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Diagnostic accuracy of 2- and 3-dimensional computed tomography and solid modeling of coronoid fractures

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Purpose: This study measured the diagnostic performance characteristics and reliability of 2-dimensional (2DCT) and 3-dimensional (3DCT) computed tomography images and modeling of coronoid fractures.
Method: The treating surgeon and first assistant evaluated 28 fractures for fracture type, specific characteristics, and proposed treatment. The observers evaluated the fractures 4 times: first based upon 2DCT computed images and radiographs; second with the addition of 3DCT images; third with the addition of 3D models; and finally based upon intra-operative exposure, which was considered the reference standard.
Results: The diagnostic performance characteristics did not improve with more sophisticate imaging and models. The addition of 3DCT reconstructions improved the inter-observer reliability for fracture classification, characteristics, and proposed treatment.
Conclusion: More sophisticated images and modeling improved reliability but not accuracy when characterizing coronoid fractures.
Level of evidence: Level II, Diagnostic Study.

Keywords: Computed tomography; coronoid fracture; fracture classification; interobserver reliability; diagnostic performance characteristics

The coronoid process is key to the stability and long-term function of the elbow.[8,14,17,19-22] In cases where the assessment of the coronoid process on radiographs is uncertain, computed tomography (CT) can be useful. A recent study by Lindenhovius et al showed that 3-dimensional CT (3DCT) scans of the coronoid fracture improved inter-observer agreement with respect to fracture classification compared with 2-dimensional (2DCT) images.[13] Prior retrospective studies found that 3DCT reconstructions are a useful adjunct to improve diagnostic performance and/or intra- and interobserver reliability in the evaluation of proximal humerus, distal humerus, distal radius, and coronoid fractures.[1-3,5-7,9,10] Those studies could not address accuracy because they did not have a prospective intra-operative reference standard.

This study evaluated the diagnostic performance characteristics of 3DCT images and 3D models in a prospective cohort study using operative findings and treatment as the reference standard for fracture type, characteristics, and treatment. Specifically, we tested the null hypothesis that there is no difference in diagnostic performance characteristics between 2D images, 3DCT images, and 3D models. In secondary analyses, the agreement of the classification,

IRB: This study has been approved by the Institutional Review Board of the Massachusetts General Hospital under protocol number: 2009-P-001019/28; MGH.

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characterization, proposed, and additional treatment of these fractures between the surgeon and first assistant was assessed.

Material and methods

Inclusion and exclusion criteria

Patients with a coronoid fracture having operative treatment in 2 hospitals were invited to enroll in this prospective cohort study. Informed consent was obtained from all patients. The Human Research Committee approved the protocol. The inclusion criteria were: (1) coronoid fracture; (2) elective surgical treatment; (3) sufficient quality of the 2D images to make 3DCT images and models; and (4) age 18 years or older. Exclusion criteria were pregnant women and patients unable to give informed consent.

Patient characteristics

Twenty-eight patients were enrolled. There were 16 (57%) men and 12 (43%) women with an average age of 51 year (range, 23-89 years). Two (7%) patients had an isolated coronoid fracture and 26 (93%) patients had a coronoid fracture with additional fractures: 14 patients had terrible triad injury of the elbow; 9 with a posterior olecranon fracture-dislocation (1 with a concomitant lateral condyle fracture); 2 with radial head fracture-dislocation; and 1 with a concomitant distal humerus fracture. Twenty-two fractures involved the left upper extremity and 6 the right.

Evaluation

Because the CT images were obtained as part of patient care rather than research several different CT scanners were used (up to 140 kV and 500-700 mAs) with different slice thickness between 0.64 and 1.25 mm. The 3DCT scans and 3D physical model constructions were made from DICOM (Digital Imaging and Communications in Medicine) files. The models were made by Medical Modeling LLC (Golden, CO, USA).

The treating surgeon and the first assistant classified each coronoid fracture based on the fracture classification of O'Driscoll et al[16] and evaluated the presence of the following 5 fracture/injury characteristics: (1) fracture of the anteromedial facet, (2) fracture of the tip of the coronoid, (3) comminution of the fracture, (4) presence of impacted articular fragments, and (5) subluxation or dislocation of the ulnohumeral joint. There was no training of observers.

Each observer proposed treatment in the following categories: (1) nonsurgical management; (2) open reduction and internal fixation (ORIF) through a lateral exposure; (3) ORIF through a medial exposure; and (4) ORIF through the olecranon fracture. In addition to the proposed treatment, the observers were asked whether they agreed or disagreed with each of the 2 following statements: (1) some of the fracture fragments cannot be reliably repaired with screws and will require small wires, sutures, or another technique; and (2) the fracture fixation will be tenuous and should be protected with a hinged external fixator.

The observers evaluated the fractures 4 times: First based upon 2D CT images and radiographs; second with the addition of 3DCT images; third with the addition of 3D models; and finally based upon intra-operative exposure, which was considered the reference standard. There were 7 separate attending observers and 22 resident or fellow observers.

Statistical analysis

According to a post-hoc power analysis 27 fractures provide 80% power ($\alpha = 0.05$, $\beta = 0.20$) to detect a difference in diagnostic characteristics between 2 imaging modalities using McNemar's test.

Sensitivity and specificity were calculated using standard formulas with the intra-operative findings of the attending surgeon as the reference standard. The operative exposure was always sufficient to characterize the fracture. Ninety-five percent confidence intervals (CI) were calculated according to Wilson score interval based on the procedure outlined by E. B. Wilson in 1927.[15,23] McNemar's test was used to test statistically significant differences ($P < .05$) between the 2D images and the 3D reconstructions.[11]

The kappa coefficient (κ) was applied to measure the interobserver agreement for the 28 patients with two observers with respect to the fracture classification, fracture characteristics and the treatment proposal for each modality.[4] Kappa values are traditionally categorized as follows: slight agreement (0.01-0.20), fair agreement (0.21-0.40), moderate agreement (0.41-0.60), substantial agreement (0.61-0.80), and almost perfect agreement ($\geq$0.81).[12,18] A P value of $<.05$ was considered significant.

Results

There were no significant differences in sensitivity or specificity for diagnosis of fracture characteristics, proposed treatment, or additional treatment with the addition of 3DCT reconstructions or 3D models (Table I).

Three-dimensional CT images improved the interobserver agreement of fracture classification; 4 of the 5 fracture characteristics (anteromedial facet fracture, tip of the coronoid fracture, impacted articular fragments, and the elbow is subluxated/dislocated or concentrically located); 1 of the 4 proposed treatments (ORIF through an olecranon exposure); and 1 of the 2 additional treatment options (Table II). (The fracture fixation will be tenuous and should be protected with a hinged external fixator).

The addition of 3D models further improved the interobserver agreement of 2 fracture characteristics (fracture of the tip of the coronoid and presence of impacted articular fragments); 1 proposed treatment option (ORIF through an olecranon exposure); and 1 additional treatment compared with 3DCT images (Table II). (Some of the fracture fragments cannot be reliably repaired with screw and will require small wires, sutures, or another technique).

Discussion

Three-dimensional CT reconstructions and models improved reliability but not accuracy, compared to intra-operative evaluation in this study. Reliability improved