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Brief report

The transverse force experienced by the radial head during axial loading of the forearm: A cadaveric study

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ABSTRACT

Background: When designing a radial head replacement, the magnitude and direction of forces applied across the proximal radio-ulnar joint (PRUJ) and the radiocapitellar joint must be included. These designs often focus on axial loads transmitted to the radial head by the capitellum; however, the radial head also bears a significant transverse force at the PRUJ. Load transmission by the central band of the interosseous ligament induces a force component in a lateral direction perpendicular to the axis of the limb, which is borne by the articular surfaces of the proximal and distal radio-ulnar joints. The objective of this study is to establish the relationship between distally applied axial forces and proximal transverse reaction forces.
Methods: Five cadaveric, human forearms with intact interosseous membranes were used to measure the magnitude of transversely-directed forces experienced by the radial head during axial loading of the forearm at the lunate fossa. A Mark-10 test stand applied a gradual and continuous axial load on the articular surface of the distal radius. A Mark-10 force gauge measured the resultant transverse force experienced by the radial head in the proximal radioulnar joint. Classical mechanics and static force analysis were applied in order to predict lateral force values that would occur when the interosseous ligament is treated as the major load transmitter between the radius and ulna.
Findings: Acquired data show that the radial head bears a force in the transverse direction that averages 18% (SD 3.89%) in magnitude of the axial force applied at the wrist. This figure is in close accordance with the predicted value of 22% that was calculated by way of free-body plotting.
Interpretation: Physiologic forearm loading results in a clinically significant transverse force component transmitted through the interosseous ligament complex. The existence of transverse forces in the human forearm may explain clinical problems seen after radial head resection and suggest that radial head implants be designed to sustain substantial transverse forces.
Level of evidence: Basic science study, anatomical.

1. Background and introduction

Forearm rotation and dexterous utility is a complex activity that involves continuous collaboration between the ulna and the radius at two different joints, the distal radio-ulnar joint (DRUJ) and the proximal radio-ulnar joint (PRUJ), and along a mid-arm ligament complex known as the interosseous membrane. Oriented obliquely from a distal ulnar to a proximal radial direction, the central band of the interosseous ligament's primary function is the transfer of axial loads from the radius to the ulna (Birkbeck et al., 1997; Markolf et al., 1998a, 2000; Noda et al., 2009; Pfaeffle et al., 2000) a role that makes it the principal stabilizer of the radius during proximal translation, particularly following removal of the radial head (Markolf et al., 1998a).

The load transfer via the interosseous membrane occurs during use of the forearm in a constantly fluctuating fashion, depending on extremity orientation. When the net force applied to the elbow by the forearm results in movement toward the valgus direction, force transmission across the radiocapitellar joint is favored and load transfer through the interosseous ligament decreases accordingly. This can theoretically occur to a point in which the radial head transmits up to 100% of the forearm load. When the net force results in movement toward a varus direction however, force transmission across the ulnohumeral joint is favored and load transfer through the interosseous ligament correspondingly increases. Likewise, this can ensue to the point where 100% of the axial load on the radius is transferred to the ulna (Markolf et al., 1998a). Thus, tension in the interosseous ligament due to weight bearing and contraction of forearm muscles during functional use of the hand is highly dynamic and depends on the type of activity being performed.

To truly understand the biomechanics of the human forearm, the magnitude and direction of forces applied across the proximal radio-

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ulnar joint (PRUJ) and the radiocapitellar joint must be included. While it has been largely acknowledged that the radial head transmits an axial load onto the capitellum (Judet et al., 1996), it is not often recognized that the radial head bears a significant force in a transverse direction. Load transmission by the central band of the interosseous ligament (Murray, 2005; Pfaeffle et al., 2000; Skahen et al., 1997) induces a force component in a transverse direction perpendicular to the axis of the limb (Birkbeck et al., 1997; Markolf et al., 1998a, 2000; Pfaeffle et al., 2000), which is borne by the articular surfaces of the proximal and distal radio-ulnar joints (Pfaeffle et al., 2000, 2005, 2006) (Skahen et al., 1997; Pfaeffle et al., 2005, 2006). This can be understood through force vector analysis, as illustrated in Fig. 1. In this study, five cadaveric arms with intact interosseous membranes are examined to seek the presence and magnitude of a transversely applied force transferred across the PRUJ, particularly onto the radial head. In order to generate such force, the distal radius will be loaded axially, as would occur during forceful gripping. After recording the data, the observed force magnitudes will be compared with the lateral loads predicted by classical mechanics.

2. Materials and methods

2.1. Cadaver specimens

Five cadaver forearms were used for the purpose of this investigation. The samples were obtained from 3 males and 2 females, whose ages at the time of death averaged 63 years (range, 55–70 years). The specimens were thawed for 24 h at room temperature prior to testing. After gross examination and fluoroscopic analysis, the specimens were found to have no abnormalities.

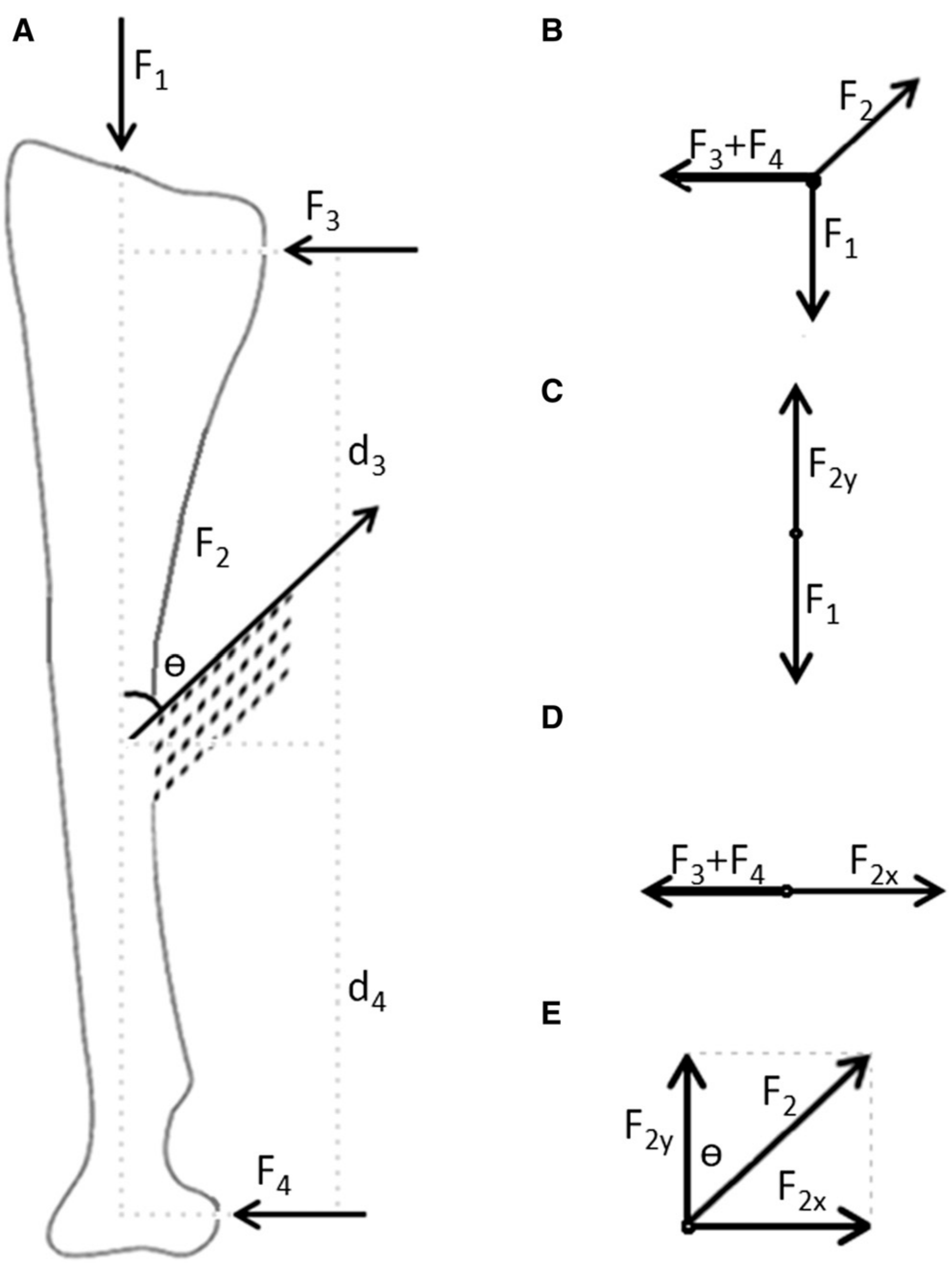

Fig. 1. Radial forces: F_1 = axial force applied to the distal radius; F_2 = sum of transverse forces applied by the interosseous ligaments, represented as the forces of the central band applied at the center of mass; F_3 = lateral force applied at the DRUJ; F_4 = lateral force applied at the PRUJ; d_3 = the distance between F_2 and F_3; d_4 = the distance between F_2 and F_4. A) Forces acting on the radius. B) Free body diagram of the forces acting on the radius at the center of mass. C) Forces acting in the axial direction (y-axis). D) Forces acting in the transverse direction (x-axis). E) Component forces of F2.