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Measurement of clavicular length and shortening after a midshaft clavicular fracture: Spatial digitization versus planar roentgen photogrammetry

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Purpose: Clavicular shortening after fracture is deemed prognostic for clinical outcome and is therefore generally assessed on radiographs. It is used for clinical decision making regarding operative or non-operative treatment in the first 2 weeks after trauma, although the reliability and accuracy of the measurements are unclear. This study aimed to assess the reliability of roentgen photogrammetry (2D) of clavicular length and shortening, and to compare these with 3D-spatial digitization measurements, obtained with an electromagnetic recording system (Flock of Birds). *Patients and methods*: Thirty-two participants with a consolidated non-operatively treated two or multi-fragmented dislocated midshaft clavicular fracture were analysed. Two observers measured clavicular lengths and absolute and proportional clavicular shortening on radiographs taken before and after fracture consolidation. The clavicular lengths were also measured with spatial digitization. Inter-observer agreement on the radiographic measurements was assessed using the Intraclass Correlation Coefficient (ICC). Agreement between the radiographic and spatial digitization measurements was assessed using a Bland–Altman plot. *Results*: The inter-observer agreement on clavicular length, and absolute and proportional shortening on trauma radiographs was almost perfect (ICC > 0.90), but moderate for absolute shortening after consolidation (ICC = 0.45). The Bland–Altman plot compared measurements of length on AP panorama radiographs with spatial digitization and showed that planar roentgen photogrammetry resulted in up to 37 mm longer and 34 mm shorter measurements than spatial digitization. *Conclusion*: Measurements of clavicular length on radiographs are highly reliable between observers, but may not reflect the actual length and shortening of the clavicle when compared to length measurements with spatial digitization. We recommend to use proportional shortening when measuring clavicular length or shortening on radiographs for clinical decision making.

1. Introduction

Non-operative treatment of displaced midshaft clavicular fractures may lead to mal-union and subsequent shortening of the clavicle (Andersen et al., 1987; Eskola et al., 1986; Hillen et al., 2010; Nordqvist and Petersson, 1994). Several studies suggested that conservative treatment of fractured clavicles with more than 15 mm shortening on the trauma radiograph may lead to unsatisfactory results, such as pain while lying on the affected side, subjectively decreased muscle strength or impaired range of motion, assumed to be caused by a change in the closed-chain mechanism of the shoulder (Eskola et al., 1986; Hill et al., 1997; Lazarides and Zafiropoulos, 2006), or even non-union (Canadian Orthopaedic Trauma Society, 2007; Wick et al., 2001). In clinical decision making, the choice between surgical fixation or non-operative treatment is not only based on the condition and wish of the patient, but also on the degree of shortening and displacement of the fractured clavicle. For the cases with more than 15 mm shortening, surgical fixation in the first two weeks after trauma is generally advocated (Canadian Orthopaedic Trauma Society, 2007; Stegeman et al., 2013). Therefore clavicular length and shortening must be measured in a reliable and valid manner.

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In current clinical practice, clavicular length and shortening are measured two-dimensionally on digital radiographs, with the fracture projected in one or two planes (frontal plane and a transverse plane tilted 15°–30° around the anteroposterior axis). Two notes of criticism about these clinically relevant measurements are in order: the accuracy of these measurements is questionable, because the use of different types of radiographs, different directions of the X-ray beam, and the conversion of three-dimensional (3D) to two-dimensional (2D) information, may lead to amplification and projection errors. The reliability and validity of clavicular length and shortening measurements on radiographs have been scarcely investigated. The other point of discussion is whether clavicular shortening should be expressed as an absolute measure (in mm). Since clavicular length varies between individuals, a certain amount of shortening may not have the same effect on the shoulder function in every patient (Smekal et al., 2008). For this reason, it may be more appropriate to express clavicular shortening as a proportional measure.

The 3D positions of predefined bony landmarks can be determined accurately and reliably with an electromagnetic tracking device (spatially digitized observations) (Meskers et al., 1999), from which bone lengths can be calculated. It may also be assumed that the 3D spatial digitization measurements reflect anatomic clavicular length more closely than 2D planar photogrammetry. In theory, spatial digitization is the best method to determine clavicular length. Currently, the agreement between measurements on radiographs and spatial digitization is not known.

This study aimed to determine the inter-observer reliability of measurements of clavicular length and absolute and proportional shortening on radiographs and to compare 2D planar roentgen photogrammetry of clavicular length with 3D spatial digitization. Furthermore, we evaluated an alternative method for calculating proportional shortening of consolidated clavicles on radiographs which accounts for inter-individual variation of clavicular length.

2. Patients and methods

This exploratory study was approved by the institutional Medical Ethics Review Committee and registered in the Dutch Trial Registry (NTR3167). The study was performed between December 2011 and April 2012.

2.1. Participants

For this exploratory study no sample size calculation was performed. Patients with a non-operatively treated two or multi-fragmented displaced midshaft clavicular fracture (type 2B1 or 2B2 according to the Robinson classification) (Robinson, 1998) that had consolidated within four months after trauma were selected from the medical databases 2006–2010 of the Leiden University Medical Centre and the Rijnland Hospital in The Netherlands. Patients were eligible for inclusion in the study if they were aged 18–60 years at time of fracture and had no associated injuries, pathological fracture, neurovascular injury, or previous acromioclavicular injury of either shoulder. Patients with non-union of the fractured clavicle were excluded. Candidates with a cardiovascular pacemaker were also excluded, since an electromagnetic field was used for the spatial digitization measurements. All 74 eligible patients were subsequently contacted by phone after having received written information. Of those, 32 patients were willing to participate in the study and visited the outpatient clinic for radiography and spatial digitization. Informed consent was obtained from each participant.

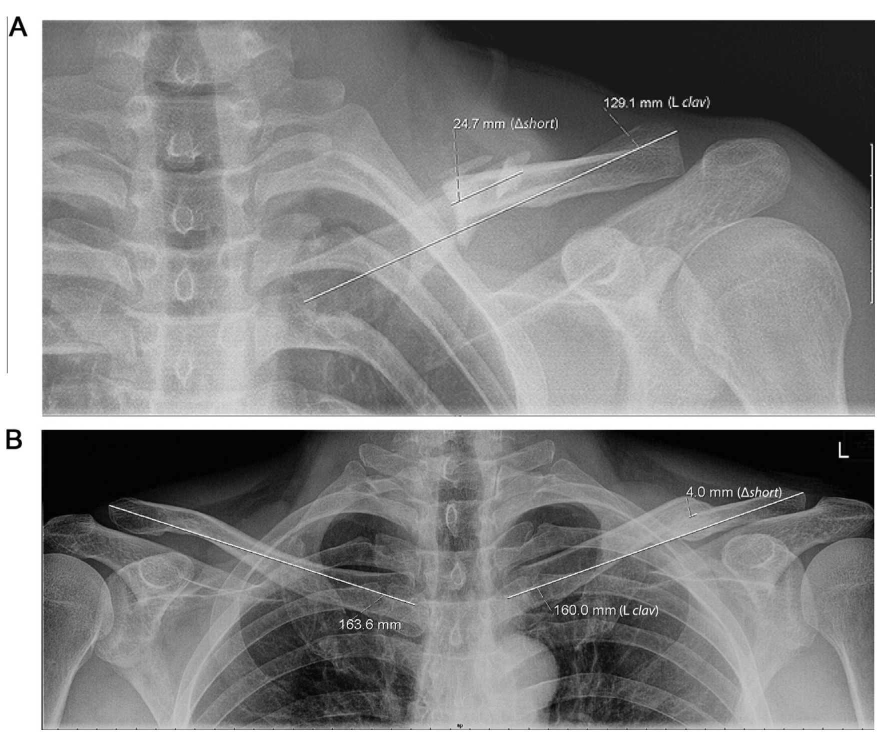

Fig. 1. Measurement of clavicular length and shortening after a midshaft fracture, on the anteroposterior trauma radiograph (A) and anteroposterior panorama radiograph (B)*. Fig. 1A: Clavicular length (L *clav*) is defined by the line connecting the middle of the medial border with the most lateral edge. Absolute shortening (Δ *short*) was calculated by connecting the cortical fragments along the axial line of the clavicle. The Clavicular Shortening Index (*CSI*) is defined as the absolute shortening divided by the length of the affected clavicle plus absolute shortening. For this case, the relative shortening is 24.7/(129.1 + 24.7) × 100 = 16.1%. Fig. 1B: Clavicular length (L *clav*) is defined by the line connecting the middle of the medial border with the most lateral edge. The length of the consolidated clavicle (L) in this example is 160.6 mm and the length of the contralateral clavicle (R) is 163.4 mm. Absolute shortening (Δ *short*) is defined as the axial distance between the cortical fragment ends. In this case, the absolute shortening is 4.0 mm. *A and B are from different patients.

2.2. Roentgen photogrammetry

The anteroposterior (AP) trauma radiographs of all participants were retrieved from the hospital records. During the study visit, an additional AP panorama radiograph comprising both clavicles was acquired of each participant. For this AP panorama radiograph, it was ensured that the candidates were standing straight and that the spinous processes of the thoracic vertebrae were projected in the midline, to eliminate thoracic rotation and clavicular protraction.

Roentgen photogrammetry was performed on the initial AP trauma radiograph of each fractured clavicle and on AP panorama radiographs that had been taken after consolidation for study purposes. Two researchers independently measured the length of the affected clavicle on the primary AP trauma radiograph, by connecting the middle of the medial border with the most lateral edge in a straight line (L *clav*) (Sectra Imtec 2009, Janköping, Sweden) (Fig. 1). The lengths of the consolidated and the contralateral clavicle on the AP panorama radiographs were measured in the same way.

The extent of shortening of the affected clavicle was measured in two ways. First, absolute shortening was measured as the axial distance in mm between the cortical fracture fragments ends (Δ *short*) on the AP trauma radiograph and the AP panorama radiograph after consolidation (Fig. 1). Second, as a measure for proportional shortening (i.e., percentage of the initial clavicular length lost after fracture), the "Clavicular Shortening Index" (*CSI*) was calculated from these measurements, by dividing the absolute shortening by the initial length. The initial length is obtained by adding the absolute shortening to the measured clavicular length. The calculation of the *CSI* is based on the formula for proportional shortening proposed by Smekal et al. (2008):

$$CSI = \frac{\Delta short}{\Delta short + \mathrm{L}\ clav} \times 100\% \qquad (1)$$

2.3. Spatial digitization

The "Flock of Birds" 3D Electromagnetic Motion Tracking Device (FoB, Ascension Technology Corp, Burlington, VT, USA) and custom made computer software (FoBVis, Clinical Graphics, Delft, The Netherlands) were used to measure the spatial length of the participants' affected and contralateral clavicles (Meskers et al., 1998b, 1999; Wu et al., 2005). The spatial length of both clavicles was determined by locating the three-dimensional coordinates of two pre-defined bony landmarks: the sternoclavicular joint (SC) and the acromioclavicular joint (AC), using an electromagnetic stylus/digitizer (Wu et al., 2005) (Fig. 2). The three dimensional position of the SC- and AC-joint was determined relative to a sensor that was placed on the sternum (thoracic sensor), in order to reduce movement artefacts related to positioning of the torso and to account for the participant's individual anatomy (Meskers et al., 1998a). The clavicular lengths were calculated in a 3-dimensional plane as the (Euclidian) distance between AC- and SC-joint, by applying the Pythagorean Theorem.

2.4. Statistical analysis

Inter-observer agreement on roentgen photogrammetry measurements (for affected and the contralateral clavicle) and *CSI* was assessed by evaluating systematic differences between the observers with paired Student's *t*-tests and by calculating Intraclass Correlation Coefficients (ICCs). The strength of agreement was interpreted according to Landis and Koch (Landis and Koch, 1977), who indicated ICC $\leqslant 0$ as poor agreement, 0.01–0.20 as slight agreement, 0.21–0.40 as fair agreement, 0.41–0.60 as moderate agreement, 0.61–0.80 as substantial agreement and 0.81–1.00 as almost perfect agreement.

A Bland–Altman plot was constructed to graphically compare the results of roentgen photogrammetry and spatial digitization. In such a plot, the difference between the measurements is plotted against the mean of the measurements for each study subject (Bland and Altman, 1986, 1999). Horizontal lines are drawn in the plot at the mean difference and at the 95% limits of agreement, which are calculated as the mean difference ±1.96 times the standard deviation of the differences (Bland and Altman, 1986, 1999). If the mean difference between both methods is close to 0, no systematic difference (bias) exists. If the differences between the measurements within the limits of agreement are considered not clinically meaningful, the methods may be used interchangeably. For this purpose we used the AP roentgen photogrammetry results of only one of the observers, since the inter-observer agreement between the two observers was high.

Statistical analyses were performed with SPSS version 20.0 (Statistical Package for Social Sciences Inc, Chicago, IL). *P*-values < 0.05 were considered statistically significant.

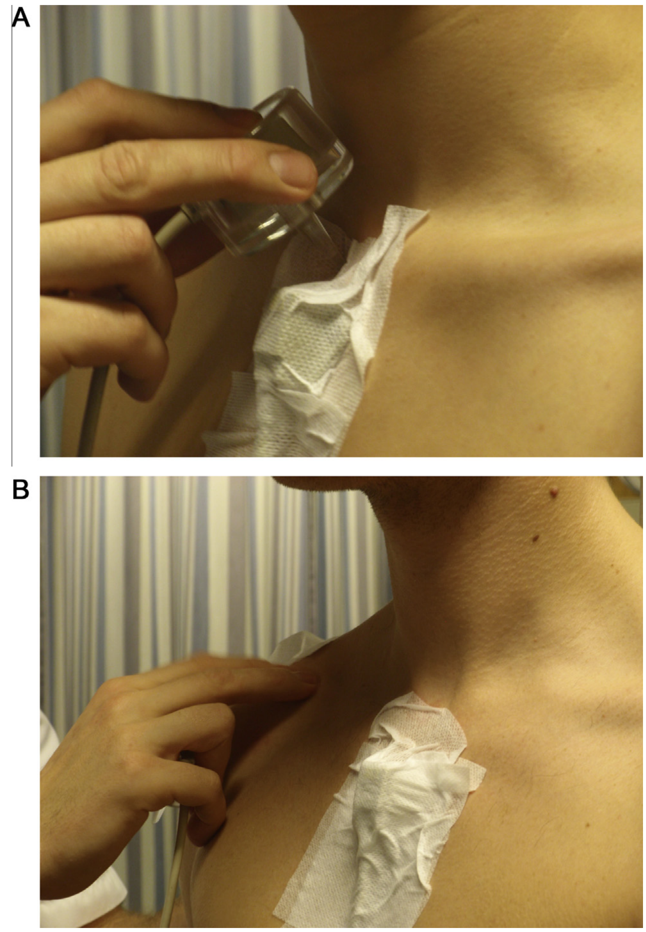

Fig. 2. Positioning of the thoracic sensor and the electromagnetic stylus on the sternoclavicular joint (A), and palpation for the acromioclavicular joint (B).

3. Results

The study group consisted of 32 participants: 27 men with a mean age of 31 years (range: 21–62 years) and 5 women with a mean age of 27 years (range: 25–31 years). In one case, the AP trauma radiograph was not calibrated and could not be used in the study. For another participant, the length of the

Table 1
Inter-observer agreement on clavicular length and shortening after non-operatively treated midshaft fractures as measured on the AP trauma radiograph and on the AP panorama radiograph taken after consolidation.

	Observer 1 mean (SD)	Observer 2 mean (SD)	Difference mean (SD)	P-value	Intraclass correlation coefficient (95% CI)
AP trauma radiograph					
Length (mm) of fractured clavicle ($n = 31$)[a]	164.7 (20.5)	164.2 (21.2)	0.5 (3.5)	0.46	0.99 (0.97–1.00)
Absolute clavicular shortening, (mm) ($n = 31$)[a]	16.9 (8.4)	17.2 (8.4)	−0.3 (1.9)	0.42	0.97 (0.95–0.99)
AP panorama radiograph after consolidation					
Length (mm) of consolidated clavicle ($n = 32$)	156.7 (13.2)	157.8 (14.2)	−1.1 (5.6)	0.28	0.92 (0.84–0.96)
Length (mm) of non-fractured clavicle ($n = 31$)[a]	170.2 (12.7)	168.9 (13.2)	1.3 (3.4)	0.05	0.97 (0.93–0.98)
Absolute clavicular shortening, (mm) ($n = 32$)	15.1 (8.1)	17.6 (7.3)	−2.5 (8.1)	0.10	0.45 (0.12–0.69)

[a] The AP trauma radiograph was in one case not calibrated and could not be used in the study. For another participant, the length of the non-fractured clavicle could not be measured due to incomplete imaging of the clavicle on the AP panorama radiograph.

non-fractured clavicle could not be measured due to incomplete imaging of the clavicle on the AP panorama radiograph. The other data of these two patients were adequate and were used for analysis.

3.1. Inter-observer agreement on roentgen photogrammetry

There were no systematic differences in measurements of the clavicular length between the observers (Table 1). The inter-observer agreement on clavicular length was almost perfect for both fractured and contralateral clavicles (ICCs > 0.90; Table 1). The inter-observer agreement on absolute shortening of the fractured clavicle on the AP trauma radiograph was also almost perfect (ICC = 0.97, 95%-confidence interval [CI]: 0.95–0.99) when measured on the AP trauma radiograph, but only moderate (ICC = 0.45, 95%-CI: 0.12–0.69) when measured on the AP panorama radiographs acquired after consolidation (Table 1). There were no systematic differences in measurements of absolute shortening on the trauma and AP panorama radiographs between the two observers (Table 1).

For each observer the *CSI* was calculated from the absolute measurements on the trauma radiographs. The overall mean *CSI* was 9.2% (range: 1.4–22.5%). In the 13 participants who had an absolute shortening of more than 15 mm, the mean *CSI* was 5.6% (range: 1.4–9.1%). Almost perfect agreement was found for *CSI* between both observers (ICC = 0.97; 95%-CI: 0.94–0.99). No systematic difference for *CSI* was found between the observers ($p = 0.42$). The agreement for *CSI* after consolidation between the observers was fair (ICC = 0.40; 95%-CI: 0.07–0.66) with no systematic difference for *CSI* ($p = 0.11$).

3.2. Agreement between roentgen photogrammetry and spatial digitization

There was no statistically significant systematic difference between the clavicular length measurements obtained with roentgen photogrammetry vs. spatial digitization (Table 2). The mean difference between planar roentgen photogrammetry minus spatial digitization for all clavicles was 1.38 mm (95%-CI: −3.21–5.98). In the Bland–Altman plot (Fig. 3), the differences between the methods were evenly spread over the range of clavicular lengths with wide limits of agreement, indicating that the clavicular length measured on the radiographs may be up to 37 mm longer or 34 mm shorter than measured with spatial digitization.

4. Discussion

The middle part of the clavicle is prone to maximum stress because of the s-shaped curvature of the clavicle, and devoid of a supporting tubular structure in the medullary cavity. Therefore, the clavicle mostly fractures midshaft when exposed to high forces (Andersen et al., 1987; Mathieu et al., 2014), causing shortening and malformation of the clavicle. Shortening of the clavicle after fracture is generally believed to have a relevant influence on patients' daily functioning and severe shortening is often considered as an indication for operative treatment. Therefore, it is important to determine the length and shortening of the fractured clavicle in a valid and reliable manner within a short time period after trauma when a choice has to be made between operative and non-operative treatment. This study showed that the inter-observer agreement on measurements of clavicular length and shortening performed on trauma radiographs was almost perfect. This finding is supported by Smekal et al. (2008), who also reported non-significant differences between measurements on radiographs. The measurements of shortening after consolidation on the other hand were less reliable, which may be explained because callus formation obscures the outer edges of the fracture on the radiograph. To determine if length measurements on radiographs (2D) concur with actual 3D clavicular length, the results of planar roentgen photogrammetry were compared to measurements obtained with spatial digitization obtained with the FoB. This is the first study to use spatial digitization data of the FoB for calculating distances. The Bland–Altman plot showed clinically relevant differences between the measurements with planar roentgen photogrammetry and spatial digitization, which indicates that these methods cannot be used interchangeably for measuring clavicular length.

Table 2
Agreement between measurements of clavicular length and of clavicular shortening with panorama AP roentgen photogrammetry and spatial digitization, in consolidated non-operatively treated midshaft fractures.

	Roentgen photogrammetry Mean (SD)	Spatial digitization Mean (SD)	Difference (bias)	
			Mean (95% CI)	P-value
Length (mm) of consolidated clavicle ($N = 32$)	156.7 (13.2)	158.2 (22.2)	−1.52 (−9.12–6.08)	0.69
Length (mm) of non-fractured clavicle ($N = 31$)	170.2 (12.7)	165.9 (17.4)	4.37 (−0.95–9.70)	0.10

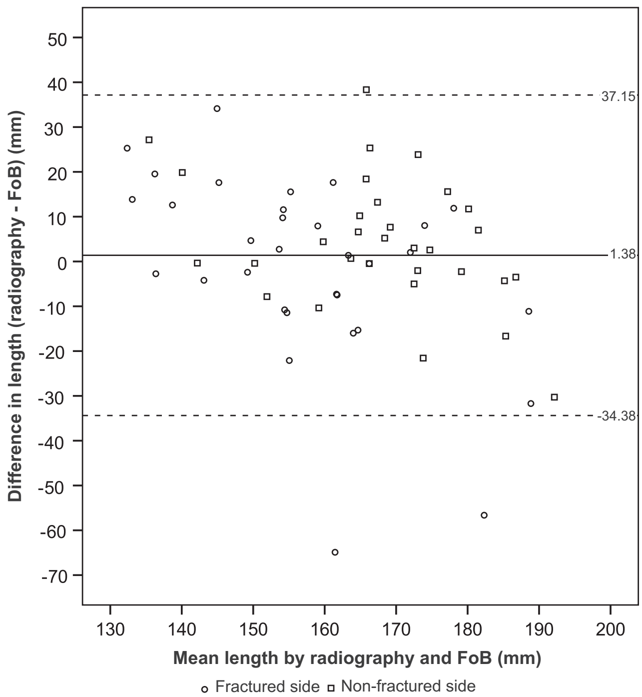

Fig. 3. Bland–Altman plot for agreement between measurements of clavicular length with panorama AP roentgen photogrammetry and spatial digitization (FoB). The continuous black line indicates the average difference between the measurements with planar radiography and spatial digitization, and the dashed lines indicate the limits of agreement.

The discrepancies between the measurements with planar roentgen photogrammetry and spatial digitization might partially be explained by the orientation of the electromagnetic stylus and clavicle during palpation for f the bony landmarks for the spatial digitization, although this palpation error is small (<3°) and not systematic. The palpation method has been proven to be accurate especially for the clavicle and the scapula, based on the intra- and inter-individual variances and this small palpation error (de Groot, 1997). However, in our case an error of 3° on a clavicular length of 15 cm would give a deviation of approximately 0.8 cm. Furthermore, the bony landmarks used for spatial digitization are slightly different from the ones used for roentgen photogrammetry, because the mid-medial border and the most lateral edge as used in roentgen photogrammetry cannot be reached with the electromagnetic stylus. This might induce a difference in length measurement between both methods. Another explanation for the length measurement differences relates to the discrepancies between two- and three-dimensional visualisation. The s-shaped curvature of the clavicle is difficult to display in a 2D image, with an average sternal curvature of 146° and an average acromial curvature of 133° (King et al., 2014). The horizontal axis of the anatomically normal non-fractured clavicle is positioned at a backward angle of 10–15° relative to the sternum (Ledger et al., 2005). Due to this sternoclavicular joint angle, the clavicles are projected out of plane on roentgen photogrammetry, which causes projection errors that do not occur with spatial digitization. This error can be even worse in case of overlapping consolidated fracture fragments. Also a slight difference in the film-to-object distance might introduce an amplification error (Sharr and Mohammed, 2003; Smekal et al., 2008). The anatomical changes in the closed-chain mechanism of the shoulder after a clavicular fracture causes the sternoclavicular joint angle to increase, which results in more retraction of the lateral end of the affected clavicle after healing. Consequently, the affected clavicle will be projected more out of plane compared to the contralateral side on roentgen photogrammetry. This 2D projection error will cause a deduction of 1–2 cm on the total length of the affected side as measured on the radiograph compared to spatial digitization. With 3D spatial digitization, the thoracic sensor placed on the participant's sternum would reduce

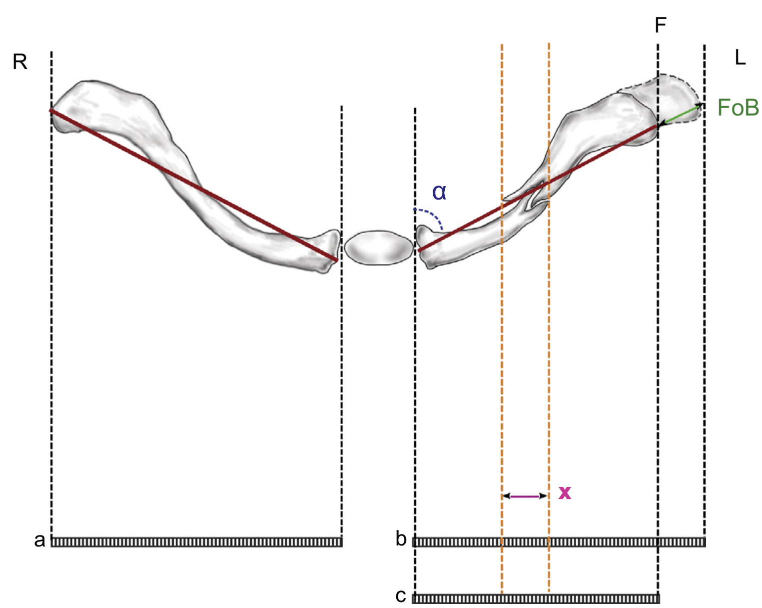

Fig. 4. Schematic cranial view of two clavicles, to illustrate the length measurement differences between spatial digitization (FoB) and roentgen photogrammetry due to projection errors on the radiograph. In this illustration, the fracture resulted in shortening of the left clavicle (L) as indicated by the line marked F. For roentgen photogrammetry the length of the non-fractured right clavicle (R) is indicated by ruler marked a. The original length of the left clavicle is indicated by b. After the fracture the length of the left clavicle is indicated by c. The purple line (x) between the two orange lines indicates in this theoretical case the absolute shortening as measured on roentgen photogrammetry. When using spatial digitization the length of the clavicles is indicated by the two red lines. The reduction in length, after fracture, for the left clavicle is indicated by the green line (red line R – red line L). As depicted the green and purple line are at an angle (α). The sternoclavicular joint angle (α) between the lines, depicted with the blue dashed line, is depending on the degree of retraction of the clavicle. The larger the degree of retraction and amount of shortening, the smaller the angle (α) and the larger the difference in length between the purple (x) and green line (FoB) will be (Pythagorean Theorem). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

this type of movement/projection artefacts, because the spatial position of the sensor changes with the bony landmarks, without changing the distance between the bony landmarks and the thoracic sensor. Since the measurements for spatial digitization are static, measured in one moment of time, these movement artefacts are near to zero. The 2D projection error phenomenon is schematically illustrated in Fig. 4.

To account for these projection errors we advocate to use the Clavicle Shortening Index (*CSI*) on AP trauma radiographs, when using shortening in clinical decision making. A similar proportional measure was also advocated by Smekal et al., who measured proportional shortening on PA thorax radiographs using the contralateral side as a reference (Smekal et al., 2008). On theoretical grounds, the *CSI* is to be preferred to the absolute measurement of clavicular shortening, or to the use of the contralateral side as reference for several reasons. First, projection errors are of less influence when using a proportional measure. Second, the *CSI* is more comparable between patients than the absolute measured shortening, because variation in clavicular length between individuals is accounted for. For example, the theory is that a certain amount of shortening may have a larger impact on the shoulder kinematics in patients with a short clavicle than in patients with a long clavicle, because of the closed-chain mechanism. It was found that protraction of the scapula on the affected side increases with 4.4° in rest position compared to the contralateral, unaffected shoulder. Also, anteflexion and abduction of the humerus till 90°, would give slightly more protraction, more lateral rotation and slightly reduced backward tilt of the scapula of the affected shoulder (Stegeman et al., 2015). Although shortening influenced the shoulder kinematics in the lower Range of Motion, no relation was found between the degree of shortening and the degree of changed scapular kinematics. Third, clavicles within individuals are asymmetrical in length (Cunningham et al., 2013; King et al., 2014; Wisanuyotin et al., 2013). If the contralateral side is used in literature as a reference, it is assumed that both sides were equally long prior to fracture (Lazarides and Zafiropoulos, 2006; Rasmussen et al., 2011; Smekal et al., 2008), but this might introduce errors in the calculation and consequently lead to unreliable results. We have therefore chosen not to use the contralateral side as a reference. Further research is needed to determine e.g. a *CSI* cut-off point that is relevant with respect to functional outcome.

A limitation of this study is that AP (panorama) radiographs were used instead of PA radiographs, as AP radiographs are standard protocol for clavicular fractures in our hospital. This could introduce a small but consistent amplification error due to the larger distance to the projection surface (Sharr and Mohammed, 2003; Smekal et al., 2008). Another limitation is that not all eligible former patients were willing to participate in this study, which could have led to selection bias. However, we do think that the participant group is a good representation of the total field of non-operatively treated midshaft clavicular fracture patients at our hospitals. Furthermore, it is important to underline that spatial digitization with the FoB is only feasible in a research setting and not in a clinical setting, because the measurements are time consuming, the equipment expensive and most importantly the palpation for bony landmarks could be painful in a patient with a fresh fracture. The use of radiographs is less invasive and probably more cost-effective than spatial digitization. Also, only clavicular length can be determined with spatial digitization and not absolute shortening, which is needed to calculate *CSI*.

5. Conclusion

Shortening of the fractured clavicle is often mentioned as an important factor in clinical decision making on treatment in the first two weeks after fracture. This study describes the potential problems of measurements of the clavicle, when acquired on standard radiographs. From the results we conclude that clavicular length and shortening can be measured reliably on radiographs acquired shortly after trauma, but the measurements may not reflect the actual length and shortening. Furthermore, the inter-observer agreement of shortening for measurements on radiographs taken after consolidation is poor. These issues should be taken into account of radiograph based clinical decision making directly after trauma. To overcome measurement errors due to two-dimensional projection, clavicular asymmetry and individual clavicular length differences, we recommend using a proportional measure for clavicular shortening (*CSI*) based on the AP trauma radiographs for treatment decisions.

Conflict of interest

No benefits or funds were received in support of this study.

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References

Andersen K, Jensen PO, Lauritzen J. Treatment of clavicular fractures. Figure-of-eight bandage versus a simple sling. Acta Orthop Scand 1987;58(1):71–4.
Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1(8476):307–10.
Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res 1999;8(2):135–60.
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.
Cunningham BP, McLaren A, Richardson M, McLemore R. Clavicular length: the assumption of symmetry. Orthopedics 2013;36(3):e343–7.
de Groot JH. The variability of shoulder motions recorded by means of palpation. Clin Biomech (Bristol, Avon) 1997;12(7–8):461–72.
Eskola A, Vainionpaa S, Myllynen P, Patiala H, Rokkanen P. Outcome of clavicular fracture in 89 patients. Arch Orthop Trauma Surg 1986;105(6):337–8.
Hill JM, McGuire MH, Crosby LA. Closed treatment of displaced middle-third fractures of the clavicle gives poor results. J Bone Joint Surg Br 1997;79(4):537–9.
Hillen RJ, Burger BJ, Poll RG, de GA, Robinson CM. Malunion after midshaft clavicle fractures in adults. Acta Orthop 2010;81(3):273–9.
King PR, Scheepers S, Ikram A. Anatomy of the clavicle and its medullary canal: a computed tomography study. Eur J Orthop Surg Traumatol 2014;24(1):37–42.
Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33(1):159–74.
Lazarides S, Zafiropoulos G. Conservative treatment of fractures at the middle third of the clavicle: the relevance of shortening and clinical outcome. J Shoulder Elbow Surg 2006;15(2):191–4.
Ledger M, Leeks N, Ackland T, Wang A. Short malunions of the clavicle: an anatomic and functional study. J Shoulder Elbow Surg 2005;14(4):349–54.
Mathieu PA, Marcheix PS, Hummel V, Valleix D, Mabit C. Anatomical study of the clavicle: endomedullary morphology. Surg Radiol Anat 2014;36(1):11–5.
Meskers CG, Fraterman H, van der Helm FC, Vermeulen HM, Rozing PM. Calibration of the "Flock of Birds" electromagnetic tracking device and its application in shoulder motion studies. J Biomech 1999;32(6):629–33.
Meskers CG, van der Helm FC, Rozendaal LA, Rozing PM. In vivo estimation of the glenohumeral joint rotation center from scapular bony landmarks by linear regression. J Biomech 1998a;31(1):93–6.
Meskers CG, Vermeulen HM, de Groot JH, van der Helm FC, Rozing PM. 3D shoulder position measurements using a six-degree-of-freedom electromagnetic tracking device. Clin Biomech (Bristol, Avon) 1998b;13(4–5):280–92.
Nordqvist A, Petersson C. The incidence of fractures of the clavicle. Clin Orthop Relat Res 1994;300:127–32.
Rasmussen JV, Jensen SL, Petersen JB, Falstie-Jensen T, Lausten G, Olsen BS. A retrospective study of the association between shortening of the clavicle after fracture and the clinical outcome in 136 patients. Injury 2011.
Robinson CM. Fractures of the clavicle in the adult. Epidemiology and classification. J Bone Joint Surg Br 1998;80(3):476–84.
Sharr JR, Mohammed KD. Optimizing the radiographic technique in clavicular fractures. J Shoulder Elbow Surg 2003;12(2):170–2.

Smekal V, Deml C, Irenberger A, Niederwanger C, Lutz M, Blauth M, et al. Length determination in midshaft clavicle fractures: validation of measurement. J Orthop Trauma 2008;22(7):458–62.
Stegeman SA, de Witte PB, Boonstra S, de Groot JH, Nagels J, Krijnen P, et al. Posttraumatic midshaft clavicular shortening does not result in relevant functional outcome changes. Acta Orthop 2015:1–8.
Stegeman SA, Roeloffs CW, van den Bremer J, Krijnen P, Schipper IB. The relationship between trauma mechanism, fracture type, and treatment of midshaft clavicular fractures. Eur J Emerg Med 2013;20(4):268–72.
Wick M, Muller EJ, Kollig E, Muhr G. Midshaft fractures of the clavicle with a shortening of more than 2 cm predispose to nonunion. Arch Orthop Trauma Surg 2001;121(4):207–11.
Wisanuyotin T, Tidchom C, Chaisiwamonkhol K, Chowchuen P, Paholpak P, Sirichativapee W, et al. Geometry of the clavicle and reliability of measurement using PACS. Surg Radiol Anat 2013;36(6):573–7.
Wu G, van der Helm FC, Veeger HE, Makhsous M, Van RP, Anglin C, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion – Part II: shoulder, elbow, wrist and hand. J Biomech 2005;38(5):981–92.

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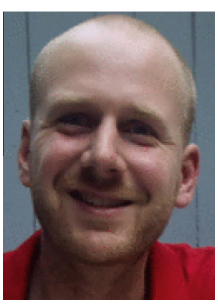

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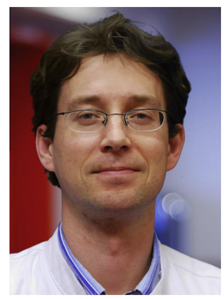

Jochem Nagels is consultant in orthopaedics and has been employed at the Leiden University Medical Center (LUMC) in The Netherlands since 2008. His medical training started in Rotterdam in The Netherlands, at the Erasmus University Medical Center (EMC) from 1990 to 1996. After a period of being a junior house officer and PhD researcher, he became a resident in orthopaedics between 2002 and 2007 and was trained at the Amphia Hospital (Breda), the HAGA-hospital (The Hague), Reinier de Graaf Gasthuis (Delft) and the LUMC (Leiden) all in The Netherlands. Since then he specialized in upper extremity surgery, especially (revision) arthroplasty of the shoulder, elbow and wrist, secondary surgery for obstetric and traumatic brachial plexus lesions, massive rotator-cuff tears and traumasurgery. He had published around 25 papers in various journals mainly addressing conditions of the upper extremity. Since 2014 he is also involved within the Medical Delta of The Netherlands (collaboration of the LUMC, the Erasmus MC and the Technical University of Delft) in development of education for a new bachelor curriculum at the Technical University of Delft: "Clinical Technology".

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