitorum profundus were digitized from 11 cadavers. Three-dimensional modeling techniques were used to quantify the origin area on bone and the interosseous ligament. The extensor pollicis longus and the abductor pollicis longus attached primarily to the interosseous ligament (81% and 62%, respectively). Although the other deep forearm muscles had larger origins on bone, relatively large areas on the interosseous ligament were observed, ranging from 31% to 47%. The muscle origins on the interosseous ligament were verified histologically, where striated muscle originated directly from the dense connective tissue of the interosseous ligament. Due to their relatively large attachment areas on the interosseous ligament, the function of the deep forearm muscles might be altered after an interosseous ligament rupture. Therefore, symptoms such as pain and weakness of the deep forearm muscles could serve as a basis for screening patients with injuries of the interosseous ligament. Furthermore, the data may help to elucidate factors limiting the healing of the interosseous ligament. Future studies should focus on quantifying the effect of an interosseous ligament rupture on the function of the deep forearm muscles and developing reconstructions that consider this function.

Combined radial head fractures and interosseous ligament ruptures often result in severe disability, causing proximal migration of the radius, chronic wrist pain, reduced grip strength, and loss of range of motion. However, the early diagnosis of interosseous ligament injuries is difficult, which might limit the ability of treatments to improve function. Although many investigators suggest that reconstruction of the interosseous ligament may improve clinical outcomes, there is currently no standard surgical intervention for treating or repairing an interosseous ligament rupture. As a result, previous in vitro studies have focused on measuring the biomechanical function of the interosseous ligament in an effort to improve clinical outcomes after interosseous ligament rupture.

Many studies have examined the force transmitted by the interosseous ligament in response to compressive loads applied to the wrist. These investigations suggest that the interosseous ligament plays an important role in load transfer between the radius and ulna. However, very little is known regarding the functional anatomy of the deep forearm muscle origins on the interosseous ligament. In anatomy texts, the locations of the muscle origins are described in...

general, but no studies have quantified the relative area of the origin that attaches to the interosseous ligament, compared to the area that attaches to bone. Additionally, there is no description of how interosseous ligament rupture affects the function of the deep forearm muscles. This information could be valuable for the early diagnosis of interosseous ligament injuries and to help elucidate factors limiting the healing of the interosseous ligament.

Therefore, we hypothesize that interosseous ligament rupture might alter the function of the deep forearm muscles, which mainly originate on the interosseous ligament. The objective of this study was to quantify the relative proportions of the deep forearm muscle origins that attach to the interosseous ligament and to bone. To achieve this goal, cadaver specimens were dissected and the attachment areas on bone and the interosseous ligament were quantified using three-dimensional (3D) modeling techniques.

**Materials and Methods**

Eleven intact fresh-frozen human cadaveric forearms, cut at the mid-humerus, were used in this study (6 left, 5 right; age 47 to 67 years). The specimens were thawed overnight at room temperature prior to testing. The specimens were then visually inspected and palpated in order to exclude any specimens with an abnormality or evidence of prior surgery from the study.

First, the skin and superficial muscles of the forearm were removed to expose the deep muscle layer. In this study, the origins of six deep forearm muscles were quantified: the extensor indicis (EI), extensor pollicis longus (EPL), extensor pollicis brevis (EPB), and abductor pollicis longus (APL) on the dorsal side (Fig. 1A) of the forearm and the flexor pollicis longus (FPL) and flexor digitorum profundus (FDP) on the volar aspect (Fig. 2A). Each muscle was carefully dissected to its origin on bone and interosseous ligament. These deep forearm muscle origins were then marked with India ink (Sanford Corporation, Bellwood, Illinois) as they were removed (Figs. 1B and 2B). After each muscle was marked and removed, the forearm was clamped at the wrist and elbow joints to keep it stationary during digitization.

A digitizing stylus (Microscribe 3DX, Immersion, San Jose, California) with an accuracy of 0.2 mm was used to digitize the radius and ulna, the interosseous ligament, and the muscle origins. First, the stylus was used to trace a series of parallel lines along the radius and ulna. Then, the interosseous ligament was digitized, followed by the origins of the deep forearm muscles, which were divided into separate regions of origin on the interosseous ligament and bone.

The digitized data were imported into a solid modeling software (Rhinoceros, Robert McNeel & Associates, Seattle,

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**Figure 1**

**A**, Deep muscles originating from the dorsal aspect of the forearm. **B**, Exposure of the origin areas of the EPL, EPB, EI, and APL. **C**, Three-dimensional image of the EPL, EPB, EI, and APL origins.

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**Figure 2**

**A**, Deep muscles originating from the volar aspect of the forearm. **B**, Exposure of the origin areas of the FDP and FPL. **C**, Three-dimensional image of the FDP and FPL origins.
Washington), and 3D models of the radius and ulna as well as all of the above muscle origins were created (Figs. 1C and 2C). The digitized spatial data were used to calculate the muscle origin surface area and the portions that originate on the bone and interosseous ligament. A repeated measures ANOVA was used to detect statistically significant differences in the area of the muscle origins on the interosseous ligament and bone. Differences were considered statistically significant when p < 0.05.

In addition, a histological analysis of the muscle origins on the interosseous ligament and bone was performed using two specimens. The attachment sites of the EPL to the interosseous ligament and to the ulna were biopsied and placed in a 10% formaldehyde solution. Samples were then fixed in a graded series of water-ethanol solutions (70%, 5%, and 100%), paraffin imbedded, and serially cross-sectioned (4 microns thick). The thin sections were stained with haematoxylin and eosin (H&E) for detecting nucleus and cytoplasm, respectively. The samples were examined with light microscopy and digitally photographed at x20 and x40.

**Results**

The EPL and APL had larger attachment areas originating from the interosseous ligament, compared to the area attaching to bone (Fig. 3). The average percent of the EPL muscle origin area attaching to the interosseous ligament was 81% (SD, 12%). The difference in area between the bony origin and ligamentous origin was statistically significant (p < 0.05). In all specimens, the bony portion of the EPL origin was located on the proximal edge, compared to the distal portion, which originated on the interosseous ligament (Fig. 1). The portion of the APL origin that was attached to the interosseous ligament was 62% (SD, 18%) of the total area.

The EI, FDP, and FPL originated more from bone, compared to the APL and EPL (Fig. 3). Only 33% (SD, 29%) of the EI origin area was attached to the interosseous ligament. The FPL and FDP had a statistically larger origin area on bone, compared to the interosseous ligament (p < 0.05). The percentages of the FPL and FDP attaching to the interosseous ligament were 31% (SD, 16%) and 33% (SD, 18%), respectively.

Out of 11 specimens, the EPB was absent in four specimens and in one specimen shared a common muscle belly with the APL. The EPB had similar origin areas attaching to bone and the interosseous ligament (Fig. 3). The proportion of the EPB origin area on the interosseous ligament was 47% (SD, 35%). The oblique cord, a ligament passing from the lateral side of the proximal ulna downward and laterally to the radius, was present in all of the specimens examined in our study.

The histology of the muscle attachment to the interosseous ligament and bone was performed using two specimens. The attachment sites of the EPL to the interosseous ligament and to the ulna were biopsied and placed in a 10% formaldehyde solution. Samples were then fixed in a graded series of water-ethanol solutions (70%, 95%, and 100%), paraffin imbedded, and serially cross-sectioned (4 microns thick). The thin sections were stained with haematoxylin and eosin (H&E) for detecting nucleus and cytoplasm, respectively. The samples were examined with light microscopy and digitally photographed at x20 and x40.

**Figure 3** Percentage of the origin area of the deep forearm muscles attaching to the interosseous ligament and bone. An asterisk denotes a statistically significant difference between the attachment areas (p < 0.05).

**Figure 4** Morphology of the extensor pollicis longus muscle origin on the interosseous ligament, stained with H&E. Note that the striated muscles attach directly to the dense connective tissue of the interosseous ligament without the presence of Sharpey’s fibers (x20 and x40 views).

**Figure 5** Morphology of the extensor pollicis longus muscle origin on bone, stained with H&E. The muscle attaches to bone via tendon, with the presence of Sharpey’s fibers (x20 and x40 views).
The morphology seen at the junction of the interosseous ligament and muscle differs (Fig. 4) from the known architecture of the muscle bone interface (Fig. 5). No Sharpey’s fibers were seen at the attachment of the muscle to the interosseous ligament; to the contrary, there was a smooth transition from striated muscle fibers to the dense connective tissue of the interosseous ligament. At the junction, blue discolorations and dark granules were observed.

**Discussion**

The anatomy and biomechanics of the interosseous ligament have been previously studied in the literature. However, other investigations have not quantified the extent to which the deep muscles of the forearm originate on the interosseous ligament. In the present study, the origin areas of the deep forearm muscles were quantified. The areas of six deep forearm muscle origins were measured using a digitizing stylus and were reconstructed in a 3D modeling software. The EPL and APL originated more on the interosseous ligament, while the EI, EPB, FPL, and FDP had larger origins on bone. The muscle origins on the interosseous ligament were microscopically verified by histological analysis. These results suggest that the interosseous ligament has a more complex role than just resisting compressive loads applied to the forearm. Disruption of the interosseous ligament might affect the function of these muscles.

Acute interosseous ligament injury should be suspected in combined radial head fractures and distal radial ulnar joint injuries. It has been noted in past works that disruptions of the interosseous ligament are difficult to diagnose, which might affect the outcome of treatment. Early diagnosis may help to improve the treatment forearm injuries involving interosseous ligament tears. Even after diagnosis, the treatment of interosseous ligament rupture is considered a difficult clinical problem.

One of the major obstacles in early diagnosis of interosseous ligament injuries is the high cost of imaging techniques and lack of a clear physical screening test. In patients with interosseous ligament injuries, plain radiographs have not been shown to reliably detect radial shortening. Several studies have shown that interosseous ligament injuries can be diagnosed by ultrasound and magnetic resonance imaging (MRI). The results of the current study may be useful in the design of a primary screening tool for forearm injuries to assist in identifying patients who might benefit from imaging to diagnosis potential injuries to the interosseous ligament. Based on the results of the current study, an interosseous ligament tear might disrupt the function of the deep forearm muscles. In particular, the function of the EPL and APL may be disrupted, due to their relatively large origins on the interosseous ligament. Since the EPL is the primary extensor of the thumb and the APL is the primary abductor of the thumb, weakness in abduction and extension could indicate that the origins of the EPL and APL on the interosseous ligament have been disrupted. Another possible indicator of interosseous ligament disruption might be pain in the forearm during passive flexion and extension of the digits. This type of screening test might be useful to identify patients who are in need of further examination, using imaging techniques such as MRI and ultrasound to detect interosseous ligament injury. Further studies on patients with interosseous ligament injuries are needed to verify these findings.

Furthermore, these findings on the muscle origin areas might explain the limited healing of the interosseous ligament after injury. Previous work has shown that the interosseous ligament is commonly ruptured by a longitudinal oblique tear of the interosseous ligament, oriented from the proximal radius to the distal ulna. The deep forearm muscles that insert on the interosseous ligament might pull apart the torn edges of the interosseous ligament, limiting the ability of the interosseous ligament to heal. In addition, the deep forearm muscle bellies could form a physical barrier between the edges of the tear. Future investigations should include research on determining the factors associated with limiting the ability of the interosseous to heal.

Studies on the reconstruction of the interosseous ligament have focused primarily on reproducing its restraining force during compressive loads applied to the wrist. These studies have not accounted for the muscle origins on the interosseous ligament and their function after such repairs. Replacing the interosseous ligament with a cord-like graft might not reproduce the functional anatomy of the deep muscle origins on the interosseous ligament. In the future, repairs should also account for the active muscle loading of the deep forearm muscles originating from the interosseous ligament. Knowledge of the origin areas of the deep forearm muscles from the interosseous ligament may help plan future reconstruction procedures, taking into account not only the biomechanical aspect of the interosseous ligament but the need to reattach the muscle bellies. Such procedures may help achieve a better result and a much improved reproducible forearm strength and function.

Currently, there is limited data on the histological description of the muscle-interosseous ligament interface in the literature. The junction of the striated muscle cells and the dense connective tissue of the interosseous ligament (Fig. 4) differed from the known junction between striated muscle and bone (Fig. 5). Specifically, no Sharpey’s fibers were observed in the junction between the striated muscle and the interosseous ligament. These findings might shed light on the interaction between the interosseous ligament and the deep muscles of the forearm. This interface should be further characterized using electron microscopy and immunohistochemistry.

In conclusion, the knowledge that deep forearm muscles originate largely from the interosseous ligament could help to explain certain injury patterns to the forearm and the lack of spontaneous healing after interosseous ligament rupture.
In addition, the data might serve as a basis for a screening test for suspected interosseous ligament injury. Such a test may allow us to increase our ability to detect injuries of the interosseous ligament early, resulting in an improved clinical outcome for the patient. Finally, these data could be useful for the design of future reconstruction techniques of the interosseous ligament.

**Disclosure Statement**

None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

**References**