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Suture button reconstruction of the central band of the interosseous membrane in Essex-Lopresti lesions: a comparative biomechanical investigation

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Abstract

Surgical reconstruction of the interosseous membrane may restore longitudinal forearm stability in Essex-Lopresti lesions. This study aimed to compare the longitudinal stability of the intact forearm with a single-bundle and a double-bundle reconstruction of the central band of the interosseous membrane using digital image correlation with a three-dimensional camera system. Single and cyclic axial loading of eight fresh-frozen forearm specimens was carried out in the intact state, after creation of an Essex-Lopresti lesion, after a single-bundle and after a double-bundle reconstruction of the central band using a TightRope® (Arthrex GmbH, Munich, Germany) construct. Instability significantly increased after creation of an Essex-Lopresti lesion. The stability of intact specimens was similar to both reconstruction techniques. The results of this study suggest that TightRope® reconstruction of the central band restores longitudinal forearm stability. However, the single-bundle technique may be less reliable than double-bundle reconstruction.

Level of evidence: Basic Science Study

Keywords

Essex-Lopresti injury, longitudinal forearm instability, interosseous membrane, reconstruction, TightRope, biomechanics

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Introduction

The combination injury consisting of rupture of the interosseous membrane, fracture of the radial head and distal radio-ulnar dissociation causes longitudinal forearm instability. It is named after Peter Essex-Lopresti (1951) who reported two cases. It represents a complex injury with potentially persisting disability (Trousdale et al., 1992; Wegmann et al., 2014). Even after reconstruction of the radial head, proximal migration of the radius with subsequent radio-capitellar impingement occurs as a result of the ruptured interosseous membrane and the dissociation of the distal radio-ulnar joint (de Vries et al., 2017; Jones et al., 2012; Kam et al., 2010; Tomaino et al., 2003). The central band is the main structure within the interosseous membrane preventing proximal radial migration (Skahen et al., 1997a). Hence, reconstruction of the interosseous membrane in Essex-Lopresti lesions has focused on the central band (Dayan et al., 2017; Drake et al., 2010; Jones et al., 2012; Kam et al., 2010; Pfaeffle et al., 2005; Sabo and Watts, 2012; Skahen et al.,

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1997b; Tejwani et al., 2005a, 2005b; Tomaino et al., 2003).

The aim of this in-vitro biomechanical study was to compare the longitudinal stability of the intact forearm over the full range of motion with a single-bundle and a double-bundle TightRope® (Arthrex GmbH, Munich, Germany) reconstruction of the central band using digital image correlation with a 3D camera system. We hypothesized that: the intact forearm would provide better longitudinal stability during forearm rotation than the reconstruction techniques; and that a double-bundle technique would provide better longitudinal stability than a single-bundle reconstruction.

Methods

Specimen dissection

Eight fresh-frozen forearm specimens were available for this study. The mean age of donors was 82.5 years (SD 1.8; range 80–84). Four left-sided and four right-sided specimens were used. Four specimens were from female and four from male donors. The specimens were stored at −20 °C and were thawed at room temperature approximately 24 h before dissection. The specimens were disarticulated at the wrist and at the elbow before the soft tissues surrounding the forearm were removed through a dorsal approach to the ulna. Care was taken to leave the interosseous membrane and the proximal and distal radio-ulnar joints intact. Fluoroscopic and macroscopic examinations confirmed normal anatomy of the specimens.

Biomechanical setup and testing of intact specimens

Biomechanical testing of specimens was done using a universal testing machine (Z010, Zwick/Roell, Ulm, Germany). Immediately after dissection, the intact specimens were mounted vertically on the testing machine by securing the ulnar shaft to the custom-made testing fixture with three to four bolts, depending on the length of the ulna. The testing fixture allowed for full forearm rotation and preservation of vertical positioning of the radius. The distal radius was fixed to the mobile traverse of the testing machine, and downward movement of the traverse thus resulted in proximal migratory forces of the radius (Figures 1 and 2(a)). The intact specimens were subjected to one cycle of single axial loading from −10 N (distraction) to +130 N (compression) at a crosshead speed of the mobile traverse of 1 mm/s in neutral rotation, in full supination and full pronation. After single loading, the specimens were cyclically loaded for 1000 cycles (each cycle from −10 N of distraction to 130 N of compression) in neutral rotation.

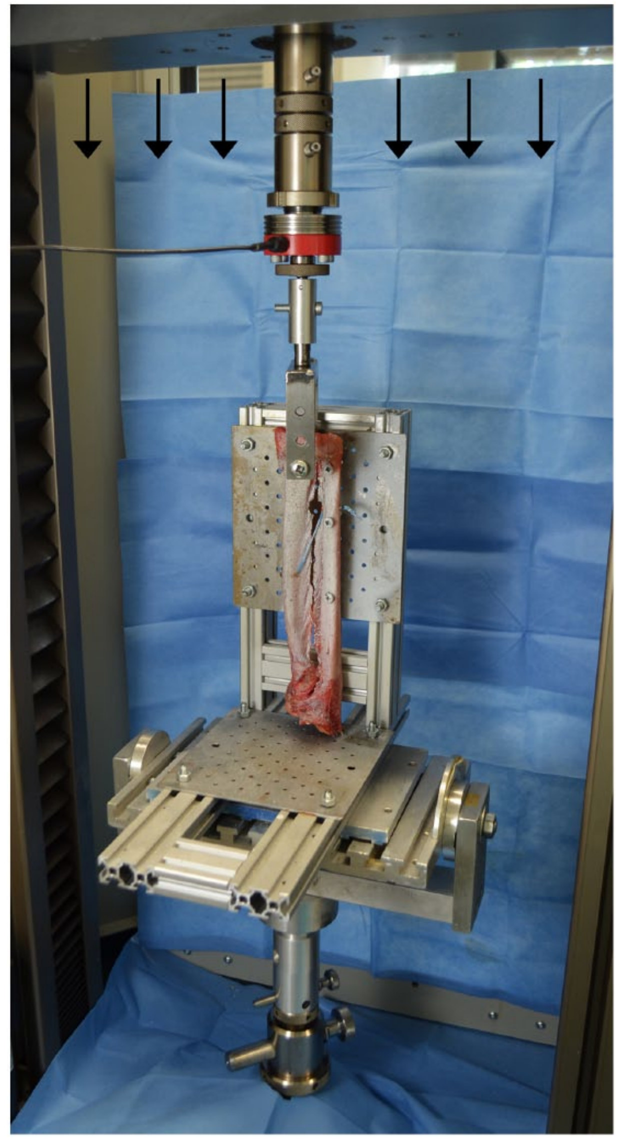

Figure 1. Biomechanical testing setup. The specimens are mounted vertically on the testing machine (Z010, Zwick/Roell, Ulm, Germany) by securing the ulnar shaft to the custom-made testing fixture. The testing rig allows full forearm rotation with vertical positioning of the radius. The distal radius is fixed to the mobile traverse of the testing machine and downward movement of the traverse thus results in axial loading (from −10 to +130 N) with proximal migration of the radius (black arrows).

Creation of an Essex-Lopresti lesion

After testing of the intact specimens, the deep and superficial fibres of the triangular fibrocartilage complex were detached from the styloid process and the ulnar fovea. The interosseous membrane was

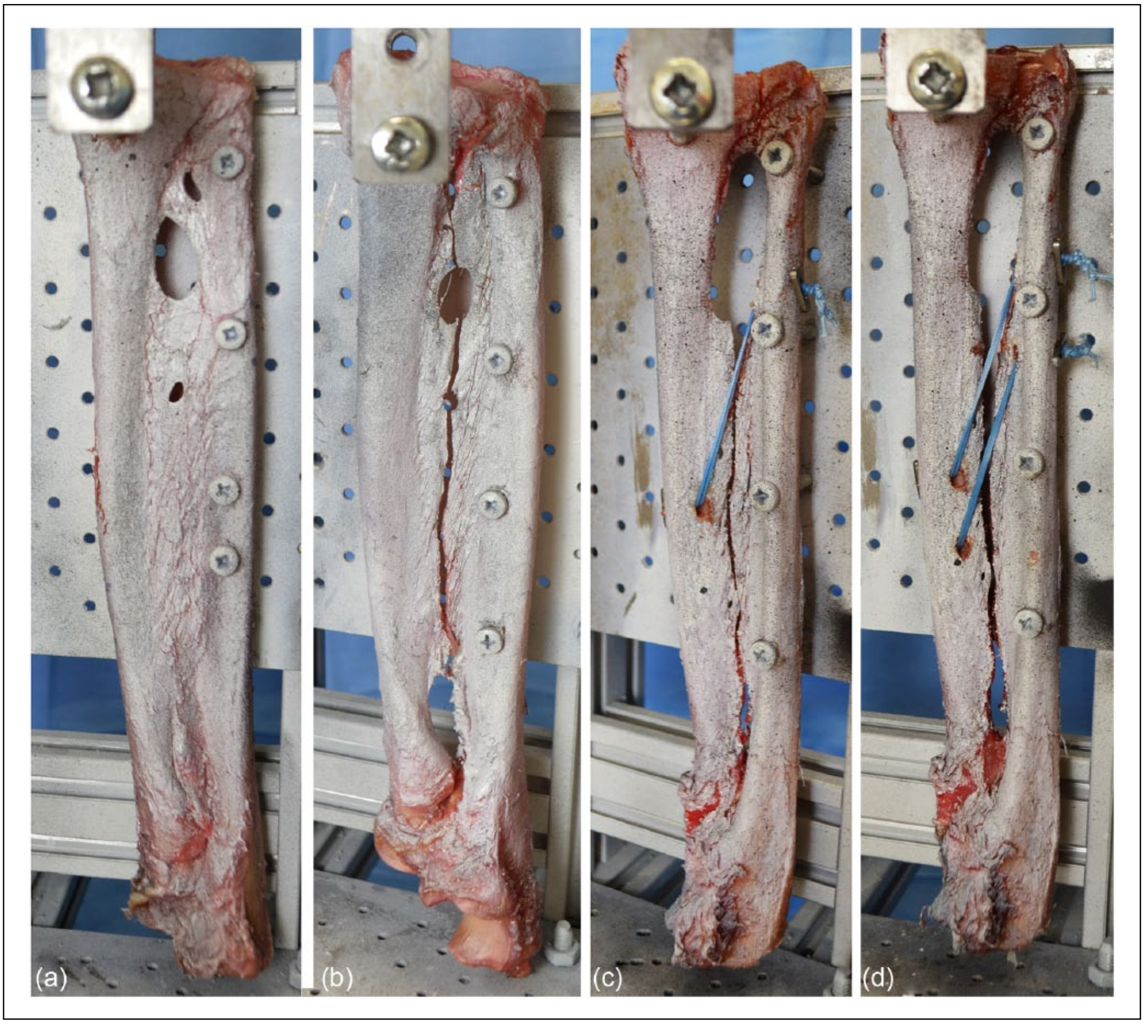

Figure 2. Test groups. (a) Intact specimens; (b) simulated Essex-Lopresti lesion; (c) single-bundle reconstruction; (d) double-bundle reconstruction.

transected with a scalpel to simulate an Essex-Lopresti lesion. Since we aimed to analyse the effect of the interosseous membrane and the distal radio-ulnar joint on longitudinal forearm stability, only forearm specimens were used for this study. Radiocapitellar compression was not investigated and the radial head was therefore not excised. The specimens were subjected to single loading from –10 to +130 N at 1 mm/s in neutral rotation to verify a significant increase in proximal migration (Figure 2(b)).

Single-bundle reconstruction

The central band was subsequently reconstructed with a single-bundle TightRope© technique in full supination (Figure 2(c)). Bicortical 2.8 mm holes were drilled at the origin of the central band at the distal ulnar shaft and at its insertion at the radial shaft. A FiberWire #0 (Arthrex GmbH, Germany) was looped through a BicepsButton™ (Arthrex GmbH, Germany) and then passed through the ulnar drill hole, placing the BicepsButton™ at the ulnar side of the drill hole. The FiberWire was then passed through the radial drill hole and tied down with seven knots onto another BicepsButton™ at the radial side of the drill hole. A constant tension of 20 N was applied using a manual tensiometer to ascertain identical tensioning of the central band reconstruction. The central band is shortest in supination (Farr et al., 2015; Malone et al., 2015) and reconstruction in this position thus provides the best possible stability. Biomechanical testing was then done in the same way as described for the intact specimens.

Double-bundle reconstruction

Finally, the central band was reconstructed with a double-bundle technique (Figure 2(d)): the previously placed TightRope® construct was replaced and an additional TightRope® was placed 1 cm proximal and parallel to the first one. Widening of the drill tunnels after previous cyclic loading of the single-bundle repair was excluded by inspection. Once again, primary and cyclic loading was carried out as described for intact specimens.

Digital data analysis

The total proximal migration of the radius after applying a compression force of 130 N (starting at –10 N of distraction) after single and cyclic loading was measured using a three-dimensional camera system (Q-400-3D, LIMESS Measurement and Software GmbH, Krefeld, Germany). Two monochrome digital cameras recorded micromotion of the radius and proximal migration was analysed through digital image correlation with the use of the Istra 4D software (Dantec Dynamics A/S, Skovlunde, Denmark). Digital image correlation relies on a speckle pattern on the surface of the specimen being examined. Therefore, the forearms were first homogeneously covered with white paint before small droplets of black paint were applied. Proximal migration of the radius in relation to the ulna can thereby be precisely evaluated by the change in distance of corresponding image points during single and cyclic loading (resolution: 2452 × 2052 pixel; accuracy: 0.01 pixel; accuracy of displacement: 1 μm).

Statistical analysis

The mean, minimum, maximum values and standard deviation of proximal radial migration are stated in millimetres. The normal distribution of data was confirmed by use of the Levene test, used to assess the equality of variances regarding a variable for more than one group. A one-way analysis of variance with a post-hoc Scheffé test was done to determine significant differences between groups after single and cyclic loading. The Scheffé method is a tool to adjust the level of significance for multiple comparisons in a linear regression analysis. The level of significance was $p \leq 0.05$.

Results

Single loading

In neutral rotation, the proximal migration of the radius was 0.9 mm (SD 0.2; range 0.7–1.2) for intact specimens, 4.3 mm (SD 1.0; range 2.1–5.2) after simulation of an Essex-Lopresti lesion, 1.1 mm (SD 0.6; range 0.6–2.5) after a single-bundle reconstruction and 0.7 mm (SD 0.2; range 0.4–0.9) after double-bundle reconstruction. Longitudinal forearm instability significantly increased following transection of the interosseous membrane and the triangular fibrocartilage complex ($p < 0.001$). Proximal migration of the radius after double-bundle reconstruction was significantly less than in intact specimens ($p = 0.02$). There was no significant difference in longitudinal forearm stability either between the intact specimens and the single-bundle technique ($p = 0.39$) or between the single-bundle and double-bundle reconstructions ($p = 0.06$).

In supination, proximal migration was 0.9 mm (SD 0.2; range 0.7–1.1) for intact specimens, 1.3 mm (SD 0.6; range 0.8–2.4) after single-bundle reconstruction and 0.9 mm (SD 0.5; range 0.5–1.9) after double-bundle reconstruction. None of the groups differed significantly from each other ($0.13 \leq p \leq 0.92$).

In pronation, proximal migration of the radius was 1.0 mm (SD 0.2; range 0.6–1.2) for intact specimens, 1.5 mm (SD 1.1; range 0.8–3.9) after single-bundle reconstruction and 0.9 mm (SD 0.3; range 0.5–1.3) after double-bundle reconstruction. Once again, no significant differences were observed ($0.16 \leq p \leq 0.63$).

Forearm rotation did not affect longitudinal forearm stability in intact specimens ($0.11 \leq p \leq 0.62$) or after single-bundle ($0.43 \leq p \leq 0.71$) or double-bundle reconstruction ($0.11 \leq p \leq 0.92$).

Cyclic loading

After cyclic loading, proximal migration of the radius was 0.9 mm (SD 0.2; range 0.5–1.2) for intact specimens, 1.2 mm (SD 0.8; range 0.6–3.0) after single-bundle reconstruction and 0.7 mm (SD 0.2; range 0.5–1.0) after double-bundle reconstruction. No significant differences were observed between the groups ($0.09 \leq p \leq 0.41$). Longitudinal forearm instability did not significantly increase after cyclic loading when compared with single loading (native specimens: $p = 0.89$, single-bundle technique: $p = 0.86$, double-bundle technique: $p = 0.58$).

Figure 3 shows the biomechanical testing results. All specimens had free forearm rotation after single- and double-bundle reconstruction. No loss of forearm rotation was noted.

Discussion

Restoration of the radial column has been shown to be necessary to avoid gross longitudinal forearm instability in Essex-Lopresti injuries (Lanting et al., 2013; Sabo and Watts, 2012; Trousdale et al., 1992;

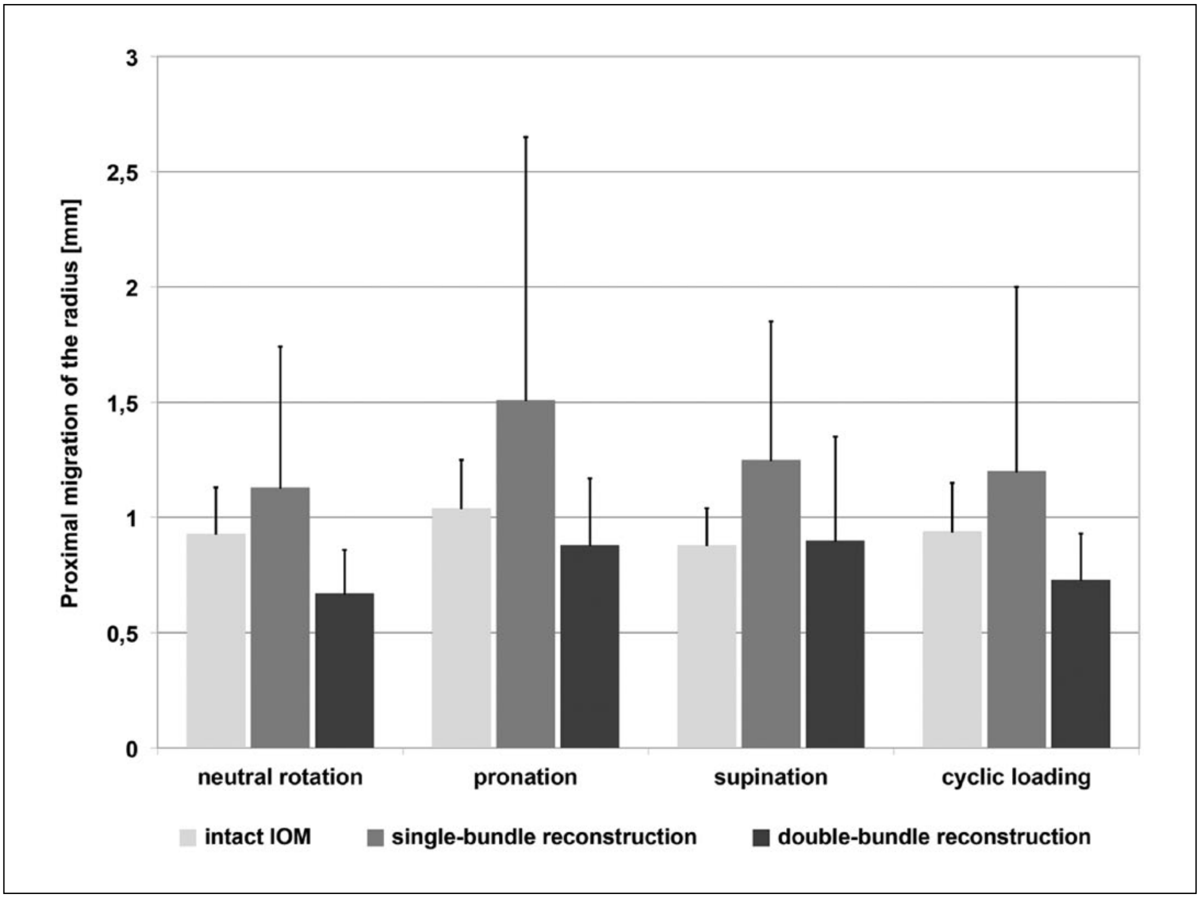

Figure 3. Results of proximal displacement of the radius for the intact specimens, after single-bundle and double-bundle reconstruction in neutral rotation, pronation and supination (single loading), as well as after cyclic loading.
IOM: Interosseous membrane.

Venouziou et al., 2014). Biomechanical evidence suggests that reconstruction of the radial head alone restores only 75% of longitudinal forearm stability (Jones et al., 2012). This might explain why Heijink et al. (2010) observed a high failure rate of monopolar radial head arthroplasties in their case series of chronic Essex-Lopresti lesions. Additional reconstruction of the ruptured interosseous membrane might improve clinical outcomes. Minimally invasive procedures have been reported using a suture button technique to reconstruct the central band of the interosseous membrane (Brin et al., 2014; Drake et al., 2010; Kam et al., 2010). Although Drake et al. (2010) reported restoration of longitudinal forearm stability to normal values, Kam et al. (2010) observed significant differences between the intact interosseous membrane and the reconstruction technique. Neither of these studies investigated the influence of forearm rotation. The current study showed that a TightRope® reconstruction restored longitudinal forearm stability to normal biomechanical values over the full range of motion.

The interosseous membrane is a complex anatomical structure. Overall, fibre strain increases in supination (Farr et al., 2015; Gabriel et al., 2004; Malone et al., 2015). However, the strain distribution within the interosseous membrane is non-uniform. Gabriel et al. (2004) postulated that a double-bundle reconstruction might be more suitable to fully reproduce the biomechanics of the interosseous membrane and more specifically the central band. Farr et al. (2015) showed that a reconstruction graft of the central band could be placed slightly distal or proximal to the native central band without altering its kinematics, as long as it was still oriented parallel to the central band. The present study compared the effect of a single-bundle and a double-bundle technique on restoration of longitudinal forearm stability. There were no significant differences in longitudinal forearm stability between the single-bundle and the double-bundle techniques. However, there were high standard deviations for the single-bundle reconstruction when compared with the intact membrane and the double-bundle TightRope®

construct. This might imply that single-bundle reconstruction is less reliable in restoring the complex strain pattern of the central band over the full range of motion.

The lack of significant differences between both reconstruction techniques may be related to the limited sample size. The advanced age of the specimens represents another potential limitation of this study. Attenuation of the drill holes during cyclic loading of the single-bundle technique might be a confounder for the results of double-bundle reconstruction. However, no macroscopic changes were observed in the drill holes. The in-vitro design of the study neglected the effect of the elbow joint on longitudinal forearm stability and this limits the transferability of the presented results to a clinical setting. Unlike similar studies however, the sophisticated testing setup with the use of digital image correlation allowed for precise and direct measurement of displacement over the full range of motion (Drake et al., 2010; Jones et al., 2012; Kam et al., 2010; Pfaeffle et al., 2005, 1996; Tejwani et al., 2005a, 2005b; Tomaino et al., 2003).

The number of Essex-Lopresti lesions is generally thought to be low and this might call into question the clinical relevance of the presented results. However, some authors suggest that Essex-Lopresti lesions may be more common than previously assumed (Duckworth et al., 2011; Hausmann et al., 2009; McGinley et al., 2014).

While treatment of acute Essex-Lopresti injuries leads to satisfying results in the majority of cases, persisting disability is common in chronic Essex-Lopresti lesions (Grassmann et al., 2014; Heijink et al., 2010; Schoonhoven et al., 2015; Trousdale et al., 1992; Venouziou et al., 2014). The clinical benefits of central band reconstruction in Essex-Lopresti injuries should be a focus of future studies (Brin et al., 2014; Sabo and Watts, 2012).

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