Complex distal humerus trauma
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CHAPTER 7
Quantitative 3D Computed Tomography of the Distal Humerus
Brouwer KM, Bolmers AEM, Ring D
Abstract

Purpose: To measure the average number, size, shape and articular surface area of articular fracture fragments of the distal humerus using quantitative analysis of 3-dimensional computed tomography (3DCT) images.

Materials and methods: Forty-eight computed tomography scans of distal humerus fractures were analyzed with quantitative 3DCT. Twenty-one patients had a capitellum and trochlea fracture and 27 had biconular fractures of the distal humerus. The volume and articular surface area of each articular fracture fragment were measured. A small fragment was defined of having a volume of less than 500 mm$^3$ or an articular surface of less than 500 mm$^2$.

Results: Biconular fractures have a mean of 9.3 fragments, 5.4 small fragments and 3.7 articular fragments per fracture. Trochlea and capitellum fractures have a mean of 3.6 fragments, 1.5 small fragments and 2.3 articular fragments per fracture. For each fracture type the number of small fragments correlated with the total number of fragments.

Conclusion: Columnar fractures had more articular fragments and more small fragments than trochlea and capitellum fractures.

Level of evidence: N/a

Keywords: Computed tomography; fractures; morphology; quantitative; distal humerus; three-dimensional; surface; volume.
Introduction
Quantitative 3-dimensional computed tomography (Q3DCT) can measure the number, volume, and articular surface area of fracture fragments \(^1, 2\). The quantitative measurements may provide a more detailed understanding of fracture morphology, which might help with treatment decisions and implant development\(^3\). We applied this technique to fractures of the distal humerus and tested the null hypothesis that bicolumnar fractures and capitellum and trochlea fractures create similar numbers of 1) fracture fragments, 2) small fragments, and 3) articular fragments in order to gain insight in fracture morphology as part of the pre-operative planning.

Materials and methods
Our Human Research Committee approved the protocol for this investigation.

Inclusion and Exclusion criteria
A search of billing records identified 72 patients with a fracture of the distal humerus who were evaluated with computed tomography (CT) between 2002 and 2008. Fifty-two CT scans had a slice thickness between 0.62 and 1.25 mm and were deemed adequate for 3-dimensional modeling, of which 48 had a bicolumnar fracture or a capitellum or trochlea fracture. Several different CT scanners were used with up to 140 kV and 500 to 700 mAs and slices from 8 to 64/ dual source. There were only 4 single column fractures and we excluded them. There were 29 women and 19 men with a mean age of 51 years (range, 18 to 88). There were 21 fractures of the capitellum and trochlea and 27 bicolumnar fractures. (Figures 1, 2)

Modeling technique
The CT scans (DICOM files; Digital Imaging and Communications in Medicine) were analyzed with an algorithm that identifies the outer margin of the highest density (cortical or subchondral) bone. (Figures 1A, B) Subcondral bone was deselected, resulting in outlines that were then stacked creating a mesh representing the outer margin of the bone. (Figure 1C). This wire model was then transformed into a polygon mesh: a hollow 3-dimensional model of the outer surface of the bone (figure 1D). Fracture fragments with articular surface attached were then identified and isolated for analysis (Figure 1E).
Three-dimensional reconstructions of a bicolumnar distal humerus fracture. A mathematical algorithm identified the outer border of the cortical and subchondral bone (points) of the distal humerus fracture fragments on two dimensional computed tomography images. These points from each CT slice were stacked to create a wire mesh model of each distal humerus fracture fragment. A polygon mesh was calculated to convert the wire mesh into a final 3-dimensional model of a bicolumnar fracture. This bicolumnar distal humerus fracture created 15 fragments. Three of the fragments involved the articular surface.
**Evaluation**

The volume and articular surface area of each individual fracture fragment and the remaining unfractured bone were measured. Volumetric measurements and surface area measurements are a standard feature in Rhinoceros (version 4.0; McNeel North America, Seattle, WA). The articular surface calculations were done by selecting the distal articular surface on the particular fracture fragment. The volume of the intact distal humerus was arbitrarily cutoff by the limit of the CT in a way that hindered meaningful measurement of this part, similar to previously executed work on radial head fractures. The volumetric measurements were arbitrarily categorized into 3 different sizes: major fragments (Greater than 1000 mm$^3$), minor fragments (500-1000 mm$^3$), and small fragments (less than 500 mm$^3$). We divided our articular surface measurements into 2 groups: large fragments (greater than 500 mm$^2$) and small fragments with a surface area of less than 500 mm$^2$.

**Statistical analysis**

The mean fragment volume and articular surface area of each fracture fragment was calculated. The percent articular surface area on each fracture fragment was calculated as a percentage of the total articular surface area. The percentage of the total articular surface area that is involved in the fracture was calculated for capitellum and trochlea fractures. Student’s T-test and Pearson correlation were used in bivariate analysis.

**Results**

In this study, 3 fractures created 1 fracture fragment, 2 created 2 fracture fragments, 7 created 3 fracture fragments and 36 created 4 or more fracture fragments. (Table 1) According to the volume measurement criterion, 177 of 348 fracture fragments (53%) were classified as small (less than 500 mm$^3$). (Table 2) Forty of the 48 fractures (83%) had at least 1 small fracture fragment. The mean number of small fracture fragments was 3.7 per fracture. According to the surface area measurement criterion, 76 of 148 articular fracture fragments were classified as small (less than 500 mm$^2$). (Table 3) Thirty-five of 48 fractures (73%) had at least 1 small fracture fragment by surface area criteria. The mean number of small fracture fragments by articular surface area criteria was 1.58 per fracture.
### TABLE I. Distal humerus fracture type and number of fracture fragment

<table>
<thead>
<tr>
<th>Fracture Type</th>
<th>1 Fragment</th>
<th>2 Fragments</th>
<th>3 Fragments</th>
<th>≥ 4 Fragments</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capitellum and trochlea fracture</td>
<td>3</td>
<td>2</td>
<td>6</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>Bicolumnar fracture</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3</strong></td>
<td><strong>2</strong></td>
<td><strong>7</strong></td>
<td><strong>36</strong></td>
<td><strong>48</strong></td>
</tr>
</tbody>
</table>

### TABLE II. Fracture fragment by volumetric criteria

<table>
<thead>
<tr>
<th>Fracture Type</th>
<th>Major (&gt; 1000 mm³)</th>
<th>Minor (500-1000 mm³)</th>
<th>Small (&lt;500 mm³)</th>
<th>Total</th>
<th>No. of small fragments by volume criterion per fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capitellum and trochlea fracture</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Fragment</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2 Fragments</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0.5</td>
</tr>
<tr>
<td>3 Fragments</td>
<td>10</td>
<td>4</td>
<td>4</td>
<td>18</td>
<td>0.67</td>
</tr>
<tr>
<td>≥ 4 Fragments</td>
<td>22</td>
<td>6</td>
<td>26</td>
<td>54</td>
<td>2.6</td>
</tr>
<tr>
<td><strong>Bicolumnar fracture</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4 Fragments</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>≥ 4 - 9 Fragments</td>
<td>51</td>
<td>14</td>
<td>60</td>
<td>125</td>
<td>3.33</td>
</tr>
<tr>
<td>≥ 10 Fragments</td>
<td>27</td>
<td>11</td>
<td>85</td>
<td>123</td>
<td>10.63</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>118</strong></td>
<td><strong>35</strong></td>
<td><strong>177</strong></td>
<td><strong>330</strong></td>
<td><strong>3.66</strong></td>
</tr>
</tbody>
</table>

### TABLE III. Fracture fragment by surface criteria

<table>
<thead>
<tr>
<th>Fracture Type</th>
<th>Major (&gt; 500 mm²)</th>
<th>Minor (&lt;500 mm²)</th>
<th>Total</th>
<th>Estimated bone loss by surface area as % of intact distal humerus</th>
<th>No. of small fragments by surface area per fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capitellum and trochlea fracture</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Fragment</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>17</td>
<td>0.2</td>
</tr>
<tr>
<td>2 Fragments</td>
<td>7</td>
<td>9</td>
<td>16</td>
<td>22</td>
<td>1.13</td>
</tr>
<tr>
<td>3 Fragments</td>
<td>6</td>
<td>9</td>
<td>15</td>
<td>19</td>
<td>1.8</td>
</tr>
<tr>
<td>≥ 4 Fragments</td>
<td>5</td>
<td>7</td>
<td>12</td>
<td>19</td>
<td>2.33</td>
</tr>
<tr>
<td><strong>Bicolumnar fracture</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;4 Fragments</td>
<td>29</td>
<td>10</td>
<td>39</td>
<td>9</td>
<td>0.67</td>
</tr>
<tr>
<td>≥ 4 Fragments</td>
<td>21</td>
<td>40</td>
<td>61</td>
<td>12</td>
<td>3.33</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>72</strong></td>
<td><strong>76</strong></td>
<td><strong>148</strong></td>
<td></td>
<td><strong>1.58</strong></td>
</tr>
</tbody>
</table>
Capitellum and Trochlea Fractures
Capitellum and trochlea fractures created an average of 3.8 fragments per fracture (range, 1 to 7) (Figure 3) with a mean volume per fracture fragment of 2164 mm$^3$ (range, 1 to 12120 mm$^3$). The average number of small fragments according to the volume criterion was 0.5 when there were 2 fragments, 0.67 when there were 3 fragments, and 2.6 when there were 4 fragments. (Figure 4)
Sixty percent of the articular fragments involved the articular surface (average 2.3 articular fragments per fracture; range, 1 to 4). The mean articular surface area of the fragments with some articular surface was 538 mm$^2$ (range, 11 to 1611 mm$^2$). The average number of small articular fragments by surface area criteria was 0.2 for single fragment fractures, 1.1 for 2-fragment fractures; 1.9 for 3-fragment fractures; and 2.3 for fractures with 4 or more fragments.(Figure 5)
The mean articular surface area of the fractured part of the articular surface of the distal humerus was 1229 mm$^2$ (range, 444 to 2515 mm$^2$) or 63% of the total articular surface (range, 27 to 100%). The percentage of the total articular surface area involved in the fracture averaged 34% for single fragment fractures; 71% for 2 fragments; 61% for 3 fragments; and 91% for fractures creating 4 or more fragments.

Bicolumnar fractures
The bicolumnar fractures had an average of 9.3 fragments per fracture (range, 3 to 29) (Figure 6). The mean volume per fracture fragment was 2577 mm$^3$ (range, 1.41 to 20682 mm$^3$). The average number of small fragments by the volume criterion was 1 for fractures with fewer than 4 fragments; 3.3 for fractures with more than 4 but less than 10 fragments; and 10.6 for fractures with more than 10 fragments (Figure 7).
Forty percent of the fracture fragments involved the articular surface (mean 3.3 fragments per fracture; range, 2 to 10 articular fragments). The fracture fragments had a mean articular surface area of 619 mm$^2$ (range, 27 to 1790 mm$^2$). The mean total articular surface of the distal humerus was 2211 mm$^2$ (range, 1140 to 3572 mm$^2$). The average number of small fragments was 0.7 for fractures with fewer than 4 articular fragments 3.3 for fractures with 4 or more fragments. (Figure 8)

Comparison of Columnar and Capitellum/Trochlea Fractures
Columnar fractures had significantly more fragments per fracture (9.3 vs. 3.6; p < 0.01) and small fragments per fracture (5.4 vs. 1.5; p < 0.01). There was a very strong correlation between the number of fragments and the number of small fragments (r = .96 with p<0.01) . (Figure 9)
FIGURE 3: Pie chart depicting distribution of the number of capitellum and trochlea fractures per number of fracture fragments.

FIGURE 4: Stacked column chart depicting the volume of capitellum and trochlea fracture fragments and the number of small fragments per number of fragments per fracture.

FIGURE 5: Stacked column chart depicting the size of articular fracture fragments and the number of small fragments per number of articular fragments per capitellum and trochlea fracture.
FIGURE 6: Pie chart depicting distribution of the number of bicolumnar fractures per number of fracture fragments.

FIGURE 7: Stacked column chart depicting the volume of bicolumnar fracture fragments and the number of small fragments per number of fragments per fracture.

FIGURE 8: Stacked column chart depicting the size of articular fracture fragments and the number of small fragments per number of articular fragments per bicolumnar fracture.
Discussion
Bicolumnar distal humerus fractures are often conceptualized as Y or T-shaped fractures with a simple, unfragmented articular fracture that can be secured with a single interfragmentary articular screw. Analysis of bicolumnar fractures with quantitative 3DCT found that bicolumnar fractures tend to create numerous fragments with articular surface, many of them small and likely difficult to repair. The common conception of capitellar fractures is that they are simple fractures involving only the capitellum that are easily repaired with a few screws. Recent literature has emphasized frequent involvement of the trochlea as well as fragmentation of the anterior and posterior parts of the fracture. Quantitative 3DCT analysis confirmed that capitellar fractures often extend into the trochlea, are often fragmented, involve a substantial portion of the articular surface area, and that many of the fragments are small and likely difficult to repair. Presumably, most surgeons simply discard many of these small and relatively inconsequential fragments, but it’s not clear because this aspect of fracture distal humerus fracture treatment is uncommonly addressed in book chapters, technique and review articles, and scientific investigations.

The strengths of this study include a mathematical algorithm for identification of the outer margin of the highest density bone that left limited room for judgment or bias on the part of the individual creating the model, although we have not tested if this is sensitive to the CT scanning techniques (e.g. slice thickness, etc.). The limitations of this study include the fact that our estimates of total articular surface area may not have accounted for lost or very small fragments; our definition of small fragments was arbitrary; the subset of patients that had a CT scan may not be representative of the average patient with a fracture of the distal humerus treated at our institution (although most distal humerus fractures that present to our Emergency Department are evaluated with CT); and we do not have adequate data on the results of treatment.
Conclusions
The majority of the distal humerus fractures in this series had 4 or more fragments and fractures with more fracture fragments had a higher percentage of small fracture fragments. More fragmented fractures are more likely to have small and difficult to repair fragments. Quantitative analysis of distal humerus fracture fragments confirmed that capitellar fractures often extend into the trochlea, that they are often fragmented, and that some of the fragments are small and likely difficult to repair. It is our hope that the ability to make quantitative measurements may improve our understanding of and management of these fractures beyond what we have achieved with observations alone.

References