JSES International 8 (2024) 1297–1303

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Coronoid height index: a reliable and reproducible technique for quantifying coronoid bone loss in elbow instability

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A R T I C L E I N F O

Keywords:
Ulna
Coronoid
Height
Fracture
Size
Measurement

Level of evidence: Anatomy Study; Imaging

Background: Coronoid fracture size is one important factor in decision-making on surgical vs. nonsurgical management. There is currently no reliable, standardized technique to measure coronoid fracture size or bone loss. Hence, decision-making remains arbitrary, and recommendations made in the literature are unreliable. The aim of the study was to develop and assess a simple, reliable computed tomography (CT)-based technique that allows measurement of apical and anteromedial facet (AMF) coronoid height and bone loss. To achieve this, we sought to understand normal coronoid height across a large patient cohort, and whether the new technique was sensitive at detecting bone loss in patients with a fracture.

Methods: 163 CT scans were manually formatted in the plane of the proximal ulna. A best fit circle was drawn in the greater sigmoid notch on the sagittal section. The coronoid coverage height (CCH) was defined as the distance (in mm) measured at 90° from the greater sigmoid notch floor to a line between the olecranon and coronoid tips (or fracture base in fractured coronoids), bisecting the center of the circle. The coronoid height index (CHI) was calculated as a % by dividing the CCH by the diameter of the circle. The measurements were performed at the coronoid apex and the center of the AMF in 108 intact coronoids to understand normative values and 55 fractured coronoids to assess the sensitivity of the technique at detecting bone loss. Measurements were independently performed by two investigators, and interobserver reliability was assessed with weighted Cohen's kappa (κ) and intraclass correlation coefficient.

Results: For intact coronoids, the mean CCH was 11.4 ± 1.4 mm at the apex and 11.6 ± 1.3 mm at the AMF. The mean CHI was 56.7 ± 4.9% at the apex and 41.1 ± 3.6% at the AMF. For fractured coronoids, the mean CCH and CHI were significantly lower ($P < .001$) at both the apical (9.7 ± 1.4 mm, 45.8% ± 6.5%) and AMF (9.8 ± 1.6 mm, 33.9% ± 6.5%) positions, confirming that the technique was capable of detecting coronoid bone loss. While the CCH (a metric measurement) was significantly higher in men than in women ($P < .001$), the CHI (a proportion) demonstrated no significant difference at both the apex ($P = .06$) and AMF ($P = .91$). Interobserver reliability was good to excellent across all parameters.

Conclusion: CHI is a reliable CT-based technique to assess coronoid height and bone loss that is independent of patient size and can be used for clinical and research purposes.

The coronoid process is a 3-dimensional (3D) structure and bifacet articulation that provides axial, varus, and rotatory stability to the elbow.[3,10] A coronoid fracture generally represents a more complex osseoligamentous injury, and the pattern of the fracture is predictive of the pattern of instability.[18] If unrecognized or mismanaged, a coronoid fracture and the resultant coronoid height loss can contribute to recurrent instability and lead to rapid arthritis of the elbow.[15]

Size, displacement, and shape of a coronoid fracture are all important factors in determining whether the fracture needs fixing as part of the wider injury. This is most pertinent in posterolateral and posteromedial fracture dislocations, where the evidence suggests that the coronoid does not always need fixing.[4,15,19] There remains ambiguity in the literature on the optimal size or bone loss

Institutional review board approval was not required for this anatomy study.

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https://doi.org/10.1016/j.jseint.2024.07.004
2666-6383/

that predisposes to adverse sequalae, which makes clinical decision-making difficult. Different studies report different critical sizes as the threshold for fixation, yet these studies cannot be compared reliably as their measurement techniques vary and do not necessarily account for the size of the patient (and therefore the size of the forearm and coronoid), and the location of the fracture on the coronoid.[12,14,15]

In a recent systematic review, we identified 30 studies with 19 different coronoid height measurement techniques. There was considerable variability among studies regarding imaging modality, plane used to assess the coronoid, landmarks to define the coronoid, technique to measure the coronoid, parameter of coronoid measured, and the location of this measurement. In addition, fewer than 50% of studies reported on the interobserver reliability of their measurement technique. Such variability makes it unreliable to apply the current evidence into clinical practice and highlights the need for a simple reproducible method to help with decision-making on when to fix acute coronoid fractures and reconstruct coronoid deficiency.[6]

Hence, the primary aim of this study was to develop a simple but reliable CT-based coronoid measurement technique that (1) was independent of variable proximal ulna landmarks, (2) quantified coronoid height as a proportion or percentage rather than a metric value to reduce variation caused by patient size, and (3) allowed measurements to be performed at both the apical and AMF positions along the coronoid. Secondary aims were to (1) determine the normal values of coronoid coverage height (CCH) and coronoid height index (CHI) in intact coronoids and (2) determine the sensitivity of these variables at detecting coronoid bone loss at the apical and AMF positions along the coronoid.

Materials and methods

This is a retrospective cohort study involving the review of 163 adult elbow CT scans obtained from our local database. An ethics application for the study was submitted to the Brighton and Sussex Medical School Research Governance and Ethics Committee and approved without a formal board review.

Inclusion criteria & sub-grouping

All CT scans were of at least 1.5 Tesla quality with a minimum slice thickness of 1 mm. Only adult patients over 18 years of age were included. Any scans with evidence of preexisting degenerative, neoplastic, metabolic, or genetic pathology, as well as, those with previous surgery were excluded. We also excluded scans with O'Driscoll type 3 (Basal) fractures as these fractures are known to require surgery without contention in the literature.

CT scans that met the inclusion criteria were divided into 2 groups as follows.

Group 1 comprised 108 patients with an intact proximal ulna and no coronoid fracture that had a CT scan for other pathology. This most commonly included other trauma patients, such as those with an isolated radial head fracture, simple elbow dislocation, or a distal humeral fracture. This group was used to determine the normative values of the coronoid size using the new technique across the cohort.

Group 2 comprised 55 patients with a coronoid fracture but an otherwise intact proximal ulna treated in our institution. This group was used to understand whether the new technique was sensitive and reliable at detecting bone loss when a fracture was present.

Computed tomography scan formatting

All CT scans were analyzed using the Sectra Picture Archiving and Communication System (PACS) software (Sectra Workstation IDS7, version 23.2.6.5161; Sectra AB, Linköping, Sweden). The scans were standardized by formatting them in the plane of the proximal ulna by selecting the multiplanar reconstruction function in Sectra PACS. This function allows reorientation of axes in the sagittal, axial, and coronal planes. We used lines perpendicular to the dorsal cortex of the ulna (on sagittal sections), the flat dorsal surface of the proximal ulna (on axial sections), and the plane through the coronoid and olecranon apices (on coronal sections), as our references for axis reorientation (Fig. 1). This ensured all measurements were consistently performed in the same orientation and at the same apical and AMF locations.

Measurement technique

Measurements were performed on the sagittal CT reconstruction at the apex and anteromedial facet for each scan. The apex was located by referencing the coronal and axial reconstructions in the same manner for intact and fractured coronoids. In fractured coronoids, the axial section was important to determine the apex as it was fractured on the coronal reconstructions (Fig. 2). A circle of best fit was then drawn in the greater sigmoid notch (GSN) on the sagittal section. A line (*line ab*) was drawn between the tip of the olecranon and tip of the intact coronoid for scans without a fracture (group 1) and between the tip of the olecranon and the highest point of the intact coronoid for scans with a fracture (group 2) (Fig. 3). A second line (*line cd*) was drawn perpendicular to *line ab* through the center of the circle. Point d was where this line met the base of the GSN. The distance in millimeters (mm) was recorded between *point d* and *line ab* along *line cd*. This was termed the CCH (Fig. 3).

The CHI was calculated as a percentage by dividing the CCH by the diameter of the circle of best fit and multiplying by 100 to give a percentage value (Fig. 3).

The midpoint of the AMF was then located on the sagittal cuts by referencing the axial and coronal reconstructions (Fig. 4). The AMF midpoint was defined as the point halfway between the apex and the medial edge of the sublime tubercle. As for the apical point, the axial cut was important to define the AMF in the fractured coronoids. The same lines were drawn and measurements repeated to calculate the CCH and CHI at the AMF on all scans (Fig. 5).

Statistical analysis

Welch's unpaired t-test was used to perform gender (male vs. female) and intergroup comparisons for CCH and CHI measurements at the apical and AMF positions. $P < .05$ was considered statistically significant.

To assess interobserver reliability of the technique, all measurements were independently performed by two investigators (J.P. and M.J.), both fellowship-trained elbow surgeons with different levels of clinical experience. Weighted Cohen's kappa (κ) and intraclass correlation coefficient (ICC) were used to assess the strength of the interobserver reliability. κ was based on the criteria by Altman[1,2] (0.8-1.0 = very good, 0.6-0.8 = good, 0.4-0.6 = moderate, 0.2-0.4 = fair, < 0.2 = poor), and ICC was based on criteria by Koo & Li[7] (0.9-1.0 = excellent, 0.75-0.9 = good, 0.5-0.75 = moderate, < 0.5 = poor).

Results

The study involved review of 163 adult elbow CT scans, 108 with intact coronoids, and 55 with fractured coronoids. Demographic data are summarized in Table I.

Group 1 (intact coronoid) comparisons

Overall results

The mean apical CCH was 11.4 mm, and the mean AMF CCH was 11.6 mm. The mean apical CHI was 56.7%, and the mean AMF CHI

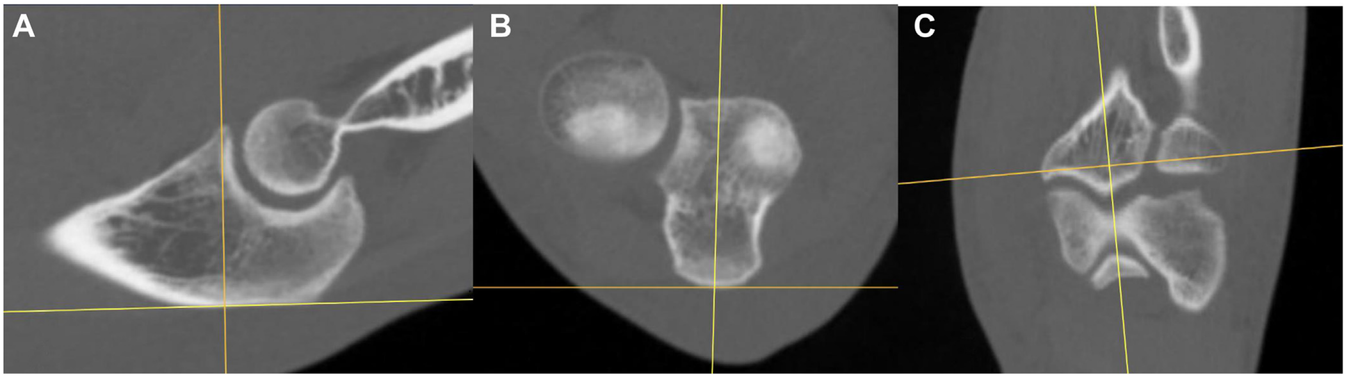

Figure 1 Computed tomography sections showing how perpendicular lines relative to the dorsal cortex of the ulna (**A**), the flat dorsal surface of the proximal ulna (**B**), and the plane through the coronoid and olecranon apices (**C**) were used as standardized references for axis reorientation.

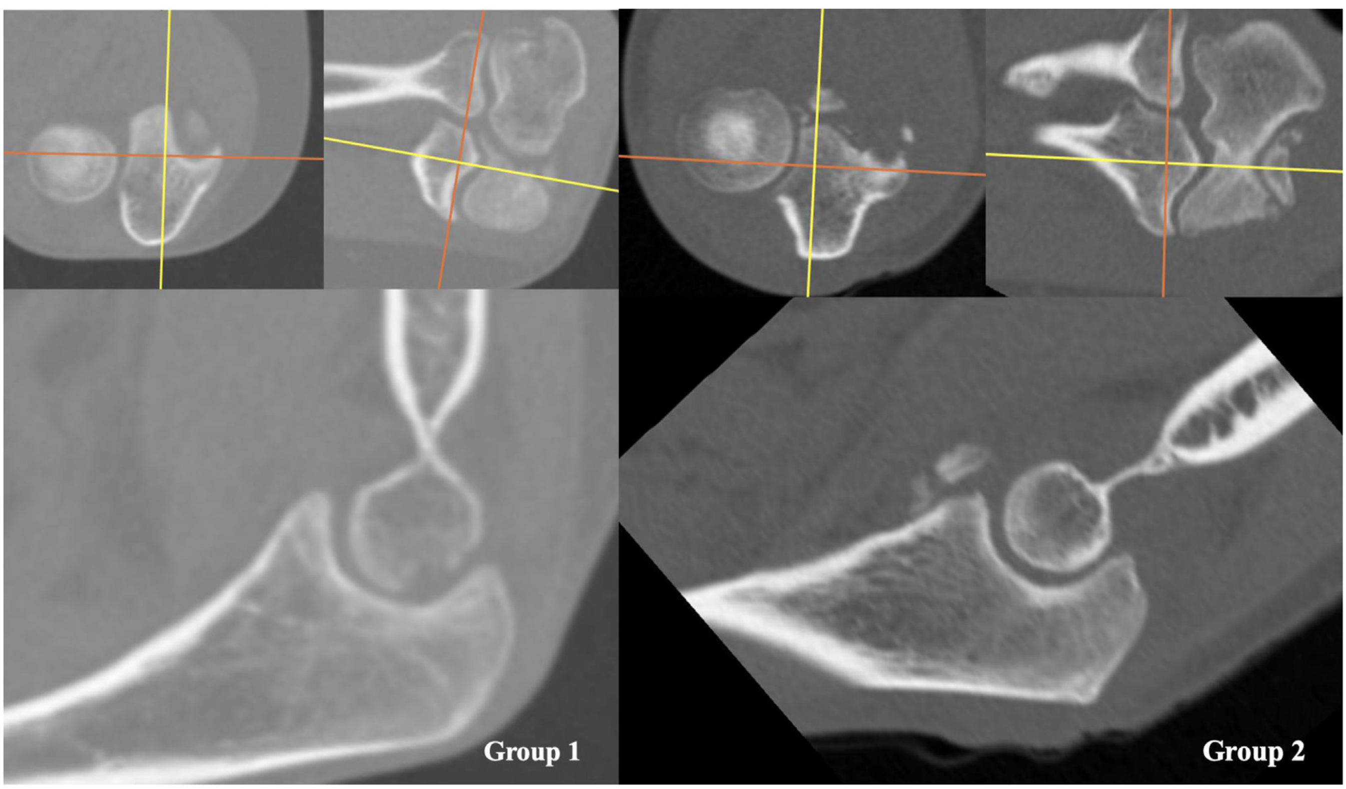

Figure 2 Lines used to define the apex in the intact coronoid (group 1) and the fractured coronoid (group 2) in all 3 planes.

was 41.1%. The means and standard deviations (SD) for all group 1 scans are summarized in Table II.

Male vs. female elbow CCH and CHI

There were 39 males and 69 females in group 1.

The mean apical CCH for males was 12.7 mm and for females it was 10.7 mm. The mean AMF CCH for males was 12.6 mm and for females it was 11.1 mm. The difference in CCH between males and females was statistically significant at both the apical ($P < .001$) and AMF ($P < .001$) positions.

Mean apical CHI for males was 57.1% and for females it was 56.0%. The mean AMF CHI for males was 41.2% and for females it was 41.1%. The difference between male and female CHI was not statistically significant at both the apex ($P = .06$) and AMF ($P = .91$) positions.

Table III summarizes male vs. female elbow CCH and CHI.

Group 2 (fractured coronoid) comparisons

Overall results

In group 2, the mean apical CCH was 9.7 mm, and the mean AMF CCH was 9.8 mm. The mean apical CHI was 45.8%, and the mean AMF CHI was 33.9% for this group. The means and standard deviations (SD) for group 2 scans are summarized in Table II.

Group 1 vs. group 2 elbow CCH and CHI

The mean CCH ($P < .001$) and CHI ($P < .001$) were significantly lower in group 2 than in group 1 at both the apical and AMF positions.

Table IV summarizes group 1 vs. group 2 CCH and CHI.

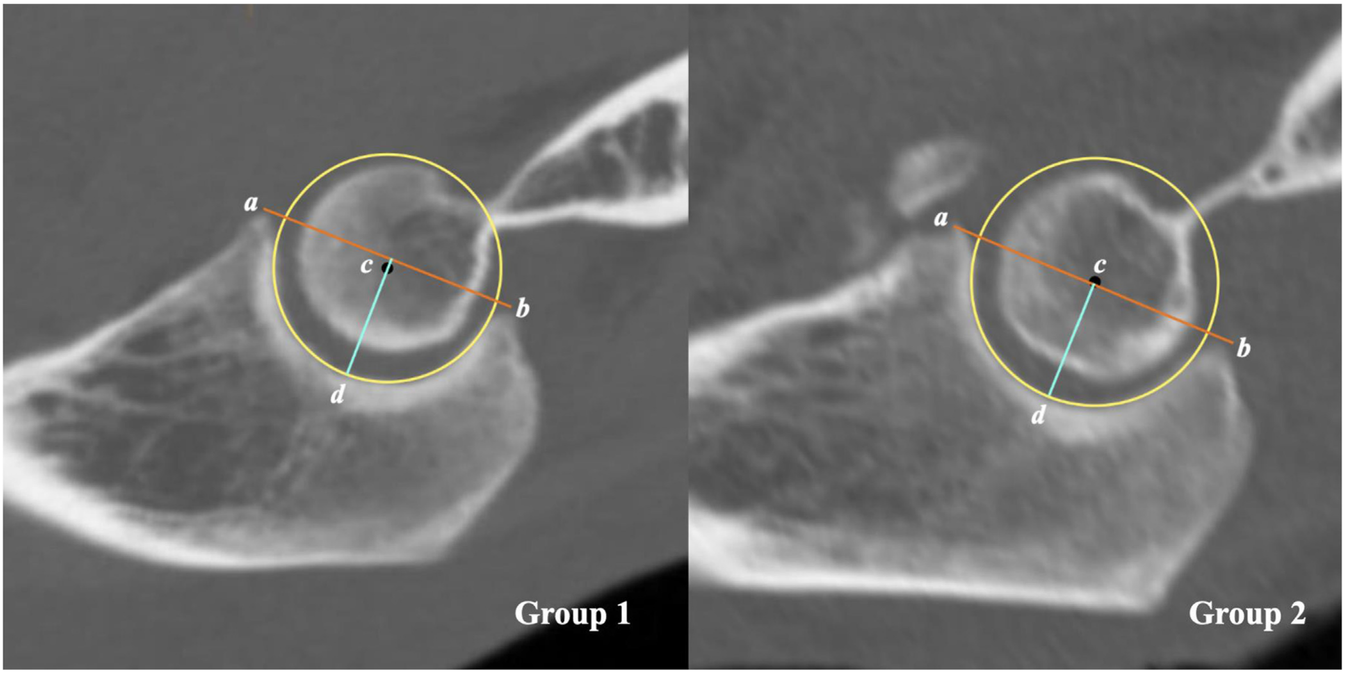

Figure 3 Technique used to measure coronoid parameters at the apex (group 1) and highest intact coronoid (group 2). Line ab is drawn between the tip of the intact or fractured coronoid and the tip of the olecranon. Line cd is drawn perpendicular to line ab through the Center of the circle of best fit. Line cd represents the coronoid coverage height. The coronoid height index is calculated as % = coronoid coverage height /circle diameter x 100.

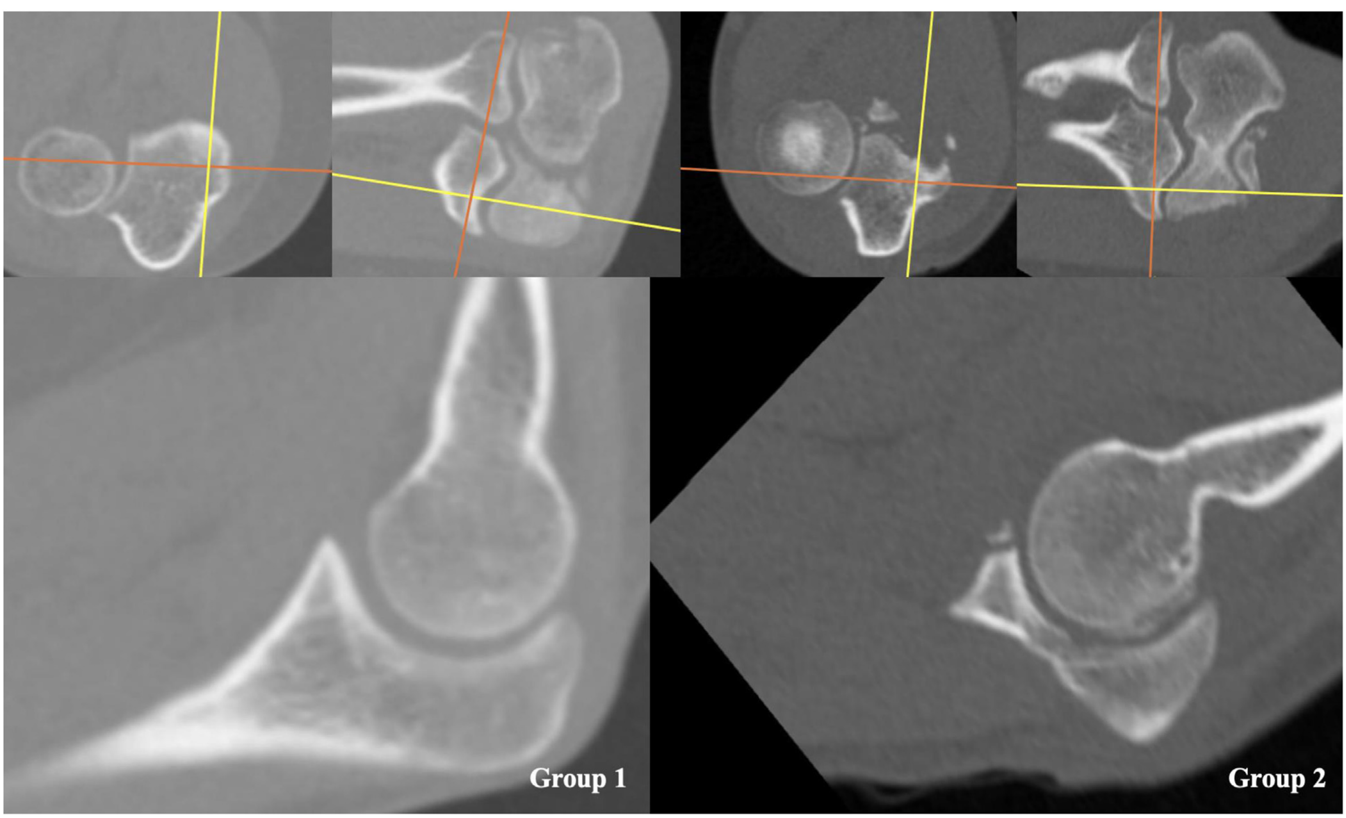

Figure 4 Lines used to define the anteromedial facet in the intact coronoid (group 1) and the fractured coronoid (group 2) in all 3 planes.

Interobserver reliability

Interobserver reliability ranged from good to excellent across all parameters, using both κ and ICC (Table V).

Discussion

The technique used to assess coronoid height and bone loss in this study found significant gender-based differences in intact

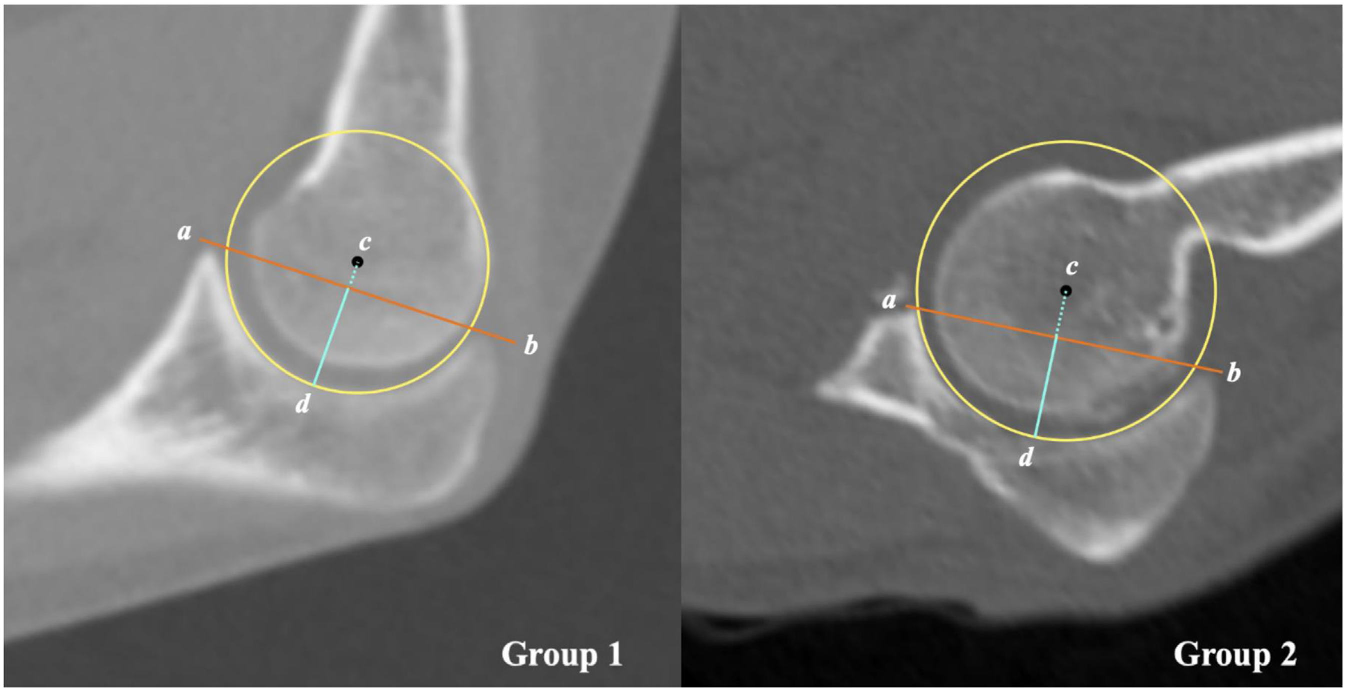

Figure 5 Technique used to measure coronoid parameters at the highest point of the normal (group 1) and intact (group 2) anteromedial facet.

Table I
Demographic data for group 1 and group 2.

Characteristics	Group 1	Group 2
N	108	55
Mean age in years (range)	56.4 (17-88)	47.1 (19-81)
Side	R = 38, L = 70	R = 29, L = 26
Gender	M = 39, F = 69	M = 35, F = 20

N, Number of scans; *R*, Right; *L*, Left; *M*, Male; *F*, Female.

coronoid height when measured as a metric value (CCH in mm). In contrast, when intact coronoid size was described as a proportion (CHI as a %), the gender-based differences did not reach significance at both the apical and AMF positions. We chose to compare normal coronoid size between male and female patients in order to understand the need for a nonmetric measurement system. Of course this would also be pertinent to variations in patient size within the same gender.

Our results support the use of techniques, such as the CHI that measure normal coronoid height and bone loss as a percentage, thereby negating variations due to patient anatomy (patient size, forearm size, and coronoid size). This method of expressing fracture size will also make comparisons across studies more reliable and hence improve clinical application of such measurements.

The present measurement technique is a CT-based method with multiple advantages over studies that use plain radiographs to measure coronoid height. Although Regan and Morrey[13] originally classified coronoid fractures on lateral plain radiographs, subsequent studies have shown plain radiographs alone to be inadequate and less accurate at identifying subtle injuries and complex fracture patterns involving the coronoid.[1,5] A recent x-ray and CT comparison study showed 12% of patients with 'normal' radiographs to have an occult fracture on CT scan.[11] 3D imaging, such as CT, has also been shown to improve interobserver reliability and provide better visualization as well as analysis of fracture characteristics, particularly the morphology and location of the coronoid fracture that are important for understanding injury pattern and associated soft-tissue pathology.[8,9] A CT-based technique such as ours also allows for assessment of coronoid height and bone loss at both the apical and AMF locations, which a plain radiograph-based technique does not allow. This has important clinical implications as it is known that fractures in the anteromedial region are more likely to require surgical treatment than those in the apical or anterolateral regions.

The GSN is a landmark that is independent of proximal ulna variability. The described technique measures coronoid height and bone loss as a percentage based on a circle of best fit within the GSN, thereby avoiding inaccuracies created by studies that use the posterior surface of the proximal ulna to measure coronoid height. These studies fail to account for considerable variations in the proximal ulna dorsal angulation, which has been reported to range from −3.0° to +14.0° with the distance of the angulation point from the olecranon tip ranging from 21 mm to 107 mm.[16,17] Hence, if the posterior surface of the proximal ulna was used to help define the coronoid base and then a measurement of coronoid height was performed, the native variation in proximal ulna dorsal angulation would render the coronoid measurement inconsistent between subjects and even more so between studies.

To determine if this technique was sensitive at detecting coronoid bone loss, we performed measurements on CT scans with intact and fractured coronoids. The CHI was found to be significantly lower at both the apical and AMF positions in group 2 (fractured coronoid) patients. This suggests that the technique is sensitive at detecting bone loss across various fracture patterns along the coronoid.

We also observed good to excellent inter-observer reliability across all parameters measured using this technique. We feel it is a user-friendly method that can be routinely used in clinical practice as well as for research purposes.

There are some limitations to the study. Our technique requires CT software such as Sectra PACS that allows reformatting of axes through its multiplanar reconstruction function in order to standardize measurements. This functionality is available in most

Table II
Apical and AMF CCH and CHI in group 1 and group 2.

Group	Apical CCH in mm	AMF CCH in mm	Apical CHI as %	AMF CHI (%)
Group 1	11.4 ± 1.4 (8.5-14.4)	11.6 ± 1.3 (7.3-15.5)	56.7 ± 5.0 (45.5-68.7)	41.1 ± 3.6 (30.6-49.0)
Group 2	9.7 ± 1.4 (6.5-m13.6)	9.8 ± 1.6 (6.7-13.5)	45.8 ± 6.5 (30.9-58.7)	33.9 ± 6.5 (21.7-48.4)

AMF, anteromedial facet; *CCH*, coronoid coverage height; *CHI*, coronoid coverage index; *SD*, standard deviation.
All values presented as mean ± SD (Range).

Table III
Comparison of male vs. female CCH and CHI in group 1.

Variable	Male	Female	*P*[*]
Apical CCH in mm	12.7 ± 1.0 (10.3-14.4)	10.7 ± 0.9 (8.5-12.8)	<.001
AMF CCH in mm	12.6 ± 1.0 (10.6-15.5)	11.1 ± 1.1 (7.3-13.4)	<.001
Apical CHI as %	57.1 ± 4.8 (51.2-68.6)	56.0 ± 5.0 (45.5-68.7)	.06
AMF CHI as %	41.2 ± 3.0 (36.1-46.4)	41.1 ± 3.9 (30.6-49.0)	.91

AMF, anteromedial facet; *CCH*, coronoid coverage height; *CHI*, coronoid coverage index; *SD*, standard deviation.
All values presented as Mean ± SD (Range).
$P < .05$ considered statistically significant.
[*]Note loss of significance when variables are considered as a percentage rather than as an absolute number.

Table IV
Comparison of group 1 vs. group 2 CCH and CHI.

Variable	Group 1	Group 2	*P*[*]
Apical CCH in mm	11.4 ± 1.4 (8.5-14.4)	9.7 ± 1.4 (6.5-13.6)	<.001
AMF CCH in mm	11.6 ± 1.3 (7.3-15.5)	9.8 ± 1.6 (6.7-13.5)	<.001
Apical CHI as %	56.7 ± 4.9 (45.5-68.7)	45.8 ± 6.5 (30.9-58.7)	<.001
AMF CHI as %	41.1 ± 3.6 (30.6-49.0)	33.9 ± 6.5 (21.7-48.4)	<.001

AMF, anteromedial facet; *CCH*, coronoid coverage height; *CHI*, coronoid coverage index; *SD*, standard deviation.
All values presented as Mmean ± SD (Range).
$P < .05$ considered statistically significant.
[*]Significantly lower CCH, and CHI, in fractured group compared to intact group.

Table V
Inter-observer reliability using κ and ICC.

Variable	K	Agreement[*]	ICC	Agreement[†]
Apical CCH	0.91 (0.87-0.96)	Very good	0.98 (0.97-0.99)	Excellent
AMF CCH	0.90 (0.86-0.94)	Very good	0.98 (0.97-0.99)	Excellent
Apical CHI	0.90 (0.87-0.93)	Very good	0.99 (0.98-0.99)	Excellent
AMF CHI	0.83 (0.75-0.91)	Very good	0.87 (0.81-0.91)	Good

AMF, anteromedial facet; *CCH*, coronoid coverage height; *CHI*, coronoid coverage index; *κ*, Weighted Cohen's kappa; *ICC*, intraclass correlation coefficient.
All values presented as mean (95% confidence interval).
[*]As per criteria by Altman.[1,2]
[†]As per criteria by Koo & Li.[7]

contemporary systems and can also be set during the original scan acquisition, if desired.

One criticism may be that 3D CT scans were not used to perform our measurements. This was considered very carefully during development of the technique; however, it was found that while 3D CT, volume rendering, and bone subtraction were all very useful for understanding the overall geographic appearance of the coronoid, it was very difficult to standardize measurements using 3D CT to the level of accuracy and simplicity required for use in clinical practice. This was important as the aim was to produce a technique that could be applied easily by other surgeons.

Despite this being the largest cohort of patients included in such a study on coronoid measurements, the numbers are still relatively small, and the distribution of male and female patients was unequal, as this was a real clinical series. Despite this, the CCH was significantly different between genders, and the CHI was sensitive at identifying bone loss. We feel these findings would likely be confirmed with an even larger cohort of patients.

Finally, the aim of this study was to develop and present a reliable technique for measuring coronoid height and bone loss assessment because of the deficiencies in the literature already outlined. The goal of the present study was not to determine what degree of coronoid bone loss constitutes a need for surgical fixation or where that bone loss fits into the wider context of a fracture dislocation where the other osseo-ligamentous constraints contribute to stability and clinical outcome. However, for that work to be done, a reliable, accurate technique was needed, and hence, our future aim is to answer these questions using the CCH and CCI measurements.

Conclusion

The CCH and CHI are simple CT-based measurements that are reliable, independent of patient anatomic variation and are sensitive at detecting bone loss anywhere in the coronoid. Moreover, they are applicable to clinical practice and for research purposes.

Disclaimers:

Funding: This study was not assisted by any outside funding or grants.
Conflicts of interest: The authors, their immediate families, and any research foundation 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.

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