Plain film measurement error in acute displaced midshaft clavicle fractures

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Background: Clavicle fractures are common and optimal treatment remains controversial. Recent literature suggests operative fixation of acute displaced mid-shaft clavicle fractures (DMCFs) shortened more than 2 cm improves outcomes. We aimed to identify correlation between plain film and computed tomography (CT) measurement of displacement and the inter- and intraobserver reliability of repeated radiographic measurements.

Methods: We obtained radiographs and CT scans of patients with acute DMCFs. Three orthopedic staff and 3 residents measured radiographic displacement at time zero and 2 weeks later. The CT measurements identified absolute shortening in 3 dimensions (by subtracting the length of the fractured from the intact clavicle). We then compared shortening measured on radiographs and shortening measured in 3 dimensions on CT. Interobserver and intraobserver reliability were calculated.

Results: We reviewed the fractures of 22 patients. Bland–Altman repeatability coefficient calculations indicated that radiograph and CT measurements of shortening could not be correlated owing to an unacceptable amount of measurement error (6 cm). Interobserver reliability for plain radiograph measurements was excellent (Cronbach $\alpha = 0.90$). Likewise, intraobserver reliabilities for plain radiograph measurements as calculated with paired $t$ tests indicated excellent correlation ($p > 0.05$ in all but 1 observer [$p = 0.04$]).

Conclusion: To establish shortening as an indication for DMCF fixation, reliable measurement tools are required. The low correlation between plain film and CT measurements we observed suggests further research is necessary to establish what imaging modality reliably predicts shortening. Our results indicate weak correlation between radiograph and CT measurement of acute DMCF shortening.

Contexte : Les fractures de la clavicule sont fréquentes, et le choix du traitement optimal ne fait pas l’unanimité. Selon la littérature récente, la fixation chirurgicale des fractures du tiers médial déplacées (FTMD) aiguës raccourcies de plus de 2 cm donnerait de meilleurs résultats. Nous avons voulu établir une corrélation entre la mesure du déplacement obtenue par radiographie simple et par tomodensitométrie (TDM) et la fiabilité inter- et intra-observateur des mesures radiographiques répétées.

Méthodes : Nous avons obtenu les radiographies et les TDM de patients ayant subi une FTMD aiguë. Trois orthopédistes et 3 résidents ont mesuré le déplacement radiographique au temps zéro et 2 semaines plus tard. Les mesures par TDM ont permis d’identifier un raccourcissement absolu en 3 dimensions (en soustrayant de la longueur de la clavicule intacte celle de la clavicule brisée). Nous avons ensuite comparé le raccourcissement mesuré par radiographie au raccourcissement en 3 dimensions mesuré par TDM. La fiabilité inter- et intra-observateur a ensuite été calculée.

Résultats : Nous avons ainsi analysé les fractures de 22 patients. Les calculs du coefficient de répétabilité de Bland et Altman ont indiqué qu’il était impossible d’établir des corrélations entre les mesures obtenues par radiographie et par TDM compte tenu de l’ampleur inacceptable de l’erreur de mesure (6 cm). La fiabilité inter-observateur a été excellente pour les mesures radiographiques (coefficient $\alpha$ de Cronbach $= 0.90$). De même, la fiabilité intra-observateur pour les mesures radiographiques calculée par test $t$ pour échantillons appariés a indiqué une excellente corrélation ($p > 0.05$ chez tous les observateurs, sauf 1 [$p = 0.04$]).

Conclusion : Pour que le raccourcissement devienne une indication de la FTMD, il faut disposer d’outils de mesure fiables. La faible corrélation que nous avons observée entre les mesures obtenues par radiographie et par TDM montre qu’il faut approfondir la recherche afin de déterminer quelle modalité permet de prédire de manière fiable le raccourcissement. Nos résultats démontrent une faible corrélation entre les mesures du raccourcissement obtenues par radiographie et par TDM dans la FTMD aiguë.
Clavicle fractures account for nearly 10% of all fractures evaluated by clinicians. Treatment of these fractures has evolved from primarily conservative methods to select indications for open reduction internal fixation (ORIF). Data presented in recent literature suggest that nonoperative treatment of displaced midshaft clavicle fractures (DMCFs) leads to a higher incidence of nonunion than previously reported as well as reduced shoulder strength and endurance. Poor functional outcome has been associated with nonoperatively treated fractures that result in an overall clavicle length 15–20 mm shorter than the contralateral (unfractured) clavicle. Consequently, 20 mm of shortening has evolved as a relative indication for operative therapy.

The literature that has established 20 mm of shortening as a relative indication for surgical management of DMCF is the product of multiple studies that use different measurement modalities. These measurement modalities include clinical estimates with tape measure, radiological estimates made on uncalibrated plain films and computed tomography (CT) measurements in both the acute fracture and chronic malunion settings. In a recent study of healed clavicle fractures, Smekal and colleagues established that neither clinical nor plain film measures of clavicle shortening correlate with those obtained by CT (used as a reference measure). Additionally, of the 3 radiographs investigated (15° up-tilted panorama and 15° standardized tilted views) only the posteroanterior (PA) thorax radiograph that demonstrated the contralateral unfractured clavicle for comparison correlated with CT measurements of clavicle shortening.

To our knowledge, no reports to date have compared clavicle shortening measured on plain film to that measured on CT in the acute fracture setting. The purpose of this study was to define the correlation of plain film measurements with CT measurements of shortening in DMCF and assess the interobserver and intraobserver reliabilities associated with radiographic measurements of displacement.

**Methods**

Institutional ethics approval was obtained. We identified clavicle radiographs with corresponding CT scans obtained from skeletally mature patients at our institution between Nov. 20, 2003, and Aug. 31, 2012. The images had been obtained as part of either a routine trauma assessment or in the work-up of a pathologic fracture. We excluded studies from the analysis if a pathologic fracture was confirmed. Patients with a unilateral midshaft clavicle fracture who had dedicated plain film radiographs of the injured clavicle as well as a high-quality chest CT scan that completely visualized both clavicles were selected for analysis. Imaging studies (radiograph and CT) were anonymized and exported into a medical imaging software DICOM viewer (Osirix, Pixmeo). Studies were excluded if more than 3 days had elapsed between the radiograph and CT scan of the acute fracture to minimize the risk that an actual change in clavicle length occurred secondary to positioning changes.

This study is based on the assumption that clavicle length is symmetric as confirmed recently by Cunningham and colleagues. For the purposes of the present study, the unfractured clavicle was considered to represent a patient’s normal clavicle length. Clavicle length was measured in 3 dimensions on axial CT scan cuts using Osirix by an author (L.A.A.) who did not serve as an observer in the plain film analysis of shortening. A point (with x, y and z coordinates) was placed at the most medial and most lateral ends of both the intact and fractured clavicles (Fig. 1). We calculated clavicle length in 3 dimensions based on the x, y, z coordinates. Absolute clavicular shortening was then calculated by subtracting the fractured clavicle length from the length of the intact clavicle for each patient.

Three orthopedic staff and 3 orthopedic residents were provided with the series of plain films loaded on Osirix for review and oriented to the use of the DICOM viewer interface. Each plain film contained a full-length view of the fractured clavicle. The reviewers were asked to estimate the extent of shortening on the plain film using the standard computerized measurement caliper. Participants were not instructed on what specific points within the fracture should be measured to estimate shortening. After a 2-week washout period, the same participants repeated shortening estimates on the provided films.

**Fig. 1:** To measure clavicle length, a point (with x, y, z coordinates) was placed at the most medial and most lateral ends of both the intact and fractured clavicles. Clavicle length was calculated in 3 dimensions based on the x, y, z coordinates.
**Statistical analysis**

We used SPSS software version 12.0 for statistical analyses. Correlation between plain film and CT measurements of shortening was investigated using the Bland–Altman reliability coefficient.\(^{21}\) We compared clavicle shortening measured on plain radiographs at each time point by each observer with clavicle shortening measured in 3 dimensions on CT. Limits of agreement were then calculated using the standard deviation (SD) obtained for each observer (± 2 SD). Interobserver reliability was evaluated using the Cronbach \(\alpha\) coefficient.\(^{22}\) Intraobserver reliability was calculated using paired \(t\) tests for each observer.

**Results**

Twenty-two patients with appropriate radiographic studies were identified: 7 female and 15 male patients with a mean age of 48 (range 19–84) years. Eighteen patients sustained their injury secondary to high-energy trauma, whereas the remaining 4 patients had minimal trauma.

Two Bland–Altman repeatability coefficient analyses were performed for each observer using the 2 data sets (time zero and 2 weeks). The results of the analysis showed that measurements obtained by 5 of 6 observers did not correlate with CT measurements at both points owing to unacceptable measurement error (Table 1). The limits of agreement calculated with this statistical method revealed a mean of ± 3.48 cm. Therefore, the error inherent in plain film measurements in this study is 6.96 cm (Table 2). Interobserver reliability calculated with Cronbach \(\alpha\) identified excellent correlation (0.90). Likewise, intraobserver reliabilities calculated with paired \(t\) tests demonstrated excellent correlation (\(p > 0.05\) in all but 1 observer \([p = 0.04]\); Table 2). It should be noted that the outlying observer was a staff orthopedic surgeon with specialty training in traumatology.

**Discussion**

Approximately 20 of every 100 000 individuals sustain a DMCF each year.\(^2\) Traditionally, acute DMCFs were managed nonoperatively. Early attempts at ORIF of clavicle fractures produced high rates of nonunion and discouraged operative treatment of these injuries.\(^{23,24}\) However, emerging evidence suggests that the risks of surgical treatment may be outweighed by functional and financial benefits for patients with midshaft clavicle fractures shortened 20 mm or more.\(^{1,13,11,25}\)

In the 1960s, Rowe and colleagues\(^{23}\) and Neer and colleagues\(^{24}\) conducted large clinical series (566 patients and 2235 patients, respectively) documenting outcomes of patients with clavicle fractures treated nonoperatively. These studies independently reported nonunion rates less than 1% and failed to identify functional compromise with nonoperative treatment. Neer and colleagues included 18 cases of nonunion in their series and attributed 10 of these failures to operative intervention.\(^{24}\) Similarly, Rowe and colleagues reported a nonunion rate associated with operative intervention more than 4 times that of nonoperative management (3.7% \(\times\) 0.8%).\(^{23}\)

Data published recently challenge the uniform treatment of acute DMCF conservatively, citing the incidence of nonunion and shoulder dysfunction as unacceptably high with nonoperative therapy. Current literature suggests that nonunion may occur in up to 30% of conservatively treated DMCFs with shortening of 20 mm or more on initial injury films.\(^{7–10,26}\) In their prospective series of 208 patients followed up to 10 years, Nowak and colleagues\(^7\) determined that lack of cortical contact between fragments and displacement of the fracture fragments on initial injury films were predictors of poorer long-term outcomes. Wick and colleagues\(^8\) demonstrated an increase in the incidence of nonunion with initial shortening.
greater than 20 mm through the prospective treatment of 39 delayed or malunited midshaft clavicle fractures. Robinson and colleagues performed a prospective cohort analysis of 868 patients with clavicle fractures and identified lack of cortical apposition as being predictive of nonunion. Furthermore, a recent study by Murray and colleagues identified lack of cortical contact between fracture fragments in acute DMCFs as a risk factor for nonunion. Finally, Hill and colleagues identified initial shortening of 20 mm or greater to be significantly correlated with risk of nonunion through their cross-sectional study of 242 patients with clavicle fractures.

Global loss of shoulder strength and endurance has been associated with symptomatic malunion resulting from nonoperative treatment of an acute DMCF shortened in the medial-lateral plane. As early as 1986, Eskola and colleagues identified increased incidence of pain and weakness associated with radiographic clavicle shortening greater than 15 mm after fracture in a population of 89 patients treated nonoperatively. In a cross-sectional study of 30 patients with DMCF treated conservatively, McKee and colleagues noted a trend toward increased shoulder disability with shortening of 20 mm or greater (mean DASH score of 24.6 and mean Constant score of 71). Another cross-sectional study of 16 patients documented statistically significant loss of adduction, internal rotation and extension strength in shoulders with clavicle malunions (defined as shortening ≥ 15 mm as compared with the normal side measured on CT scan). In the same study, the authors demonstrated abnormal static anatomic relationships of the sternoclavicular joint and increased scapular anteversion with clavicle malunions, citing these anomalies as potential explanations for functional differences. A biomechanical study of 12 cadaveric shoulders recently demonstrated decreased posterior tilt and external rotation of the scapula during shoulder motion with more than 10% shortening of the clavicle. Matsumura and colleagues state that such anomalous biomechanics may explain shoulder dysfunction after clavicle shortening. Recently, Ristevski and colleagues quantified the degree of scapular deviation from normal positioning associated with clavicular malunion and identified scapular winging as a possible complication of scapular malposition. Lending the strongest clinical support for improved outcomes with ORIF of acute DMCF, a randomized control trial by Altamimi and McKee demonstrated significantly superior outcomes when operative therapy was selected for acute DMCF (10-point improvement in both mean DASH and mean Constant scores for operatively treated patients). Substantial additional literature supports accepting 20 mm or more of shortening in an acute DMCF as a relative, and potentially absolute, indication for ORIF.

Despite evidence to suggest clavicle shortening causes shoulder dysfunction, controversy remains. Nordqvist and colleagues failed to demonstrate an association between shortening and functional shoulder outcome in a review of 71 patients with clavicle fractures. Similarly, Oroko and colleagues found that shortening of the clavicle had no functional impact in 41 patients studied 3 or more months after clavicle fracture. Most recently, Robinson and colleagues failed to demonstrate an improvement in shoulder function associated with ORIF of DMCF compared with fractures treated nonoperatively in the absence of nonunion, suggesting that the benefit to ORIF lies in the decreased incidence of nonunion and not prevention of malunion.

Clavicle shortening has been estimated by several methods, including direct clinical measurement with tape measure, radiographic measurement from plain radiographs or calculation from CT data. Measurement from plain film is associated with significant error, highlighting the potential drawback of using this modality as a screening tool to identify operative candidates. Several pitfalls inherent in plain radiography potentially compromise the use of this modality as a reliable measuring tool for clavicle fractures. First, the complex s-shaped morphology of the clavicle prevents the bone from being positioned truly perpendicular to the radiograph cassette, and second, true orthogonal imaging of the clavicle is not easily obtained. Figure 2 illustrates the limitations of radiographic assessment of clavicle fractures and displays the same clavicle fracture in 3 projections (cephalad projection angle changed by 25° each time). Additionally, patient positioning (supine v. upright) and distance of the patient from the radiograph cassette may contribute to error in measurement of clavicle shortening on plain films. In the present study, 18 patients sustained clavicle fractures as a result of high-energy trauma. As a result, not all patients could sit upright for clavicle films; however, each CT scan was obtained with the patient supine. Based on the study by Backus and colleagues, it is likely that a degree of measurement error was introduced by the inconsistent positioning of patients in this study during plain film radiography.

Open reduction and internal fixation of acute clavicle fractures exposes patients to risks, such as infection, symptomatic hardware, refracture after hardware removal and damage to adjacent neurologic and vascular structures. Justification of these risks requires appropriate patient
selection. If clavicle shortening of greater than 20 mm is to be used as an indication for surgery, reliable methods of measurement are required to accurately identify patients who will benefit from operative therapy. Although interobserver and intraobserver reliability were high in our study, comparison of measurements generated on plain film to those obtained in 3 dimensions using CT demonstrate correlation only if a large amount of error (6 cm) is accepted. Given the established indication of improved outcome for patients presenting with 20 mm of shortening, 6 cm of error is not acceptable. Of note, recent studies suggest that lack of cortical apposition may be an adequate surrogate measure for shortening when deciding which patients with acute DMCF would benefit from ORIF.²⁷,³² Use of surrogate measures for shortening may enable appropriate patient selection in the absence of a reliable radiographic measuring tool.

Limitations

Limitations of this study include the inability to control for patient positioning for radiograph and CT scans, which could at least in part account for the measurement error observed in this study. Intraobserver reliability reported in this study may have been biased secondary to participant recall of the clavicle plain films (and measurements) between time points. However, the high intraobserver and interobserver reliability in this study suggests that individual recall of images was unlikely to be a significant source of error. Heterogeneity in the experience levels of participants reviewing the radiographs could be viewed as a shortcoming of this study. Orthopedic residents at various levels of training as well as orthopedic specialists with and without fellowship hand and upper limb training formed the observer group. Residents were in either their second, fourth or fifth years. In clinical practice, however, orthopedic surgeons with diverse backgrounds treat these fractures and, as such, the heterogeneity in the observer group may actually be representative of the real-world scenario.

Conclusion

Plain film measurements of acute DMCF do not reliably predict shortening. Computed tomography is an additional tool orthopedic surgeons can use to improve the accuracy of patient selection for surgery if it is available as part of a routine trauma work-up. However, when a CT scan is not a part of a patient’s routine trauma work-up, additional cost, time and radiation exposure are consequences of
obtaining further imaging. Therefore, further study to determine which plain film projection most closely approximates CT measurements of clavicular shortening in acute DMCFs would be beneficial. Alternatively, surrogate measures of shortening on plain films, such as lack of cortical contact between clavicle fracture fragments (on at least 1 of 2 radiographic views), may prove to be more appropriate selection criteria for determining which patients with acute DMCF would benefit from treatment with operative fixation.

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