SCIENTIFIC ARTICLE

Distribution of Coronoid Fracture Lines by Specific Patterns of Traumatic Elbow Instability

Jos J. Mellema, MD, Job N. Doornberg, MD, PhD, George S. M. Dyer, MD, David Ring, MD, PhD

Purpose To determine if specific coronoid fractures relate to specific overall traumatic elbow instability injury patterns and to depict any relationship on fracture maps and heat maps.

Methods We collected 110 computed tomography (CT) studies from patients with coronoid fractures. Fracture types and pattern of injury were characterized based on anteroposterior and lateral radiographs, 2- and 3-dimensional CT scans, and intraoperative findings as described in operative reports. Using quantitative 3-dimensional CT techniques we were able to reconstruct the coronoid and reduce fracture fragments. Based on these reconstructions, fracture lines were identified and graphically superimposed onto a standard template in order to create 2-dimensional fracture maps. To further emphasize the fracture maps, the initial diagrams were converted into fracture heat maps following arbitrary units of measure. The Fisher exact test was used to evaluate the association between coronoid fracture types and elbow fracture-dislocation patterns.

Results Forty-seven coronoid fractures were associated with a terrible triad fracture dislocation, 30 with a varus posteromedial rotational injury, 1 with a anterior olecranon fracture dislocation, 22 with a posterior olecranon fracture dislocation, and 7 with a posterior Monteggia injury associated with terrible triad fracture dislocation of the elbow. The association between coronoid fracture types and elbow fracture-dislocation patterns, as shown on 2-dimensional fracture and heat maps, was strongly significant.

Conclusions Our fracture maps and heat maps support the observation that specific patterns of traumatic elbow instability have correspondingly specific coronoid fracture patterns. Knowledge of these patterns is useful for planning management because it directs exposure and fixation and helps identify associated ligament injuries and fractures that might benefit from treatment.

Clinical relevance Two-dimensional fracture and heat mapping techniques may help surgeons to predict the distribution of coronoid fracture lines associated with specific injury patterns.

Key words Coronoid, fractures, mapping, elbow, injury.

Observations and studies based on patient care and computed tomography (CT) scans led to an association of specific coronoid fracture patterns with the overall pattern of traumatic elbow instability.[1,2] Knowledge of coronoid fracture types and pattern of traumatic elbow instability contributed to a useful guide to treatment.[3] Small transverse tip fractures are associated with terrible triad

From the Orthopaedic Hand and Upper Extremity Service, Massachusetts General Hospital; the Department of Orthopaedic Surgery, Brigham and Women's Hospital, Boston, MA; and the Orthotrauma Research Center Amsterdam, Academic Medical Center, Amsterdam, The Netherlands.

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Corresponding author: David Ring, MD, PhD, Orthopaedic Hand and Upper Extremity Service, Yawkey Center, Suite 2100, Massachusetts General Hospital, 55 Fruit St., Boston, MA 02114; e-mail: dring@partners.org.

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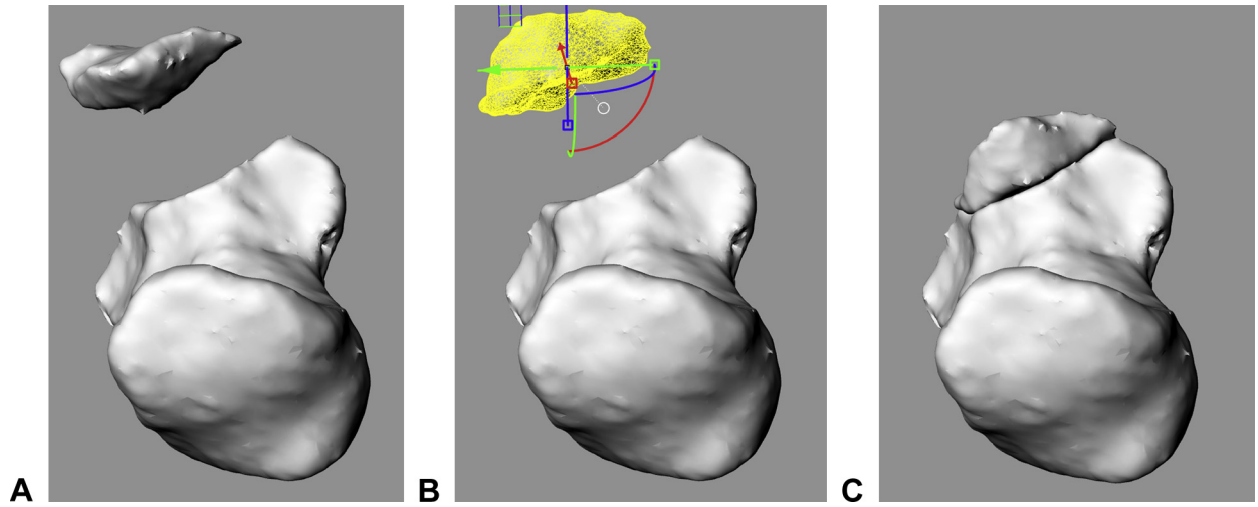

FIGURE 1: Images show fracture fragment reduction of 3-dimensional mesh reconstructions in Rhinoceros (McNeel, Seattle, WA). **A** Imported 3-dimensional mesh reconstruction. **B** Fracture fragment selected for reduction. **C** Image of 3-dimensional mesh reconstruction after reduction of the fracture fragment.

injuries, anteromedial facet fractures with varus posteromedial rotational instability injuries, and larger basal fractures of the coronoid process with anterior and posterior olecranon fracture dislocations.[4–6]

This study used recently described 2-dimensional fracture mapping techniques in which a map of the most common fracture lines is created by superimposing fracture lines from a large number of injuries[7,8] after creating quantitative 3-dimensional computed tomography (Q3DCT) models. We also applied heat mapping techniques whereby fracture line intensity is graphically represented in color. These techniques were used to define the location, frequency, distribution, and pattern of fracture lines of the coronoid. We tested the null hypothesis that specific coronoid fractures do not associate with specific overall traumatic elbow instability injury patterns and depicted this on fracture maps and heat maps.

METHODS

Subjects

Our institutional review board approved a retrospective search of our billing data for patients with a coronoid fracture between July 2001 and January 2014 at 2 level I trauma centers. *The International Classification of Disease,* Ninth Revision, *Clinical Modification* (code 813.0x for closed fracture and 813.1x for open fracture) and *Current Procedural Terminology* (codes 24586–24685, including elbow dislocations, Monteggia type of fractures, radial and ulnar fractures) were used to search the billing data. Two hundred seven patients with coronoid fractures were identified. Inclusion criteria were patients aged 18 years or older with an acute fracture of the coronoid and a CT scan displaying the complete fracture. One hundred twenty-one patients met the inclusion criteria. We excluded 11 patients with prior elbow injury, low-quality CT images, or artifacts on CT scan. Therefore, 110 fractures were available for study.

Two-dimensional fracture mapping

Two-dimensional fracture maps represent fracture line distribution on a 2-dimensional template by superimposing fracture lines from a large number of injuries. Images of coronoid fractures needed for 2-dimensional fracture mapping were based on Q3DCT modeling techniques. The original Digital Imaging and Communications in Medicine files of selected CT scans were obtained through the Picture Archiving Communications System database of the 2 hospitals. All CT scans had a slide thickness between 0.625 mm and 3.000 mm. The digitally imaged files were loaded into 3D Slicer (Boston, MA). The 3D Slicer is a software program used for analysis and visualization of medical images. Bony structures were manually marked on transverse, sagittal, and oblique CT slides using the Paint Effect and additional Threshold Paint option available in this program. After marking all bony structures of the proximal ulna on each CT slide, 3-dimensional polygon mesh reconstructions were created in 3D Slicer. These 3-dimensional mesh reconstructions were imported in Rhinoceros (McNeel, Seattle, WA) for reduction of the fracture fragments (Fig. 1).

Using the method of Cole et al[8] and Armitage et al,[7] fracture lines were graphically superimposed onto a