Influence of Tilt and Rotation on Coracoclavicular Distance Measurements and Rockwood Classification in Panorama View Radiographs in the Diagnosis of Acromioclavicular Dislocations

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Background: The severity of acromioclavicular (AC) joint dislocation is evaluated through bilateral anterior-posterior radiographs of the AC joint. AC joint dislocations are graded based on the classification system of Rockwood, which is the foundation for further decision-making regarding therapy regimen.

Purpose/Hypothesis: The purpose of this study was to simulate technical irregularities in obtaining panoramic views and the effect they might have on the measured coracoclavicular (CC) distance. It was hypothesized that vertical tilt and horizontal rotation of the radiographic panoramic view of the AC joints affect the measured CC distance and, therefore, the Rockwood classification and reliability of the measurement method.

Study Design: Level IV, Diagnosis Study, Case Series.

Methods: A retrospective analysis including 14 patients with AC joint dislocations and available computed tomography scans of the upper body was conducted. Three-dimensional models of a simulated bilateral panoramic view were tilted and rotated from −15° to 15° in 5° increments around the vertical and horizontal axes. Three raters with different experience levels independently measured the CC distance and repeated this process with a minimum 6-week interval. The intra- and interclass correlation coefficients for intra- and interrater reliability were calculated. Changes in CC distance and Rockwood classification due to rotation or tilt were reported.

Results: The measurements of intra- and interclass correlation coefficients in the neutral (0° position) showed a high intra- and interrater reliability (0.878 and 0.952 for intrarater reliability; 0.851 and 0.952 for interrater reliability). By adding vertical tilt and horizontal rotation to simulated panoramic views, the intra- and interreliability of the 3 raters decreased. Vertical tilt showed a higher impact on the measurement reliability than horizontal rotation. In 10 of 14 cases, the initially determined Rockwood classification changed through adding tilt (9/14) or rotation (5/14). In 5 cases, the injury was graded more severe. In 3 cases, the classification was changed to a milder grade according to Rockwood. In 2 cases, the injury was changed to a higher or a lower type in the Rockwood classification, respectively, depending on the amount of tilt or rotation. Of the 10 cases that were reclassified by tilt and rotation, 5 were Rockwood type 3 injuries.

Conclusion: Vertical tilt and horizontal rotation in simulated panoramic views of the AC joints were demonstrated to have a significant influence on CC distances and Rockwood classification as well as intra- and interrater reliability. This effect was more pronounced with a higher degree of tilt/rotation. This may affect clinical decision-making, whether to treat this injury nonoperatively or operatively.

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Clinical Relevance: The panoramic view is widely used as the gold standard for diagnosing and classifying AC joint dislocations according to Rockwood. Thus, it is a decisive criterion to choose the best treatment. This study investigates the reliability of the radiographic diagnosis of AC joint dislocations when adding tilt and rotation, which may occur in clinical practice while obtaining the panoramic view.

Keywords: AC joint separation; AC joint dislocation; Rockwood classification; bilateral radiographs; panoramic view

Acromioclavicular (AC) joint injuries often occur in contact sports, such as rugby, football, or martial arts, and account for up to 9% of all shoulder girdle injuries.[13] The initial diagnosis relies on clinical and radiographic findings.

Radiographs are typically the first and only imaging modality used for suspected AC joint injury.[7,16] For the correct evaluation of AC joint dislocations, various kinds of radiographs can be used.[14] The AC joint is seen on standard anterior-posterior (AP) shoulder radiographs, where it might be variably angulated and overpenetrated.[24] A plain AP radiograph at 10° to 15° of angulation, the so-called Zanca view, allows projection of the AC joint itself.[26] The Zanca projection reduces overlap of the scapula and the clavicle, enabling a better assessment of the AC joint as well as reducing radiation dose.[1,7] To evaluate vertical instability, bilateral AP stress views, as opposed to single AP radiographs of the joint, are recommended.[8] Lateral Alexander views, with the arm in an adducted horizontal stress position, or axial shoulder views are used to evaluate horizontal instability.[7]

In 1984, Rockwood described a 6-type classification system of AC joint injuries, which is based on the bilateral radiographic view of the AC joints. A bilateral view of the AC joints enables a comparison of coracoclavicular (CC) distance from the injured to noninjured side. The measured CC distance of the injured site increases with the severity of the injury, ranging from type 1 (no radiographic abnormality) to type 5 (100%-300% superior displacement of clavicle) and type 6 (subacromial/subcoracoid displacement of the clavicle). The radiographic classification of Rockwood was based on unweighted AP views of the AC joint, although the use of stress views was suggested as a possibility to better differentiate lower-graded AC joint dislocations.[18]

Consensus exists that type 1 and 2 injuries are treated nonoperatively, whereas type 4 through 6 injuries are more likely to be treated operatively. The management of type 3 injuries remains controversial, with some authors considering surgical treatment, while others advise against it.[5,22]

The Rockwood classification combined with the clinical examination constitutes the basis of therapeutic decisions for AC joint dislocations.[3,9,23] Therefore, it is crucial to ensure the reliability of the classification system. Misinterpretation of radiographs due to technical shortcomings, such as adding rotation or tilt when obtaining panoramic views, may lead to misdiagnosis and inadequate therapy. Various studies have shown different outcomes in intra- and interrater reliability of the Rockwood classification system.[6,11,16,17,21]

So far, the influence of tilt and rotation in panoramic views on CC distance is unknown. Therefore, this study aimed to investigate intra- and interrater reliability, changes in CC distance measurements, and Rockwood classification by simulating panoramic views with different view angles (rotated and tilted). The purpose was to simulate technical irregularities in acquiring panoramic views and the effect they might have on the measured CC distance.

We hypothesized that vertical tilt and horizontal rotation of the radiographic panoramic view of the AC joints affect the measured CC distance and, therefore, the Rockwood classification and reliability of the measurement method.

METHODS

Before the study, approval of the local ethical committee was obtained (EA1/258/22).

A retrospective analysis of patients diagnosed with a chronic or acute unilateral AC joint dislocation was performed. Computed tomography (CT) scans were obtained

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Ethical approval for this study was obtained from Charité-Universitätsmedizin Berlin (EA1/258/22).

Figure 1. Three-dimensional computed tomography bilateral views of the acromioclavicular joints with different degrees of horizontal rotation. Injured side: left.

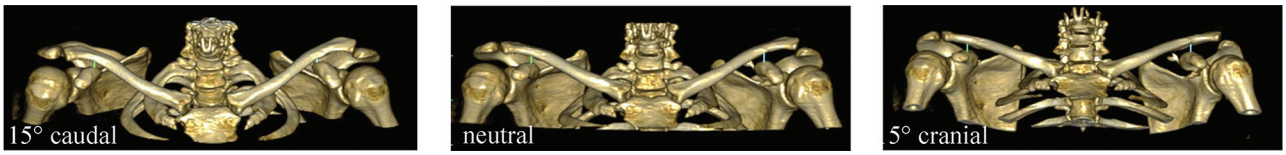

Figure 2. Three-dimensional computed tomography bilateral views of the acromioclavicular joints with different degrees of vertical tilt. Injured side: left.

by screening the database of our university hospital for patients with AC joint dislocations who had undergone a CT scan of the upper body, viewing both shoulders. Eighteen CT scans between April 2012 and October 2020 were collected. Some of the included CT examinations were part of full-body CT scans that were initially performed on polytraumatized patients. The remaining CT scans included were obtained in patients with chronic AC joint dislocation to obtain more information about bone structure and joint characteristics. Inclusion requirements were patients with an acute or chronic AC joint dislocation who had undergone a bilateral CT scan of both shoulders. Patients with additional injuries to the shoulder influencing the CC distance were excluded, as well as patients with AC joint arthrosis greater than Kellgren and Lawrence type 2. Fourteen patients met the inclusion criteria. The CT scans were exported to DICOM (Digital Imaging and Communications in Medicine) files with a slice thickness of 0.625 mm using the image viewing software Visage (Visage Imaging). The exported CT data sets were then used to create 3-dimensional (3D) panoramic views of both AC joints using the image processing software OsirX (Version 12.5.2; Pixmeo SARL).

Measurements and ratings were performed by 3 independent raters, 1 current shoulder fellow with 5 years of experience, 1 resident in their third year of trauma and orthopaedic surgery, and 1 advanced medical student (K.K., S.F., A.P.).

Imaging and Measurement Methods

Three-dimensional models were created using the bilateral CT scans of the shoulders. All 3 raters independently chose the image best resembling a panoramic bilateral radiograph. As proposed by the International Society of Biomechanics, the seventh cervical vertebra, sternal notch, and xiphoid process were used as thoracic landmarks.[25] A clear projection of the sternoclavicular joint and the AC joint, the 2 bony landmarks of the clavicle, was important in the choice of the neutral position. In the case of diverging individual choices, a consensus was found after a joint discussion. The collectively chosen image was used as a starting point (neutral position).

Using these starting images, each rater performed tilting and rotating. The starting images, which represented the bilateral AP view of the AC joint, were rotated in 5° increments horizontally left and right. For every image, the CC distance was measured and documented. The bilateral panoramic views were then tilted vertically in 5° increments. Again, CC distance was measured bilaterally for each image (Figures 1 and 2). Overall, 196 images were obtained. Although injured left shoulders were included, everything was documented for an injured right shoulder. In horizontal rotation, rotating toward the injured AC joint was documented as positive rotation, whereas rotating toward the healthy side was documented as negative rotation. All measurements were independently completed by the 3 raters using the image processing software Osirix (Version 12.5.2; Pixmeo SARL). The raters were not blinded to the amount of tilt and rotation. The CC distances for both sides were measured and documented for each of the 196 images. The CC distance was measured from the superior point of the coracoid process to the shaft of the clavicle (inferior cortex), using the 3D CT model. Tilting vertically occasionally led to a crossover of the coracoid process and the clavicle, resulting in a nonmeasurable CC distance. In those cases, the value 0 was noted.

The 3 raters completed the measurements independently. The second rating of each image was repeated a minimum of 6 weeks after the first measurements by all raters.

Statistical Analysis

Continuous variables were tested for normal distribution using the Shapiro-Wilk test and each variable's histogram

and Q-Q plot. They are reported as mean (SD). Nominal data are presented as number (percent).

All analyses were conducted using R (R Foundation for Statistical Computing) and the packages *lme4*, *lmerTest*, and *MuMIn*.[2,10,15] Intraclass correlation coefficients (ICC) and interclass correlation coefficients were calculated as estimates of reliability by investigating the variance components that raters, tilt/rotation, and patients accounted for in a linear mixed model predicting the ratio of the distance measurements between the 2 shoulders. To be able to test the various conditions for differences in intra- and interclass correlation coefficients, 500 random samples were bootstrapped and the variance of each condition was obtained. Values <0.5 indicate poor reliability, 0.5 to 0.75 represents fair reliability, >0.75 to 0.9 indicates good reliability, and values >0.9 represent excellent reliability.[16] In case of a significant main effect tilt/rotation within the linear mixed model, dependent *t* tests were conducted to test for differences between 0° and all other tilts and rotations.

In the second part of the analysis, we analyzed the actual ratios of the overall CC distances for the healthy compared with the injured side. For this, overall CC distances were first averaged across repetitions (week 1 and week 6) and raters (1-3). The relative ratio was then obtained by the following formula for each tilt/rotation:

$$\textit{Relative difference of overall CC distance} = (\textit{overall CC distance of the healthy side} / \textit{overall CC distance of the injured side}) * 100 - 100.$$

Therefore, relative increases of the overall CC distance of the injured compared with healthy side could be reported as a percent for each condition. Next, a repeated-measures analysis of variance (ANOVA) with the main effect tilt/rotation was used to analyze the relative overall CC distances across conditions. In case of a significant main effect, dependent *t* tests were conducted to compare conditions.

Finally, we investigated the Rockwood types that would be assigned based on the ratios obtained in the various conditions. The Rockwood types were calculated for each image with added tilt and rotation. Changes (increases and decreases) in Rockwood types were determined. Because of the complex statistical structure, changes in Rockwood classification were reported only in a descriptive manner (absolute number of changes in Rockwood classification for each direction).

Within the linear mixed model ANOVA, R^2 was reported as an effect size, displaying the amount of variance explained by the main effect tilt/rotation. For the repeated-measures ANOVA, the partial Eta^2 was reported as an effect size, with 0.01 indicating a small effect, 0.06 a moderate effect, and 0.14 a strong effect. For post hoc comparisons, the effect size Cohen *d* was calculated, with 0.3 representing a small effect, 0.5 a moderate effect, and 0.8 a strong effect.

RESULTS

Fourteen patients were included in the study, 11 men and 3 women. There were 7 left and 7 right shoulders with AC joint injuries of various severity based on measurements of the neutral view. One (7.1%) patient had a Rockwood type 1 injury, 2 (14.3%) patients a Rockwood type 2 injury, 6 (42.9%) patients a Rockwood type 3 injury, and 5 (35.7%) patients a Rockwood type 5 injury. None of the patients meeting inclusion criteria had a Rockwood type 4 or 6 injury. Four (28.6%) of the cases were classified as chronic and 10 (71.4%) as acute injuries, based on patient history.

Intrarater Reliability (ICCs)

Intrarater reliability was good to excellent for every degree of horizontal rotation. At 0° of tilt and rotation, the ICCs were high, indicating a good to excellent intrarater reliability. Horizontal rotation did have a significant main effect on intrarater reliability ($F_{(6,493)}$ = 11.69; $P < .001$; R^2 = 0.125), with 0° showing a significantly higher intrarater reliability compared with −15° ($P < .001$; $d = -0.264$), and a significantly lower intrarater reliability compared with any other rotation ($P < .001$; $d \geq 0.188$) (see Table 1 for details).

Tilting vertically had a higher impact on intrarater reliability (main effect vertical tilt: $F_{(6,493)}$ = 87.21; $P < .001$; R^2 = 0.515). With increasing tilt, the ICCs dropped and showed a significantly lower intrarater reliability. The effect was especially visible at ±15° of tilt ($P < .001$, $d = -1.87$; $P < .001$, $d = -1.202$), whereas 10° ($P < .001$; $d = -0.349$) and 5° of tilt still showed excellent ICCs ($P = .021$; $d = -0.103$) (see Table 2 for details).

Interrater Reliability (Interclass Correlation Coefficients)

When testing for interrater reliability, the mean interclass correlation coefficients for 0° of tilt/rotation indicated a good to excellent interrater reliability. Adding horizontal rotation, from 15° to −10°, the interclass correlation coefficients for interrater reliability were good to excellent. Horizontal rotation from −15° to −5° actually improved interclass correlation coefficients compared with the neutral position. There was a notable decrease in interclass correlation coefficients with −15° of horizontal rotation (Table 3). Adding vertical tilt again showed good to excellent interclass correlation coefficients within ±10° of tilt, with the interclass correlation coefficients dropping considerably at ±15° (0.529, $P < .001$, $d = -1.953$; 0.530, $P < .001$, $d = -1.205$) (Table 4).

Overall Measurements of the CC Distances

When calculating a mean of the relative measurements of the CC distances, at 0° of tilt, the mean values were at 131% (horizontal) and 135% (vertical) (Figure 3). The high means of 131% and 135% overall emerged from high absolute CC distances in the Rockwood type 5 injuries (5/14), often exceeding 150%. For the relative overall CC

TABLE 1
ICCs for Intrarater Reliability With Added Horizontal Rotation[a]

		Statistics (Pairwise Comparison)		
Horizontal Rotation, deg	Mean ICCs for Intrarater Reliability	*P*		*d*
15	0.986	<.001		0.583
10	0.942	<.001		0.337
5	0.934	<.001		0.279
0	0.878		0° vs	
–5	0.919	<.001		0.187
–10	0.920	<.001		0.188
–15	0.787	<.001		–0.264

[a]ICC, intraclass correlation coefficient.

TABLE 2
ICCs for Intrarater Reliability With Added Vertical Tilt[a]

		Statistics (Pairwise Comparison)		
Vertical Tilt, deg	Mean ICCs for Intrarater Reliability	*P*		*d*
15	0.549	<.001		–1.870
10	0.909	<.001		–0.349
5	0.939	.021		–0.103
0	0.952		0° vs	
–5	0.925	<.001		–0.269
–10	0.941	<.001		–0.264
–15	0.574	<.001		–1.202

[a]ICC, intraclass correlation coefficient.

TABLE 3
Interclass Correlation Coefficients for Interrater Reliability With Added Horizontal Rotation

		Statistics (Pairwise Comparison)		
Horizontal Rotation, deg	Mean Interclass Correlation Coefficients for Interrater Reliability	*P*		*d*
15	0.984	<.001		0.484
10	0.889	.006		0.123
5	0.937	.001		0.304
0	0.851		0° vs	
–5	0.903	<.001		0.156
–10	0.850	.906		–0.005
–15	0.589	<.001		–0.558

distances, no significant main effect of horizontal rotation (P = .525; Eta^2_p = 0.039) and vertical tilt (P = .273; Eta^2_p = 0.122) was found within the repeated-measures ANOVA. However, we noted an increase of the CC measurements in horizontal rotation and a decrease in vertical tilt of ±15°. Detailed numbers are shown in Table 5.

Changes in Rockwood Classification

In the neutral view, there was 1 patient with a Rockwood type 1 injury, 2 patients with a Rockwood type 2 injury, 6 patients with a Rockwood type 3 injuries, and 5 patients with a Rockwood type 5 injury.

In 10 of 14 cases, the Rockwood classification changed with tilt and/or rotation during the measurements. In 5 cases, the injury was graded more severe by adding tilt and/or rotation. In 3 cases, the classification was changed to a milder grade according to the Rockwood classification. In 2 cases, both Rockwood type 2 injuries, with differing tilt and rotation, the injuries were changed to a higher type and a lower type, respectively, in the Rockwood classification. Tilting vertically led to a reclassification in 9 of 14 cases. In 5 of 14 cases, horizontal rotation caused

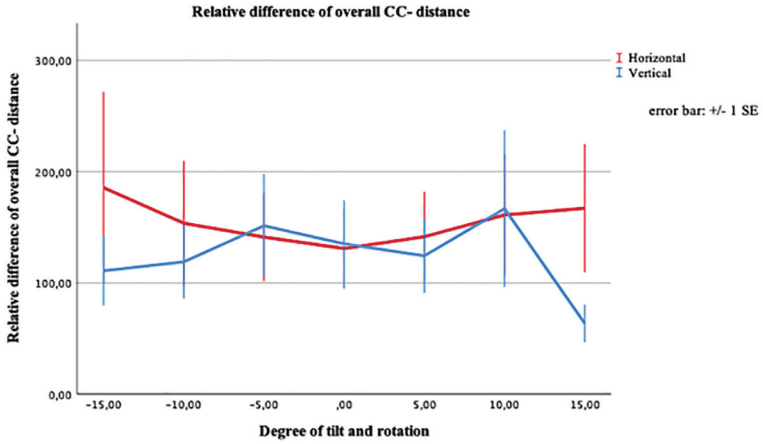

Figure 3. Percent increase of overall coracoclavicular (CC) distances with added horizontal rotation and vertical tilt. SE, standard error.

TABLE 4
Interclass Correlation Coefficients for Interrater Reliability With Added Vertical Tilt

		Statistics (Pairwise Comparison)		
Vertical Tilt, deg	Mean Interclass Correlation Coefficients for Interrater Reliability	*P*		*d*
15	0.529	<.001		–1.953
10	0.741	<.001		0.992
5	0.789	<.001		–0.689
0	0.952		0° vs	
–5	0.890	<.001		–0.331
–10	0.937	<.001		–0.311
–15	0.530	<.001		–1.205

TABLE 5
Relative Overall CC Distances for Each Rotation and Tilt[a]

	Relative Difference of CC Distances	
Horizontal Rotation and Vertical Tilt, deg	Horizontal, % (SD)	Vertical, % (SD)
15	167 (223)	64 (61)
10	161 (211)	167 (273)
5	142 (156)	124 (129)
0	131 (139	135 (151)
–5	141 (153)	151 (180)
–10	154 (217)	119 (124)
–15	186 (334)	111 (113)

[a]CC, coracoclavicular.

a reclassification of the injury. The effect was especially visible in moderate AC joint dislocations (types 2 and 3). Of the 10 cases that were reclassified by tilt and rotation, 5 were Rockwood type 3 injuries. Two type 5 injuries were reclassified to a type 3 injury. Two type 2 injuries were reclassified to a lower and a higher graded injury, respectively, by differing tilt and rotation. One Rockwood type 1 injury was reclassified to a Rockwood type 2 graded injury.

In 6 of the 10 cases, the treatment regimen would have changed, assuming that only Rockwood type 5 injuries would be treated operatively.

DISCUSSION

The main finding of this study was that technical shortcomings in acquiring panoramic views by adding rotation

and/or tilt in the diagnosis of AC joint dislocations led to an over- or underestimated injury severity in >70% of the cases. Furthermore, at higher degrees of rotation and tilt, the intra- and interrater reliability in the assessment of panoramic view radiographs significantly decreased, with vertical tilt showing a higher impact on the ICCs and interclass correlation coefficients than horizontal rotation. At 15° of vertical tilt, the relative CC distances showed a drastic decrease. This could be explained by an occasional crossover of the coracoid process and the clavicle, as described above. The value 0 noted in case of a crossover led to a lower relative CC distance and falsely high ICCs and interclass correlation coefficients at 15° of tilt.

Several authors have examined the reliability of the Rockwood classification, and the results have been rather controversial.[6,11,17,21] Nevertheless, it is the most accepted and widely used classification system in AC joint dislocations among shoulder specialists.[19]

In a review published by Pogorzelski et al[16] in 2017, a missing consensus in viewing and classifying acute AC joint injuries was detected after summarizing the current literature. In 2014, Cho et al[6] showed an overall lack of reliability of the Rockwood classification and of decisions regarding the treatment of AC joint dislocations. Poor intra- and interobserver reliability was reached with the use of bilateral panoramic plain radiographic views and 3D CT scans. Especially between experienced shoulder surgeons, a poor interrater reliability was shown. The addition of 3D CT scans did not improve the reliability of classification and treatment of AC joint injuries.[6] Ringenberg et al[17] also demonstrated that the Rockwood classification system had a limited inter- and intrarater reliability. In their study, 50 unilateral radiographic views were rated. Contrary to that, a study by Schneider et al[21] published in 2016 showed an excellent intra- and interrater reliability for CC distance measurement among young residents and trained surgeons with shoulder expertise when using bilateral panoramic stress and axial view radiographs.

In a recently published study, the use of bilateral Zanca views was examined. It was shown that a standardized radiographic protocol improved the reliability of the Rockwood classification.[11]

Our study correlates with those findings. It shows that following a standardized protocol and correct angulation of AP views lead to high agreement between the raters. With rising tilt and rotation, the intraclass and interclass correlation coefficients decrease, especially when tilting or rotating >10°. This corresponds with the mentioned studies, indicating that the method is dependable when correctly executed but predisposed for errors in clinical practice.

In the current literature, there is no exact definition of how a panoramic radiographic view should be acquired or, in other words, how rotation and tilt can be avoided. Our results show the importance of avoiding particularly vertical tilt >10° for correct classification. It is possible that irregularities in obtaining the bilateral radiographic view influence the reliability of the measurements. Focusing on the exact implementation and defining a unified way to acquire the bilateral radiographs could be a way to increase the accuracy and reliability of the Rockwood classification system. Here, a correct depiction of the bony landmarks for the shoulder and clavicle, as defined by the International Society of Biomechanics, should be taken into consideration.[25] Further studies are needed to investigate possible quality improvement while obtaining panoramic view radiographs, for example, the development of checklists and quality control protocols.

A recent study compared radiographic findings with magnetic resonance imaging (MRI) examinations in acute AC joint dislocations. It was shown that with the use of MRI, additional information about the severity of the injury was gained. In some cases, this led to a change of the Rockwood classification initially determined via bilateral radiograph. It was shown that gaining further information about the capsuloligamentous structures of the AC joint via MRI might influence the pathway of treatment.[14]

In conclusion, several factors should be considered when evaluating and classifying AC joint dislocations. The quality of the bilateral panoramic radiographic view is a possible source of irregularities while measuring CC distances. Therefore, clearly defined quality criteria should be discussed when obtaining bilateral views.

Limitations

There are some limitations to this study that should be considered. The number of 14 patients was relatively low; however, the rating of the resulting 196 images allowed a proper statistical analysis.

During the CT scans, the patient was in a supine position, which causes a different scapulothoracic orientation and can therefore lead to different CC measurements when compared with panoramic views in the standing position. In a previous comparative CT study, the clavicle center was shown to be located more inferiorly, posteriorly, and laterally in a standing position compared with a supine position. However, absolute measured differences were small, with the clavicle center located at 23.3 ± 6.0 mm superior, 19.9 ± 6.5 mm posterior, and 85.4 ± 6.5 mm lateral to the sternal notch in the supine position.[12] Moreover, in our measurements, the CC distances with additional tilt and rotation were always put in relation to the neutral position, documenting a relative change in CC distance with the scapulothoracic orientation held constant.

In our study, the CT scans represented a bilateral, unweighted AP view, as described in the original Rockwood publication.[18] In a previous study, the use of weighted views was proposed to limit the influence of muscle spasms and unmask potential ligament injuries.[8] Muscle spasms in young, healthy patients were described to result in a misdiagnosis of a high-grade injury as a lower-grade one. In contrast to that, in the consensus papers by Beitzel et al[4] in 2014 and Rosso et al[19] in 2021, both came to the conclusion that unweighted views are sufficient in diagnosing an AC joint dislocation.

CONCLUSION

Vertical tilt and horizontal rotation can lead to an over- or underestimated injury severity when measuring the CC distance in bilateral AP views of the AC joint. This effect was especially visible with higher degrees of tilt and rotation. A correct execution and analysis of the bilateral panoramic view is therefore critical for a correct assessment of the severity of an AC joint injury and the Rockwood classification. Giving the high susceptibility to errors, it is questionable whether radiographic examinations should still be the basis to classify a purely ligamentous injury. Future research could focus on evaluating alternative diagnostic tools, such as MRI, while classifying AC joint dislocations. A revision of the Rockwood classification could be useful, considering the recent discussion in treating high-grade AC joint injuries nonoperatively.[20]

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