J Shoulder Elbow Surg (2019) 28, 1877–1885

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Three-dimensional clavicle displacement analysis and its effect on scapular position in acute clavicle midshaft fracture

Jung-Han Kim, MD, Heui-Chul Gwak, MD, Chang-Wan Kim, MD, Chang-Rack Lee, MD, Young-Jun Kim, MD, Hyeong-Won Seo, MD*

Department of Orthopedic Surgery, Inje University Busan Paik Hospital, Inje University College of Medicine, Busan, Republic of Korea

Background: The purpose of this study was to measure the distance of the clavicle in 3 dimensions (3D) and each direction (anterior to posterior, medial to lateral, and superior to inferior) and to analyze the correlation of the angular orientation of the scapula according to each directional distance of the clavicle.
Methods: Sixty-seven patients with Robinson 2B1 and 2B2 clavicle midshaft fracture (46.0 ± 17.4 years, men = 50, women = 17) were selected as final subjects. Patients' computed tomography was reconstructed using an image processing program (3D Slicer 4.3 software). Anteroposterior (AP) distance, medial-to-lateral distance, superior-to-inferior distance, and 3D distance of both clavicles were measured. The plane connecting the 3 points (superior pole, inferior pole, and center of glenoid) of the scapula was used to calculate differences in the angular orientation between both scapulae.
Results: Among each directional distance of the clavicle, only the AP distance showed negative correlation with scapular angular orientation with anterior tilting, internal rotation, and upward rotation of the scapula (Pearson's correlation coefficient: −0.68, −0.24, and −0.28; $P < .001$, $P = .048$, and $P = .021$).
Conclusion: The shortening of the AP distance of the clavicle was related to the angular orientation of the scapula in acute clavicle fracture. AP shortening should be considered when determining the treatment of clavicle fracture.
Level of evidence: Anatomy Study; Imaging

Keywords: Clavicle midshaft fracture; three-dimensional displacement; scapular position

Clavicle fractures account for 5% to 10% of all fractures,[6,8,12] and the prevalence rate is gradually increasing because of the increase in sports population.[6] Among these fractures, midshaft fractures account for 75% to 80%[3,8] of all clavicle fractures, but the indication for surgical treatments in clavicle midshaft fractures remains controversial.[3] Recent studies reported that the shortening of clavicle midshaft fractures caused a high risk of nonunion, changes in scapulothoracic biomechanics, and winging of the scapula.[5] Therefore, surgical management is recommended for fractures with shortening of more than 10% of its original length or with severe comminution.[2] Many studies have measured such shortening in 2-dimensional (2D) image plane

This study was approved by the institutional review board of Inje University Busan Paik Hospital (IRB No.: 18-0096).

*Reprint requests: Hyeong-Won Seo, MD, Department of Orthopedic Surgery, Inje University Busan Paik Hospital, Inje University College of Medicine, Busan, Republic of Korea

E-mail address: pointingx77@gmail.com (H.-W. Seo).

1058-2746/$ - see front matter © 2019 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
https://doi.org/10.1016/j.jse.2019.03.019

radiography.[1] However, because the clavicle has a complex S shape, it can be observed in various shapes depending on the direction of the 2D image, and the deforming forces can displace fractured fragments in various directions. For this reason, the degree of displacement in various directions in 3-dimensional (3D) space cannot be completely identified by the 2D plain radiographic image.[10,13] To overcome these limitations, several studies have measured clavicular shortening using computed tomography (CT) scans.[10,14] However, no studies have analyzed the degree of shortening in 3D space in anterior-to-posterior (AP), medial-to-lateral (ML), and superior-to-inferior (SI) distance. In addition, previous studies only analyzed the relationship between clavicular shortening and scapular motion,[5,7,11] but no studies have investigated which directional shortening (AP, ML, SI) affects the static angular orientation of the scapula. The purpose of this study was to (1) measure the distance of the clavicle in 3D and each direction (AP, ML, SI) and (2) to analyze the correlation of angular orientation of the scapula according to each directional distance of the clavicle. Our hypothesis was that not only ML shortening but also AP and SI shortening could affect the angular orientation of scapula.

Materials and methods

Study design and setting

Our study is a retrospective study of 274 patients with clavicle fractures from January 2012 to June 2016 who visited our hospital and was performed after approval of the institutional review board. The inclusion criteria included the following: (1) clavicle midshaft fracture (Robinson 2B1 and 2B2) and (2) bilateral shoulder CT taken after the injury. The exclusion criteria were as follows: (1) patients under 19 years, (2) associated injuries such as scapular fractures, and (3) previous surgical history on any of the shoulder. A total of 67 patients (46.0 ± 17.4 years, men = 50, women = 17) were selected as final study subjects (Table I).

Table I Demographic data

Variable	Frequency (n)	Ratio (%)
Total patients	67	
Sex		
Male	50	74.6
Female	17	25.4
Age, yr	46.0 ± 17.4	
Affected limb		
Right	27	40.3
Left	40	59.7
Dominant limb		
Right	61	91.0
Left	6	9.0
Injury mechanism		
High energy	48	71.6
Low energy	19	28.4

CT imaging protocol

All scans were obtained with the patient in the supine position with the arms on their side and the hand on the lateral aspect of the thigh. All imaging was performed on a Siemens (SOMATOM 128, Definition AS+) scanner (Siemens Healthcare, Forchheim, Germany) using a single-energy CT protocol with 120 kVp, 180 mA with dose modulation, 0.6-mm collimation, effective pitch of 0.8, B60 (sharp) reconstruction kernel, reconstructed slice thickness of 1.0 mm, and slice increment of 1.0 mm.

Image reconstruction and assessment

Digital Imaging and Communications in Medicine file from CT scans were reconstructed into a volume model using image processing software (3D Slicer 4.3 software). After choosing a conventional 4-panel view, we marked center points of each clavicle end (center of the sternal surface and center of the acromial surface) on the volume model. The point was indicated on each coronal, sagittal, and axial plane of the CT scans. Therefore, we can confirm the center point that we marked as a reliable center of each end of the clavicle. Two points of clavicles were indicated to measure the length in 3D space in both fractured and unfractured clavicles (Fig. 1).

The 3D distance module in the software was used to calculate the distance between the 2 points in the 3D space. We used the Euclidean distance that is a measure of the true straight line distance between 2 points in Euclidean space. Therefore, 3D distance means the true straight line distance between 2 points (center of the sternal surface and center of the acromial surface) in 3D space. We also decompose the 3D distance into 3D components: ML, AP, and SI distances in both fractured and unfractured clavicles (Fig. 2).

We subtracted each value of the fractured clavicle from those of the unfractured clavicle. Negative and positive values according to the subtracted results were defined as shortening and lengthening, respectively. To evaluate the angular orientation of the scapula between the fractured and unfractured sides, we set the scapula plane and body reference plane (sagittal, coronal, and axial planes). Three points (superior pole, inferior pole, and center of glenoid) were used to represent the scapular plane in space. For the reference plane, the sagittal plane was first created by connecting 3 points (the most posterior endpoint of the T4 vertebra spinous process, the posterior endpoint of the C7 vertebra spinous process, the midpoint of the anterior border of the C7 vertebral body) and coronal and axial planes orthogonal to the sagittal plane were constructed using the same method (Fig. 3).

The angle between the scapular plane and the body reference plane was calculated to determine the angular orientation of the scapular plane. Three angles were used to represent the angular orientation of the scapular plane. Angle 1 was defined as the degree of anterior/posterior tilting of the scapular plane with respect to the coronal plane, angle 2 was defined as the degree of external/internal rotation of the scapular plane with respect to the coronal plane, and angle 3 was defined as the degree of upward/downward rotation of the scapular plane with respect to the sagittal plane. We subtracted each angular orientation of the fractured side scapula

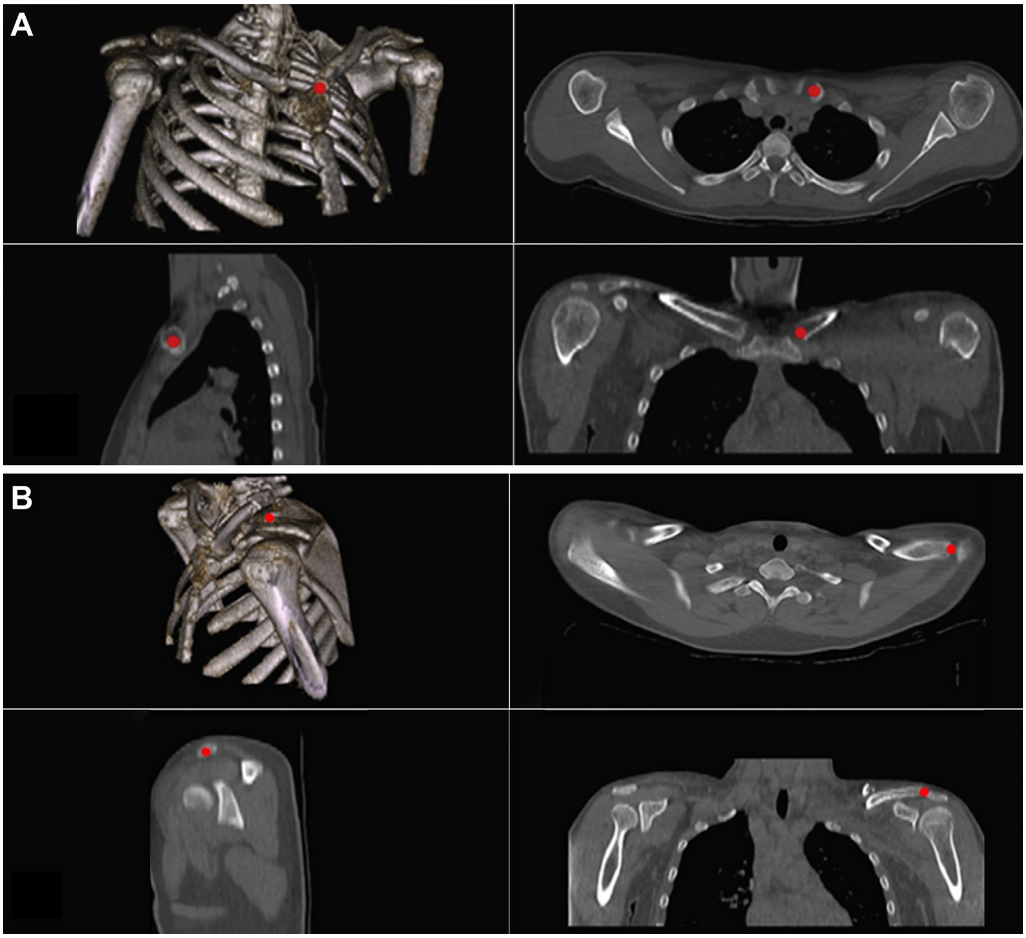

Figure 1 Registration of reference points. When setting the reference point in 3-dimensional space, the exact position was confirmed in the 2-dimensional sagittal, coronal, and axial plane. (**A**) Reference point of center of the sternal surface and (**B**) reference point of center of the acromial surface.

from those of the unfractured scapula to determine the difference in the angular orientation of both scapulae. Two orthopedic surgeons specializing in the shoulder took the measurements twice at 2-week intervals to confirm interobserver and intraobserver reliability. A positive value in the calculation means more anterior tilting, internal rotation, and upward rotation than the other side of the scapula relatively (Fig. 4). The analyses focused on the incidence of shortening and lengthening of each 3D directional component, relationship between clavicle distance in 3D and each direction (AP, ML, and SI), correlation of the difference in the angular orientation of the scapula according to the difference in clavicle distance, and comparison of the angular orientation of the scapula according to shortening and lengthening of the ML and AP components.

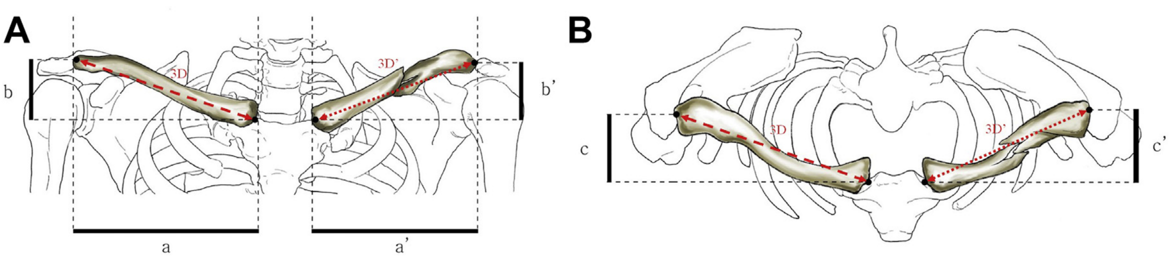

Figure 2 Schematic image of measuring each component; medial-to-lateral (ML) distance, anterior-to-posterior (AP) distance, superior-to-inferior (SI) distance, and 3-dimensional (3D) distance of both clavicles. (**A**) Anterior view of both clavicles; (**B**) superior view of both clavicles. *a*, ML distance of the unfractured clavicle; *b*, SI distance of the unfractured clavicle; *c*, AP distance of the unfractured clavicle; *3D*, 3D distance of the unfractured clavicle; *a'*, ML distance of the fractured clavicle; *b'*, SI distance of the fractured clavicle; *c'*, AP distance of the fractured clavicle; *3D'*, 3D distance of the fractured clavicle.

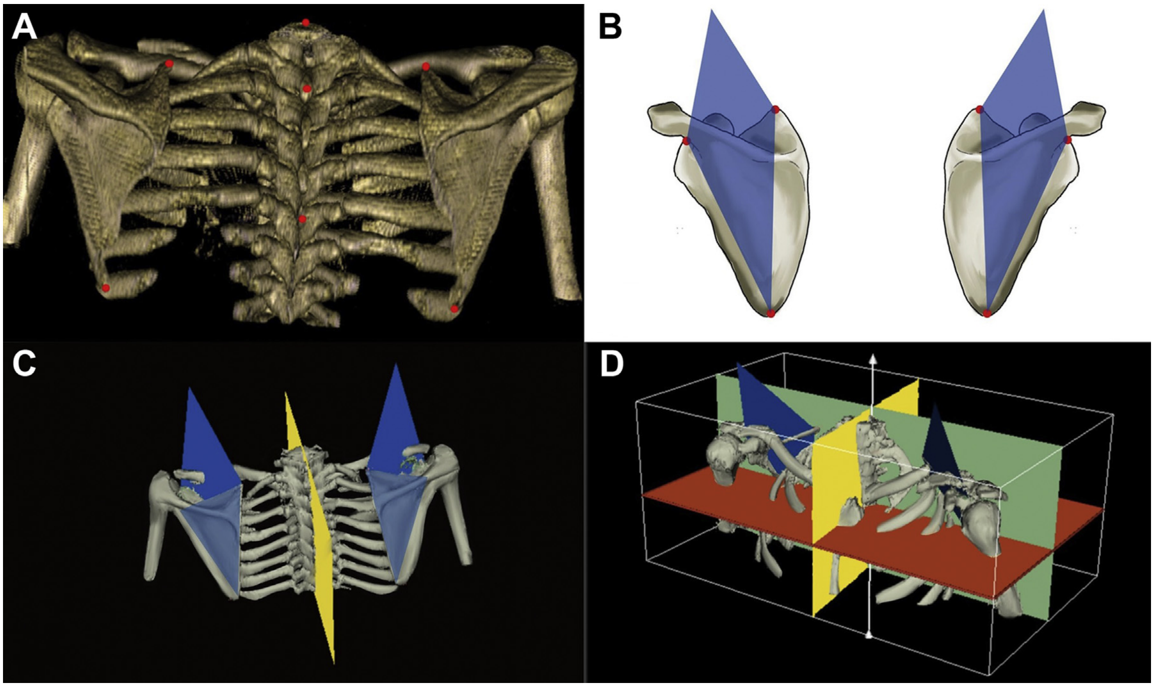

Figure 3 Setting of the scapula plane and body reference plane. (**A**) Registration of reference points of the scapula and vertebral spine. Register 3 points (superior pole, inferior pole, center of glenoid) of the scapula and 3 points (the most posterior end point of the T4 vertebra spinous process, the posterior end point of the C7 vertebra spinous process, the midpoint of the anterior border of the C7 vertebral body) of the vertebrae. (**B**) Schematic image of the scapular plane. (**C**) Both scapular and body sagittal planes were set. (**D**) Coronal and axial body planes orthogonal to the body sagittal plane were set. Blue plane, scapular plane; yellow plane, sagittal body plane; green plane, coronal body plane; red plane, axial body plane.

Statistical analysis

Statistical analysis was performed using SPSS ver. 24.0 (IBM Co., Armonk, NY, USA). Analysis of variance was used to analyze the difference in demographic factors between the groups. Student's *t*-test was used for continuous variables and the Mann-Whitney *U* test for nonnormal distributions. Categorical variables were tested by the χ^2 test or the Fisher exact test. Postanalysis was performed using the Bonferroni test. The reliability of the measurements of the radiologic parameters was expressed as an intraclass correlation coefficient (ICC). The ICCs for intraobserver reliability for all measurements were 0.84 and 0.89. In addition, the ICCs for the interobserver reliability were 0.81 and 0.84. All tests were analyzed with a 95% confidence level. The level of significance was set at 0.05.

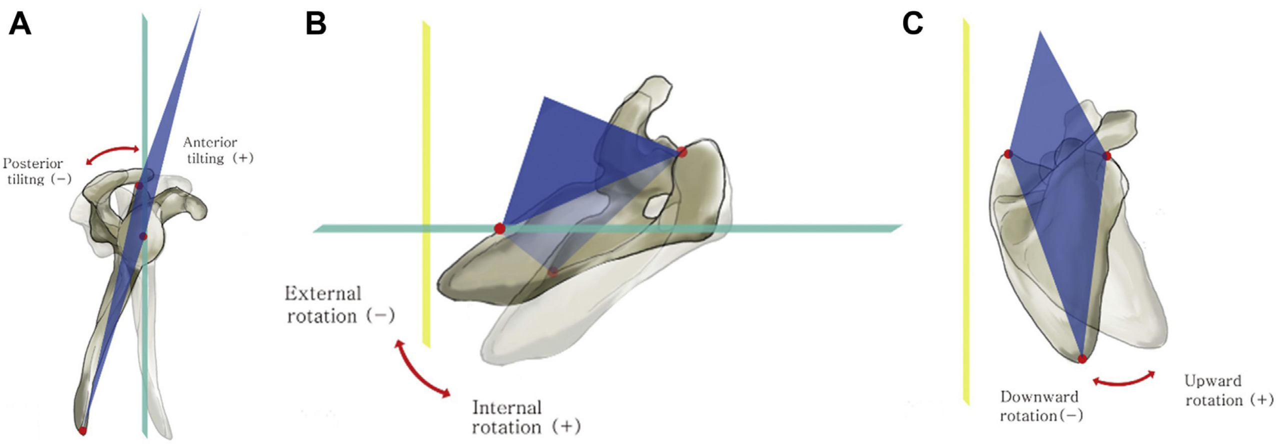

Figure 4 Angular orientation of the scapula. (**A**) Anterior or posterior tilting of the scapula. (**B**) External or internal rotation of the scapula. (**C**) Downward or upward rotation of the scapula. Blue plane, scapular plane; yellow plane, sagittal body plane; green plane, coronal body plane.

Results

Incidence of shortening and lengthening of each 3D directional component

With regard to group comparison according to each directional difference in distance, 19 cases (43.2%) of AP shortening developed in the ML shortening group and 25 cases (56.8%) of AP lengthening developed in the ML shortening group. Moreover, 29 cases (65.9%) of SI shortening developed in the ML shortening group and 15 cases (34.1%) of SI lengthening developed in the ML shortening group. A total of 17 cases (73.9%) of AP shortening developed in the ML lengthening group and 6 cases (26.1%) of AP lengthening developed in the ML lengthening group. Nineteen cases (82.6%) of SI shortening developed in the ML lengthening group and 4 cases (17.4%) of SI lengthening developed in the ML lengthening group. Twenty-eight cases (78%) of SI shortening developed in the AP shortening group and 8 cases (23%) of SI lengthening developed in the AP shortening group. Twenty cases (65%) of SI shortening developed in the AP lengthening group and 11 cases (35%) of SI lengthening developed in the AP lengthening group (Fig. 5).

The mean 3D distance of the fractured and unfractured clavicles and the mean value that was measured by calculating the true straight line distance between 2 points (center of the sternal surface and center of the acromial surface of clavicle) in 3D space were 144 ± 13.4 mm and 150 ± 12.5 mm, respectively. The fractured clavicle showed a mean shortening of 6 ± 8.3 mm in 3D distance relative to the unfractured side. The difference in 3D distance was positively related to the difference in the ML, AP, and SI distance. Pearson correlation coefficients were 0.401, 0.465, and 0.331 ($P = .001$, $P < .001$, and $P = .006$), respectively.

With regard to the relation of each component's difference in distance, the difference in ML distance showed a statistically significant and moderate negative relation with the difference in SI distance (Pearson correlation coefficient 0.527, $P < .001$); otherwise, minimal and no relation with any other directional component difference was found (Table II).

Correlation of the difference in the angular orientation of the scapula according to the difference in clavicle distance

The correlation analysis between the difference in angular orientation of the scapula and the difference in the clavicle distance between the fractured and contralateral sides is shown in Table III. The difference in AP distance showed a moderate negative relation with anterior tilting (−0.684, $P < .001$) (Fig. 6).

Among ML shortening patients, the AP shortening group showed a higher anterior tilting difference than the AP lengthening group (9° ± 1.4°, −1° ± 5.9°), and this difference was statistically significant. Among ML lengthening patients, the AP shortening group showed a higher anterior tilting difference than the AP lengthening

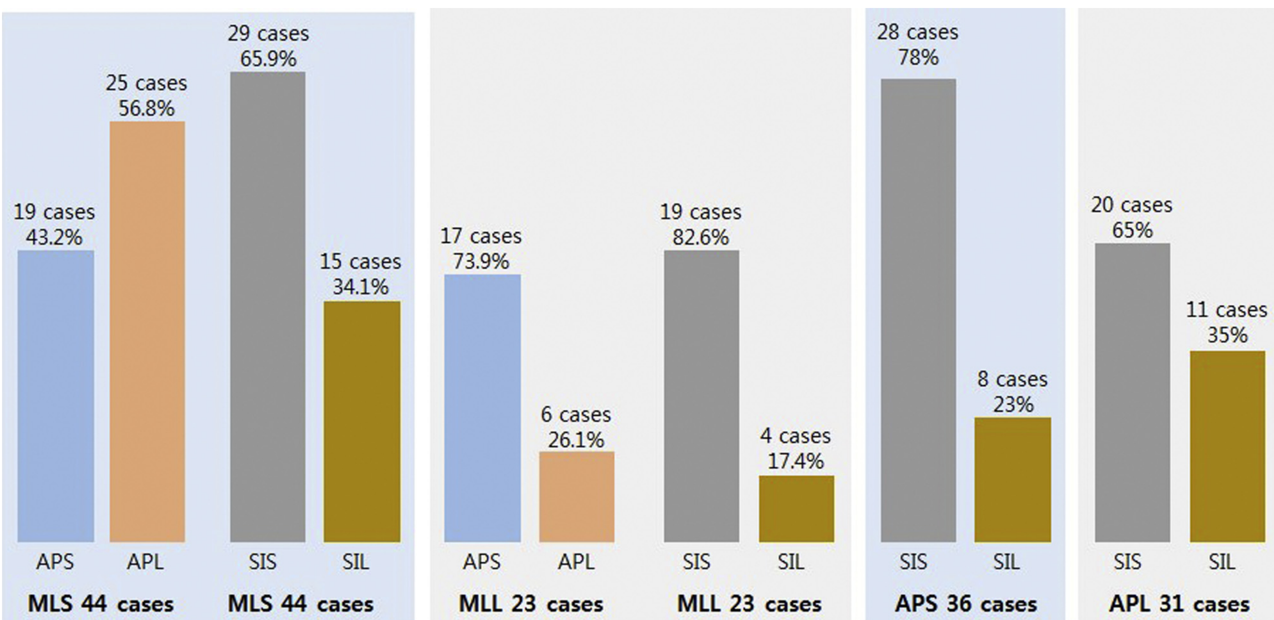

Figure 5 Vertical bar graph showing incidence of shortening and lengthening of each 3-dimensional directional component. *MLS*, medial-to-lateral directional shortening; *MLL*, medial-to-lateral directional lengthening; *APS*, anterior-to-posterior directional shortening; *APL*, anterior-to-posterior directional lengthening; *SIS*, superior-to-inferior directional shortening; *SIL*, superior-to-inferior directional lengthening.

Table II Relation of distance of clavicle in 3D and each direction (AP, ML, and SI)

	Δ3D distance	ΔML distance	ΔAP distance	ΔSI distance	ΔMean distance
Δ3D distance	1				−6 ± 8.3
ΔML distance	0.401**	1			−5 ± 10.5
ΔAP distance	0.465**	−0.312*	1		0 ± 18.4
ΔSI distance	0.331*	−0.527**	0.24	1	−7 ± 16.3

3D, 3-dimensional; *AP*, anterior-to-posterior; *ML*, medial-to-lateral; *SI*, superior-to-inferior.
Δ directional distance: value obtained by subtracting the distance of the unfractured clavicle from the distance from the fractured clavicle.
* $P < .05$.
** $P < .001$.

group (5° ± 5.0°, −3° ± 4.6°), and this difference was statistically significant. Among the ML shortening patients, the AP shortening group showed a higher internal rotation difference than the AP lengthening group (6° ± 0.7°, −2° ± 6.1°), and this difference was statistically significant. Among ML lengthening patients, the AP shortening group showed a higher internal rotation difference than the AP lengthening group (5° ± 9.6°, 1° ± 10.4°), but this difference was not statistically significant. Among ML shortening patients, the AP shortening group showed a higher upward rotation difference than the AP lengthening group (6° ± 4.9°, −3° ± 10.5°), and among ML lengthening patients, the AP shortening group showed a higher internal rotation difference than the AP lengthening group (6° ± 11.4°, 1° ± 12.7°), but these differences were not statistically significant (Fig. 7).

Discussion

This study evaluated the relationship between the length difference of the clavicle and angular rotation of the scapula and defined which directional component of the length difference affects the scapula. When we look at the relationship between the differences of the clavicle length in 3D space: difference of the 3D distance between fractured and unfractured side and its directional elements (AP, ML, and SI), the length difference in the 3D space was related to each directional component of length difference: AP, ML, and SI. However, each component of the length difference was not related to one another. In addition, in 44 ML shortening cases, AP shortening occurred in 19 cases and AP lengthening occurred in 25 cases. This finding means that shortening in AP, ML, and SI directions occurs independently regardless of fractures and implies that distal fragments were not displaced in a uniform pattern. Moreover, Oki et al,[9] in their study of 3D deformities of nonoperative clavicle fracture by surface matching analysis, reported that the distal fragment could angulate upwardly or downwardly in the coronal plane and anteriorly or posteriorly in the axial plane, depending on the fracture pattern. Considering our results that each directional shortening does not always mean one directional shortening, we raised the question: which directional shortening affects the static angular orientation of the scapula more than any other? The distal clavicle is connected with the scapular acromion by the acromioclavicular joint, and distal clavicle displacement after clavicle fracture may change the orientation of the scapula. Previous studies showed that as the clavicle became shorter in the shortening model, the internal rotation and anterior tilting of the scapula increased.[4,11] More internally rotated position of the scapula can be developed in clavicle fracture because although the medial border of the scapula is retained posteriorly by holding the rib cage, the lateral side of the scapula is forced inside through the acromioclavicular joint when the clavicle is shortened.[5] In addition, increased anterior tilting of the scapula can be developed when the shortening clavicle could also pull the upper portion of

Table III Correlation of the difference of the angular orientation of the scapula according to the difference of the clavicle distance

	Δ3D distance	ΔML distance	ΔAP distance	ΔSI distance	Mean angle difference
Angle 1 difference	−0.338**	0.180	−0.684**	−0.151	0 ± 6.3
Angle 2 difference	−0.079	0.121	−0.242*	−0.078	2 ± 9.1
Angle 3 difference	−0.011	0.180	−0.282*	0.021	2 ± 11.8

3D, 3-dimensional; *ML*, medial-to-lateral; *AP*, anterior-to-posterior; *SI*, superior-to-inferior.
Δ directional distance: value obtained by subtracting the distance of the unfractured clavicle from the distance from the fractured clavicle; Angle 1, degree of anterior or posterior tilt; Angle 2, degree of internal or external rotation; Angle 3, degree of downward or upward rotation.
* $P < .05$.
** $P < .01$.

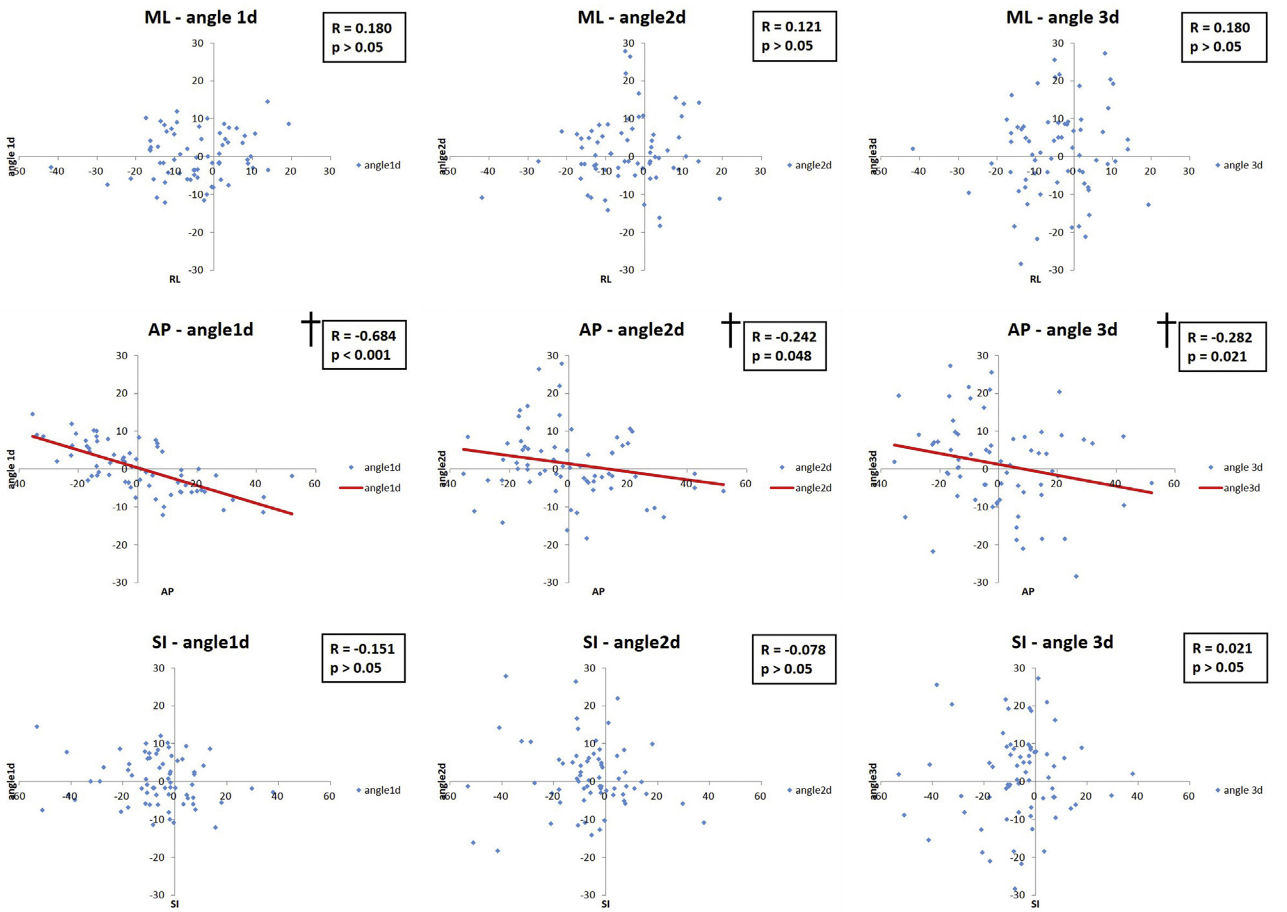

Figure 6 Scatter plot of the difference of angular orientation of the scapula according to the difference of clavicle distance. (**A-C**) Difference of angular orientation of the scapula according to the difference of medial-to-lateral (ML) distance. (**D-F**) Difference of angular orientation of the scapula according to the difference of anterior-to-posterior (AP) distance. (**G-I**) Difference of angular orientation of the scapula according to the difference of superior-to-inferior (SI) distance.

the scapula more anteriorly, while the chest wall restricts the movement of the inferior part of the scapula.[5]

In the present study, the difference in length in 3D between the fractured and unfractured clavicles showed a negative relation with the anterior tilting difference. This means that the more the difference, the greater the shortening, and more anterior tilting of the scapula of the fractured side occurs compared with the unfractured side.

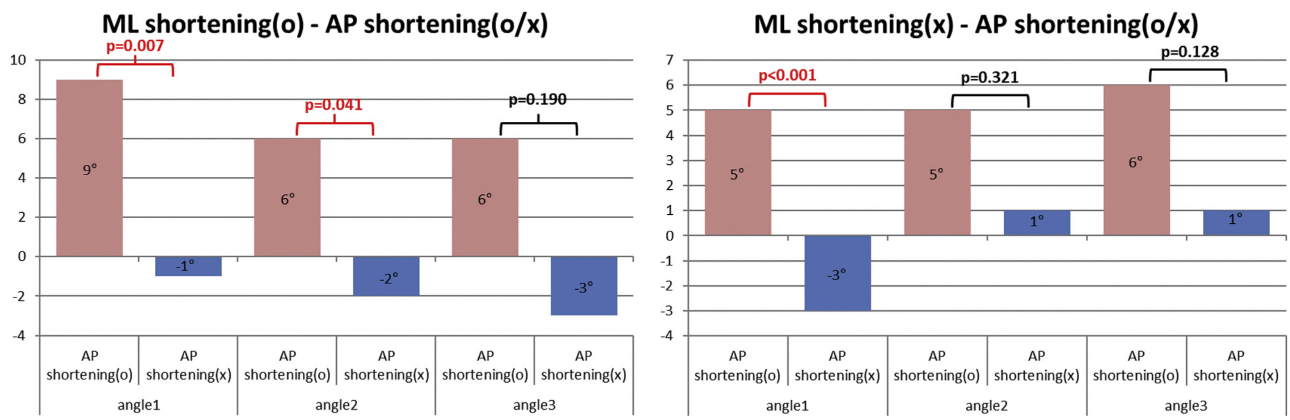

Figure 7 Vertical bar graph shows the comparison of the angular orientation of the scapula according to shortening and lengthening of the medial-to-lateral (ML) and anterior-to-posterior (AP) components.

However, the positional change of the distal fragment that is related to the orientation of the scapula may not be represented by the difference in length in the 3D space. Therefore, we decomposed the difference in 3D clavicle length into 3 directional length differences and evaluated the relationship of each component of length difference with the angular orientation of the scapula. In our result, the AP directional length difference showed a statistically significant relationship with anterior tilting, internal rotation, and upward rotation of the scapula. Especially, anterior tilting showed a moderate negative correlation with the AP directional length difference between the fractured and opposite clavicles. This means that with a more negative value, that is, as the AP directional length of the fractured clavicle decreases, more anterior tilting of the fractured side of the scapula occurs. However, other directional length differences did not show any correlation with the angular orientation of the scapula.

To evaluate the importance of the AP directional difference in clavicle length, we compared the difference in the angular orientation of the scapula in each group by setting shortening and lengthening cases in AP and ML directions as variables, respectively. In ML shortening patients, the anterior tilting difference was 9° (standard deviation [SD]: 1.4) in the AP shortening group and −1° (SD: 5.9) in the AP lengthening patient ($P = .007$). Among ML lengthening patients, the anterior tilting difference was 5° (SD: 5.0) in the AP shortening group and −3° (SD: 4.7) in the AP lengthening group, showing a statistically significant difference ($P < .001$). An interesting finding is that regardless of the ML length difference, the AP length difference showed a significant difference in anterior tilting ($P < .01$); The ML length difference did not affect the static angular orientation of the scapula more than the AP length difference. Oki et al[9] suggested that the distal fragment usually rotated anteriorly because of its anatomical relationship in midshaft clavicle fracture, and clavicular shortening is not the only factor related to the severity of displacement. Our finding also implied that shortening is not an independent risk factor associated with static scapular malposition. We believe that 3D deformity such as angular deformity might be more related to the static angular orientation of the scapula, and the change in the AP length of the clavicle may play an important role in angular deformity that leads to scapular malposition as well as 3D clavicular shortening.

Study limitations

This study had several limitations. First, the CT image was obtained with patients in the supine position and both arms on their trunk. Because this position relaxes the musculature of the shoulder girdle and may minimize the shortening deformity, this supine position may not have the same effects as the sitting position on the clavicle, and subtle changes in position due to pain could cause bias. Second, we cannot suggest whether the static angular orientation of the scapula causes the displacement of the distal fragment or result from the displacement. Third, this study is a retrospective case study. Therefore, CT images could not be taken in clavicle fracture patients in sitting position and determine the difference in AP length difference which significantly affected the degree of anterior tilting compared with ML length. This limitation can affect bias and our result should be interpreted with caution. Fourth, we evaluated only the static angular rotation of the scapula. Clavicle malunion is reported to be related to scapular motion and the change in dynamic scapular kinematics. Therefore, a further study on scapular kinematics with regard to the components of length difference should be considered. Fifth, the present study did not evaluate the relationship between the 3D deformity, such as angular deformity of the clavicle, and angular orientation of the scapula. However, angular deformity is difficult to quantify. Therefore, we tried to use the component of distant differences and thought that using distance is more objective and reproducible. Finally, we did not evaluate the clinical outcome according to scapular rotation; thus, whether this difference may affect the clinical outcome is not concluded in this study.

The strength of this study is that we reconstructed a CT image and compared the length differences between the fractured and unfractured clavicles in terms of 3D distances, and by decomposing the 3D distance into each directional component (AP, ML, and SI), we were able to compare each element. In addition, we quantified the static orientation of the scapula with reference to body plane (sagittal, coronal, and axial planes). To the best of the authors' knowledge, this study is the first to analyze each directional component of length difference of both clavicles in the setting of acute clavicle injury and demonstrate which component of length difference affects the angular rotation of the scapula more than any other component.

Conclusion

Our study showed that AP shortening is not correlated with ML shortening and AP shortening is correlated with the static angular orientation of the scapula. These findings imply that evaluating clavicular shortening in 2D methods such as X-ray imaging represents ML shortening, not AP shortening. This might cause bias in determining the angular orientation of the scapula. Therefore, when determining the treatment of clavicle fracture, it may be necessary to consider AP shortening. In addition, research on AP shortening and the relationship between malunion and scapular dyskinesis should be considered.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Archer LA, Hunt S, Squire D, Moores C, Stone C, O'Dea F, et al. Plain film measurement error in acute displaced midshaft clavicle fractures. Can J Surg 2016;59:311-6. https://doi.org/10.1503/cjs.003016
2. De Giorgi S, Notarnicola A, Tafuri S, Solarino G, Moretti L, Moretti B. Conservative treatment of fractures of the clavicle. BMC Res Notes 2011;4:333. https://doi.org/10.1186/1756-0500-4-333
3. de Lima Figueiredo GS, Tamaoki MJS, Dragone D, Utino AY, Netto NA, Matsumoto MH, et al. Correlation of the degree of clavicle shortening after non-surgical treatment of midshaft fractures with upper limb function. BMC Musculoskelet Disord 2015;16:151. https://doi.org/10.1186/s12891-015-0585-3
4. Hillen RJ, Bolsterlee B, Veeger DHEJ. The biomechanical effect of clavicular shortening on shoulder muscle function, a simulation study. Clin Biomech (Bristol, Avon) 2016;37:141-6. https://doi.org/10.1016/j.clinbiomech.2016.07.005
5. Hillen RJ, Burger BJ, Pöll RG, van Dijk CN, Veeger DH. The effect of experimental shortening of the clavicle on shoulder kinematics. Clin Biomech (Bristol, Avon) 2012;27:777-81. https://doi.org/10.1016/j.clinbiomech.2012.05.003
6. Kihlström C, Möller M, Lönn K, Wolf O. Clavicle fractures: epidemiology, classification and treatment of 2 422 fractures in the Swedish Fracture Register; an observational study. BMC Musculoskelet Disord 2017;18:82. https://doi.org/10.1186/s12891-017-1444-1
7. Matsumura N, Ikegami H, Nakamichi N, Nakamura T, Nagura T, Imanishi N, et al. Effect of shortening deformity of the clavicle on scapular kinematics: a cadaveric study. Am J Sports Med 2010;38:1000-6. https://doi.org/10.1177/0363546509355143
8. Nordqvist A, Petersson C. The incidence of fractures of the clavicle. Clin Orthop Relat Res 1994;300:127-32.
9. Oki S, Matsumura N, Kiriyama Y, Iwamoto T, Sato K, Nagura T. Three-dimensional deformities of nonoperative midshaft clavicle fractures: a surface matching analysis. J Orthop Trauma 2017;31:e385-9. https://doi.org/10.1097/BOT.0000000000000931
10. 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. https://doi.org/10.4055/cios.2016.8.4.367
11. Patel B, Gustafson PA, Jastifer J. The effect of clavicle malunion on shoulder biomechanics; a computational study. Clin Biomech (Bristol, Avon) 2012;27:436-42. https://doi.org/10.1016/j.clinbiomech.2011.12.006
12. Postacchini F, Gumina S, De Santis P, Albo F. Epidemiology of clavicle fractures. J Shoulder Elbow Surg 2002;11:452-6. https://doi.org/10.1067/mse.2002.126613
13. Stegeman SA, de Witte PB, Boonstra S, de Groot JH, Nagels J, Krijnen P, et al. Measurement of clavicular length and shortening after a midshaft clavicular fracture: Spatial digitization versus planar roentgen photogrammetry. J Electromyogr Kinesiol 2016;29:74-80. https://doi.org/10.1016/j.jelekin.2015.07.007
14. 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 2014;36:573-7. https://doi.org/10.1007/s00276-013-1225-y