



Measurement of midshaft clavicle vertical displacement is not influenced by radiographic projection

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Background: Measured shortening of midshaft clavicle fracture fragments is known to be influenced by multiple factors. The influence of radiographic projection on vertical displacement is unclear. The aims of this study were (1) to quantify the difference in measurements of vertical displacement in an absolute, relative, and categorical manner between 5 different projections; (2) to quantify the differences in interobserver and intraobserver agreement using a standardized method for measuring vertical displacement; and (3) to assess the association between categorical and continuous descriptions of vertical displacement.

Materials and methods: A clinical measurement study was conducted on 31 sets of digitally reconstructed radiographs in 5 different projections (15° and 30° caudocranial, anteroposterior, and 15° and 30° craniocaudal views). Categorical data on vertical displacement in quartiles from 0%–200% were obtained followed by measurements using a standardized method by 3 observers at 2 points in time. Interobserver and intraobserver agreement for each of the 5 views was calculated.

Results: The absolute and relative vertical displacement showed no statistically significant difference between any of the caudocranial, anteroposterior, and craniocaudal views. Intraclass correlation coefficients for intraobserver and interobserver agreement were good to excellent. The correlation between categorical outcomes and both absolute and relative vertical displacement was very strong.

Conclusion: Unlike shortening, absolute and relative vertical displacement of the midshaft clavicle fracture is not significantly influenced by radiographic projection. Standardized measurements of vertical displacement may not be necessary for clinical use because the correlation between categorical and continuous measurements was found to be very strong.

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Multiple studies have commented on the lack of a standardized and uniform method of measuring shortening and displacement of the fractured midshaft clavicle.^{3,9,10,12} Various techniques and modalities have been described, and it seems that their measurements of the fractured clavicle do not produce the same results.^{9,10} Measured shortening of midshaft clavicle fracture fragments is known to be influenced by factors such as patient positioning, timing after trauma, and radiographic projection.^{2,3,9,13,16} The influence of radiographic projection on measured shortening has

previously been investigated.^{2,9} It was shown that a significant difference exists between projections and craniocaudal projections represent the length of the fracture elements and the amount of shortening most accurately.^{2,9} However, a recent study reported an increased tendency to surgically treat the same clavicle fracture when projected in the caudocranial direction.⁸ This discrepancy could be explained by possible vertical displacement differences between radiographic projections and its influence on decision making. This is in contrast to the results of a survey among surgeons indicating that shortening, not vertical displacement, is considered most important in the decision algorithm.¹¹

The influence of radiographic projection on measured vertical displacement, however, is unclear. Because the clinical consequence of vertical displacement of more than 100% between the fracture elements on the initial radiograph is associated with inferior clinical outcomes, it is important to evaluate the influence

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of projection on the measured vertical displacement.⁶ An increased amount of vertical displacement has been reported to be found compared with computed tomography (CT) measurements when quantifying displacement on a 20° caudocranial view compared with an anteroposterior (AP) view.²⁰ Studies commenting on vertical displacement do not necessarily quantify this in absolute numbers but rather in a categorical manner. Some studies have reported good to excellent reproducibility of qualifying displacement according to fracture classification.^{3,11,12,18}

An unanswered question remains whether a categorical description of vertical displacement is sufficient to be used in the decision-making algorithm (rather than necessitating quantitative measurements) to identify patients who could benefit from operative intervention. Because vertical displacement may be influenced—just like shortening⁹—by projection, further research on this topic is warranted. The specific aims of this study were (1) to quantify the difference in measurements of vertical displacement in an absolute, relative, and categorical manner between 5 different (30° and 15° caudocranial, AP, and 15° and 30° craniocaudal) views of the fractured clavicle; (2) to quantify the differences in interobserver and intraobserver agreement using a standardized method for measuring vertical displacement and for categorical data per projection; and (3) to assess the association between categorical and continuous descriptions of vertical displacement.

Materials and methods

We conducted a clinical measurement study quantifying the difference in the absolute measurements of vertical displacement and in a categorical manner between 5 different views of the fractured clavicle. A previously used deidentified database extracted from the National Trauma Registration (NTR) in The Netherlands was used.⁹ This database contained consecutive patients who received a diagnosis of a clavicle fracture in the emergency department and underwent a thoracic CT scan during advanced trauma life support screening in the Radboud University Medical Center, The Netherlands, 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 (≥ 18 years old) were eligible for inclusion.

The CT scans were obtained using a Toshiba Aquilion One (Tustin, CA, USA) or Siemens Somatom 16 or 64 (Erlangen, Germany) scanner, and scans were uploaded and analyzed with the hospital's IMPAX software (version 6.5.3.1005; Mortsel, Belgium). Digitally reconstructed radiographs (DRRs) were created for each CT data set at 5 equally spaced angles: AP, 15° and 30° craniocaudal, and 15° and 30° caudocranial views. Each DRR represented a 2-dimensional x-ray film of the fractured clavicle.

First, categorical data on vertical displacement were obtained. The arbitrarily chosen categories were quartiles of displacement from 0%–200%: no displacement or displacement of 1%–50%, 51%–100%, 101%–200%, or more than 200% of the shaft's width.

A standardized method for measuring displacement was used as follows (Fig. 1): To determine the diameter of the clavicle, a line was drawn perpendicular to the shaft on either the medial or lateral side closest to the fracture. In case of an oblique fracture, this line was drawn at the point where the shaft was intact in its entire circumference (D_s). To quantify the amount of vertical displacement, a perpendicular line to the axis of the medial fragment was drawn between matching cortices of both fracture elements. In case the fracture elements were not overlapping, a reference line (dashed line in Fig. 1) was drawn parallel to the medial fragment cortex, followed by a perpendicular line between the matching cortex on the lateral fragment. The length of this perpendicular line

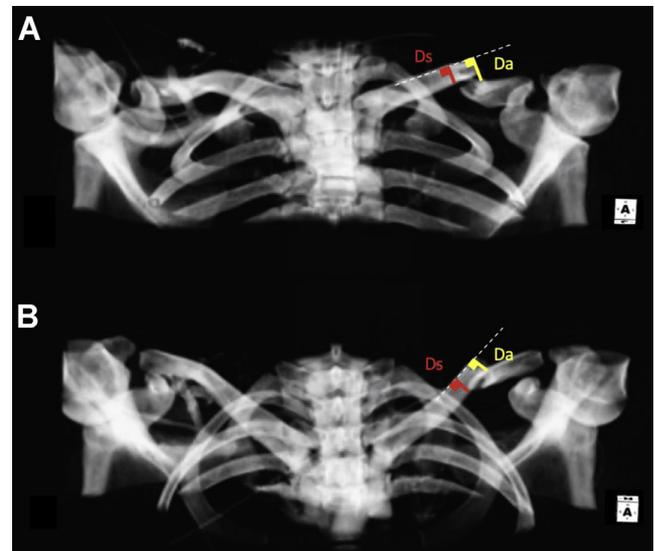


Figure 1 Example of digitally reconstructed radiographs of the same clavicle fracture and standardized measurement: 15° caudocranial view (A) and 15° craniocaudal view (B). The diameter of the clavicle is measured by drawing a line perpendicular to the shaft on either the medial or lateral side closest to the fracture (D_s). A reference line (dashed line) is drawn parallel to the medial fragment cortex. A perpendicular line is drawn between the matching cortices or reference line and the matching cortex on the lateral fragment. The length of this perpendicular line (in millimeters) is considered the absolute amount of vertical displacement (D_a).

(in millimeters) was considered the absolute amount of displacement (D_a). Relative displacement (D_r) was calculated by the formula: $D_r = D_a/D_s \times 100\%$.

All measurements were performed on the 5 different DRR projections of each patient. The 5 DRRs for each patient were evaluated in random order by 3 observers (2 trauma fellowship-trained orthopedic surgeons [A.N.E.N. and Z.M.W.] and 1 medical student [A.C.]), as described earlier. To calculate intraobserver agreement, the same observers performed a second evaluation of the same randomized DRRs 2–4 weeks after the first round of measurements was performed. Before the start of the study, a training session took place with each observer. 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).

Descriptive statistics were used to summarize the data. Intra-class correlation coefficients (ICCs) were used to assess the interobserver and intraobserver agreement for each of the 5 radiographic projections. Interobserver and intraobserver agreement for the categorical data concerning vertical displacement classification was reported using the Gwet AC_1 coefficient.⁷ The Gwet AC_1 coefficient was used as an alternative to the Cohen κ because it provides a chance-corrected agreement coefficient, which is better in line with the percentage level of agreement and less sensitive to prevalence and symmetry than the Cohen κ .^{7,19} ICCs and the Gwet AC_1 coefficient 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.⁴ For intraobserver agreement, ICC estimates and their 95% confidence intervals were calculated based on a single-observer, absolute-agreement, 2-way mixed-effects model. For interobserver agreement, ICC estimates and their 95% confidence intervals were calculated based on a single-observer, absolute-agreement, 2-way random-effects model. Mean displacement as measured by the 3 observers was used in descriptive statistics and further statistical analyses. The “limits of agreement with the mean”—a modification of the Bland-Altman—type methodology

Table I
Intraobserver agreement of measurements of absolute and relative vertical displacement

Projection	ICC absolute vertical displacement (95% CI)			ICC relative vertical displacement (95% CI)		
	Observer 1	Observer 2	Observer 3	Observer 1	Observer 2	Observer 3
30° caudocranial	0.77 (0.58-0.88)	0.83 (0.68-0.91)	0.86 (0.72-0.93)	0.78 (0.60-0.89)	0.87 (0.74-0.94)	0.83 (0.68-0.92)
15° caudocranial	0.61 (0.33-0.79)	0.85 (0.70-0.92)	0.94 (0.88-0.97)	0.65 (0.39-0.81)	0.83 (0.67-0.91)	0.92 (0.85-0.96)
AP	0.45 (0.12-0.69)	0.82 (0.66-0.91)	0.92 (0.85-0.96)	0.52 (0.22-0.74)	0.79 (0.61-0.89)	0.94 (0.88-0.97)
15° craniocaudal	0.79 (0.62-0.90)	0.88 (0.69-0.95)	0.86 (0.73-0.93)	0.86 (0.73-0.93)	0.84 (0.65-0.93)	0.86 (0.73-0.93)
30° craniocaudal	0.79 (0.62-0.90)	0.89 (0.75-0.95)	0.81 (0.65-0.90)	0.83 (0.67-0.91)	0.90 (0.76-0.95)	0.77 (0.57-0.88)

ICC, intraclass correlation coefficient; CI, confidence interval; AP, anteroposterior.

described by Jones et al¹¹ 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 for agreement between the 3 observers. Friedman 1-way repeated-measures analysis of variance by ranks was used to test for differences in (absolute and relative) vertical displacement 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. 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. The association between the absolute and relative vertical displacement and the categorical outcomes was calculated using the Spearman rank correlation coefficient. The correlation coefficients were interpreted as follows: less than 0.20, very weak; 0.20-0.39, weak; 0.40-0.59, moderate; 0.60-0.79, strong; and 0.80-1.00, very strong.⁵

Statistical analyses were performed using R (version 3.5.2; R Foundation for Statistical Computing, Vienna, Austria). $P < .05$ was considered statistically significant.

Results

Thirty-one patients with displaced midshaft clavicle fractures and adequate CT imaging were included, and for all 31 patients, DRRs in 5 different projections were created. The study population included 23 men and 8 women, and the average age was 39.7 years (range, 19-78 years). Of the fractures, 12 involved the right side and 19 involved the left.

The ICCs were excellent for both the intraobserver measurements of absolute vertical displacement (range, 0.81-0.94) and the calculations of the relative displacement (range, 0.77-0.94) in all projections for the 2 trauma fellowship-trained observers (Table I). For the third observer, the ICCs for absolute displacement on the 15° caudocranial and AP views were good (0.61) and fair (0.45), respectively. The ICCs for relative displacement on these 2 projections were good (0.65) and fair (0.52), respectively.

Table II
Interobserver agreement of continuous measurements and categorical descriptions of vertical displacement

Projection	ICC (95% CI)	Gwet AC ₁ or AC ₂ coefficient (95% CI)	Limits of agreement with mean, mm
30° caudocranial	0.64 (0.44-0.79)	0.56 (0.4-0.73)	-4.9 to 4.9
15° caudocranial	0.69 (0.52-0.82)	0.45 (0.28-0.65)	-5.1 to 5.1
AP	0.65 (0.47-0.80)	0.50 (0.33-0.67)	-5.2 to 5.2
15° craniocaudal	0.75 (0.60-0.86)	0.64 (0.49-0.79)	-4.3 to 4.3
30° craniocaudal	0.79 (0.65-0.89)	0.50 (0.35-0.65)	-3.7 to 3.7

ICC, intraclass correlation coefficient; CI, confidence interval; AP, anteroposterior.

The interobserver agreement was good for the AP view and both caudocranial views (range, 0.64-0.69). For the craniocaudal projections, the interobserver agreement was excellent (range, 0.75-0.79) (Table II). The maximum limit of agreement with the mean was -5.2 to 5.2 mm for the AP view, indicating that individual observers can be discordant with the mean of the estimated vertical displacement measured by the 3 observers on an AP view by as much as 5.2 mm (Table II). The limits of agreement were the smallest for the 2 craniocaudal views.

The smallest measured median vertical displacement was 6.4 mm on the 30° caudocranial projection and 8 mm on the AP view (Table III). The median absolute vertical displacement of the fracture elements relative to each other showed no statistically significant difference between any of the caudocranial, AP, and craniocaudal views (Fig. 2, A). No statistically significant differences were found for the measured median shaft diameter and the relative displacement (Fig. 2, B and C).

The correlation between the categorical outcomes and the absolute vertical displacement (range, 0.83-0.94) and relative vertical displacement (range, 0.87-0.96) was very strong (Table IV). However, the Gwet AC coefficient for interobserver agreement was fair to good (range, 0.45-0.64) (Table II). The intraobserver agreement ranged from fair to excellent (0.58-0.85) for the fellowship-trained orthopedic surgeons (Table V).

Discussion

In this study, we aimed to quantify and describe the difference in measurements of vertical displacement in an absolute, relative, and categorical manner between 5 different radiographic projections of the midshaft clavicle fracture. We did not find a statistically significant difference in absolute or relative vertical displacement between the 5 different views. This is an important finding because together with shortening and comminution, vertical displacement is an important factor in the decision-making algorithm.¹¹ The reason is that vertical displacement of more than 100% between the fracture elements on the initial radiograph is associated with inferior clinical outcomes.⁶ Although projection does not seem to be influential on vertical displacement, other variables such as

Table III
Measurements of all 5 different views

Projection	Median (IQR, range)		
	Measured absolute vertical displacement, mm	Measured diameter shaft, mm	Calculated relative vertical displacement, %
30° caudocranial	6.4 (5.3, 2-15)	10.9 (2.5, 8-16)	57.9 (57.5, 16-172)
15° caudocranial	7.5 (7.1, 2-17)	11.4 (2.3, 9-17)	76.9 (64.2, 21-149)
AP	8.0 (5.4, 0-15)	12.0 (1.5, 9-16)	69.5 (46.6, 0-132)
15° craniocaudal	7.6 (6.3, 2-17)	12.7 (2.2, 9-16)	59.3 (40.4, 17-162)
30° craniocaudal	7.1 (5.6, 2-18)	12.3 (2.5, 9-16)	58.4 (47.3, 19-180)

IQR, interquartile range; AP, anteroposterior.

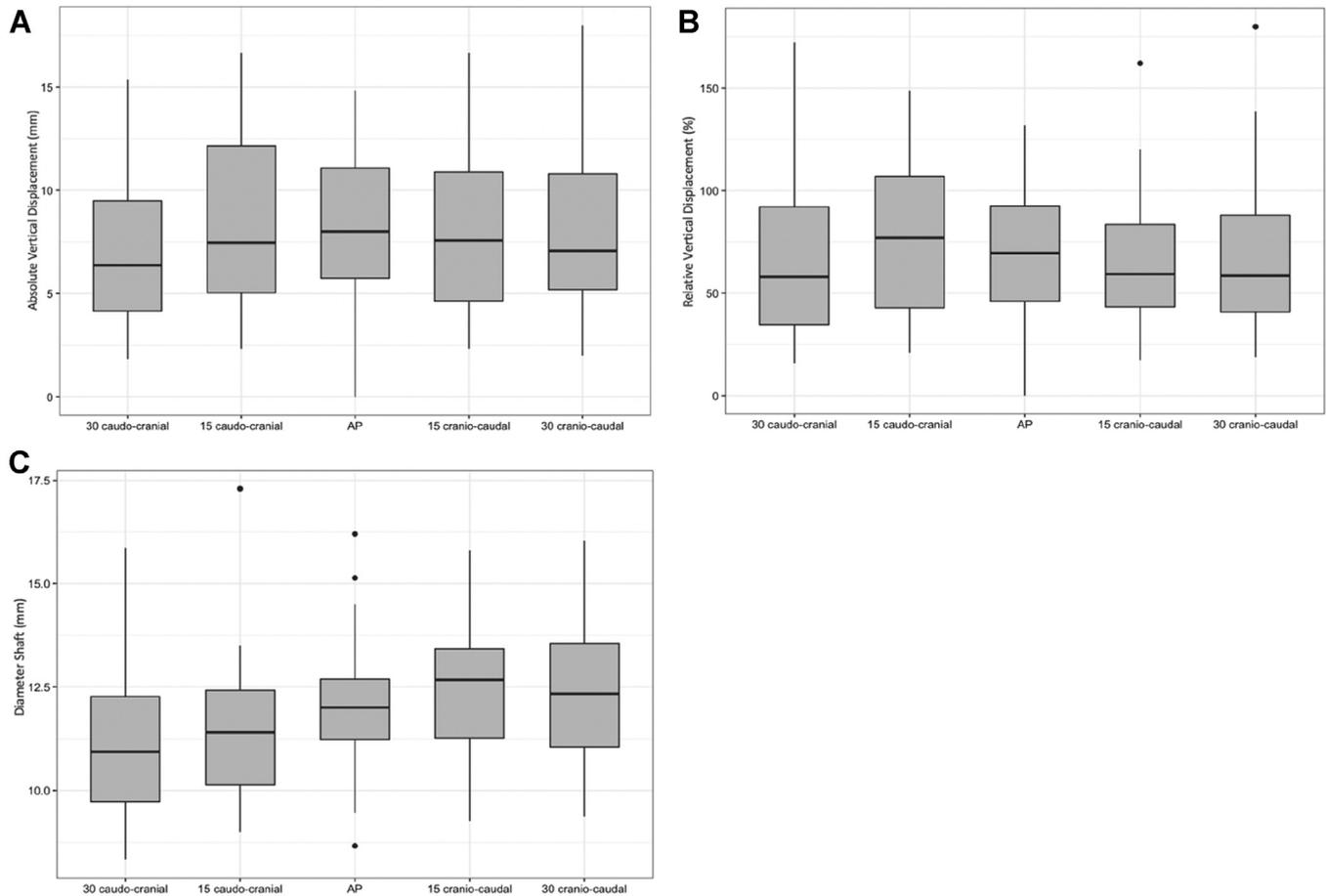


Figure 2 Box plots showing median absolute vertical displacement (in millimeters) (A), median relative vertical displacement (as a percentage) (B), and median diameter shaft (in millimeters) (C) per radiographic projection. AP, anteroposterior.

patient positioning and time are influential.^{3,13,14} Alternatively, projection is influential on the amount of measured shortening and choice of treatment strategy.^{8,9}

We found excellent intraobserver agreement in measurements between the 5 different radiographic projections using a standardized method for measuring vertical displacement, signifying that the proposed method is reproducible and could be used for future quantification of vertical displacement. Concerning the interobserver agreement, we found the ICCs were higher for the craniocaudal views. These craniocaudal views also seem to be the projections that most accurately visualize the length of the fracture elements and shortening.^{2,9,15–17} Given the findings in previous reports^{2,9,15–17} and our study, it may be a consideration to include a craniocaudal view into the standard workup of the displaced midshaft clavicle fracture. One must be aware that adding

projections to the standard workup of such fractures may lead to increased rates of operative treatment.¹

Furthermore, we assessed the association between categorical and continuous descriptions of vertical displacement and found the correlation to be very strong. The Gwet AC coefficient for interobserver agreement was fair to good, and the intraobserver agreement ranged from fair to excellent for the fellowship-trained orthopedic surgeons. The intraobserver agreement was lower when evaluations were performed by the medical student. This is possibly caused by a lack of experience in evaluating radiographs and classifying fractures accordingly. It is interesting to note that the craniocaudal projections again seem to show a trend toward higher agreement. Jones et al¹¹ reported similar poor to good inter-rater agreement for the categorical analysis of fracture displacement. They reported an ICC of 0.76 for intrarater agreement. Stegeman et al¹⁸ found moderate to almost perfect agreement for

Table IV
Correlation between categorical outcomes and absolute and relative vertical displacement

Projection	Spearman rank correlation coefficient (95% CI)	
	Category: absolute vertical displacement	Category: relative vertical displacement
30° caudocranial	0.88 (0.76–0.94)	0.90 (0.80–0.95)
15° caudocranial	0.94 (0.87–0.97)	0.96 (0.92–0.98)
AP	0.83 (0.67–0.91)	0.87 (0.74–0.94)
15° craniocaudal	0.90 (0.80–0.95)	0.92 (0.83–0.96)
30° craniocaudal	0.90 (0.79–0.95)	0.90 (0.80–0.95)

CI, confidence interval; AP, anteroposterior.

Table V
Intraobserver agreement of categorical descriptions of vertical displacement

Projection	Gwet AC ₁ coefficient (95% CI)		
	Observer 1	Observer 2	Observer 3
30° caudocranial	0.50 (0.28–0.72)	0.65 (0.46–0.85)	0.58 (0.36–0.79)
15° caudocranial	0.39 (0.17–0.61)	0.65 (0.45–0.85)	0.69 (0.50–0.88)
AP	0.55 (0.33–0.76)	0.69 (0.49–0.88)	0.68 (0.48–0.88)
15° craniocaudal	0.77 (0.60–0.94)	0.65 (0.45–0.85)	0.73 (0.55–0.91)
30° craniocaudal	0.58 (0.37–0.79)	0.81 (0.64–0.97)	0.85 (0.70–0.99)

CI, confidence interval; AP, anteroposterior.

fracture classification of displaced clavicle fractures. Li et al¹² reported excellent agreement for categorical descriptions of vertical displacement. However, they only used the following categories: (1) none or minimal, (2) mild or angulated, and (3) complete. The very strong correlation between continuous measurements and categorical descriptions leads to the conclusion that the latter would suffice in reporting vertical displacement in the future. On the other hand, continuous measures were found to have higher ICCs, which could be helpful in discerning more reliably what amount of vertical displacement would be clinically important in the treatment of displaced midshaft clavicle fractures.

One of the strengths of this study is that DRRs were used. These DRRs are not subject to magnification by diverging x-ray beams or influenced by patient positioning, patient movement between radiographs, or different distances of the fracture to the detector. This creates static conditions to truly evaluate the possible differences in vertical displacement per projection; however, it is also one of the limitations of the study because it is unknown how DRRs relate to standard radiographs, and further research on this topic is warranted. Another strength of this study is the use of a standardized method for measuring vertical displacement as proved by the good to excellent intraobserver and interobserver agreement.

A potential limitation of this study is that all CT scans and, as a consequence, the DRRs were fabricated with supine positioning. This may lead to an underestimation of the measured vertical displacement in reality.^{3,13} This would be a very important limitation when reporting on choice of treatment and/or its results; however, in this study, the main goal was to identify differences in measurements between different projections and to evaluate the intraobserver and interobserver agreement. The results of our study can be used in further discerning the optimal imaging and measurement techniques of the fractured midshaft clavicle fracture.

Conclusion

Unlike shortening, absolute and relative vertical displacement of the midshaft clavicle fracture is not significantly influenced by radiographic projection. Although reproducible and possibly useful for research purposes, the standardized measurements of vertical displacement may not be necessary for clinical use because the correlation between categorical and continuous measurements was found to be very strong.

Disclaimer

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