Interosseous Membrane of the Forearm

Robert Matthias, MD¹ Thomas W. Wright, MD²

¹Department of Orthopaedics and Rehabilitation, University of Florida, Gainesville, Florida

²Orthopaedics and Sports Medicine Institute, University of Florida, Gainesville, Florida

Address for correspondence Thomas W. Wright, MD, Orthopaedics and Sports Medicine Institute, University of Florida, 3450 Hull Road, Gainesville, FL 32611 (e-mail: wrightw@ortho.ufl.edu).

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Abstract

Keywords

- ▶ central band
- ▶ distal radial ulnar joint
- ▶ Essex–Lopresti injury
- ▶ interosseous membrane
- ▶ proximal radial ulnar joint

Background Injuries of the interosseous membrane (IOM) of the forearm are frequently unrecognized, difficult to treat, and can result in a devastating sequelae for the wrist and elbow.

Purpose The purpose of this review article is to evaluate the diagnosis, biomechanics, clinical results, and propose a treatment approach to this rare complex entity.

Methods The biomechanical and clinical literature is reviewed. A treatment approach is described based on the known biomechanics and clinical experience of the senior author (T. W. W.).

Results Multiple different reconstructive methods have been proposed for the treatment of both acute and chronic IOM injuries. The results of the published series are reviewed. IOM injuries can have reasonable outcomes particularly if diagnosed and treated early.

Conclusion There are multiple methods for treating patients with IOM injuries. Physicians should be highly suspicious about this injury when a patient presents with a highly displaced radial head fracture associated with wrist pain. Treatment with reconstruction of the central band of the IOM with radial head replacement (do not overstuff) and temporary uploading the construct with K-wires from the ulna to the radius will give the most predictable results.

The human forearm is uniquely adapted to bear significant load while it rotates nearly 180 degrees. This allows humans to place the hand virtually anywhere in space. To accomplish this remarkable task, the radius and ulna must articulate at both the ends, through the proximal radial ulnar joint (PRUJ) and the distal radial ulnar joint (DRUJ). This entire construct is held together by the intricate interosseous membrane (IOM) complex, which includes the IOM proper and critical central band (CB), the distal oblique ligament, and ligamentous support about both the PRUJ and DRUJ.

An Essex–Lopresti injury is an injury to the IOM that is fortunately rare. However, when an IOM injury does occur the sequella can be devastating to the function of the forearm and the entire upper limb. A dysfunctional IOM allows for radial

shortening, radial capitellar impingement and arthritis, ulnar impaction of the carpus, and loss of the beautiful rotation of the radius about the ulna.

This article reviews the known IOM anatomy and biomechanics. It then evaluates the different treatment methods for management of acute and chronic IOM injuries. Finally, the senior author (T. W. W.) presents his technique for treating this very complex and daunting injury.

Anatomy

Understanding the anatomy of the IOM is possible only when the anatomy of the forearm in its entirety is considered. The forearm is a complex structure consisting of two bones (the radius and ulna), two articulating joints between them, the PRUJ and DRUJ,

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ligaments, joint capsules, the triangular fibrocartilage complex (TFCC), and the IOM. Each of these structures imparts some degree of forearm stability. Stabilizers of the forearm exist proximally, centrally, and distally.

In addition to these essentially static restraints, stability of the forearm is also affected by the dynamic contributions of the muscles of the forearm, both those that originate from the IOM and those that do not. The muscles are oriented obliquely from the ulna to the radius and load the distal radius through the hand-wrist unit.¹ These muscles can also load the IOM, providing stability by pulling the radius and ulna together.²

The anatomy of the IOM has been studied by numerous authors. All agree on the basics of the anatomy, but a consensus in several areas—the names of specific portions of the IOM, the exact insertion sites, and the biomechanical functions—has not been reached. The proximal and distal sections of the IOM are more ligamentous than the central section. Not all structures of the IOM that have been described are found universally in each cadaver specimen. Each portion is anatomically and functionally unique in its contribution to the IOM.

Proximal

The proximal portion of the IOM was described by Noda et al as having two components: the proximal oblique cord and the dorsal oblique accessory cord. The proximal oblique cord, also known as the ligament of Weitbrecht,^{3,4} originates from the anterolateral aspect of the coronoid, lies on the surface of the biceps tendon, and inserts just distal to the radial tuberosity. The dorsal oblique accessory cord originates in the distal ulna at approximately the junction of the proximal one-third and distal two-third and inserts on the interosseous crest of the radius. This cord lies deep to the abductor pollicis longus muscle.⁵

Middle

The middle portion of the IOM is comprised of the CB and an accessory band (AB). The CB is the widest and thickest ligament of the middle portion and the IOM. The CB originates in the interosseous crest of the radius and inserts more distal on the interosseous border of the ulna. Skahen et al reported that the fibers of the CB are oriented distally and ulnarly at an angle 21 degrees to the longitudinal axis of the forearm.⁶ The CB is the best studied and described portion of the IOM and is found universally in study specimens.

Histologically, the CB has features of both a ligament and a tendon. The histology is similar to a tendon with a collagen arranged in an orderly manner with a surrounding elastin sheath. With both an origin and an insertion on bone, the CB is similar to a ligament.⁷

The ABs vary in number and can be found essentially paralleling the CB in the same plane either proximally or distally. Fibers are more commonly found distal to the CB and tend to be stouter than fibers found proximal to the CB.⁵ However, none of these structures is as stout as the CB proper.

Distal

The distal portion of the IOM underlies the pronator quadratus muscle and is made of a membranous tissue and a thicker, more ligamentous structure called the distal oblique bundle (DOB). The DOB is found in the same plane but is distal to the CB and AB. It is not found in all specimens. It originates in the distal one-sixth of the ulnar shaft and inserts along the inferior edge for the sigmoid notch. Fibers of the DOB extend distally both volarly and dorsally until they blend into the fibers of the volar and dorsal distal radioulnar joint ligaments of the TFCC.⁵

The innervation and vascular supply to the IOM comes from the anterior and posterior interosseous nerves and arteries. These structures run longitudinally along the anterior and posterior surfaces of the IOM midway between the radius and ulna. Both vessels, the anterior being larger, send perforating vessels to the IOM and the radius and ulna.¹

Biomechanics

The IOM serves several important biomechanical functions.

1. Transmits load from the wrist to the elbow
2. Transfers load from the radius to the ulna
3. Maintains forearm stability
4. Helps maintain DRUJ stability

Load

In an ulnar-neutral wrist under normal conditions, 80% of the axial load is transmitted through the radiocarpal joint while 20% is transmitted through the ulnocarpal joint. As this force is transmitted proximally, the interosseous membrane transfers some of the load from the radius to the ulna so that at the elbow 60 to 70% of the axial load is borne by the radio-capitellar joint and 30 to 40% by the ulnohumeral joint.^{8,9}

The load properties of the IOM under pathologic conditions have been studied with varied results and limitations. Some studies have been performed with an intact radial head, others with the radial head excised or with the elbow in varus, limiting radial head contact with the capitellum. No functional system of measuring active loading of the forearm has been designed, so all biomechanical studies to date have been performed with passive loading of the wrist, a technique that less closely simulates in vivo forces.

Hall and Travill first measured force transmission through the IOM with the radial head intact.¹⁰ They concluded that no significant force was transmitted through the IOM when the forearm was loaded. Markolf et al demonstrated that positioning of the forearm and elbow in the coronal plane affects IOM loading and confirmed transfer of load from the radius to ulna by the IOM.¹¹ When the forearm was loaded with the elbow in valgus, the average force was 2.8% at the distal ulna (97.2% distal radius) and 11.8% at the proximal ulna (89.2% proximal radius). When the forearm was loaded with the elbow in varus with no contact between the radius and capitellum, the average force was 7% at the distal ulna (97% distal radius) and 93% at the proximal ulna (7% proximal radius). Hotchkiss et al excised the radial head from 12

cadaver forearms and loaded them longitudinally.¹² Without a radial head, 8% of forearm stiffness was from the TFCC, and 71% was from the CB of the IOM. The authors also found that without a radial head, 90% of the axial load through the forearm was borne by the IOM. Finally, Birkbeck et al transected the IOM and loaded the forearm. They found that with no functional IOM, the radius and ulna bear load separately and independently with no transfer of load between them.^{1,8}

Forearm Stability

The forearm is a dynamic structure with complex requirements for longitudinal and transverse stability. This stability must be maintained through varying degrees of pronation/supination, and wrist and elbow range of motion as external and internal forces are exerted.

Longitudinal stability of the forearm is most important in pathologic conditions. IOM dysfunction, particularly in the face of a fractured or absent radial head, can lead to proximal migration of the radius. Rabinowitz et al demonstrated that the radial head was the primary restraint to proximal migration of the radius.¹³ With the radial head excised and the IOM and TFCC intact, little proximal migration of the proximal radius occurred when an axial load was applied. When the radial head was excised and the IOM and TFCC were not intact, an axial load resulted in proximal migration of the radius, radial-capitellar abutment, and transfer of load back to the radius. Morrey et al demonstrated these findings clinically.¹⁴ In a long-term study of patients following radial head excision, only 1.9 mm of proximal migration of the radius was noted with greater migration prevented by an intact IOM.

The IOM also provides transverse stability to the forearm. The force vectors pull the radius and ulna toward each other, preventing splaying of the two bones.² This occurs because of the orientation of the IOM fibers. As the radius migrates proximally under load, the transverse distance between the origin and insertion of the IOM decreases, effectively pulling the two bones together.

DRUJ Stability

Most studies of the IOM have focused on the CB. More recently, the importance of the distal portion of the IOM has been evaluated. In an anatomic study, Noda et al found a discreet, thick, fibrous portion of the distal IOM he termed the DOB. Its fibers originated in the distal ulnar shaft, blended into the DRUJ capsule, and inserted into the inferior rim of the sigmoid notch. Some fibers also extended to the distal volar and dorsal radiocarpal ligaments. The presence of the DOB is not universal. In cadaver studies it has been found consistently in approximately 40% of specimens.^{5,15}

Functionally, Moritomo et al found that the DOB is "an isometric collateral ligament with the TFCC."¹⁶ Kitamura et al demonstrated that cadaver specimens with a DOB had significantly greater DRUJ stability when stressed than when not stressed.¹⁷ Watanabe et al evaluated cadaver forearms in varying degrees of pronation and supination and found that the distal IOM contributed to DRUJ stability in all positions.¹⁸ They also found that for dorsal DRUJ disloca-

tion to occur, both the TFCC and the distal IOM must be disrupted. Arimitsu et al evaluated the stabilizing effect of the DOB following ulnar shortening osteotomy.¹⁵ They performed two types of ulnar shortening osteotomies—one proximal and one distal to the origin of the DOB. They found that osteotomies proximal to the DOB origin tightened the DOB and resulted in less DRUJ laxity throughout full pronation and supination when compared with osteotomies performed distally.

Clinically, Rigenbach et al performed a biomechanical study of a novel technique for DOB reconstruction.^{19,20} They restored DRUJ stability in cadaver specimens using a tendon graft to recreate the DOB. This technique has been used clinically, with good early results reported (Dell [Gainesville, Florida], personal oral communication, March 28, 2016). Using another technique for DOB reconstruction for patients with DRUJ instability, Hannemann and Brink successfully restored DRUJ stability to 13 out of 14 patients with "bidirectional instability of the DRUJ" and a minimum of 16-months follow-up.²¹

Treatment

The majority of IOM injuries are missed on acute presentation.²² The mechanism of injury is a fall on the outstretched hand with load propagating up the forearm tearing the distal oblique ligament, the IOM, and the supporting structures of the DRUJ, and the PRUJ, finally resulting in a highly displaced and comminuted radial head fracture. The degree of radial head displacement should be a warning sign that this injury represents more than a simple radial head fracture. Simple excision of the radial head or replacement alone of the radial head without treating the IOM results in failure.

Some other clues to the possibility of an IOM injury are the presence of concomitant wrist pain, an unstable DRUJ on examination, or a large ulnar plus deformity on wrist X-ray. Both MRI and ultrasound have been used in the definitive diagnosis of an Essex-Lopresti injury.^{23,24} Kachooei et al demonstrated a definitive technique of recognizing an IOM injury by measuring the amount of proximal radius lateral displacement.²⁵ They showed that 5.5 mm of lateral displacement with the elbow in supination and extension was associated with an IOM injury.²⁵ After radial head fracture and excision with an intact IOM the radial neck should be able to be displaced by 2 mm distally. If the radial neck can be displaced significantly more than 2 mm distally, and certainly if it can be displaced 5 mm,²⁶ the surgeon should highly suspect an Essex-Lopresti injury. It is the authors' belief, and there are some data to support, that the best opportunity to get a good result with this injury is acutely with the first operation; the biology of healing is on the side of the surgeon and multiple operations have never been in the best interest of the patient. Grassman et al treated 12 acute Essex-Lopresti injuries with radial head reconstruction or replacement and reduction of the DRUJ and pinning with a final outcome at 59 months showing a Mayo elbow performance score of 87.²⁴ However, Gong et al report a failure of the IOM to heal in a patient treated with a bipolar radial head and pinning of the

Fig. 1 (A) A 28-year-old male patient injured in high-energy fall—AP forearm demonstrates a displaced radial head and dislocated DRUJ consistent with an Essex–Lopresti injury. (B) Lateral of the forearm of the same patient as ▶Fig. 1A. (C) AP wrist showing the markedly ulnar plus deformity secondary to injury to the IOM. AP, anteroposterior; DRUJ, distal radial ulnar joint; IOM, interosseous membrane.

DRUJ.²⁷ Brin et al describe a minimally invasive treatment method for acute IOM injuries using an Arthrex tightrope device (Arthrex, Naples, FL).²⁸ The advantage of treating the acute Essex–Lopresti injury is that the radius has not had time to migrate proximally and become fixed in that position, which occurs in the chronic setting. ▶Figs. 1 and 2 present a case of an acute Essex–Lopresti injury treated in a similar fashion as just outlined (▶Figs. 1 and 2).

Chronic Essex–Lopresti injuries are very complex as the radius has migrated proximally, the capitellum may have been overloaded and severely arthritic, and the DRUJ is chronically dislocated with distal ulna impaction on the carpus. In most chronic cases any reconstruction needs to be performed concomitantly with a joint-leveling procedure, usually an ulna shortening. Multiple types of grafts have been described to reconstruct the central band of the IOM including autograft or allograft patellar bone tendon bone,^{29–31} palmaris longus, and synthetic grafts,³² to name a few.

Fig. 2 (A) Ulnar variance of same patient as in ▶Fig. 1, 1-year postoperatively, treated acutely with reconstruction of the IOM with semitendinosus allograft, tight rope, distal pinning, and radial head replacement. Note that this patient is only slightly ulnar positive. (B) Lateral 1-year postoperative image of the elbow with the radial head well centered. (C) AP of the elbow 1-year postoperatively. There is no overstuffing of the radial head and no significant capitellar erosion at this point. AP, anteroposterior; IOM, interosseous membrane.

Regarding chronic Essex–Lopresti injuries, there is a general consensus that the IOM needs to be reconstructed and the DRUJ needs to be leveled; however, what to do at the PRUJ, radiocapitellar joint, and DRUJ is not as well elucidated. In the ideal setting the radial head would be replaced, taking care not to overstuff the radiocapitellar joint; however, this is frequently not the case as these patients often have had a previous radial head replacement that has failed and destroyed the capitellum. If the capitellum has been severely compromised, radial head resection of the previously failed prosthesis may be all that can be done, recognizing that the reconstructed IOM will now bear more load. An additional issue is the DRUJ that has been chronically dislocated. Once the DRUJ is leveled after the ulnar shortening osteotomy, should it merely be pinned, or should the TFCC be repaired if present or the volar and dorsal DRUJ ligaments reconstructed? There is no compelling data to guide the surgical management of the chronic DRUJ dislocation.

Senior Author's (T. W. W.) Preferred Treatment

Diagnosis of acute IOM injuries rarely occurs in our clinics as most present after previous surgery. Nevertheless, in the rare situation in which we have an acute Essex–Lopresti injury I recommend repairing or replacing the radial head, taking care not to overstuff the radiocapitellar joint. I do not use a bipolar implant as they do not provide adequate stability for this particular injury. I then unload the injured IOM by using either a tight rope (Arthrex) or, more recently, a fiber tape and double dog bone (Arthrex) reconstruction, essentially suspending the radius from the ulna. The advantage of these synthetic devices is that they are minimally invasive. I repair the TFCC and cross-pin the DRUJ just proximal to the joint using two 0.062 Kirschner wires that penetrate all four cortices in case they break. The Kirschner wires are removed after 8 weeks.

In the chronic setting the IOM no longer has any biological potential to heal. In the setting of a chronic Essex–Lopresti injury, I perform an ulnar shortening osteotomy, and subsequently address the radial capitellar joint that in most cases already has a failed radial head implant with severe capitellar arthritis. If a failed radial head is present then I remove

it and look at the capitellum; if it is abnormal (it always is) then no attempt to place a radial head is made. Next, the reduced DRUJ is cross-pinned as described above in supination. A 2-cm incision along the subcutaneous border of the ulna is developed down to bone at the junction of the distal one-third and proximal two-thirds of the ulna. A line angled proximally to the radius is then drawn at 21 degrees from the longitudinal axis of the ulna. This replicates the anatomy of the central band of the IOM. A guide pin is drilled from this point through the ulna and through the radius. A 1-cm incision is made over the radius over the guide pin once the surgeon is satisfied with the position of the pin, taking care not to injure the radial sensory nerve. A cannulated drill is then drilled over the guide pin. A plastic cannula (straw) is placed over the drill and follows the drill as it is withdrawn; this can be a little tricky. A suture passer is placed through the cannula and a loop of fiber tape is shuttled through both the ulna and radius. The loop of fiber tape is placed over a dog bone on the radius and tensioned and tied over a dog bone on the ulna. The biggest problem with this minimally invasive technique is the prominence of the fiber tape knot on the ulnar border. One to 2 cm proximal or distal to this fiber tape reconstruction, depending on where the ulna shortening plate ends, a second parallel tunnel through both the ulna and radius is performed in the exact same manner just described. Through this tunnel either a palmaris longus autograft or, in my hands, a semitendinosis allograft is shuttled, tensioned, and sutured to itself on both the radius and ulna. In this manner the synthetic reconstructed IOM unloads the biologic reconstructed IOM, giving it time to heal and be the permanent solution. The surgeon can then repair the TFCC, which at this point is often atrophic, reconstruct the DRUJ ligaments with allograft, or simply leave the joint pinned and reduced and do nothing. **Fig. 3** illustrates a chronic Essex–Lopresti injury treated in this manner (**Fig. 3**).

This minimally invasive synthetic unloading of the acute IOM injuries and the more complex reconstruction of the chronic injuries have worked well in a limited series of patients in my experience. These patients are made substantially better with decreased elbow and wrist pain but are still far from being normal. I have not had to salvage any of these patients to date with further procedures, including the ultimate salvage—a one-bone forearm.

Conclusion

An understanding of the sophisticated anatomy and biomechanics of the forearm–IOM complex has made great progress over the last decade. With this knowledge the surgeon can now treat this rare but at one time hopeless Essex–Lopresti injury with a reasonable expected outcome. The challenge is to recognize the acute injury and treat it aggressively before the radius can migrate proximally, the capitellum is destroyed, or the ulna impacts on the carpus. However, even in late, unrecognized cases of failed radial head replacement there are viable salvage options without having to resort to the debilitating one-bone forearm procedure.

Fig. 3 (A) Lateral radiograph of a chronic Essex–Lopresti injury s/p five procedures, 2 years after the last procedure, which was excision of the failed radial head implant, reconstruction of the IOM with semitendinosis allograft, fibertape double dog bones, ulnar shortening, and DRUJ ligament reconstruction with allograft semitendinosis. (B) AP forearm of the same patient 2 years postoperatively. She reports little to no pain in the wrist and elbow but poor forearm rotation. AP, anteroposterior; DRUJ, distal radial ulnar joint; IOM, interosseous membrane; s/p, status post.

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Conflict of Interest

None.

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