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CHAPTER 3

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

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Submitted

ABSTRACT

Purpose

Clavicular shortening after fracture is deemed prognostic for clinical outcome and is therefore generally assessed on radiographs for clinical decision making, although the reliability and accuracy of these measurements are unclear. This study aimed to assess the reliability of measurements of clavicular length and shortening on radiographs, and to compare these with three-dimensional (3D) measurements obtained with a spatial electromagnetic recording system.

Patients and Methods

Thirty-two participants with a consolidated non-operatively treated midshaft clavicular fracture were analysed. Two observers measured clavicular lengths and absolute and proportional clavicular shortening before and after fracture consolidation. The clavicular lengths were also measured in 3D with the electromagnetic Flock of Birds system. 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 comparing measurements of length on AP panorama radiographs with spatial digitization showed substantial differences.

Conclusion

Measurements of clavicular length on radiographs are highly reliable between observers, but may not reflect the actual length, since 2D measurements (radiographs) differed from 3D measurements (Flock of Birds). We recommend to use proportional shortening when measuring clavicular length or shortening on radiographs for clinical decision making.

INTRODUCTION

Non-operative treatment of displaced midshaft clavicular fractures may lead to mal-union and subsequent shortening of the clavicle.¹⁻⁴ Several studies suggested that conservative treatment of fractured clavicles with more than 15 mm shortening on the trauma radiograph may lead to poor functional outcome^{2,5,6} or non-union.^{7,8} For these cases, surgical fixation in the first weeks after trauma is generally advocated.^{7,9} However, if applied in clinical decision making, clavicular length and shortening must be measured in a reliable and valid manner.

In current clinical practice, clavicular length and shortening are measured on (two-dimensional) digital radiographs, with the fracture projected in one or two planes. Two notes of criticism about these clinically relevant measurements are in place: 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 magnification 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.¹⁰ 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 accurate and reliable with an electromagnetic tracking device (spatially digitized observations),¹¹ 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. However, this method is only feasible in a research setting. 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 these 2D photogrammetry measurements of clavicular length with spatially digitized 3D measurements. Furthermore, we evaluated an alternative

method for calculating proportional shortening of consolidated clavicles on radiographs which accounts for inter-individual variation of clavicular length.

PATIENTS AND METHODS

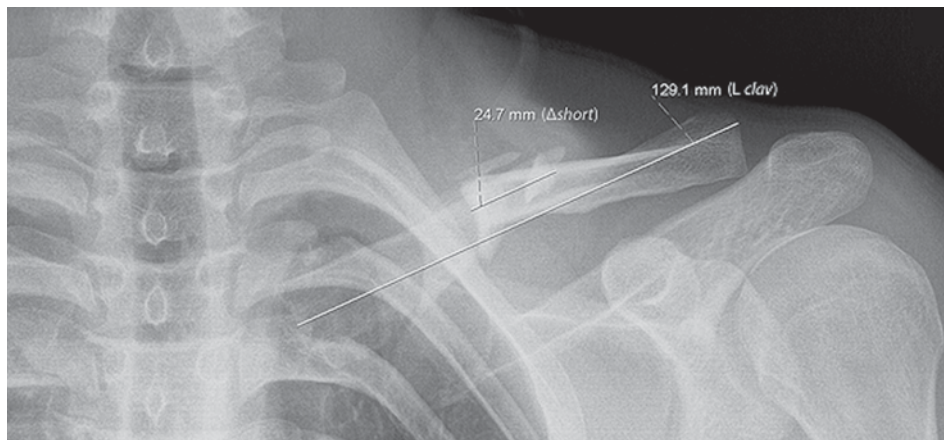
This exploratory study was approved by the institutional Medical Ethics Review Committee and registered in the Dutch Trial Registry (NTR3167). The study was performed between December 2011 and April 2012.

Participants

For this exploratory study no sample size calculation was performed. Patients with a non-operatively treated displaced midshaft clavicular fracture 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 to 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.

Roentgen photogrammetry

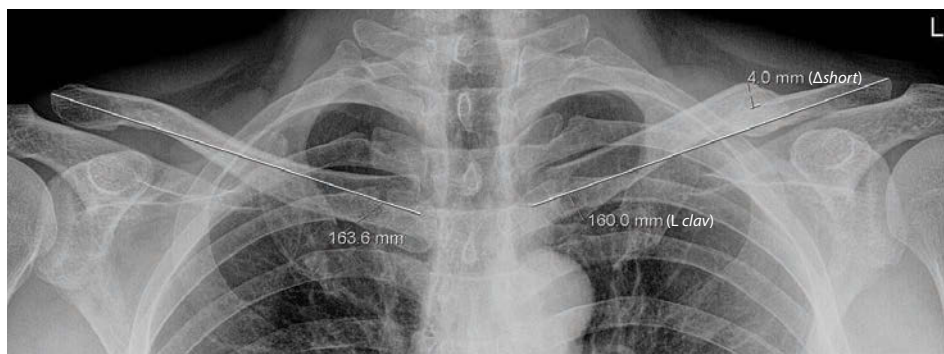
The anteroposterior (AP) trauma radiographs of all participants were retrieved from the hospital records. During the study visit, an additional AP panorama radiograph comprising both clavicles was acquired of each participant. For this AP panorama radiograph, it was ensured that the candidates were standing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



(A) Anteroposterior trauma radiograph*

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 $24.7/(129.1+24.7) \times 100 = 16.1\%$.



(B) Anteroposterior panorama radiograph taken after consolidation*

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.

* Figures 1A and 1B are from different patients.

Figure 1 Measurement of clavicular length and shortening after a midshaft fracture, on the anteroposterior trauma radiograph (A) and anteroposterior panorama radiograph (B).



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) (Figure 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 ($\Delta short$) on the AP trauma radiograph and the AP panorama radiograph after consolidation (Figure 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.¹⁰:

$$CSI = \frac{(\Delta short)}{(\Delta short + L clav)} \times 100\% \quad (\text{Eq. 1})$$

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.¹¹⁻¹³ 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.¹³ The three dimensional position of the SC- and AC-joint was determined relative to a sensor that was placed on the sternum, in order to reduce movement artefacts and to

account for the participant's individual anatomy.¹⁴ The clavicular lengths were calculated in a 3-dimensional plane as the (Euclidian) distance between AC- and SC-joint, by applying the Pythagorean Theorem.

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,¹⁵ who indicated $ICC \leq 0$ as poor agreement, 0.01 to 0.20 as slight agreement, 0.21 to 0.40 as fair agreement, 0.41 to 0.60 as moderate agreement, 0.61 to 0.80 as substantial agreement and 0.81 to 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.^{16,17} 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.^{16,17} 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.

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 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.

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

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	Observer 2	Difference	P-value	Intraclass Correlation
	mean (SD)	mean (SD)	mean (SD)		Coefficient (95%-CI)
<i>AP trauma radiograph</i>					
Length [mm] of fractured clavicle (n=31)*	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)*	16.9 (8.4)	17.2 (8.4)	-0.3 (1.9)	0.42	0.97 (0.95 – 0.99)
<i>AP panorama radiograph after consolidation</i>					
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)*	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)

* 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.

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* ($p=0.11$).

Agreement between roentgen photogrammetry and spatial digitization

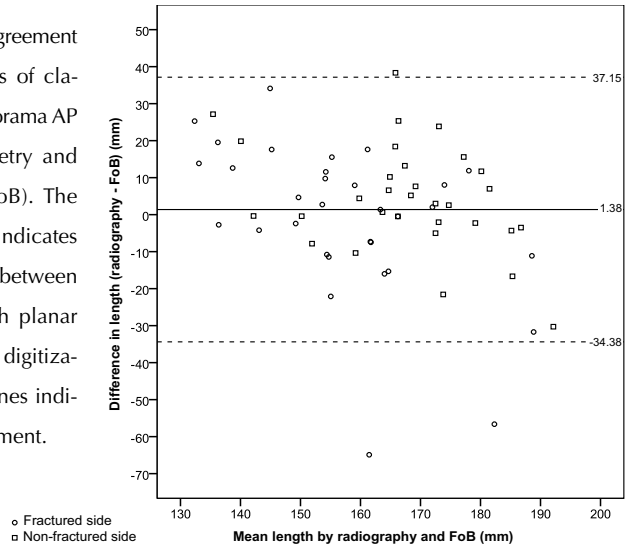
There was no statistically significant systematic difference between the clavicular length measurements obtained with roentgen photogrammetry vs. spatial digitization (Table 2). The mean difference between planar roentgen photogrammetry and spatial digitization for all clavicles was 1.38 mm (95%-CI: -3.21 – 5.98). In the Bland-Altman plot (Figure 2), 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.

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	Spatial	Difference (bias)	
	photogrammetry	digitization	Mean (95%-CI)	P-value
	Mean (SD)	Mean (SD)		
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



Figure 2 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.



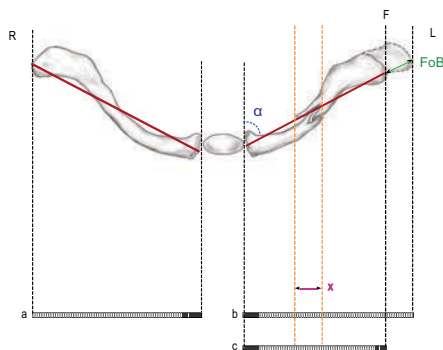
DISCUSSION

Shortening of the clavicle after consolidation is generally believed to have a relevant influence on patients' daily functioning. Therefore, it is important to determine the length and shortening of the fractured clavicle in a valid and reliable manner. This study showed that the inter-observer agreement on measurements of clavicle length and shortening performed on trauma radiographs was almost perfect. 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 clavicle length, the results of planar roentgen photogrammetry were compared to measurements obtained with spatial digitization. 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.

The discrepancies between the measurements with planar roentgen photogrammetry and spatial digitization might partially be explained by the movement of the skin during palpation for determination of the bony landmarks for

the spatial digitization, although this palpation error is small and not systematic.¹⁸ 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 horizontal axis of the anatomically normal non-fractured clavicle is positioned at a backward angle of 10-15 degrees relative to the sternum.¹⁹ Due to this sternoclavicular joint angle, the clavicles are projected out of plane on roentgen photogrammetry, which causes projection errors that do

Figure 3 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).



not occur with spatial digitization. This error can be even worse in case of overlapping consolidated fracture fragments. 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 fractured 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. The 2D projection error phenomenon is schematically illustrated in Figure 3.

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.¹⁰ 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, 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. Third, clavicles within individuals are asymmetrical in length,^{20,21} and therefore it is best not to use the contralateral side as reference. However, further research is needed to determine e.g. a *CSI* cut-off point that can be used in clinical decision making.

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.^{10,22} 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.

Conclusion

Shortening of the fractured clavicle is often mentioned as an important factor in clinical decision making for fracture treatment. This study describes the potential problems of measurements of the clavicle, when acquired on standard radiographs. From the results we conclude that (2D) 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. 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.



REFERENCES

1. Andersen, K., Jensen, P.O., and Lauritzen, J. (1987) *Treatment of clavicular fractures. Figure-of-eight bandage versus a simple sling.* Acta Orthop. Scand. 58 (1): 71-74.
2. Eskola, A., Vainionpaa, S., Myllynen, P., Patiala, H., and Rokkanen, P. (1986) *Outcome of clavicular fracture in 89 patients.* Arch. Orthop. Trauma Surg. 105 (6): 337-338.
3. Hillen, R.J., Burger, B.J., Poll, R.G., de, G.A., and Robinson, C.M. (2010) *Malunion after midshaft clavicle fractures in adults.* Acta Orthop. 81 (3): 273-279.
4. Nordqvist, A. and Petersson, C. (1994) *The incidence of fractures of the clavicle.* Clin. Orthop. Relat Res.(300): 127-132.
5. Hill, J.M., McGuire, M.H., and Crosby, L.A. (1997) *Closed treatment of displaced middle-third fractures of the clavicle gives poor results.* J. Bone Joint Surg. Br. 79 (4): 537-539.
6. Lazarides, S. and Zafiroopoulos, G. (2006) *Conservative treatment of fractures at the middle third of the clavicle: the relevance of shortening and clinical outcome.* J. Shoulder. Elbow. Surg. 15 (2): 191-194.
7. Canadian Orthopaedic Trauma Society (2007) *Non-operative treatment compared with plate fixation of displaced midshaft clavicular fractures. A multicenter, randomized clinical trial.* J. Bone Joint Surg. Am. 89 (1): 1-10.
8. Wick, M., Muller, E.J., Kollig, E., and Muhr, G. (2001) *Midshaft fractures of the clavicle with a shortening of more than 2 cm predispose to nonunion.* Arch. Orthop. Trauma Surg. 121 (4): 207-211.
9. Stegeman, S.A., Roeloffs, C.W., van den Bremer, J., Krijnen, P., and Schipper, I.B. (2013) *The relationship between trauma mechanism, fracture type, and treatment of midshaft clavicular fractures.* Eur. J. Emerg. Med. 20 (4): 268-272.
10. Smekal, V., Deml, C., Irenberger, A., Niederwanger, C., Lutz, M., Blauth, M., and Krappinger, D. (2008) *Length determination in midshaft clavicle fractures: validation of measurement.* J Orthop. Trauma. 22 (7): 458-462.
11. Meskers, C.G., Fraterman, H., van der Helm, F.C., Vermeulen, H.M., and Rozing, P.M. (1999) *Calibration of the "Flock of Birds" electromagnetic tracking device and its application in shoulder motion studies.* J. Biomech. 32 (6): 629-633.
12. Meskers, C.G., Vermeulen, H.M., de Groot, J.H., van der Helm, F.C., and Rozing, P.M. (1998) *3D shoulder position measurements using a six-degree-of-freedom electromagnetic tracking device.* Clin. Biomech. (Bristol, Avon.). 13 (4-5): 280-292.

13. Wu, G., van der Helm, F.C., Veeger, H.E., Makhsous, M., Van, R.P., Anglin, C., Nagels, J., Karduna, A.R., McQuade, K., Wang, X., Werner, F.W., and Buchholz, B. (2005) *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. 38 (5): 981-992.
14. Meskers, C.G., van der Helm, F.C., Rozendaal, L.A., and Rozing, P.M. (1998) *In vivo estimation of the glenohumeral joint rotation center from scapular bony landmarks by linear regression*. J Biomech. 31 (1): 93-96.
15. Landis, J.R. and Koch, G.G. (1977) *The measurement of observer agreement for categorical data*. Biometrics. 33 (1): 159-174.
16. Bland, J.M. and Altman, D.G. (1986) *Statistical methods for assessing agreement between two methods of clinical measurement*. Lancet. 1 (8476): 307-310.
17. Bland, J.M. and Altman, D.G. (1999) *Measuring agreement in method comparison studies*. Stat. Methods Med Res. 8 (2): 135-160.
18. de Groot, J.H. (1997) *The variability of shoulder motions recorded by means of palpation*. Clin. Biomech. (Bristol. , Avon.). 12 (7-8): 461-472.
19. Ledger, M., Leeks, N., Ackland, T., and Wang, A. (2005) *Short malunions of the clavicle: an anatomic and functional study*. J. Shoulder. Elbow. Surg. 14 (4): 349-354.
20. Cunningham, B.P., McLaren, A., Richardson, M., and McLemore, R. (2013) *Clavicular length: the assumption of symmetry*. Orthopedics. 36 (3): e343-e347.
21. Wisanuyotin, T., Tidchom, C., Chaisiwamonkhol, K., Chowchuen, P., Paholpak, P., Sirichativapee, W., Kosuwan, W., and Jeeravipoolvarn, P. (2013) *Geometry of the Clavicle and Reliability of Measurement using PACS*. Surg. Radiol. Anat. 36 (6): 573-577.
22. Sharr, J.R. and Mohammed, K.D. (2003) *Optimizing the radiographic technique in clavicular fractures*. J. Shoulder. Elbow. Surg. 12 (2): 170-172.

