



# A biomechanical study on the interosseous membrane and radial head in cadaveric forearms

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**Objective:** Our aim was to evaluate the biomechanical properties of the interosseous membrane (IOM) and radial head and investigate the pathomechanics of the Essex-Lopresti injury.

**Methods:** Twelve adult fresh frozen upper limbs of human cadavers were chosen for test. First, the 12 intact specimens were mounted onto a materials testing machine to carry out biomechanical tests in pronation, supination and neutral positions, respectively. An axial load of 100 N was applied along the longitudinal axis of the forearm for 30 seconds in each position. Then, the twelve specimens were randomly divided into two groups. The radial head was resected in 6 specimens. And the central band of IOM was severed in another 6 specimens. Each group was tested by the same method. Finally, both the radial head and the IOM were excised in all specimens and biomechanical tests were performed.

**Results:** The rotational position of the forearm or simple severance of the IOM had no effect on longitudinal displacement. The radial longitudinal displacement increased significantly after resection of the radial head. The severance of the IOM had no effect on compressive stiffness of the radius. However, compressive stiffness of the radius decreased significantly after resection of the radial head.

**Conclusion:** The radial head fracture combined with the IOM injury was the most important cause of the Essex-Lopresti injury, and the radial head fracture was the major factor. The IOM was the major structure to maintain the longitudinal stability of the forearm after resection of the radial head.

**Key words:** Biomechanical; Essex-Lopresti injury; forearm; interosseous membrane; radial head.

The interosseous membrane (IOM) is an important structure deep in the forearm that extends from the radius to the ulna, filling the space between, and linking the two bones. It is made up of a membranous portion, a central band, accessory bands, and a proximal interosseous band.<sup>[1]</sup> The Essex-Lopresti injury is a rare simultaneous multiple injury, which consists of fracture of the radial head, rupture of the interosseous membrane, and disruption of the distal radioulnar joint (DRUJ). It accounted for approximately 1% of the radial head fractures.<sup>[2]</sup> Missed diagnosis is clinically

common because IOM cannot be imaged by routine X-ray. Trousdale et al.<sup>[3]</sup> reviewed 20 cases with the Essex-Lopresti injury, of which only 5 cases with IOM injury were accurately diagnosed at first presentation. A missed diagnosis may lead to radial upwards displacement, instability of the DRUJ, weakness of the muscles, chronic pain of the wrist, limitation of the forearm rotation, and dysfunction of the elbow.<sup>[3-6]</sup>

For a better understanding of this kind of injury, many authors have investigated biomechanical properties of the IOM from different perspectives. Wallace et

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al.<sup>[7]</sup> studied the structure and function of the IOM in 11 cadaver preparations. Pfaeffle et al.<sup>[8]</sup> measured proximal radial migration and 3-dimensional force vectors acting in the distal radius, distal ulna, IOM, proximal radius, and proximal ulna with the IOM intact, cut, and reconstructed with single and double flexor carpi radialis allografts in 12 cadaveric forearms. In a biomechanical study, Stabile et al.<sup>[9]</sup> evaluated structural properties of the IOM and several reconstruction constructs. They concluded that all graft constructs tested were structurally inferior to the intact IOM. These studies evaluated biomechanical properties of the IOM. However, the effects of the radial head were not investigated in the meanwhile. The objective of the present study was to evaluate biomechanical properties of both IOM and radial head, and investigate pathomechanics of the Essex-Lopresti injury.

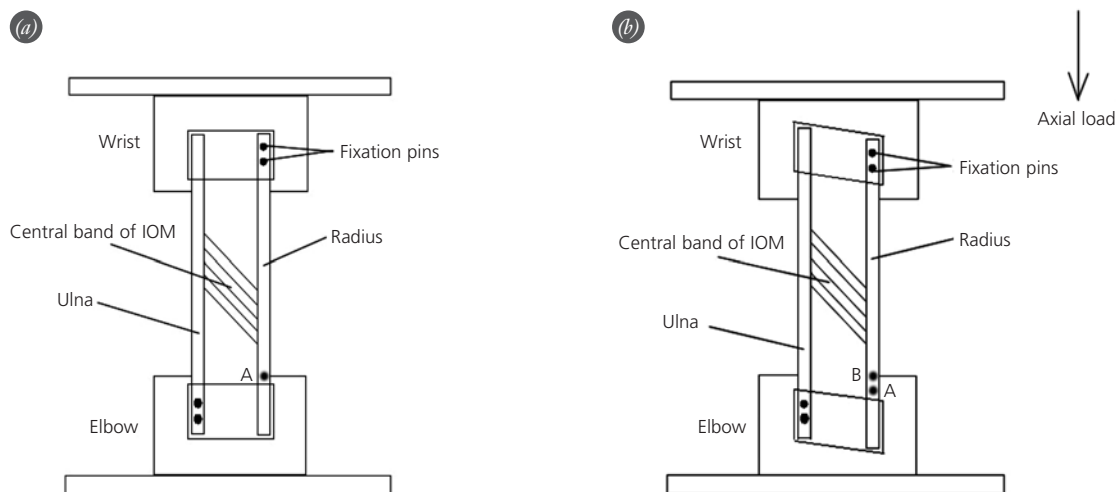
## Materials and methods

Twelve intact adult upper limbs of human cadavers ranging in age from 20 to 54 (mean: 32.7) years were obtained according to the protocols of the Anatomy Department. There were 7 right and 5 left upper limbs. None of the specimens had previous upper-limb injuries. All the specimens were stored fresh frozen at  $-20^{\circ}\text{C}$  until testing. Then, they were thawed at room temperature. The study was approved by the Institutional Review Board.

All the skin, subcutaneous tissue and muscles were removed to expose the shafts of the radius and ulna, while the IOM, the elbow and wrist joints were kept

intact. Amputations of the upper limbs were performed 5 cm above the elbow at the proximal end. Amputations of the wrists were performed at the distal end, while reserving the carpal bones. A Steinman pin of 4 mm in diameter was inserted into the radial marrow cavity from the capitae and lunate bones. Another Steinman pin was inserted into the ulnar marrow cavity from the humeral marrow cavity, with the elbow in extension. The two pins were used to limit the lateral displacement of the wrist and elbow. The specimens were wrapped in saline soaked gauze. Then, they were stored in sealed plastic bags and preserved in refrigerator at  $-30^{\circ}\text{C}$  for future use.

The specimens were taken out from the refrigerator, and then thawed at the room temperature. The twelve specimens with the intact radial head and IOM (named as ‘the intact group’) were fixed to the custom-made mounting frames by pins. Biomechanical tests were performed on a materials testing machine (MTS model 858, Minneapolis, MN, USA) with the forearm in pronation, supination and neutral position respectively (Figs. 1a and b). An axial load of 100 N was constantly applied along the longitudinal axis of the forearm. The load lasted 30 seconds in each position.<sup>[8,10,11]</sup> Then, the 12 specimens were randomly divided into two groups. Each group had 6 specimens. In one group, the radial neck was exposed via the lateral approach and the radial head was resected at the junction of the radial head and neck. The articular capsule was sutured. The annular ligament and IOM were kept intact. This group was named as ‘the head resected



**Fig. 1.** Diagram of the biomechanical test on a materials testing machine. **(a)** A cadaveric forearm in neutral position with the intact radial head and interosseous membrane (IOM) fixed to the custom-made mounting frames by pins. **(b)** An axial load was applied to the wrist along the longitudinal axis of the forearm. The longitudinal displacement of the radius was defined as the distance between points A and B.

group'. In another group, the radial head was kept intact while the central band of IOM was severed when the forearm was in the neutral position. This group was named as 'the IOM severed group'. Each group underwent biomechanical test in pronation, supination and neutral positions, respectively by using the same method. Finally, the radial head was resected and the IOM was severed in all specimens. This group was named as 'the head resected and IOM severed group'. Then, all specimens underwent biomechanical test in pronation, supination and neutral positions. Data were collected and the load-displacement curve was plotted from the records by the materials testing machine. The compressive stiffness was determined according to the load-displacement curve. Using a micrometer with an accuracy of 0.02 mm, we took a direct measurement of the compressive/longitudinal displacement (Figs. 1a and b).

SPSS 13.0 statistical software package (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis of the experimental data. The effects of the anatomical position of the radial head, IOM and the rotational position of the forearm on the radial compressive/longitudinal displacement and compressive stiffness were analyzed by the Student-Newman-Keuls (SNK) test, with a  $p < 0.05$  considered to be statistically significant.

## Results

The radial compressive/longitudinal displacement and compressive stiffness were presented in different anatomical position of the radial head and IOM, and in different rotational position of the forearm (Table 1). The radial longitudinal displacement in 'the head resected and IOM severed group' was larger than that in 'the head resected group' ( $p < 0.05$ ). And the radial

longitudinal displacement in 'the head resected group' was larger than that in 'the IOM severed group' and 'the intact group' ( $p < 0.05$ ). However, there was no statistical difference between 'the IOM severed group' and 'the intact group' ( $p > 0.05$ ). And no statistically significant difference was observed in the radial longitudinal displacement between the pronation and neutral positions in each group ( $p > 0.05$ ). However, the supination position had an effect on the radial longitudinal displacement in 'the head resected group' and 'the head resected and IOM severed group' ( $p < 0.05$ ; Fig. 2).

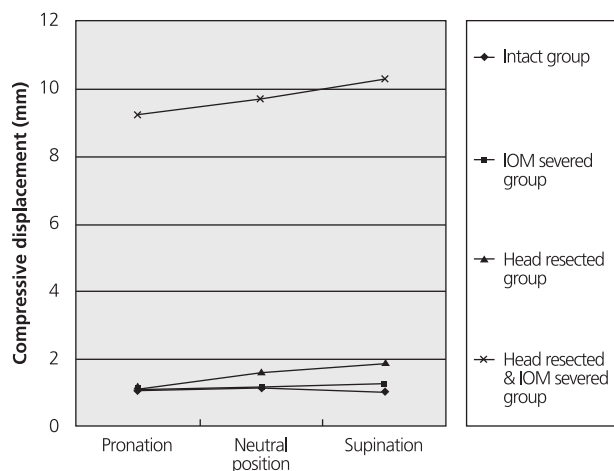
The compressive stiffness in 'the head resected and IOM severed group' was smaller than that in 'the head resected group' ( $p < 0.001$ ). And the compressive stiffness in 'the head resected group' was smaller than that in 'the IOM severed group' and 'the intact group' ( $p < 0.001$ ). However, there was no statistically significant difference between 'the IOM severed group' and 'the intact group' ( $p > 0.05$ ). And no statistically significant difference was observed between the pronation and neutral positions in each group ( $p = 0.06$ ). The compressive stiffness in supination position was larger than that in pronation and neutral positions in each group ( $p < 0.001$ ). The anatomical position of the radial head and rotational position of the forearm had no synergistic effect on the compressive stiffness of the radius ( $p = 0.69$ ; Fig. 3).

## Discussion

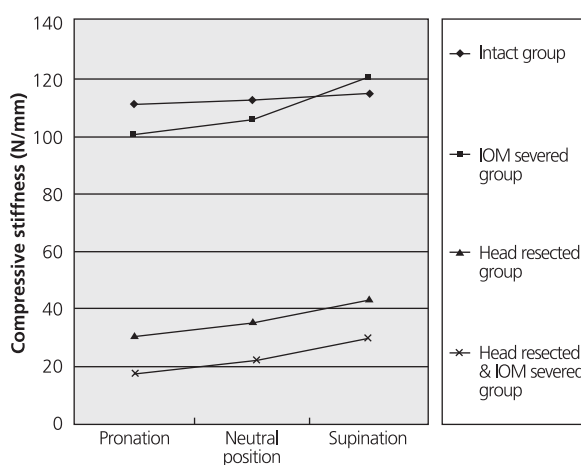
An Essex-Lopresti injury is usually a result of a high-energy fall onto an outstretched hand, creating a longitudinal compression force on the wrist, forearm, and ultimately the elbow. This powerful longitudinal compression force leads to fracture and displacement of the radial head, displacement together with further rup-

**Table 1.** The compressive displacement and stiffness in different anatomic and rotation status of the forearm.

Anatomical position	Rotational position	Compressive displacement (mm)	Compressive stiffness (N/mm)
Intact status (n=12)	Pronation	1.08±0.06	111.23±7.23
	Neutral position	1.15±0.07	112.71±11.10
	Supination	1.05±0.17	114.99±5.10
Reserving head&severing membrane (n=6)	Pronation	1.09±0.03	100.52±0.65
	Neutral position	1.16±0.04	105.72±2.27
	Supination	1.26±0.02	120.40±1.11
Resecting head&reserving membrane (n=6)	Pronation	1.41±0.62	30.97±1.59
	Neutral position	1.63±0.85	35.49±3.42
	Supination	1.89±1.18	43.52±1.49
Resecting head&severing membrane (n=12)	Pronation	9.24±0.08	17.78±2.21
	Neutral position	9.72±0.04	22.14±6.21
	Supination	10.30±0.22	29.93±0.89



**Fig. 2.** Compressive displacement of the radius in different anatomic and rotation status of the forearm (IOM: interosseous membrane).



**Fig. 3.** Compressive stiffness of the radius in different anatomic and rotation status of the forearm (IOM: interosseous membrane).

ture of the IOM.<sup>[9,12]</sup> There may be no obvious damage on the DRUJ in an early stage of the Essex-Lopresti injury, whereas the central band of IOM might be damaged to some extent, leading to radial displacement toward the proximal end.

The IOM is important in compressive load transfer from the wrist to the elbow. At the DRUJ, the radius bears about 80% of a compressive load and the ulna about 20%. At the proximal radioulnar joint, the radius bears about 60% of the force, whereas the ulna bears about 40%.<sup>[13]</sup> These data imply that the IOM is loaded under tension when the forearm is axially loaded. The distal to proximal load transfer from the radius to the ulna takes the burden off the proximal radius and radial head. The IOM also acts in the transverse direction in the forearm to pull the radius and ulna together, thereby decreasing bending stresses in the two bones, and applying stabilizing compressive forces. An intact IOM can help limit proximal migration of the radius when the radial head was resected.<sup>[14-16]</sup>

The results of our study demonstrated that severance of the central band of IOM had little effect on the longitudinal displacement of the radius and the longitudinal stability of the forearm when the radius and ulna remained intact. However, longitudinal displacement of the radius increased significantly and longitudinal stability of the forearm decreased obviously after resection of the radial head. It indicated that the radius head was the major structure for maintaining longitudinal stability of the forearm. This conclusion was consistent with the results of some previous studies.<sup>[17,18]</sup> The alteration would be more obvious if the central band of IOM was severed. It demonstrated that the central band of IOM

was the major structure for maintaining longitudinal stability of the forearm after resection of the radial head. Hotchkiss et al.<sup>[19]</sup> found that the central band of the IOM was responsible for 71% of the total longitudinal stiffness of the IOM after radial head excision. Rabinowitz et al.<sup>[20]</sup> demonstrated that the central portion of the IOM is the crucial structure acting as a restraint to the proximal radial migration. In a cadaveric study, Wallace et al.<sup>[7]</sup> also found that the central band of the IOM was the primary restraint to proximal migration of the radius after radial head resection. The results are generally comparable to our results

Several studies have examined the strain and load distribution of the IOM in relation to the forearm rotation. Pfaeffle et al.<sup>[8]</sup> demonstrated that the IOM was involved not only in the longitudinal load transfer, but also in the maintenance of transverse stability of the forearm. Manson et al.<sup>[21]</sup> found that strain distribution of the IOM changed with the forearm rotation, and the highest strain was observed in neutral rotation. In this study, we investigated biomechanical properties of the IOM and radial head in different anatomical and rotational positions of the forearm. We found that the rotational position of the forearm had an effect on compressive stiffness of the radius, whereas it had no effect on radial longitudinal displacement. The compressive stiffness in supination was larger than that in pronation and neutral positions in each group. The anatomical position of the radial head and rotational position of the forearm had no synergistic effect on compressive stiffness of the radius. These findings demonstrated that the Essex-Lopresti injury was not merely caused by the longitudinal force, and it might also have involved rotational violence.

However, the present study had several limitations. In order to limit lateral displacement of the wrist and elbow, two Steinman pins were inserted into the distal radial and proximal ulnar marrow cavities. Whether it had an impact on the results of the study remains unknown. And the biomechanical tests were performed only with the axial load. No other form of load was tested. These problems are worthy of further investigation.

In conclusion, the present study evaluated biomechanical properties of both IOM and radial head in different anatomical and rotational positions of the forearm, and demonstrated that the radial head fracture combined with the IOM injury was an important cause of the Essex-Lopresti injury, and the radial head fracture was the major factor. The IOM was the major structure to maintain the longitudinal stability of the forearm after resection of the radial head.

**Conflicts of Interest:** No conflicts declared.

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