Using 3-Dimensional Fluoroscopy to Assess Acute Clavicle Fracture Displacement: A Radiographic Study

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Abstract

Midshaft clavicle fractures are often treated successfully by nonoperative means. However, recent clinical studies have found benefit from surgical fixation in cases with particular fracture characteristics, such as complete fracture fragment displacement with no cortical contact, and fractures with axial shortening of more than 20 mm. Accurately determining the extent of displacement and shortening can therefore be important in guiding treatment recommendations.

To our knowledge, the literature includes only 2 reports of studies that have compared different radiographic views and their accuracy in measuring fracture shortening, and no study has determined the best radiographic view for evaluating fracture displacement.

We retrospectively studied the cases of 10 patients to determine which radiographic view best captured the most fracture fragment displacement. Acute midshaft clavicle fractures were assessed with simulated angled radiographs created from preoperative upright 3-dimensional fluoroscopy scans.

Results showed that 15° angulated radiographs captured the most fracture fragment displacement. Given this finding, we recommend upright posteroanterior 15° caudal radiographs for midshaft clavicle fractures to best assess the extent of fracture displacement.

Clavicle fractures are common injuries, accounting for 2.6% to 5% of all adult fractures.[1,2] Most clavicle fractures (69%-82%) occur in the middle third or midshaft.[3,4] Midshaft clavicle fractures are often treated successfully with nonoperative means consisting of shoulder immobilization with either a sling or a figure-of-8 brace. Operative indications historically have been limited to open or impending open injuries and to patients with underlying neurovascular compromise. However, recent clinical studies have found that fractures with particular characteristics may benefit from surgical fixation. Important relative indications for open reduction and internal fixation of midshaft clavicle fractures are complete fracture fragment displacement with no cortical contact, and fractures with axial shortening of more than 20 mm.[5,6]

Accurately determining the extent of displacement and shortening can therefore be important in guiding treatment recommendations. The standard radiographic view for a clavicle fracture is upright or supine anteroposterior (AP). Typically, an AP radiograph with cephalic tilt of about 20° is obtained as well. On occasion, other supplemental radiographs, such as a 45° angulated view, as originally described by Quesada,[7] are obtained. To our knowledge, the literature includes only 2 reports of studies that have compared different radiographic views and their accuracy in measuring fracture shortening[8,9]; no study has determined the best radiographic view for evaluating fracture displacement.

We conducted a study to determine which radiographic view best captures the most fracture fragment displacement. Acute midshaft clavicle fractures were assessed with simulated angled radiographs created from preoperative upright 3-dimensional (3-D) fluoroscopy scans. Our hypothesis was that a radiographic view with 20° of cephalic tilt would most often detect the most fracture displacement. In addition, we retrospectively reviewed our study patients' initial AP injury radiographs to determine if obtaining a different view at maximum displacement would have helped identify a larger number of completely displaced midshaft clavicle fractures.

Patients and Methods

Institutional review board approval was obtained. Using our institution's trauma registry database, we retrospectively identified 10 cases of patients who had undergone preoperative 3-D fluoroscopy for midshaft clavicle fractures. Study inclusion criteria were age 18 years or older, acute midshaft clavicle fracture, and preoperative 3-D fluoroscopy scan of clavicle

Authors' Disclosure Statement: The authors report no actual or potential conflict of interest in relation to this article. The views expressed in this article are those of the authors and do not necessarily reflect the official policy or position of the US Department of the Navy, US Department of Defense, or the US Government.

available. Pediatric patients, nonacute injuries, and clavicle fractures of the lateral or medial third were excluded.

Three-dimensional fluoroscopy was used when the treating surgeon deemed it necessary for preoperative planning. All imaging was performed with a Philips MultiDiagnost Eleva 3-D fluoroscopy imager with patients in the upright standing position. (Informed patient consent was obtained.) Software bundled with the imager was used to create representative radiographs of differing angulation.

The common practice at most institutions is to obtain 2 radiographic views as part of a standard clavicle series. The additional AP angulated radiograph typically is obtained with 20° to 45° cephalic tilt from the horizontal axis. Therefore, simulated radiographs ranging from 15° to 50° of angulation in 5° increments were created, and the amount of superior displacement of the medial fragment was measured. As the simulated views were constructed from a 3-D composite image, there was none of the magnification error that occurs with AP or posteroanterior (PA) views. The stated degree of angulation mimics a radiograph's AP cephalic tilt or PA caudal tilt (**Figures 1A, 1B**). For all radiographic images, displacement between fracture fragments was determined by measuring the distance between the superior cortices at the fracture site of the medial and lateral fragments. Each simulated radiograph was measured by 2 readers using standard computerized radiographic measurement tools. Final displacement was taken as the mean of the 2 measurements.

After determining which radiographic angulation demonstrated the largest number of maximally displaced fractures, we compared the simulated radiographs at that angulation with the injury AP images for all patients. Total number of patients with a completely displaced midshaft clavicle fracture and no cortical contact was recorded for the 2 radiographic views.

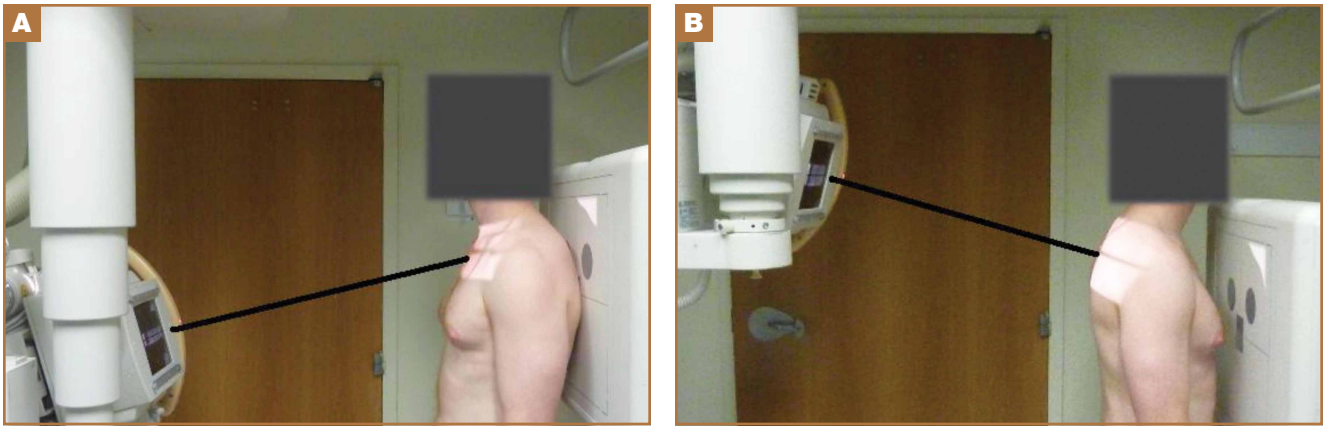

Figure 1. Clinical example: (A) 15° cephalic angulated anteroposterior radiograph and (B) 15° caudal angulated posteroanterior radiograph.

Table 1. **Measurements of Clavicle Fracture Displacement**

	Fracture Displacement, mm								Superior Displacement	
Case	15°	20°	25°	30°	35°	40°	45°	50°	Maximum	Minimum
1	18.6	18.9	19.3	20.0	21.8	23.3	24.2	24.8	50°	15°
2	14.4	13.8	14.4	17.0	12.6	12.1	20.1	11.5	45°	50°
3	17.1	15.9	16.8	12.4	12.6	12.3	12.8	12.5	15°	40°
4	27.0	24.1	23.4	24.1	24.4	22.1	22.7	20.3	15°	50°
5	17.1	17.0	17.0	15.1	14.9	14.0	14.4	14.1	15°	40°
6	20.2	23.3	24.1	22.8	23.9	25.1	25.5	28.0	50°	15°
7	17.8	17.2	15.8	15.3	13.6	12.6	11.6	10.1	15°	50°
8	15.4	16.3	17.6	15.7	14.7	15.2	13.6	10.1	25°	50°
9	20.6	17.8	16.2	16.8	21.9	12.5	10.8	10.1	35°	50°
10	23.5	22.4	21.8	20.5	18.6	16.5	14.9	13.8	15°	50°
									15° in 5/10	50° in 6/10

The Orthopaedic Trauma Association classification system[8] was used to classify the clavicle fractures. Statistical analysis was performed with the Fisher exact test and a regression model, using SPSS Version 19.0 (IBM SPSS Statistics).

Results

Ten patients met the study inclusion criteria. Mean age was 32.9 years (range, 18-65 years). Seven of the 10 patients were male. Six patients had right-side clavicle fractures. Of the 10 patients, 5 had the comminuted wedge fracture pattern (15-B2.3), 2 had the simple spiral pattern (15-B1.1), 2 had the spiral wedge pattern (15-B2.1), and 1 had the oblique pattern (15-B1.2).

Table 1 summarizes the fracture displacement measurements obtained with the different radiographic views. Of the 10 cases, 5 showed the most displacement with the 15° tilted view ($P = .004$), and the other 5 showed maximum displacement with different radiographic angulations. In addition, 6 patients showed the least displacement with the 50° angulated view ($P < .001$). Results of the regression analysis are summarized in **Tables 2 and 3**.

Initial horizontal AP imaging showed completely displaced midshaft clavicle fractures in 9 of the 10 patients, and 15° simulated radiographs showed completely displaced fractures in all 10 patients ($P = .50$).

Discussion

Our study results demonstrated that an upright 15° radiographic tilt (AP cephalad or PA caudal) identified the most fracture displacement in the most patients with acute midshaft clavicle fractures. To our knowledge, this is the first study to identify the radiographic angulation that best shows the most clavicle fracture fragment displacement.

Other investigators have studied the accuracy of different radiographic views in the assessment of midshaft clavicle fractures, but they concentrated on fracture shortening. Smekal and colleagues[9] used computed tomography (CT) and 3 different radiographic views to evaluate malunited midshaft clavicle fractures. Comparing the horizontal clavicular length measurements obtained with radiographs and CT scans, they determined that PA thoracic radiographs were in highest agreement with the CT scans. The results, however, were not statistically significant. In their study, supine CT was successful because the fractures were healed, and the displacement and shortening amounts were not affected by patient position. Sharr and Mohammed[10] studied the accuracy of different views in the assessment of clavicle length in an articulated cadaver specimen. They obtained multiple AP and PA radiographs of different horizontal (medial, lateral) and vertical (cephalad, caudal) angulations. Actual clavicle length was then directly measured and compared with the length measured on the different views. The authors concluded that a PA 15° caudal radiograph was most accurate in assessing clavicular length. Both Smekal and colleagues[9] and Sharr and Mohammed[10] recommended the PA radiograph because it decreases the degree of magnification on AP radiographs by minimizing the film-to-object distance.

Our findings are important because more accurate determination of fracture displacement in patients with midshaft clavicle fractures may change clinical management. Nowak and colleagues[11] investigated various patient and clavicle fracture characteristics that were predictive of a higher rate of long-term sequelae. They found that complete fracture displacement was the strongest radiographic predictor of patients' beliefs that they were fully recovered from injury at final follow-up. The authors concluded that fractures with no bony contact should receive more "active" management. Robinson and colleagues[12] studied a cohort of patients with nonoperatively managed midshaft clavicle fractures and concluded that complete fracture displacement significantly increased risk for nonunion (this risk was 2.3 times higher in patients with displaced fractures than in patients with nondisplaced fractures). Last, McKee and colleagues[13] found that shoulder strength and endurance were significantly decreased in nonoperatively treated displaced midshaft clavicle fractures than in the same patients' uninjured shoulders.

Extending the results of these studies, recent prospective randomized control trials and a meta-analysis have compared the clinical outcomes of nonoperatively and operatively managed displaced midshaft clavicle fractures.[14-18] With few exceptions, these studies found improved clinical results with operative fixation. In one such study, the Canadian Orthopaedic Trauma Society[14] randomized patients with displaced midshaft clavicle fractures to either operative plate fixation or sling immobilization. The operative group was found to have improved Disability of the Arm, Shoulder, and Hand scores, improved Constant shoulder scores, increased patient satisfaction, faster mean time to bony fracture union, higher satisfaction with shoulder appearance, and lower rates of nonunion and malunion. Given the results of these studies, accurate identifica-

Table 2. Statistical Results for Maximum Fracture Displacement Measurements

	Maximum Displacement				
	No	Yes	OR	95% CI	*P*
15° angle	5	5	Reference	Reference	Reference
All other angles combined	65	5	0.077	0.017-0.358	.004

Abbreviations: CI, confidence interval; OR, odds ratio.

Table 3. Statistical Results for Minimum Fracture Displacement Measurements

	Minimum Displacement				
	No	Yes	OR	95% CI	*P*
50° angle	4	6	Reference	Reference	Reference
All other angles combined	66	4	0.040	0.008-0.204	<.001

Abbreviations: CI, confidence interval; OR, odds ratio.

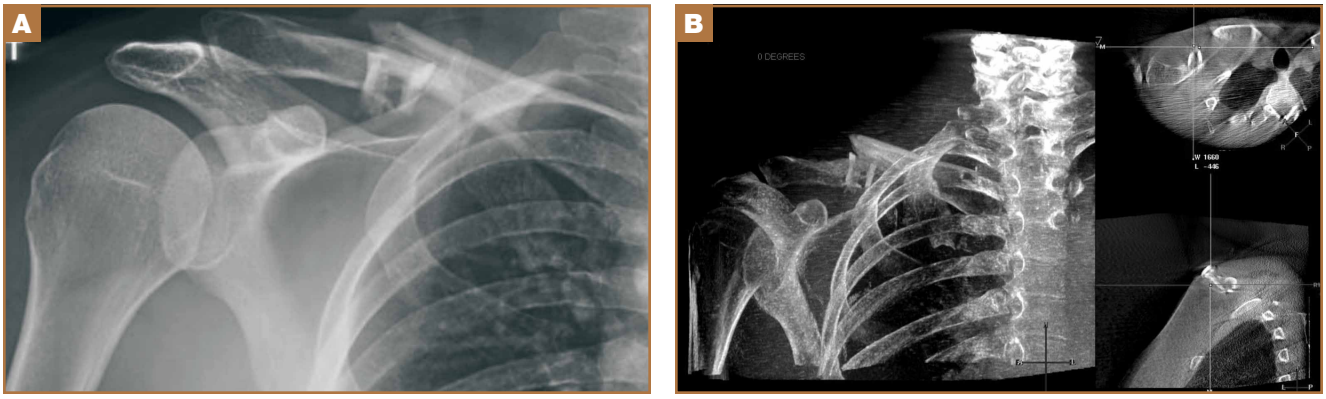

Figure 2. Patient's partial clavicle fracture fragment displacement shown on (A) anteroposterior injury radiograph and (B) simulated anteroposterior radiograph created from preoperative 3-dimensional fluoroscopy scan.

tion of a displaced midshaft clavicle fracture with no cortical contact is fundamental in deciding whether to recommend operative fixation.

Retrospective review of our cohort's initial radiographs revealed 1 case in which the patient's completely displaced midshaft clavicle fracture would not have been diagnosed solely with an AP horizontal image. Cortical contact was seen on a standard AP clavicle radiograph (**Figures 2A, 2B**), and a 15° tilt radiograph created from 3-D fluoroscopy scan showed complete fracture fragment displacement (**Figure 3**). A change in fracture classification from partially displaced to fully displaced could alter the type of management used by a treating surgeon.

There were obvious weaknesses to this study. First, its sample size was small (10 patients). Nevertheless, we had sufficient numbers to find a statistically significant angulation. Second, a wider range of radiographic angles could have been studied. Our intent, however, was to investigate the accuracy of the 2 most common supplementary clavicle views (20° and 45° cephalic tilt). Therefore, we selected a range of simulated radiographs that began 5° outside these angulations. Third, we measured only the degree of fracture displacement; we were unable to accurately access fracture shortening, as the 3-D fluoroscopic images were limited to the injured clavicles. A potential solution to this problem is to widen the exposure field in order to include the entire chest and allow clavicular length comparison against the uninjured side. Doing this would have been possible, but at the expense of increasing the patient's radiation exposure.

This innovative study used 3-D fluoroscopy to capture clavicle fracture images with patients in an upright position. Unlike standard CT, in which patients are supine, this 3-D imaging technology better emulates the patient positioning used for upright radiographs, thereby avoiding potential fracture fragment alignment changes caused by shifts in body position. In addition, 3-D fluoroscopy allows us to create multiple precise simulated radiographic angulations without the magnification error of AP radiographs and, to a lesser extent, PA radiographs. Having a standing PA 15° caudal tilt radiograph obviates the need for CT with 3-D reconstruction. More fine detail may be revealed by CT with 3-D reconstruction than by a standing PA 15° caudal tilt radiograph, but the patient faces less radiation risk and cost with the radiograph.

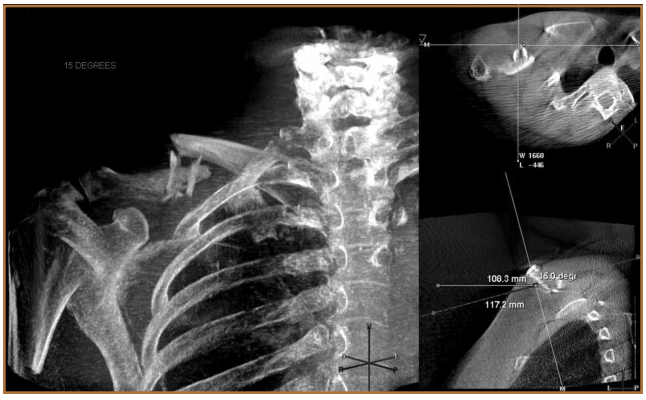

Figure 3. Simulated 15° angulated radiograph of same patient (Figure 2) shows complete fracture fragment displacement.

There is no consensus as to what constitutes the standard radiographic series for clavicle fractures. Radiographic technique can vary with respect to supplemental view angulation, supine or upright patient positioning, and AP or PA radiographic views. Although our study did not address the effect of supine versus upright patient positioning on acute midshaft clavicle fracture displacement, we think that, for all clinical and research purposes, upright 15° caudal PA radiographs should be obtained for patients with acute midshaft clavicle fractures.

Conclusion

Our retrospective study of 10 patients with acute midshaft clavicle fractures and preoperative upright 3-D fluoroscopy scans found that a 15° angulated radiograph most often demonstrated the most fracture fragment displacement. Given these findings, we recommend obtaining an additional PA 15° caudal radiograph in the upright position for patients with midshaft clavicle fractures to best assess the extent of fracture displace-

ment. Accurately identifying the degree of fracture displacement is important, as operative management of completely displaced fractures has been shown to improve clinical outcomes.

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Am J Orthop. 2015;44(10):E365-E369.

References

1. Postacchini F, Gumina S, De Santis P, Albo F. Epidemiology of clavicle fractures. *J Shoulder Elbow Surg*. 2002;11(5):452-456.
2. Nordqvist A, Petersson C. The incidence of fractures of the clavicle. *Clin Orthop Relat Res*. 1994;(300):127-132.
3. Robinson CM. Fractures of the clavicle in the adult. Epidemiology and classification. *J Bone Joint Surg Br*. 1998;80(3):476-484.
4. Rowe CR. An atlas of anatomy and treatment of midclavicular fractures. *Clin Orthop Relat Res*. 1968;(58):29-42.
5. Jeray KJ. Acute midshaft clavicular fracture. *J Am Acad Orthop Surg*. 2007;15(4):239-248.
6. Khan LA, Bradnock TJ, Scott C, Robinson CM. Fractures of the clavicle. *J Bone Joint Surg Am*. 2009;91(2):447-460.
7. Quesada F. Technique for the roentgen diagnosis of fractures of the clavicle. *Surg Gynecol Obstet*. 1926;42:424-428.
8. Marsh JL, Slongo TF, Agel J, et al. Fracture and dislocation classification compendium—2007: Orthopaedic Trauma Association Classification, Database and Outcomes Committee. *J Orthop Trauma*. 2007;21(10 suppl):S1-S133.
9. Smekal V, Deml C, Irenberger A, et al. Length determination in midshaft clavicle fractures: validation of measurement. *J Orthop Trauma*. 2008;22(7):458-462.
10. Sharr JR, Mohammed KD. Optimizing the radiographic technique in clavicular fractures. *J Shoulder Elbow Surg*. 2003;12(2):170-172.
11. Nowak J, Holgersson M, Larsson S. Can we predict long-term sequelae after fractures of the clavicle based on initial findings? A prospective study with nine to ten years of follow-up. *J Shoulder Elbow Surg*. 2004;13(5):479-486.
12. Robinson CM, Court-Brown CM, McQueen MM, Wakefield AE. Estimating the risk of nonunion following nonoperative treatment of a clavicular fracture. *J Bone Joint Surg Am*. 2004;86(7):1359-1365.
13. McKee MD, Pedersen EM, Jones C, et al. Deficits following nonoperative treatment of displaced midshaft clavicular fractures. *J Bone Joint Surg Am*. 2006;88(1):35-40.
14. 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*. 2007;89(1):1-10.
15. Judd DB, Pallis MP, Smith E, Bottoni CR. Acute operative stabilization versus nonoperative management of clavicle fractures. *Am J Orthop*. 2009;38(7):341-345.
16. Smekal V, Irenberger A, Struve P, Wambacher M, Krappinger D, Kralinger FS. Elastic stable intramedullary nailing versus nonoperative treatment of displaced midshaft clavicular fractures—a randomized, controlled, clinical trial. *J Orthop Trauma*. 2009;23(2):106-112.
17. Witzel K. Intramedullary osteosynthesis in fractures of the mid-third of the clavicle in sports traumatology [in German]. *Z Orthop Unfall*. 2007;145(5):639-642.
18. McKee RC, Whelan DB, Schemitsch EH, McKee MD. Operative versus nonoperative care of displaced midshaft clavicular fractures: a meta-analysis of randomized clinical trials. *J Bone Joint Surg Am*. 2012;94(8):675-684.