Ashdin Publishing
Journal of Orthopaedics and Trauma
Vol. 3 (2013), Article ID 235627, 3 pages
doi:10.4303/jot/235627

Research Article

Fractures of the Clavicle: Which X-Ray Projection Provides the Greatest Accuracy in Determining Displacement of the Fragments?

Daniel Axelrod,[1] Ori Safran,[2] Terry Axelrod,[1] Cari Whyne,[1] and Omri Lubovsky[2]

[1] *Orthopaedic Biomechanics Laboratory (OBL), Sunnybrook Health Sciences Centre, 2075 Bayview Avenue, Toronto, ON, Canada M4N 3M5*
[2] *Barzilai Medical Center, 3 Haistadrut St., Ashkelon 78278, Israel*
Address correspondence to Omri Lubovsky, omrilu@gmail.com

Received 14 August 2012; Accepted 31 October 2012

Abstract Recent studies favor surgical management of displaced clavicle fractures. Displacement is measured using anterior-posterior (AP) X-rays. Since displacement can occur in all three dimensions, however, standard methods of evaluation can be difficult and inaccurate. This study was conducted to determine the X-ray angle that provides the most accurate assessment. Nine CT scans of acute displaced clavicle fractures were analyzed with AmiraDev imaging software. 3D measurements for degrees of shortening and fracture displacement of the fracture clavicle were taken. Using a segmentation and manipulation module, five digitally reconstructed radiographs (DRRs) mimicking AP X-rays were created for every CT, with each DDR differing slightly by projection angle. After comparison to the original CTs, all samples using an AP view with a 20° downward tilt yielded displacements closest to the 3D "gold standard" or true measurements. Therefore, it is suggested that using this projection would provide the most accurate indication of fracture displacement.

Keywords clavicle; fracture; displacement; X-ray projection angle; digitally reconstructed radiographs

1. Introduction

Fractures of the clavicle are relatively common [5], and occur mostly in young, active individuals [2]. In recent years, there has been a major change in the principles of management of these fractures. Traditionally, supported by historical publications, fractures of the clavicle have largely been managed non-operatively [6]. In 1997, Hill et al. [3] published a study indicating that fractures of the clavicle with displacement of greater than 2 cm gave poor results. This study indicated that fractures with greater than 2 cm of shortening had a 15% incidence of non-union. McKee and the Canadian Orthopaedic Trauma Society published a landmark paper in 2008 titled "Nonoperative treatment compared with plate fixation of displaced midshaft clavicular fractures" [1]. This prospective randomized, multicenter clinical trial concluded that completely displaced clavicle fractures had superior patient centered outcomes with surgical management as opposed to non-operative closed treatment. McKee defined a displaced clavicle fracture as "no cortical contact between the main proximal and distal fragments" [1].

With these publications, there has been a major change in the approach to clavicle fracture management. Surgeons are moving much more readily to surgical treatment than in the past. The indication for surgical treatment has expanded to include displacement of the fracture fragments of greater than 2 cm. The COTS Study suggests, "completely displaced" [1] as the criteria for surgical management rather than a specific measurement distance as with Hill et al. [3]. Nonetheless, common practice seems to be based on the 2-cm displacement criteria.

Currently, fracture displacement is measured using simple anterior-posterior or posterior-anterior two-dimensional X-rays of the clavicle [9]. Since displacement can occur in all three dimensions, evaluation of the amount of displacement through the use of plain radiographs can be difficult and inaccurate. Many factors can influence the degree of displacement seen on traditional plain X-rays. These include patient positioning, supine vs. upright, angle of the X-ray beam projection, rotation of the chest wall, and the support or lack thereof of the affected arm. The purpose of this investigation was to assess the influence of different radiographic projections on the accuracy of clinical fracture displacement measurements and to determine the best projections for accurate measurements.

2. Materials and methods

This study was performed after receiving Investigational Review Board approval. Of 96 patients with acute clavicle fractures presenting between 2008 and 2010, 15 individuals had CT scans of the clavicle performed as part of their diagnostic work up. Of these 15 CT scans, 9 were of sufficient quality to allow detailed further image analysis. All scans were conducted utilizing a GE light speed VCT helical scan with voxel size of $1.25 \times 0.816 \times 0.816$ mm. The

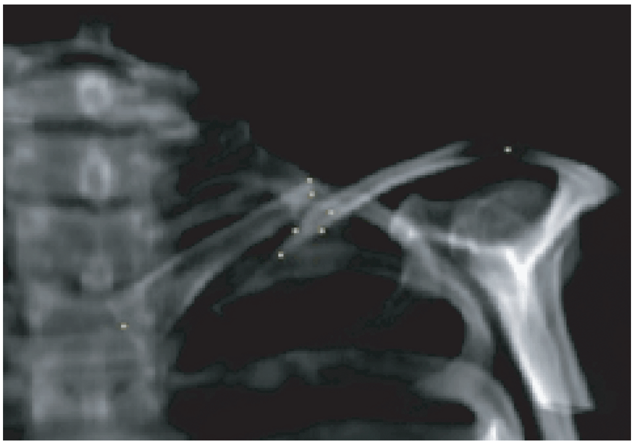

Figure 1: Measurements taken on a 20° downward tilted DRR showing the most medial and lateral edges of the broken clavicle as well as the fracture edges enabling measurement of the shortening of the fracture.

scans were uploaded and analyzed within AmiraDEV5.22 image analysis software [8].

The degree of shortening and fracture displacement of the fractured clavicle were first determined on each reconstructed CT image by measuring the horizontal distance between matching points along the two fracture lines (uppermost and lowermost fracture edges). These measurements represent the 3D fracture displacement and serve as the "gold standard" reference values.

Digitally reconstructed radiographs (DRR) were created for each CT data set in AmiraDev using a segmentation and manipulation module (ITK insight toolkit) to mimic a realistic diverging radiation field. Film and target distances of 200 and 300 mm, respectively, were used. DRRs were then created at five angles; standardized AP, 10° downward tilted AP, 10° upward tilted AP, 20° downward tilted AP (Figure 1), and 20° upward tilted AP. These DRR's represent two-dimensional X-rays of the fractured clavicle, in different projections.

Scaled measurements on the DRRs were taken using 3D landmarks on the fractured clavicle: entire clavicle length, distance from vertebrae to fracture (medial fragment length), distance from fracture to acromium (lateral fragment length), horizontal shortening, and vertical length of the clavicle measured at the fracture.

Since DRRs are not scaled to true dimensions, scaling was done by comparing the width of T2 vertebrae as appearing in the 2D and 3D data sets. The ratio between the measured distances reflected the linear scaling factor.

Fracture displacement measurements obtained from the different DRR's of each patient were then compared to the measurements conducted in the CT images, representing the "gold standard" 3D displacement.

3. Results

Digitally reconstructed radiographs were successfully generated from the 9 CT scans of clavicle fractures at five angles. Scaled measurements were taken of the entire clavicle length, distance from vertebrae to fracture (medial fragment length), distance from fracture to acromion (lateral fragment length), horizontal shortening, and vertical length of the clavicle measured at the fracture. The 20° downward tilted AP DRR was found to consistently yield the most accurate measurement of the fracture shortening based on comparisons with the true CT derived values. Comparing the CT based measurements with the 20° downward tilted AP DRR yielded a Pearson coefficient of correlation of 0.965, t critical of 1.746, and a P value of 0.875.

The results indicate little variance between the 20° downward tilted DRR and the gold standard measures, obtained from the CT scans. The 20° upward tilted DRR showed the greatest variance from the CT measured values.

4. Discussion

The generation of 2D images representing plain X-rays in multiple projections from clinical CT image data allows direct comparisons of clinically relevant 2D and 3D measurements. Employing this methodology allowed direct comparison of measured clavicle fracture displacements in 2D images to "gold standard" 3D CT-based measures. In this, 2D clavicle fracture displacement measured on an AP view with 20° downward tilt consistently yielded measurements closest, and not significantly different from the "gold standard" 3D CT measures. As such the 20° downward tilt AP radiograph, if routinely included in the evaluation of every clavicle fracture, would allow determination of the maximal extent of fracture displacement. This represents an easily accessible, low-cost, low radiation dose alternative to CT imaging for the evaluation of clavicle fracture displacement.

While this study did not use actual clinical X-rays taken of the patients with clavicle fractures at multiple angulations, the techniques used in this experiment to create the DRRs are representative of clinical images. Past models of X-ray projection used to create DRRs have utilized parallel rays used to create X-ray projections from CT data [9]. However, this creates images that are too perfect and have limited functional use or resemblance to clinical X-ray images, as X-rays themselves are non-parallel diverging rays. The DRRs in our study utilize non-parallel diverging rays to emulate clinical X-ray images [4].

These results agree with previous data that was collected on cadaveric models examined with X-ray film [7]. The advantage of the DDR is that it enables the creation of standard AP radiographs from which accurate tilt can be measured. The large deviation in measurements on different projections may call for considerations regarding standardization with respect to X-ray projection angles.

When considering the results of the study, certain limitations need to be kept in mind. Although we attempted to standardize the land marking procedure so that it was consistent for every sample, land marking was done manually. The distance measured between landmarks was automated through a computer function, however imperfections concerning the placement of the landmarks that determined the amount of displacement were inevitable. Furthermore, the sample size used was small and limited to clavicle fractures of patients with poly-trauma, as typically clavicular fractures do not warrant CT scans alone. However, measurement accuracy should not be dependant on clavicular fracture type. In the future, we will attempt to increase our sample size to include a wide range of patients with clavicular fractures. As well, further study will incorporate a 20° downward tilt AP radiograph in the initial fracture assessment of patients presenting with clavicle fractures. A comparison of the amount of displacement noted on this projection with the standard radiographs would likely lead to support for this new projection as the best way of determining maximal displacement of the fracture.

Acknowledgments This paper was presented as a poster at the Computer Assisted Orthopaedic Surgery (CAOS) conference in London, UK in June 2011. Daniel Axelrod was the recipient of the University of Toronto Summer Student Research Grant, which helped to fund this project.

References

[1] Canadian Orthopaedic Trauma Society, *Nonoperative treatment compared with plate fixation of displaced midshaft clavicular fractures. A multicenter, randomized clinical trial*, J Bone Joint Surg Am, 89 (2007), 1–10.

[2] A. H. Crenshaw, *Fractures of the shoulder girdle, arm and forearm*, in Campbell's Operative Orthopaedics, A. H. Crenshaw, ed., Mosby, St. Louis, 8th ed., 1992, 989–1052.

[3] J. M. Hill, M. H. McGuire, and L. A. Crosby, *Closed treatment of displaced middle-third fractures of the clavicle gives poor results*, J Bone Joint Surg Br, 79 (1997), 537–539.

[4] C. T. Metz, *Digitally reconstructed radiographs*, master's thesis, Utrecht University, 2005.

[5] C. Neer, *Fractures of the clavicle*, in Fractures in Adults, C. A. Rockwood Jr. and D. P. Green, eds., Lippincott, Philadelphia, PA, 2nd ed., 1984, 707–713.

[6] C. R. Rowe, *An atlas of anatomy and treatment of midclavicular fractures*, Clin Orthop Relat Res, 58 (1968), 29–42.

[7] J. R. Sharr and K. D. Mohammed, *Optimizing the radiographic technique in clavicular fractures*, J Shoulder Elbow Surg, 12 (2003), 170–172.

[8] Visage Imaging, Carlsbad, CA, USA, Amira medical imaging software.

[9] C. Yang, M. Guiney, P. Hughes, S. Leung, K. H. Liew, J. Matar, et al., *Use of digitally reconstructed radiographs in radiotherapy treatment planning and verification*, Australas Radiol, 44 (2000), 439–443.