Involvement of the proximal radial ulnar joint in partial radial head fractures: a novel three-dimensional computed tomography scan evaluation method

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Abstract

Background: Partial radial head fractures (PRHF) can involve the proximal radioulnar joint (PRUJ) or be restricted to the 'safe zone' (SZ) during forearm rotation. The objective of the present study was to develop an assessment method for PRUJ involvement in radial head fractures using axial computed tomography (CT) scans.

Methods: The area of the radial head in contact with the PRUJ zone was identified, and defined on 18 cadaveric elbows CT scans; the quantitative relationship between PRUJ zone and radial tuberosity was established. Then, four evaluators validated it on PRHF CT scan axial views, classifying the fractures as involving the PRUJ or not.

Results: Using the radial tuberosity as the 0° of a 360° circle, the SZ was within 108° to 212° clockwise for a right elbow and counter clockwise for the left elbow. Fifty-five consecutive (30 men, 25 women, mean age of 49 years) partial radial head fracture CT scans were classified: four in the SZ only, three in the PRUJ zone and 48 in both the PRUJ and SZ. The kappa for the inter- and intra-observer agreement was 0.517 and 0.881, respectively.

Conclusions: Ninety-three percent of partial radial head fractures will involve the PRUJ and the geometric model developed allows their classification, potentially helping surgeons decide on optimal treatment.

Level of evidence: Retrospective basic science study. Level III: anatomic study, imaging

Keywords

3D CT-scan, PRUJ, radial head fracture

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Introduction

Radial head fractures are relatively common, representing approximately one-third of all elbow fractures.^{1–3} Treatment is generally guided by the modified Mason classification,⁴ which divides fractures into four types based on location, associated dislocation, comminution and the presence of a mechanical block.⁵

Displacement in this classification has always been in reference to the radiocapitellar joint. However, displacement in the proximal radio ulnar joint (PRUJ) zone is likely to be equally as important. The safe zone (SZ) is described as an arc of approximately 110° around the radial head that never articulates with the PRUJ.^{5–7} This concept can also be useful

to evaluate whether a radial head fragment involves the PRUJ. Fractures contained entirely within this safe zone should not have an impact on pronosupination.⁸ To our knowledge, there are no tools available to determine pre-operatively whether the fragments of a partial

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radial head fracture involve the PRUJ or not. The potential impact of such a tool would be to give surgeons more confidence in treating these fractures non-operatively.

The objective of the present study was to develop an assessment method to determine whether the partial radial head fracture involves the PRUJ zone, using computed tomography (CT) scans.

Materials and Methods

This was a two-part study combining a cadaveric model study, followed by a clinical radiological review.

Part I: Cadaveric study – development of a measurement method

Specimens. In the present cadaveric study, 18 fresh frozen cadaveric elbows (nine pairs; six male and three female cadavers) were used. The average age at death was 69 years (range 43 years to 87 years). None of the specimens had undergone a previous operation and we only included cases with no elbow, forearm or wrist pathology.

Preparation and identification of safe zone. Dissection was divided in two parts: with the forearm in maximal pronation and in maximal supination. The positions were achieved with the elbow in 90° of flexion with passive positioning by an evaluator. With the forearm in maximal pronation, a lateral skin incision was created and the Kaplan interval was used to split and elevate the extensor muscles. The lateral collateral and annular ligaments were kept intact. An anterior arthrotomy to the lateral collateral ligament was performed to visualize the radial head and the ulna. Using a curved osteotome perpendicular to the joint surface, a notch was made on the radial head's articular surface in the maximal pronation position, at the boundary with the ulna (Fig. 1). The notch was then deepened using a 1-mm oscillating saw, taking care to include the kerf in the safe zone, to provide better visualization. For the dissection with the forearm in maximal supination, the Kocher approach was used with deep dissection and lifting of the anconeus muscle. A similar procedure was performed to identify the limit on the radial head's articular surface in maximal supination, at the same time as keeping the ligaments intact. The smaller arc joining these notches was defined as the safe zone (SZ) and the complementary angle was named the PRUJ zone (Fig. 2).

Imaging and reconstruction. Axial CT scans were taken for each cadaveric elbow. The boundaries of the scanned area were the distal humerus, proximally, and the wrist,

Figure 1. Notch made perpendicular to the radial head articular surface with the forearm in maximal pronation position. The annular ligament was released in this example for visualization purposes (for a clearer view, the osteotomy here is oblique).

distally. CT scans were taken with a Lightspeed VCT (GE Medical Systems, Milwaukee, WI, USA) CT scanner (0.625 mm slice thickness and 0.781 mm pixel resolution).

Dedicated software (SliceOmatic; TomoVision, Magog, Québec, Canada) was used to reconstruct each radius from the CT scans. Computer aided design software (CATIA V5R21; Dassault System, Vélizy-Villacoublay, France) were used for measurements. An axial cut was chosen at radial head level, where the identified safe zone appeared the largest. A second axial cut was chosen at radial tuberosity (RT) level, where the tendon insertion could be seen more clearly. The centre of each cut was used as reference to superimpose one over the other, by adding two plans with the CATIA software. The RT-SZ angle was located between the radial tuberosity and the beginning of the SZ (Fig. 2). This angle, calculated from a fixed landmark, provided the number of degrees required to reach the SZ, no matter the position of the forearm during the scan. The SZ angle was obtained by calculating the angle between the two notches of the radial head, including the kerf (Fig. 2). For a right elbow, the angle was measured clockwise, whereas for a left elbow, the angle was measured counter-clockwise. The result was the RT-SZ angle.

Classification of a partial head fracture based on PRUJ involvement. As an example, in a right elbow CT scan, the 0° would be applied on the radial tuberosity tip. Moving clockwise, the safe zone would begin at the mean RT-SZ angle, and would end at an angle corresponding to the mean SZ angle. To decrease the odds of missing a fracture involving the PRUJ, we decided to remove the applicable standard deviation (SD) to each

Figure 2. Superposition of axial section of the radial head and the radial tuberosity for a right elbow. RH radial head; RT, radial tuberosity; SZ, safe zone; PRUJ, proximal radioulnar joint.

limit of the safe zone. This will increase the PRUJ zone to make it more inclusive.

Stencil to determine whether the fracture is within the PRUJ on CT scan. To effectively implement the measurement method, we created a simple stencil, easily applicable in orthopaedics. As previously described, the angle corresponding to the mean degree for the SZ was drawn on acetate allowing a quick visualization of the position of the radial head fracture in relation to the PRUJ zone. The validation of the stencil is described in the second part of our study (Fig. 3).

Part 2: Clinical validation

A database was constructed using ICD-9 codes to identify all patients with radial head fractures at our institution from 2007 to 2014. X-rays and CT scans were then evaluated to identify potential patients. Inclusion criteria were: partial radial head fracture (OTA/OA type B classification), X-ray and CT scan available with good image quality to visualize the biceps tendon.⁹ Exclusion criteria included a fracture involving the entire head or neck of the radius, inability to visualize the biceps tendon on axial CT scan, open physis and previous elbow disease.

Radial head fractures were classified according to the Mason classification. Associated elbow injuries were recorded and the fragment size of the partial radial head fracture measured in degrees. In cases of comminution, the global arc was measured.

Figure 3. Stencil applicable on the axial view of the scan of the radial head. SZ, safe zone.

For the CT scan, the cuts used were the centre of the thickness of the radial head on the axial plane. For the radial tuberosity, we used an axial cut of the summit of the radial tuberosity where the bicipital tendon can easily be seen.

The assessment method described above was applied to the CT using the stencil. Fractures were classified according to whether they involved the SZ only, the PRUJ zone only, or both. Classification was performed by four observers to ensure inter-observer validation. One observer also repeated the measurements 4 weeks later to test for intra-observer reliability with the cases in random order.

Statistical analysis. In Part 1, all continuous data are expressed as the mean range and SD. The Mann–Whitney test was used to compare mean angles between right and left. $p < 0.05$ was considered statistically significant.

In Part 2, a kappa statistic (k) was used to calculate the intra- and inter-observer agreement with respect to fracture classification (SZ only, PRUJ only or SZ and PRUJ) with the stencil.

Results

Part 1: Cadaveric study – development of evaluation measurement method

We applied a 360 dial on the radial head, aligning the ‘zero’ degree with the radial tuberosity. The mean SZ angle was 122° (range 95° to 157° ; SD 18°) for all specimen, left and right. The SZ angle for left elbows was 117° (range 99° to 142° ; SD 17°) and 126° for right elbows (range 95° to 157° ; SD 19°), with $p = 0.283$. The mean RT-SZ angle, representing the angle between the radial tuberosity and the beginning of the safe zone, was 84° (range 50° to 127° ; SD 24°). The RT-SZ angle for left elbows was 89° (range 50° to 127° ; SD 28°) and 79° for right elbows (range 53° to 110° ; SD 20°), with $p = 0.725$. The results are shown in Table 1. We then used the combined mean values of the right and left specimens to achieve final measurements because the

results were similar and it was more practical in a clinical setting.

The mean RT-SZ (84°) determined the starting value when the SZ (122°) was added to the RT-SZ for the ending value. However, because our goal was to determine the safest angle possible, considering that anatomy can vary, we added the SD (24°) to the limit measures of the RT-SZ to identify the greatest number of fractures that could potentially involve the PRUJ. Therefore, the starting value of the RT-SZ was 108° [84° (24°) (SD)] as the minimal SZ angle boundary. Then, we added the SZ (122°) for a total of 230° . Again, to ensure maximum safety, we subtracted the SZ SD (18°), resulting in an angle of 212° as the maximal SZ angle boundary. Thus, the angle demonstrating that the radial head fracture was in the SZ only, starting from the radial tuberosity, was between 108° and 212° , clockwise for a right elbow and counter-clockwise for a left elbow.

Part 2: Clinical validation – development of an evaluation method

In total, 344 patients with a radial head fracture were identified. Of these, 281 had no available CT scan. Of the 63 cases with a CT scan, one had rheumatoid arthritis involving the elbow; this patient was excluded. No CT scans were excluded as a result of an incapacity to see the distal biceps and tuberosity.

This group included 62 patients with a mean (SD) age of 49 (17) years (range 18 years to 91 years) and a male-to-female ratio of almost 1 : 1. Using the Mason classification, there were 13 type I fractures (20%), 27 (43%) type II fractures, seven (13%) type III fractures and 15 (24%) type IV fractures.^{4,5} The seven type III fractures were excluded. This left a total of 55 fractures to be included in the study of which close to half the fractures (27/55) had significant comminution.

Table 1. Safe zone and radial tuberosity-safe zone angles

	Mean ($^\circ$)	SD ($^\circ$)	Maximum ($^\circ$)	Minimum ($^\circ$)
Right and left elbow safe zone angle (SZ)	122	19	157	95
Right elbow safe zone angle (SZ)	126	20	157	95
Left elbow safe zone angle (SZ)	117	17	142	99
Right and left elbow radial tuberosity-Safe zone angle (RT-SZ)	84	24	127	50
Right elbow radial tuberosity-Safe zone angle (RT-SZ)	80	20	110	53
Left elbow radial tuberosity-Safe zone angle (RT-SZ)	88	28	127	50

SZ, safe zone; RT, radial tuberosity.

Table 2. Patient characteristics

	All patients (n = 55)
Age, mean (SD), years	49 (17)
Sex, n (%)	
Men	30 (55)
Women	25 (45)
Side of injury, n (%)	
Right	21 (38)
Left	34 (62)
Mason classification, n (%)	
Type I	13 (20)
Type II	27 (43)
Type III*	7 (13)
Type IV	15 (24)
Associated injuries, n (%)	
Olecranon fracture	10 (18)
Coronoid fracture	27 (49)
Distal humeral fracture	12 (22)
Medial epicondyle fracture	3 (5)
Lateral epicondyle fracture	9 (16)
Dislocation	14 (25)
Supinator crest fracture	8 (15)
Comminutive fracture, n (%)	
Yes	27 (49)
No	28 (51)
Angle of fracture, mean (SD) (degrees)	141 (49)
Zone classification, n (%)	
SZ only**	4 (7)
PRUJ only	3 (6)
SZ and PRUJ	48 (87)
Treatment, n (%)	
Operative	24 (44)

(continued)

Table 2. Continued

	All patients (n = 55)
Non-operative	31 (56)
Type of operative treatment, n (%)***	
Plate and screws	9 (16)
Screws	10 (18)
Prothesis	9 (16)
External fixation	2 (4)

SZ, safe zone; PRUJ, proximal radioulnar joint.

*Some patients had more than one type of operative treatment.

**Safe zone patient characteristics (Table 4).

Coronoid fractures were the most commonly associated injury, involving 27 cases (47%). There was an associated elbow dislocation in 25% ($n = 13$) of the fractures. The average measured fracture angle of the 55 radial head partial articular fractures was 141° (range 40° to 250° ; SD 49°). The fractures were classified as: four (7%) in the SZ only, three (6%) in the PRUJ zone only and 48 (87%) involving both SZ and PRUJ. More than half the patients received non-operative treatment (Table 2). The characteristics of the four patients with SZ only fractures are shown in Table 3.

The 55 selected CT scans were then evaluated with the stencil by four observers (CA, RD, HDJ and LGY). They classified the radial head fracture according to their involvement in the SZ only, the PRUJ zone only, or both the SZ and the PRUJ zone (Fig. 3). The majority of cases involved both zones 87% (48/55).

According to the classification based on the involvement of radial head fractures in the SZ, the PRUJ or both the SZ and PRUJ zone (Table 4), the average kappa for inter-observer reliability was 0.579 (range 0.496 to 0.663). The kappa for intra-observer reliability was 0.902 (range 0.691 to 1.000).

Discussion

Surgical treatment for displaced partial radial head fractures is usually indicated for fractures that restrict elbow range of motion; however, this can sometimes be difficult to assess in the acute setting as a result of pain and swelling. To date, there are no studies that describe the effect of PRUJ involvement on pronosupination. On the other hand, it is intuitive to think that a fracture is unlikely to affect pronosupination if it is located in the radial head safe zone. For example, in practice, the orthopaedic surgeon who operates a fracture requiring a plate ensures that it remains within the SZ to avoid

Table 3 Patient characteristics with Safe Zone only for classification

	All patients
	(n = 4)
Age, mean (SD), years	60 (18)
Sex, n (%)	
Men	2 (50)
Women	2 (50)
Side of injury, n (%)	
Right	1 (25)
Left	3 (75)
Mason classification, n (%)	
Type I	4 (100)
Associated injuries, n	
Olecranon fracture	2 (50)
Coronoid fracture	2 (50)
Distal humeral fracture	2 (50)
Medial epicondyle fracture	0
Lateral epicondyle fracture	2 (50)
Luxation	0
Supinator crest fracture	1 (25)
Comminutive fracture, n (%)	
Yes	1 (25)
No	3 (75)
Angle of fracture, mean (SD) (degrees)	65 (22)

Table 4 Incidence of the localization of the fracture (number) using different observers

Classification	SZ only	PRUJ only	SZ and PRUJ
Observer 1	4	1	50
Observer 2	4	3	48
Observer 3	4	6	40
Observer 4	5	3	47

SZ, safe zone; PRUJ, proximal radioulnar joint.

interference with the PRUJ. The present study has successfully developed the first pre-operative tool to determine the location of a fracture with regard to the safe zone. In cases with an element of uncertainty, the developed method can help in treatment decision. We consider that this has important ramifications on treatment with the potential to avoid surgery in patients where initial lack of motion is mostly a result of pain.

Knowing the SZ and RT-SZ angles, it is now possible to predict whether a radial head fracture involves the PRUJ or not. Our mean SZ (degrees) is smaller than that of Ries¹⁰ (mean 133°; range 119° to 147°), who defined their SZ with a similar method but used pins instead of lines made with a bone saw. On the other hand, our SZ is larger than that of Smith and Hotchkiss⁶ (mean 110°; range 105° to 120°) and Caputo et al.⁷ (mean 113°; range 106° to 120°).¹¹

The radial tuberosity is a useful landmark to help predict whether a partial radial head fracture will affect the PRUJ. According to Mazzocca et al.,¹² in most patients, the radial tuberosity is a single ridge (88% of the 178 cadaveric elbows used in the study).¹² The stencil, created from the RT-SZ angle between 108° and 212° from the radial tuberosity, is a quick and easy tool for detection of radial head fractures involving the PRUJ and does not require image processing software. According to the benchmark scale of Landis and Koch,¹³ the intra-observer agreement was almost perfect. The inter-observer agreement was much lower, although still fair. There were two significant factors affecting this outcome. First, several measurements were made on reconstructed axial CT scans to be in the appropriate plane. These reconstructions had lower quality images and subsequently decreased measurement precision. Our radiology protocol has subsequently been modified to eliminate these imperfections. Second, several fracture lines exited very close to the safe zone. Combining these two issues can help explain the lower inter-observer reliability.

The 55 radial head fractures analyzed with the stencil were classified according to their position in relation to the SZ. Four were in the SZ only, three in the PRUJ only, and 48 in both the SZ and PRUJ. In our cohort of 55 CT scans, only 7% of the radial head fractures were in the SZ only. We agree with the existing literature that surgical treatment is only necessary for displaced radial head fractures that block forearm rotation. Although the SZ-only group was quite small, we are not advocating that the other 93% of fractures in the present study merit surgical treatment. Rather, we consider that identifying these fractures, although rare, would allow surgeons to confidently recommend non-operative management, without using invasive procedures such as lidocaine injection. However, a larger sample is needed to confirm this conclusion. The large amount

of fractures involving both SZ and PRUJ is consistent with several studies reporting that the majority of radial head fractures involve the anterolateral quadrant.^{14–18} This quadrant corresponds to 132° to 222° from the radial tuberosity. According to a radiological study from Van Leeuwen et al.,¹⁶ the average angle for a radial head fracture (for a sample comprising 24 elbows) is 170°. When compared with 141° in the present study, we can presume that the majority of fractures involve more than the anterolateral quadrant, and more than the safe zone angle.

There are several limitations to the present study. First, in the cadaveric study, nine pairs of elbows were used, for a total of 18 elbows. It would have been preferable to have nonpaired elbows to benefit from a greater diversity. Second, fresh frozen cadaveric elbows do not reflect the anatomical structure properties of a functional elbow, except for the muscles that have been shown to be unaffected by freezing but are still sensitive to even a few cycles of mechanical loading.¹⁹ Third, radial tuberosity shape and position of the tuberosity relative to the radial head is variable. The radial tuberosity appears as a single ridge in 60% to 88% according to Gupta et al.¹² and Mazzocca et al.,²⁰ respectively. In our cohort, all 55 elbows had an easily identifiable radial tuberosity. Fourth, the technical protocol and the stencil are tools that imperatively require an axial CT scan. We recognize that obtaining CT scans for every radial head fracture would be cumbersome and represent a large financial burden on the healthcare system. We consider that this should be reserved for cases lacking clear operative indications in patients with limited motion. We feel that this patient population may benefit the most from this tool. Another potential limitation is that using a tool with a generic, standardized range may lead to an error when assessing the true PRUJ involvement. Finally, some SZ-only fractures, even if they do not impact pronosupination, are sometimes fixed for stability purposes. These aspects were not evaluated in the present study.

Future studies should evaluate this method in conjunction with an evaluation of chronic disability after radial head fracture. This could help to identify the position of plates or radial head malunion in the evaluation of pronosupination block. Such a measurement method could also be included in a smartphone application.

The vast majority of partial radial head fractures involve the PRUJ. Displaced radial head fractures in the axial plane, visible on a CT scan, are at risk of forearm rotation blockage. The tool developed in the present study is a reliable method for pre-operatively assessing whether a radial head fracture involves the PRUJ or not. A stencil can easily be applied on the

axial view of the scan to classify the fracture as PRUJ positive or negative. Further studies will focus on the clinical applicability of this tool and its impact on surgical decision-making.

Declaration of Conflicting Interests

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Ethical Review and Patient Consent

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