Role of the Interosseous Membrane in Preventing Distal Radioulnar Gapping

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Abstract

Background Damage to the interosseous membrane (IOM) can alter load transmission between the radius and ulna and decrease their axial stability. Less is known about the effect of IOM sectioning on the transverse stability between the radius and ulna.

Purpose The purpose of this study was to quantify the radioulnar gapping at the distal radioulnar joint (DRUJ) during forearm rotation when the IOM was experimentally sectioned while maintaining the integrity of the distal radioulnar ligaments.

Methods In 12 fresh-frozen cadaver forearms tested in a combined wrist–forearm simulator, the increase in gap between the radius and ulna, at the level of the DRUJ, was determined during cyclic forearm rotation following IOM sectioning.

Results IOM sectioning caused a significant increase in dorsal gapping at the DRUJ by 2.1 mm in supination and 0.6 mm in pronation. It also caused an increase in palmar gapping by 1.3 mm in supination and 0.5 mm in pronation.

Conclusion This experiment has shown that the IOM has an important role in stabilizing the DRUJ, especially in supination, and that IOM sectioning caused greater loads on the palmar and dorsal radioulnar ligaments. Since DRUJ instability is primarily treated by fixing the laxity at the dorsal radioulnar ligament (DRUL) and palmar radioulnar ligament (PRUL), untreated IOM damage could permit additional injury and instability to the radioulnar ligaments or their reconstruction.

Clinical Relevance Reconstruction of a torn IOM should be considered in the presence of persistent DRUJ instability following DRUJ reconstruction.

Keywords

- distal radioulnar joint
- interosseous membrane
- stability

The central band (►**Fig. 1**) of the interosseous membrane (IOM) is an important stabilizer of the forearm. Previous studies have shown that the IOM and the triangular fibrocartilage complex (TFCC) (►**Fig. 2**) are both important in providing axial stability of the radius in the presence of a proximal radial head fracture.[1,2] Various surgical treatments have been developed to repair or provide a substitute for the IOM[3–7] or the TFCC[8] in the presence of axial instability. With respect to forearm transverse stability, the IOM and the annular ligament have been shown to provide stability of the forearm preventing subluxation or dislocation of the proximal radial head.[9]

Less is known about whether damage to the IOM affects transverse stability of the distal radioulnar joint (DRUJ) during forearm rotation. Watanabe et al have evaluated the role of the IOM in providing DRUJ dorsal/volar constraint at specific forearm positions.[10] Watanabe et al also examined the role of the joint capsule in providing dorsal/volar constraint at the DRUJ.[11] Due to the oblique orientation of the IOM,[12] it would appear to have a role in providing transverse stability as suggested by Orbay et al[13] and by Pfaeffle et al.[14] In the presence of intact ligaments of the DRUJ but with a torn IOM, continued instability of the DRUJ may require additional surgery.

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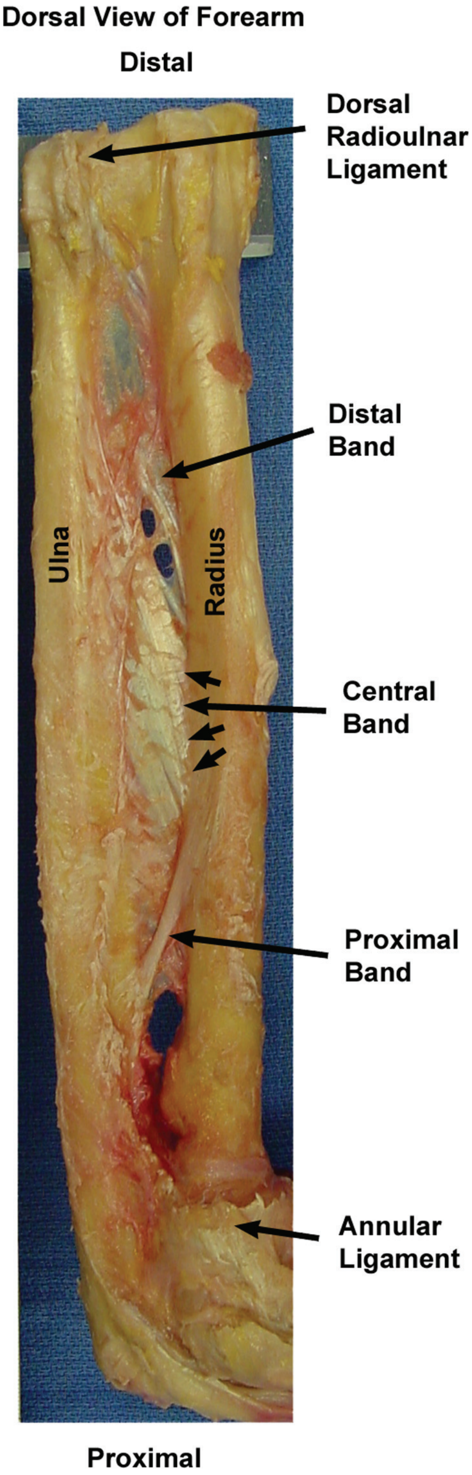

Fig. 1 The ligamentous structures of the forearm include the dorsal radioulnar ligament which is shown in this dorsal view while the palmar ligament is hidden. The three portions of the interosseous membrane; the distal, central, and proximal bands, are shown along with the annular ligament. (Reprinted with permission from Werner et al.[17])

The purpose of this study was to quantify the radioulnar gapping at the DRUJ during forearm rotation when the IOM was experimentally sectioned while maintaining the integrity of the distal radioulnar ligaments.

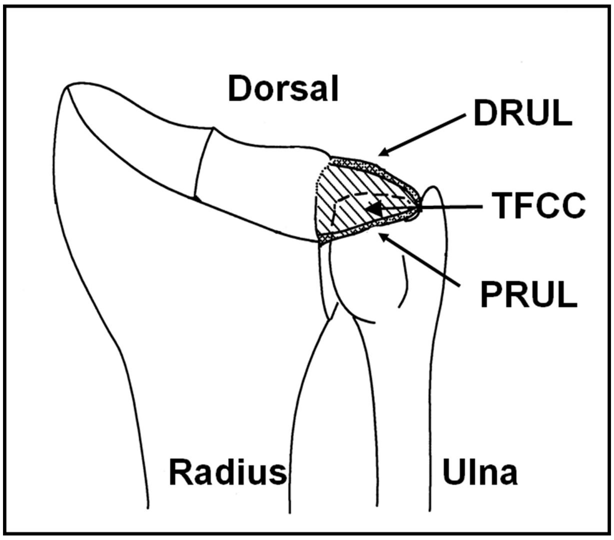

Fig. 2 A simplified oblique volar view of the distal radioulnar joint (DRUJ) where DRUL is the dorsal radioulnar ligament and PRUL is the palmar radioulnar ligament. (Reprinted with permission from Kihara H, Short WH, Werner FW, Fortino MD, Palmer AK. The stabilizing mechanism of the distal radioulnar joint during pronation and supination. J Hand Surg Am 1995;20(6):930–936.)

Materials and Methods

Twelve fresh frozen cadaver forearms were tested in a combined wrist-forearm simulator. These arms had been previously tested[9] and the effect of IOM sectioning on proximal radial head motion has been analyzed and reported. However, the consequences of IOM sectioning on instability of the DRUJ was not examined.

In these forearms, the arm was free of all soft tissues while leaving the wrist flexor and extensor tendons (extensor carpi ulnaris, extensor carpi radialis brevis, extensor carpi radialis longus, flexor carpi radialis, and flexor carpi ulnaris), the pronator teres tendon, biceps tendon, pronator quadratus muscle, supinator muscle, elbow capsule, and ligaments. Using a modification of our previous control theory,[15,16] these arms were cyclically moved from 60 degrees of supination to 60 degrees of pronation by using hydraulic actuators attached to the pronator teres and biceps tendons and to anchors that were attached to the insertion sites of the pronator teres and supinator (►**Fig. 3**). During forearm motion, the wrist was kept in neutral by forces applied to the five wrist tendons. These forces were applied by hydraulic actuators and dynamically varied to maintain the neutral wrist position using the original control algorithm.[16] The neutral wrist position and the radial rotation were monitored by electromagnetic sensors attached to the third metacarpal and distal radius respectively.

During forearm rotation, the motion of the radius and ulna were also monitored by optical sensors (NDI, Ontario, Canada) attached to the radius and ulna (►**Fig. 3**). Upon completion of the study, the surfaces of the radius and ulna were digitized using a stylus to create a cloud of points to represent each bone. Surface models of each bone were created and subsequently animated by applying the motion

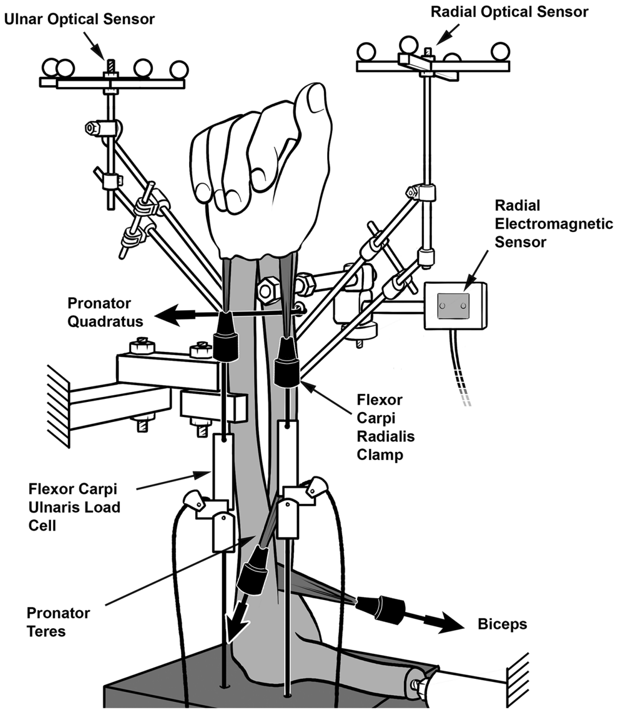

Fig. 3 The wrist and forearm simulator setup included optical sensors attached to the radius and ulna to quantify bone motion during forearm rotation caused by forces applied to the wrist and forearm tendons. Four tendons are not shown (extensor carpi ulnaris, extensor carpi radialis brevis, extensor carpi radialis longus, and supinator). The load cells are shown for the flexor carpi ulnaris and flexor carpi radialis. Only the tendon clamps are shown for the biceps and pronator teres. (Reprinted with permission from Anderson et al[9]

data acquired during the experiment. In the resultant models, the ulna was fixed.

Data were collected while all structures of the IOM were intact and then after complete sectioning of distal, central, and proximal bands of the IOM, and the annular ligament. However, neither the dorsal or palmar radioulnar ligaments were sectioned.

After the animation models were completed, specific landmarks were identified on the radius and ulna of each forearm at the level of the ulnar fovea (►**Fig. 4**). These points were a) a point on the dorsal aspect of the sigmoid notch, near where the dorsal radioulnar ligament (DRUL) attaches, b) a point at the center of the concavity of the sigmoid notch, and c) a point at the palmar aspect of the sigmoid notch, near where the palmar radioulnar ligament attaches. A point at the base of the ulnar fovea was also found. Changes in displacements between the three points on the radius and the point on the ulna were computed during forearm rotation in three ways. These distances were computed first at the extremes of pronation and supination, then at a common extreme of rotation for each arm, whichever was smallest in the intact versus after IOM sectioning for that arm (since the extremes of rotation sometimes varied when the structures were cut). The distance between the sigmoid notch and the ulnar fovea was also computed when the forearm was rotated 5 degrees after each extreme of motion since that was approximately when the muscle forces were greatest. The distance between these points were tabulated and compared

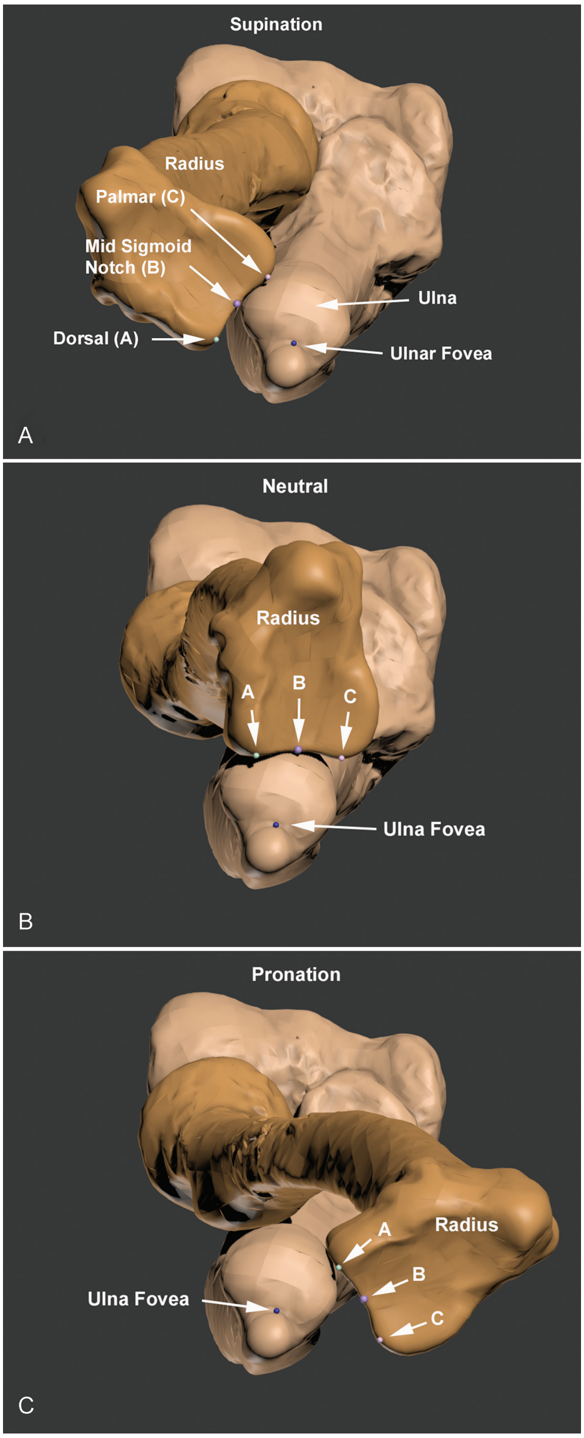

Fig. 4 (**A**) Three points on the radius of each forearm were identified using an axial view of the radius and ulna, here shown in supination. Point A is near the radial attachment of the dorsal radioulnar ligament. Point B is at the mid-point of sigmoid notch. Point C is near the radial attachment of the palmar radioulnar ligament. (**B**) Three points on the radius of each forearm were identified using an axial view of the radius and ulna, here shown in neutral. Point A is near the radial attachment of the dorsal radioulnar ligament. Point B is at the midpoint of sigmoid notch. Point C is near the radial attachment of the palmar radioulnar ligament. (**C**) Three points on the radius of each forearm were identified using an axial view of the radius and ulna, here shown in pronation. Point A is near the radial attachment of the dorsal radioulnar ligament. Point B is at the midpoint of sigmoid notch. Point C is near the radial attachment of the palmar radioulnar ligament.

Table 1 Stiffness Construct Values (N/mm^2) determined from a non-linear model for each ligament (standard deviation [SD])

Forearm position	Neutral	Pronation	Supination
Annular ligament	5.5 (2.1)	–[a]	–[a]
Central band of the IOM	35.9 (39.7)	31.0 (33.2)	22.6 (17.5)
Distal band of the IOM	13.6 (9.5)	9.4 (7.1)	5.6 (3.1)
Proximal band of the IOM	14.9 (17.7)	14.9 (15.6)	18.4 (27.7)
Dorsal radioulnar ligament	15.9 (19.4)	15.3 (18.0)	6.7 (7.6)
Palmar radioulnar ligament	2.7 (1.0)	2.9 (1.5)	2.7 (0.4)

Abbreviation: IOM, interosseous membrane

Source: Reprinted with permission from Werner et al.[17]

[a] There are no results for the annular ligament in the pronation or supination positions.

using a two-way repeated measures analysis of variance. As appropriate, a Bonferroni correction for multiple comparisons was used in the post hoc tests.

The increase in force in the dorsal and palmar radioulnar ligaments was computed based on the increase in the gap at the DRUJ following IOM sectioning. In a previous study,[17] we determined the linear and nonlinear stiffness coefficients of six forearm ligaments with the forearm in neutral, in supination, and in pronation. Using bone-ligament-bone constructs extracted from seven cadaver forearms, we nondestructively tested each ligament by applying forces to each construct while measuring the resultant displacement. Of the distal, central and, proximal bands of the IOM, the dorsal and palmar radioulnar ligaments, and the annular ligament, the central band was found to be the stiffest stabilizing structure (►**Table 1**). Based on these stiffness coefficient results, the increase in force in the PRULs and DRULs were computed.

Results

Complete sectioning of the IOM led to the proximal dislocation of the radial head in one forearm. This arm was thus excluded from the data analysis.

IOM sectioning caused a significant ($p = 0.001$) increase in dorsal gapping at the DRUJ by 2.1 mm in supination and 0.6 mm in pronation (average of 3 methods of computing the gapping). It also caused an increase in palmar gapping by 1.3 mm in supination and 0.5 mm in pronation (►**Table 2**). The gap increase was significantly more in supination than in pronation ($p < 0.01$) for all three methods of gap computation. Typically, no significant differences in the gap distance were found between the dorsal and palmar gap locations.

The force in the DRUL increased by 5 to 30 N and from 1 to 6 N in the PRUL following sectioning of the IOM (►**Table 3**).

Discussion

This study examined the question whether in the presence of intact dorsal and palmar radioulnar ligaments, a torn IOM might allow persistent instability of the DRUJ and therefore may require additional surgery. The purpose of this specific study was to quantify the radioulnar gapping at the DRUJ during forearm rotation when the IOM was experimentally sectioned while maintaining the integrity of the distal radioulnar ligaments.

The limitations to this study include it being a cadaver experiment which may inadequately represent normal in vivo motion. Only four forearm muscles were used to cause forearm rotation which was limited to 60 degrees of supination and 60 degrees of pronation. The inclusion of additional muscles or greater ranges of motion may show greater differences in gapping between the radius and ulna. The gap measurements were based on single point locations on the distal radius and ulna instead of over a region which may have resulted in greater or smaller gaps.

This experiment showed that the IOM has an important role in stabilizing the DRUJ, especially in supination. Watanabe et al. showed that the IOM is important in restraining dorsal dislocation of the radius at the DRUJ[10] and that the role of the DRUJ joint capsule becomes important at increasing angles of forearm rotation.[11] In the current study, increased gapping at the DRUJ when the IOM was cut, placed greater loads on the primary ligamentous stabilizers of the DRUJ, that is, the PRUL and DRUL. Since DRUJ instability is primarily treated by fixing the laxity at the level of the DRUL and PRUL, untreated IOM damage could allow additional injury and instability to the radioulnar ligaments or their reconstruction. Reconstruction

Table 2 Increase in DRUJ gap (mm) between ulnar fovea and sigmoid notch following IOM sectioning (standard deviation [SD])

Forearm Position	Gap location	At extremes of rotation	Common extreme of rotation	Just after extreme position
Supination	Dorsal (A; DRUL)	2.0 (1.7)	2.1 (1.8)	2.1 (1.7)
	Mid sigmoid notch (B)	2.2 (1.8)	2.1 (1.2)	1.9 (1.1)
	Palmar (C; PRUL)	1.5 (1.0)	1.4 (1.0)	0.9 (0.9)
Pronation	Dorsal (A; DRUL)	0.6 (0.5)	0.6 (0.6)	0.5 (0.5)
	Mid sigmoid notch (B)	0.6 (0.4)	0.7 (0.4)	0.6 (0.4)
	Palmar (C; PRUL)	0.5 (0.7)	0.5 (0.6)	0.5 (0.5)

Abbreviations: DRUJ, distal radioulnar joint; DRUL, dorsal radioulnar ligament; IOM, interosseous membrane; PRUL, palmar radioulnar ligament.

Table 3 Increase in force (N) in the dorsal and palmar radioulnar ligaments following IOM sectioning

Forearm position	Gap location	At extremes of rotation	Common extreme of rotation	Just after extreme position
Supination	Dorsal (A; DRUL)	27.3	30.1	29.7
	Palmar (C; PRUL)	6.2	5.3	2.3
Pronation	Dorsal (A; DRUL)	4.9	6.4	4.5
	Palmar (C; PRUL)	0.8	0.9	0.6

Abbreviations: DRUL, dorsal radioulnar ligament; IOM, interosseous membrane; PRUL, palmar radioulnar ligament.

of a torn IOM should be considered in the presence of persistent DRUJ instability following DRUJ reconstruction.

Location

This study was conducted at Department of Orthopedic Surgery, SUNY Upstate Medical University, 750 E. Adams Street, Syracuse, NY 13210.

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Conflict of Interest

Werner owns stock in Moximed, Inc (unrelated to current study). LeVasseur, Harley, and Anderson report no conflict of interest. The institution of the authors has received funding from Moximed, Inc and from Conventus, Inc.

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