J Shoulder Elbow Surg (2018) ■■, ■■–■■

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

ORIGINAL ARTICLE

Influence of x-ray direction on measuring shortening of the fractured clavicle

Paul Hoogervorst, MD[a,*], Anand Appalsamy, MD[a], Arnoud R. van Geene, MD[b], Sebastiaan Franken, MD[c], Albert van Kampen, MD, PhD[a], Gerjon Hannink, PhD[a]

[a]*Department of Orthopedics, Radboud University Medical Center, Nijmegen, Netherlands*
[b]*Department of Orthopedic Surgery, Onze Lieve Vrouwe Gasthuis, Amsterdam, Netherlands*
[c]*Department of Radiology, Radboud University Medical Center, Nijmegen, Netherlands*

Background: Midshaft clavicle fractures are often associated with a certain degree of shortening. There is great variety in the imaging techniques and methods to quantify this shortening. This study aims to quantify the difference in measurements of shortening and length of fracture elements between 5 views of the fractured clavicle. Furthermore, the interobserver and intraobserver agreement between these views using a standardized method is evaluated.

Materials and methods: Digitally reconstructed radiographs were created for 40 computed tomography datasets in the anteroposterior (AP), 15° and 30° craniocaudal, and 15° and 30° caudocranial views. A standardized method for measuring the length of fracture elements and the amount of shortening was used. Interobserver and intraobserver agreement for each of the 5 views was calculated.

Results: The interobserver and intraobserver agreement was excellent for all 5 views, with all intraclass correlation coefficient values greater than 0.75. The measured differences in relative and absolute shortening between views were statistically significant between the 30° caudocranial view and all other views. The increase in median shortening measured between the commonly used 30° caudocranial view (2.7 mm) and the AP view (8.5 mm) was 5.8 mm ($P < .001$). The relative median shortening between these views increased by 3.5% ($P < .001$).

Conclusion: The length of fracture elements and the amount of shortening in the fractured clavicle can be reliably measured using a standardized method. The increase in absolute and relative shortening when comparing the caudocranial measurements with the AP and craniocaudal measurements may indicate that the AP and craniocaudal views provide a more accurate representation of the degree of shortening.

Level of evidence: Level II; Diagnostic Study

Keywords: Clavicle; fracture; imaging; shortening; inter-rater agreement; intrarater agreement

In the past few decades, there has been an increased tendency to surgically treat displaced, shortened and/or comminuted clavicle fractures as operative treatment provides a significantly lower rate of nonunion, as well as an earlier functional return and increased patient satisfaction, compared with nonoperative treatment.[12,14,18,30]

The study protocol was approved by our Institutional Review Board (CMO Arnhem-Nijmegen 2015-1768).

*Reprint requests: Paul Hoogervorst, MD, Department of Orthopedics, Radboud University Medical Center, PO Box 9101, NL-6500 HB, Nijmegen, Netherlands.

E-mail address: paul.hoogervorst@radboudumc.nl (P. Hoogervorst).

1058-2746/$ - see front matter © 2018 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
https://doi.org/10.1016/j.jse.2018.02.054

Because of the specific anatomy of the clavicle and its surrounding tissues, midshaft clavicle fractures (MSCFs) are often associated with a certain degree of shortening. This shortening is identified as a determinant for poorer outcomes concerning union rates and long-term effects such as pain, loss of strength, rapid fatigue, hyperesthesia of the hand and arm, difficulty sleeping on the affected side, and esthetic complications.[7,10] Godfrey et al[9] reported that the degree of symptomatology and occurrence of malunion and nonunion after MSCF are related to the extent of shortening and displacement of the fracture elements.

Biomechanical studies and simulations have shown that a shortened clavicle can lead to altered scapular kinematics and shoulder function.[11,16,27] Weinberg et al[28] reported that there is a strong association between shortened clavicles and the occurrence of glenohumeral joint arthritis.

Recently, Woltz et al[29] performed a systematic review regarding the influence of shortening on shoulder function after union of nonoperatively treated MSCFs. They concluded that shortening alone is currently not an evidence-based indication to operate for the goal of functional improvement. However, this conclusion is based on a heterogeneous group of methods, definitions, and measuring techniques. Furthermore, functional improvement is not the only important outcome parameter in the treatment of MSCFs. To evaluate whether shortening can be used or should be discarded as an indicator for surgery, it is important to identify an evidence-based, standardized, accurate and reliable method to measure shortening.

There is great variety in the imaging techniques and measurements of the fractured clavicle, and adequate measurements of the fractured clavicle are subject to a plethora of influences such as patient positioning,[2,15] timing,[19] methods of measuring,[23] physiological side-to-side differences,[4] and direction of the x-ray beams.[22,24]

In acute MSCFs, the most commonly used views to determine shortening are the standard anteroposterior (AP) view and a 15°-30° caudocranial view. However, there are reports that suggest these views might not be the most accurate and reliable.[1,13,24]

Therefore, the aims of this study were (1) to quantify the difference in measurements of shortening and length of fracture elements between 5 different views of the fractured clavicle (15° and 30° caudocranial, AP, and 15° and 30° craniocaudal) and (2) to identify and quantify the differences in interobserver and intraobserver agreement between the 5 different views using a standardized method for measuring shortening and the length of fracture elements.

Materials and methods

A clinical measurement study quantifying the difference in measurements of shortening and length of fracture elements between 5 different views of the fractured clavicle was conducted. The database of the Nederlands Trauma Register was used to search for consecutive patients who were diagnosed with a clavicle fracture in the emergency department and underwent a thoracic computed tomography (CT) scan during advanced trauma life support screening in our hospital between June 2009 and August 2014. Patients who (1) had a Robinson type 2B1 fracture of the clavicle, (2) had adequate and complete imaging of the fractured clavicle on CT scan, and (3) were skeletally mature (aged ≥ 18 years) were eligible for inclusion.

The CT scans were made using a Toshiba Aquilion One (Canon Medical Systems, Tustin, CA, USA) and Siemens Somatom 16 or 64 scanner (Siemens, Erlangen, Germany), and scans were uploaded and analyzed with TeraRecon Aquarius iNtuition (TeraRecon, Foster City, CA, USA). Digitally reconstructed radiographs (DRRs) were created for each CT dataset at 5 angles: AP view, 15° and 30° craniocaudal views, and 15° and 30° caudocranial views. Each DRR represented a 2-dimensional x-ray film of the fractured clavicle (Fig. 1).

A standardized method for measurement as described by Silva et al[23] was used, as shown in Figure 2. In short, lines through both the medial and lateral fragments of the clavicle were drawn from the center of the acromioclavicular or sternoclavicular joint to the center of the fracture plane. The lengths of these lines represented the lengths of the fragments. Next, a perpendicular line was drawn from the line through the medial fragment at the fracture plane. Subsequently, a parallel line was drawn to this line at the point where the line through the lateral fragment intersected the fracture plane. The difference between the latter 2 lines indicated the amount of shortening in millimeters.

All measurements were performed on the 5 different DRR views of each patient to determine the length of fracture elements and amount of shortening. The 5 DRRs for each patient were evaluated as described earlier in random order by 3 observers (2 orthopedic residents [P.H. and A.R.v.G.] and 1 medical student [A.A.]). To calculate intraobserver agreement, the same observers performed a second evaluation of the same randomized DRRs 2-4 weeks after the first measurements were performed. Before the start of the study, a training session with each observer took place. The precise definition of the reference points was agreed on between the observers. Measurements were performed using the hospital's IMPAX software (version 6.5.3.1005; AGFA, Mortsel, Belgium).

Descriptive statistics were used to summarize the data. Intraclass correlation coefficients (ICCs) were used to assess the interobserver and intraobserver agreement for each of the 5 views. ICC values were interpreted as follows: less than 0.40, poor; 0.40-0.59, fair; 0.60-0.74, good; and 0.75-1.00, excellent.[3] The ICC was calculated from a 2-way random-effects model for absolute agreement. Mean shortening as measured by the 3 observers was used in descriptive statistics and further statistical analyses when ICC values were excellent. The "limits of agreement with the mean"—a modification of the Bland-Altman–type methodology described by Jones et al[13] that can be used for more than 2 observers and retains the ability to evaluate consistency of agreement over different magnitudes of continuous measurements—were calculated.

Friedman 1-way repeated-measures analysis of variance by ranks was used to test for differences in (absolute and relative) shortening obtained from the 5 different views, followed by Wilcoxon signed rank tests for pair-wise comparisons. The Benjamini-Hochberg procedure with a false discovery rate (FDR) of 0.05 was used for multiple testing corrections.[8] FDR control is a statistical method used in multiple-hypotheses testing to correct for multiple comparisons. Among tests that are declared significant, the FDR is the expected fraction of those tests in which the null hypothesis is true. Statistical analyses were performed using R (version 3.4.0; R Foundation