ORIGINAL ARTICLE

Effects of Upright and Supine Radiograph on Shortening and Displacement of Middle Clavicle Fracture

Sirisomboon Towiwat, MD[1], Napol Ratanasermsub, MD[1]

[1] Department of Orthopedics, Sunpasittiprasong Hospital, Ubon Ratchathani, Thailand

Objective: To compare the difference in degree of shortening and displacement in middle clavicle fracture between upright and supine radiograph.

Materials and Methods: Two hundred fifty-nine patients with a median age of 36 years old and between 18 to 80 years with acute displaced clavicular fractures that occurred within two weeks were included in the present study. Standardized upright and supine AP radiograph of bilateral clavicles were obtained. The fractures were classified into three subtypes, simple for 85 patients, wedge for 123 patients, and complex for 51 patients. Shortening and displacement were measured and compared between the two positions.

Results: Shortening was higher in upright radiograph at 10.00 mm (–7.60 to 33.20) compared to supine radiograph at 6.90 mm (–11.80 to 21.40). Median difference of shortening was significant at 2.60 mm (–8.30 to 21.10) (p<0.001). The differences of shortening were also significant, in the three subtypes with simple at 2.40 mm (–5.60 to 11.70) (p<0.001), wedge at 2.20 mm (–8.30 to 21.10) (p<0.001), and complex at 4.60 mm (–7.40 to 13.80) (p<0.001). Displacement was greater when measured on upright radiograph at 18.30 mm (4.40 to 36.40) compared to supine radiograph at 8.20 mm (2.00 to 29.30). Median difference of displacement was significant at 8.10 mm (0.10 to 23.50) (p<0.001). The differences of displacement were significant also the three subtypes with simple at 7.20 mm (0.10 to 20.40) (p<0.001), wedge at 8.70 mm (0.50 to 21.70) (p<0.001), and complex at 12.20 mm (2.90 to 23.50) (p<0.001). The intraclass correlation was 0.91 (95% CI 0.88 to 0.93) for shortening, 0.86 (95% CI 0.75 to 0.92) for displacement, and 0.88 (95% CI 0.84 to 0.93) for OTA fracture classification, all indicating excellent agreement. The number of patients who met operative indication, which was a shortening or displacement greater than 20 mm, in upright position were greater than those in supine position.

Conclusion: Significant discrepancies in shortening and displacement of middle clavicle fracture among the positions were obtained in all fracture subtypes. The ability of upright radiograph to demonstrate maximal shortening and displacement may influence the decision on the treatment courses.

Keywords: Clavicle fracture; Displacement; Shortening; Upright radiograph; Supine radiograph

Received 26 June 2023 | Revised 24 November 2023 | Accepted 28 November 2023

J Med Assoc Thai 2023;106(12):1114-20

Website: http://www.jmatonline.com

Clavicle fractures are one of the most common fractures, which account for 2.6% to 10% of all adult fractures[1]. Approximately 80% of clavicle fractures occur in the midshaft and often are displaced[2]. Historically, the majority of clavicle fractures had been treated non-operatively. This approach was based on initial studies that reported a low non-union rate of 0.1% to 0.8% in fractures treated non-operatively[2]. On the contrary, more recent studies revealed that midshaft clavicle fractures with 100% displacement are particularly at risk of non-union and symptomatic malunion, hence requiring additional treatment despite the initial interventions[3]. In a systematic review, Zlowodski et al[4]. reported an overall non-union rate of 5.9% for acute midshaft clavicle fractures and 15.1% for displaced fractures. Moreover, a recent report suggested that fracture displacement and comminution are independent radiographic risk factors for prediction of non-union[5]. Because of poorer outcomes (higher non-union rates, delayed recovery, and adverse sequelae) associated with non-operatively treated displaced midshaft clavicle fractures, operative fixation has become increasingly more popular in recent years[6]. Studies have shown improved functional outcomes and decreased non-union rates with either plate and screw fixation or intramedullary nailing[7-9]. The indications for surgery of midshaft clavicle fracture have evolved based on factors such as

Correspondence to:

Towiwat S.

Department of Orthopedics, Sunpasittiprasong Hospital, Muang District, Ubon Ratchathani 34000, Thailand.

Phone: +66-99-2645259

Email: towiwats@yahoo.co.th

How to cite this article:

Towiwat S, Ratanasermsub N. Effects of Upright and Supine Radiograph on Shortening and Displacement of Middle Clavicle Fracture. J Med Assoc Thai 2023;106:1114-20.

DOI: 10.35755/jmedassocthai.2023.12.13922

fracture pattern, associated injuries, and patient factors. The traditional absolute indications were open fractures, neurovascular compromise, and soft tissue compromise that indicated impending open fractures. Other indications included fractures with shortening or displacement greater than 2 cm, severe comminution, multi-limb injuries, and young active or athletic patients[10]. Operative decisions are based on radiographic results. Displacement and shortening are crucial factors in determining patients' treatment course. As a part of the initial evaluation, radiographic assessment is performed to determine facture pattern, shortening, and displacement. However, despite their importance, the effects of patients' positions (upright and supine) during the time of radiographs on degrees of fracture displacement and shortening has not been elucidated[5,7,10,11].

The authors hypothesize that the difference in deforming forces between upright and supine radiograph might have a previously unrecognized role in operative decisions. Considering the effects that gravity has on the fracture alignment at the time of radiographic evaluation, upright radiograph may assess the severity of midshaft clavicle fracture more accurately than supine radiograph in all fracture patterns (simple, wedge, or complex). This discrepancy may influence the decision on the treatment courses.

Materials and Methods

The present study was approved by the Institutional Research Ethics Committee of Sunpasitthiprasong Hospital, Thailand (CA code 093/2564). All patients provided informed consent prior to the data collection.

The observational study was conducted at the Department of Orthopedics, Sunpasitthiprasong hospital, Ubonratchathani, Thailand. Sample size was calculated by using N4Studies application as following formula[12,13]:

$$N = \frac{(Z_{1-\alpha/2} + Z_{1-\beta})^2 \sigma^2}{d^2}$$

N is number of study subjects

Z is the values from standard normal distribution (Z=1.96 for CI 95%)

σ is the standard deviation of outcome variable (from previous study SD=8.9)(14)

d is difference in means (20% of SD=1.78)

α is a signification level=0.05, β is a type II error probability=0.2 and power 80% were determined

The minimum number of subjects was 197.

Patients with clavicle fracture who went to emergency room of Sunpasitthiprasong Hospital were recruited prospectively between January 2021 and June 2022. Eligible patients were at least 18 years old, presented with acute closed unilateral displaced midshaft complete clavicle fracture that occurred within two weeks after injury, without signs of impending open fracture such as soft tissue compromise, who were able to be positioned standing upright and supine at the time of initial radiographic exams. Patients were excluded if they suffered from floating shoulder or multifocal shoulder girdle injury, pathological clavicular fracture, associated brachial plexus injury, or contralateral malunion clavicle. Moreover, patients with insufficient radiographic examination, improper radiographic position or pregnancy were also ineligible.

Radiographic evaluation and protocol

The radiographs were made using EcoRay SMS-CM-N, a digital radiographic device. Picture Archiving and Communicating System (PACS), Infinit G3 program, was employed to evaluate clavicle fracture pattern and be used for all measurements.

The radiographic protocol included upright AP clavicle view, which made the patient in a standing position, hand close to body without hanging weight and supine AP bilateral clavicle view. Both were centered on the midline of the body at the level of sternal notch. The beam was perpendicular to the subject's body. Source image receptor distance (SID) was 100 cm. Proper quality of radiographs comprised of adequate exposure, midline spinous process to negate rotation, and clear coverage of both clavicles.

Measurement of shortening and displacement

Shortening or lengthening (mm) was determined by the clavicular length difference between the injured clavicle and contralateral uninjured clavicle. Clavicle length was assessed by measuring the distance between the center of the medial edge of clavicle at the sternoclavicular joint to the most lateral edge of clavicle[14] (Figure 1). A positive value indicated shortening of injured side while a negative value indicated lengthening of injured side.

Displacement (mm) was defined as the measured distance between the midpoint of fracture line which is drawn from fracture tip of upper outer cortex to fracture tip of lower outer cortex of the most proximal and distal fragments[15] (Figure 2).

Shortening and displacement were measured from both upright and supine radiographs separately (Figure 3). The fractures were classified based on the

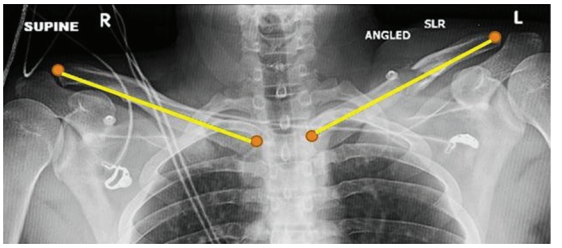

Figure 1. Shortening (or lengthening) (mm) was determined by the clavicular length difference of injured clavicle side compared to the contralateral uninjured side. Clavicle length was assessed by measuring the distance between the centers of the medial edge of clavicle at the sternoclavicular joint to the most lateral edge of clavicle.

Modified from Backus JD, Merriman DJ, McAndrew CM, Gardner MJ, Ricci WM. Upright versus supine radiographs of clavicle fractures: does positioning matter? J Orthop Trauma 2014;28:636-41.

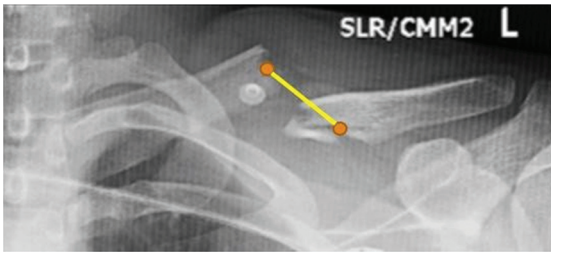

Figure 2. Displacement (mm) was the measured distance between the midpoint of fracture line (line between fracture tip of upper outer cortex and fracture tip of lower outer cortex) of the most proximal and distal fragments.

Modified from Backus JD, Merriman DJ, McAndrew CM, Gardner MJ, Ricci WM. Upright versus supine radiographs of clavicle fractures: does positioning matter? J Orthop Trauma 2014;28:636-41.

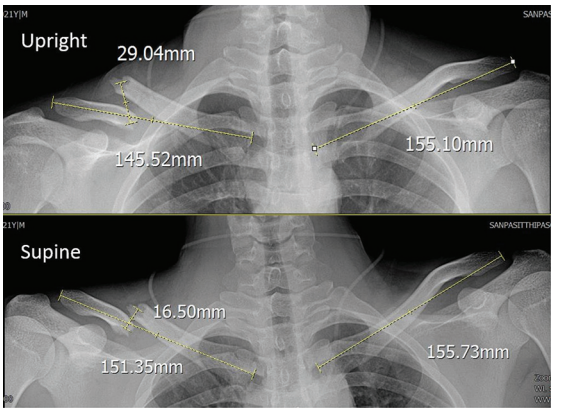

Figure 3. Both shortening and displacement measurements were obtained from upright and supine radiographs for each patient.

AO/OTA classification system[15]. All radiographs were independently evaluated in a random order by two blinded investigators, which included one senior orthopedic resident and one consultant orthopedic surgeon. Both investigators performed a second evaluation of the same data set one month after the first measurements were performed. Final shortening and displacement for each participant were the averaged value between the investigators.

Statistical analyses

Descriptive statistics, including frequencies, means, median, and standard deviations were calculated. Tests of normality were based on Kolmogorov-Smirnov formula. The Wilcoxon signed-rank test was used to compare the median of shortening and displacement between upright and supine radiographs. The alpha level was set at p-value less than 0.05. Apart from mean value, 95% confidence intervals (CIs) were also calculated. Mcnemar test was used to compare the number of patients who have met operative indication, which is the shortening or displacement of greater than 20 mm in supine position to upright position.

Intraclass correlation (ICC) in measurements of displacement and shortening was assessed between the investigators, using a two-way mixed effects model and an absolute agreement definition to evaluate the reproducibility of quantitative measurements. ICC values were interpreted as less than 0.40 for poor, 0.40 to 0.59 as fair, 0.60 to 0.74 as good, and 0.75 to 1.00 as excellent[16]. Median shortening and displacement were eligible for descriptive statistics and further statistical analyses only when the ICC values were excellent, or greater than 0.75. All fractures of OTA-B types underwent the same analysis. All statistical analyses were performed using IBM SPSS Statistics, version 23.0 (IBM Corp., Armonk, NY, USA).

Results

Demographics of the study population

Three hundred twenty-six patients were recruited in the present study. Two hundred fifty-nine patients were eligible according to inclusion and exclusion criteria. Patients' demographics are presented in Table 1. The median age was 36.0 years, with a range of 18 to 80, and 75.3% were men. The injuries were 52.1% on the left and 47.9% on the right. All clavicle fractures were classified according to the AO/OTA classification using the initial injury radiographs. There were 85 simple diaphyseal fractures (OTA15-B1) (32.8%), 123 wedge diaphyseal fractures (OTA15-B2) (47.5%), and 51 complex diaphyseal fractures (OTA15-B3) (19.7%).

Table 1. General characteristic of patients (n=259)

	Values (n=259); n (%)
Sex	
Male	195 (75.3)
Female	64 (24.7)
Age (years)	
<20	25 (8.9)
20 to 29	78 (30.1)
30 to 39	55 (21.2)
40 to 49	58 (22.4)
50 to 59	22 (8.5)
>60	23 (8.9)
Median (min-max)	36.0 (18 to 80)
Side	
Left	135 (52.1)
Right	124 (47.9)
AO/OTA classification 15-B	
Simple (15-B1)	85 (32.8)
Wedge (15-B2)	123 (47.5)
Complex (15-B3)	51 (19.7)

Shortening

Shortening was greater when measured on upright radiographs at 10.00 mm (–7.60 to 33.20) compared to supine radiographs at 6.90 mm (–11.80 to 21.40). Median difference of shortening between the two positions was statistically significant at 2.60 mm (–8.30 to 21.10) (p<0.001), The median differences in shortening retained their significances even when analyzed separately in each fracture subtypes with simple fracture (OTA15B-1) at 2.40 mm (–5.60 to 11.70) (p<0.001), and 8.10 mm (–7.60 to 25.40) in upright versus 4.30 mm (–11.80 to 18.50) in supine, wedge fracture (OTA15B-2), at 2.20 mm (–8.30 to 21.10) (p<0.001), and 9.60 mm (–5.20 to 33.20) in upright versus 6.80 mm (–5.00 to 11.70) in supine, and complex fracture (OTA15B-3), at 4.60 mm (–7.40 to 13.80) (p<0.001), and 15.60 mm (2.50 to 24.90) in upright versus 12.00 mm (–4.20 to 18.00) in supine (Table 2). The ICC for shortening between investigators was 0.91 (95% CI 0.88 to 0.93) indicating excellent agreement.

Displacement

Displacement was greater when measured on upright radiographs at 18.30 mm (4.40 to 36.40) compared to supine radiographs at 8.20 mm (2.00 to 29.30). Median difference of displacement between the two positions was statistically significant at 8.10 mm (0.10 to 23.50) (p<0.001). The median differences in displacement retained their significances even when analyzed separately in each fracture subtypes with simple fracture (OTA15B-1) at 7.20 mm (0.10 to 20.40) (p<0.001), and 15.60 mm (4.40 to 33.20) in upright versus 7.10 mm (2.00 to 28.20) in supine, wedge fracture (OTA15B-2) at 8.70 mm (0.50 to 21.70) (p<0.001), and 17.20 mm (6.90 to 32.10) in upright versus 7.50 mm (2.10 to 21.80) in supine, and complex fracture (OTA15B-3), at 12.20 mm (2.90 to 23.50) (p<0.001), and 26.20 mm (14.50 to 36.40) in upright versus 12.50 mm (4.10 to 29.30) in supine (Table 2). The ICC displacement between investigators was 0.86 (95% CI 0.75 to 0.92), indicating excellent agreement.

The number of patients who met operative indications, based on fracture shortening of more than 20 mm, was greater in upright position with 16 patients than those in supine position with only three patients (p<0.001) (Table 3).

The number of patients who met operative indications, based on fracture displacement of greater than 20 mm, was greater in upright position with 99 patients than those in supine position with 23 patients,

Table 2. Shortening and displacement between upright and supine position

	n	Upright; median (min-max)	Supine; median (min-max)	Differences; median (min-max)	p-value
Shortening (mm)					
Total	259	10.00 (–7.60 to 33.20)	6.90 (–11.80 to 21.40)	2.60 (–8.30 to 21.10)	<0.001*
Simple	85	8.10 (–7.60 to 25.40)	4.30 (–11.80 to 18.50)	2.40 (–5.60 to 11.70)	<0.001*
Wedge	123	9.60 (–5.20 to 33.20)	6.80 (–5.00 to 11.70)	2.20 (–8.30 to 21.10)	<0.001*
Complex	51	15.60 (2.50 to 24.90)	12.00 (–4.20 to 18.00)	4.60 (–7.40 to 13.80)	<0.001*
Displacement (mm)					
Total	259	18.30 (4.40 to 36.40)	8.20 (2.00 to 29.30)	8.10 (0.10 to 23.50)	<0.001*
Simple	85	15.60 (4.40 to 33.20)	7.10 (2.00 to 28.20)	7.20 (0.10 to 20.40)	<0.001*
Wedge	123	17.20 (6.90 to 32.10)	7.50 (2.10 to 21.80)	8.70 (0.50 to 21.70)	<0.001*
Complex	51	26.20 (14.50 to 36.40)	12.50 (4.10 to 29.30)	12.20 (2.90 to 23.50)	<0.001*

p-value from Wilcoxon signed-ranks test, * Significant at the 0.05 level

Table 3. Number of patients who met operative indication (shortening >20 mm)

Operative indication: Shortening >20 mm		Supine		Total
		Met	Not met	
Upright	Met	3	13	16
	Not met	0	243	243
Total		3	256	259

p-value from McNemar test <0.001

Table 4. Number of patients who met operative indication (displacement >20 mm)

Operative indication: Displacement >20 mm		Supine		Total
		Met	Not met	
Upright	Met	23	76	99
	Not met	0	160	160
Total		23	236	259

p-value from McNemar test <0.001

(p<0.001) (Table 4).

The ICC for diaphyseal clavicle fracture OTA15B classification was 0.88 (95% CI 0.84 to 0.93), indicating excellent agreement.

Discussion

As the non-union rates of non-operative treatment for displaced midshaft clavicle fracture in current literatures exceeded the previously reported rates, operative fixation is becoming increasingly more favored[2]. Consequently, the indications for operative management were expanded. To elaborate this further, a direct relationship between increased vertical displacement and poor functional outcomes has been brought to light[7]. Robinson et al. reported an 18.5-fold increase in non-union likelihood for displaced fractures when compared to non-displaced fractures[10]. In addition, they suggested that greater than 100% clavicle fracture displacement was a risk factor for non-union. Murry et al. found that fracture displacement, which included shortening and vertical translation, was an independent risk factor in predicting clavicle non-union, apart from the smoking status and fracture comminution[5]. A study by Hill et al. revealed that all patients with shortening of greater than 20 mm suffered from non-union and subsequently reported an unsatisfactory result[11]. These emphasized the vital need of an accurate displacement and shortening measurement upon initial evaluation, as they inevitably dictate the patient's treatment. Standardized imaging protocol that covers the patient is crucial not only for reliable prediction of the non-union and malunion risk but also determining the need for operative intervention. To the best of the authors' knowledge, explicit direction on radiographic positions largely remains unclear. Hence, the possibility that a portion of radiographic supine positions in the literature could not be excluded. Therefore, the fractures shortening, and displacement in the studies could have been underestimated. The present study could fill this potential knowledge gap as the presented results suggested that upright radiograph was superior to supine radiograph for it could demonstrate maximal shortening and displacement, which influence the decision on treatment courses.

To complicate matters, a retrospective review by Plocher et al. reported that some clavicle fractures exhibited progressive displacement despite their minimal initial displacement. This progression consisted of horizontal shortening combined with vertical translation and could usually be seen on subsequent radiographic evaluation in the healing period[17]. In their study, most clavicular and shoulder radiographs were done in the supine position. They proposed that supine versus upright radiographs may alter the amount of displacement of clavicle fractures. This proposal was later validated on the two following retrospective studies[6,14]. Backus et al. suggested that when compared with supine radiograph, upright clavicle radiograph provided better estimation of maximal displacement[14]. There was an 89% increase in average vertical displacement on upright radiographs when compared to supine radiographs. Increased shortening 4.3 mm was also noted on upright radiographs compared to supine. Malik et al. compared shortening and displacement on supine, semi-upright, and upright position against each other, using chest radiograph taken no more than two weeks apart[6]. They found that changes in position increased both vertical displacement and fracture shortening in a stepwise fashion. Over three times more patients met operative indications once placed in the upright versus supine position. A recent prospective study, Onizuka et al. evaluated 15° cephalic tilted AP single-clavicle upright and supine view[18]. The parameters of displacement were greater on upright than supine radiographs with 2.4 mm greater vertical translation and 3.9° greater angulation. They also found that progressive displacement of 10 mm or more occurred in 16 out of 50 patients (32%) of the cases. However, changes in medialization were not statistically significant in their series.

Strengths of the present study are discussed as follows. The power to demonstrate statistically significant increases in both median displacement and shortening between the positions might have been enhanced from the considerable number of participants. The presented result is in line with the prior reports[6,14,17,18]. Imaging protocol applied in the present study was standardized. The upright and supine radiographs must be done concurrently. Bilateral clavicle AP view was employed to optimize patient's body rotation and to include contralateral clavicle to be a reference of fracture shortening. AP radiograph without beam tilting was selected because of its feasibility and reproducibility in acute care setting. The present results indicated that the patient's position had an effect on displacement and shortening in all fracture subtypes and had an impact on the need for surgery. Shortening was greater at 2.60 mm (–8.30 to 21.10) ($p<0.001$) when measured on upright radiographs compared to supine radiographs. Displacement was also greater at 8.10 mm (0.10 to 23.50) ($p<0.001$) when measured on upright. The number of patients that met operative indications, which is the shortening or displacement of greater than 20 mm, in upright position were greater than those in supine position, which may be clinically significant and could potentially explain poorer outcomes if non-operative treatment was chosen by degrees of displacement and shortening suggested from supine radiograph.

ICC revealed excellent agreement among investigators for AO/OTA fracture classification, displacement measurement, and shortening. This supports that the measuring methods described here are reproducible despite varying amount of experience and training of orthopedic surgeons.

However, the present study is not without limitations. Firstly, the quality of radiographs, patient's posture, and body rotation can affect measurements of fracture displacement and shortening on radiographs. To prevent these interferences, the authors tried their best to negate these factors. However, despite the authors' attempt, some participants were excluded due to insufficient radiographic exams or deviated patient's position. Secondly, the present study lacked radiographic markers to define absolute displacement, hence, comparison between the positions were measured, as a substitute, to indicate relative displacement. In addition, SID of 100 cm was strictly implemented, and contralateral clavicle was used as an interna control. Moreover, the present study's protocol did not include orthogonal views, therefore maximal displacement might have been undetected in some cases. Additional radiographic view[19,20] or 3-D computed tomography may provide more accurate deformity assessment[21], but this must be weighed against the increased radiation exposure and cost. Lastly, investigators interpreting the radiographs were not blinded to the patients' positions. That may introduce bias in the measurement of the fractures. However, within the standardized of the imaging protocol and the specific measurement methods in the present study, it would make the measurement more accurate.

Conclusion

Significant discrepancies in shortening and displacement of middle clavicle fracture between the positions were obtained in all fracture subtypes. Considering the effects that gravity has on the fracture alignment at the time of radiographic evaluation, the ability of upright radiograph to demonstrate maximal shortening and displacement may influence the decision on the treatment courses and clinical outcomes. The authors recommend obtaining upright radiographic bilateral clavicle AP view during the initial evaluation of the patients with clavicle fracture. If any unavoidable circumstance such as altered level of consciousness poses limitation to patient's radiographic position, a second radiographic evaluation within two weeks is highly warranted.

What is already known on this topic?

Operative decisions on treatment of middle clavicle fracture are based on radiographic results. The diagnostic method for evaluating clavicle fracture is bilateral clavicle AP radiograph. However, there is still no definite pattern of the patient's position on radiograph.

What does this study add?

The present study suggested that upright radiograph was superior to supine radiograph on middle clavicle fracture evaluation as it could demonstrate maximal shortening and displacement, which influence the decision on treatment courses.

Acknowledgment

The authors would like to express our deepest gratitude to all patients who made the present study possible, support from the Department of Orthopedics, Sunpasitthiprasong Hospital. Wichai Termsombatborworn, Chanon Chivisest, and Parinya Chamnan were wholeheartedly appreciated.

Contribution from Chanatip Tongyonk in the present manuscript was also treasured. Finally, the authors have to recognize the radiographic technologist team for their assistance in the present work.

Conflict of interest

The authors have nothing to disclose.

References

1. Postacchini F, Gumina S, De Santis P, Albo F. Epidemiology of clavicle fractures. J Shoulder Elbow Surg 2002;11:452-6.
2. Neer CS 2nd. Nonunion of the clavicle. J Am Med Assoc 1960;172:1006-11.
3. McKee RC, Whelan DB, Schemitsch EH, McKee MD. Operative versus nonoperative care of displaced midshaft clavicular fractures: a meta-analysis of randomized clinical trials. J Bone Joint Surg Am 2012;94:675-84.
4. Zlowodzki M, Zelle BA, Cole PA, Jeray K, McKee MD. Treatment of acute midshaft clavicle fractures: systematic review of 2144 fractures: on behalf of the Evidence-Based Orthopaedic Trauma Working Group. J Orthop Trauma 2005;19:504-7.
5. Murray IR, Foster CJ, Eros A, Robinson CM. Risk factors for nonunion after nonoperative treatment of displaced midshaft fractures of the clavicle. J Bone Joint Surg Am 2013;95:1153-8.
6. Malik A, Jazini E, Song X, Johal H, O'Hara N, Slobogean G, et al. Positional change in displacement of midshaft clavicle fractures: An aid to initial evaluation. J Orthop Trauma 2017;31:e9-12.
7. 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;89:1-10.
8. Smekal V, Irenberger A, Struve P, Wambacher M, Krappinger D, Kralinger FS. Elastic stable intramedullary nailing versus nonoperative treatment of displaced midshaft clavicular fractures-a randomized, controlled, clinical trial. J Orthop Trauma 2009;23:106-12.
9. Witzel K. Intramedullary osteosynthesis in fractures of the mid-third of the clavicle in sports traumatology. Z Orthop Unfall 2007;145:639-42.
10. Robinson CM, Court-Brown CM, McQueen MM, Wakefield AE. Estimating the risk of nonunion following nonoperative treatment of a clavicular fracture. J Bone Joint Surg Am 2004;86:1359-65.
11. 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;79:537-9.
12. Rutterford C, Copas A, Eldridge S. Methods for sample size determination in cluster randomized trials. Int J Epidemiol 2015;44:1051-67.
13. Ngamjarus C. Sample size calculation for health science research. Khon Kaen, Thailand: Khon Kaen University Printing House; 2021.
14. Backus JD, Merriman DJ, McAndrew CM, Gardner MJ, Ricci WM. Upright versus supine radiographs of clavicle fractures: does positioning matter? J Orthop Trauma 2014;28:636-41.
15. Marsh JL, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA, et al. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma 2007;21(10 Suppl):S1-133.
16. Cicchetti DV. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. Psychol Assess 1994;6:284-90.
17. Plocher EK, Anavian J, Vang S, Cole PA. Progressive displacement of clavicular fractures in the early postinjury period. J Trauma 2011;70:1263-7.
18. Onizuka N, Anderson JP, Gilbertson JA, MacCormick LM, Cole PA. Displacement of diaphyseal clavicle fractures related to patient position and progressive displacement in the peri-injury period. J Shoulder Elbow Surg 2018;27:667-73.
19. Austin LS, O'Brien MJ, Zmistowski B, Ricchetti ET, Kraeutler MJ, Joshi A, et al. Additional x-ray views increase decision to treat clavicular fractures surgically. J Shoulder Elbow Surg 2012;21:1263-8.
20. Wright J, Aresti N, Heuveling C, Di Mascio L. Are standard antero-posterior and 20° caudal radiographs a true assessment of mid-shaft clavicular fracture displacement? J Clin Orthop Trauma 2016;7:221-4.
21. Omid R, Kidd C, Yi A, Villacis D, White E. Measurement of clavicle fracture shortening using computed tomography and chest radiography. Clin Orthop Surg 2016;8:367-72.