The correlation between the teardrop angle and anterior lunate facet displacement in plating distal radial fractures

Teun Teunis¹, Sjoerd Meijer², Jesse Jupiter³, DRF-VALCP study group⁴ and Daniel Rikli⁵

Abstract
This study aimed to determine the association of teardrop angle and anteroposterior distance with anterior lunate facet displacement and articular congruity before and after anterior plating of distal radial fractures. We included 36 patients with complete intra-articular distal radial fractures with separate anterior lunate facet fragments. On radiographs we determined the teardrop angle and anteroposterior distance. On digital three-dimensional models we measured proximal-distal, anteroposterior and ulnoradial anterior lunate facet displacement, and we outlined the gap surface area. Preoperatively, teardrop angle was highly associated with the extent of anterior lunate facet displacement. Increased anteroposterior distance was mainly associated with articular incongruity after anterior plate fixation. This information may reduce the need of preoperative computed tomography scans in fractures with a normal tear drop angle. This is particularly useful in low-resource settings.

Keywords
Distal radius, anterior lunate facet, teardrop angle, anteroposterior distance

Date received: 29th June 2018; revised: 22nd October 2018; accepted: 7th December 2018

Introduction
Medoff (2005) introduced the teardrop angle as a measure of articular incongruity on plain radiographs of distal radial fractures. The teardrop represents the U-shaped outline of the rim of the anterior lunate facet. The angle is determined between a line drawn down the central axis of the teardrop (parallel to the subchondral bone) and the central axis of the radial shaft. When axial loading injuries create a split lunate facet, the anterior lunate fragment can rotate posteriorly. In such cases reduction might restore anterior tilt and radial inclination, but significant articular incongruity can remain. It is postulated that a depression of the teardrop angle is the only radiographic indicator of such remaining incongruity.

Another potential measure for articular incongruity is anteroposterior (AP) distance (Medoff, 2005). This is the distance between the apex of the posterior rim and the anterior rim of the lunate facet. As the lunate is driven down and fractures the radial's articular surface, the anterior and posterior rim move away from each other, resulting in an increased AP distance.

Quantitative three-dimensional computed tomography (Q3DCT) can accurately determine individual three-dimensional (3D) fragment displacement...
Teunis et al., 2016). A reliable measure of articular displacement on plain radiographs could potentially reduce the number of CT scans, and could be useful in low resource settings or situations when CT is impractical, for example during surgery or regular follow-up.

We aimed to determine how well teardrop angle and AP distance measured on radiographs relate to actual anterior lunate facet displacement. For distal radial fractures and operated distal radius fractures, we asked: (1) Do the teardrop angle and AP distance measured on radiographs correlate with anterior lunate facet overall displacement measured in a 3D model? (2) Do the teardrop angle and AP distance correlate with (a) proximal–distal displacement, (b) posteroanterior displacement, and (c) radial–ulnar displacement of the anterior lunate facet? (3) Do the teardrop angle and AP distance correlate with gap surface area on a 3D model and correlate with gap and step-off measured on sagittal CT scans? We specifically tested the primary null hypothesis that after distal radial fracture, the tear drop angle does not correlate with overall anterior lunate facet displacement.

Materials and methods

Study design

This retrospective study was a secondary analysis of a prospective multicentre trial (registered ClinicalTrials.gov, protocol number NCT01103297) (Teunis et al., 2017). The initial study enrolled 73 consecutive patients over 18 years old with isolated AO/OTA (Arbeitsgemeinschaft für Osteosynthesefragen/ American Orthopaedic Trauma Association) type B or C distal radial fractures who were eligible for anterior plate fixation. We excluded pregnant women and patients with previous ipsilateral or current pathologic fractures. Institutional review board approval was obtained at each centre. Post-fracture and postoperative radiographs and CT scans were obtained in a standardized fashion (AO Clinical Investigation and Documentation, 2010). Thirty-six patients with an AO/OTA type C fracture and a separate anterior lunate facet fragment identified on CT scan were included in this study.

Radiographic measures

On lateral radiographs we measured the teardrop angle between a line drawn down the central axis of the teardrop (parallel to the subchondral bone) and the central axis of the radial shaft (Medoff, 2005) (Figure 1). The AP distance was defined as the distance between the apex of the anterior and posterior rim.

Measurements on 3D models

The CT scans were used to create digital 3D models to facilitate quantitative Q3DCT analysis. Using Q3DCT we outlined the edges of the fracture gap at the articular surface, resulting in the surface area of the articular gap. We then measured the proximal-distal, posteroanterior and ulnoradial displacement of the anterior lunate facet fragment on a fixed 3D grid. Negative displacement means greater proximal, posterior or ulnar displacement. Positive displacement means greater distal, anterior or radial displacement. By combining these measures one can calculate the 3D vector of anterior lunate facet fragment displacement (Figure 2) (Teunis et al., 2016):

$$\text{3D displacement} (\text{mm}) = \sqrt{(\Delta x^2 + \Delta y^2 + \Delta z^2)}.$$
from the new position, we calculated the proximal–distal, posteroanterior and ulnar radial displacement.

**Measurements on CT scans**

CT sagittal step-off and gap at the anterior lunate facet were determined according to the arc method (Figure 3) [Cole et al., 1997]. TT and SM performed all radiographic, 3D and CT measurements according to previously described methods [Medoff, 2005; Teunis et al., 2016].

**Reliability**

We previously found interobserver agreement intraclass correlation of the teardrop angle to be 0.66 (95% confidence interval [CI] 0.40 to 0.81), AP distance 0.89 (95% CI 0.82 to 0.94), 3D vector displacement 0.82 (95% CI 0.69 to 0.90), and gap surface area 0.93 (95% CI 0.74 to 0.98), CT sagittal step-off of 0.56 (95% CI 0.33 to 0.73), sagittal gap 0.85 (95% CI 0.74 to 0.92) [Teunis et al., 2016, 2017].

**Study population**

Of the original cohort of 73 patients, 36 were included in this study because each one had a separate anterior lunate facet fragment. The patient demographics and fracture measurements are detailed in Tables 1 and 2.

**Statistical analysis**

Continuous data are presented as mean (SD), and discrete data are presented as percentage and number. We used Pearson correlations to compare two continuous variables. We had no missing variables. Apriori power analysis for our primary null hypothesis indicated that a sample of 35 participants would provide 80% statistical power, with alpha set at
0.05, to find a correlation of 0.46 or higher. This was based on a previous study (Fujitani et al., 2012), and only a rather large correlation would make the radiographic teardrop angle a reliable measure for anterior lunate facet displacement.

**Results**

**Overall 3D displacement**

Teardrop angle and AP distance measured on radiographs were not associated with overall 3D displacement of the anterior lunate facet in a digital model after fracture or after surgery (Table 3).

**Q3DCT displacement**

Greater teardrop angle after fracture was associated with greater distal and anterior displacement of the anterior lunate facet fragment. After surgery the teardrop angle was not associated with any other measures of displacement of the anterior lunate fragment (Table 3).

Greater AP distance after fracture was associated with greater proximal displacement of the anterior lunate facet. After surgery the AP distance was not associated with any other measures of displacement of the anterior lunate fragment (Table 3).

**Gap surface area and CT displacement**

Greater teardrop angle after fracture was associated with greater step-off on sagittal CT scan. After surgery, the teardrop angle was not associated with any measures of displacement on CT. After fracture, the AP distance was not associated with any measures of displacement on CT. After surgery, greater AP
distance was associated with greater surface area of the articular gap, greater CT sagittal step-off and gap (Table 3).

Discussion

The teardrop angle and AP distance have been noted to be important measures of articular displacement in distal radial fractures – particularly, displacement of the anterior lunate facet. This postulation is based on wisdom instead of objective measurement. We used Q3DCT analysis on digital fracture models to determine how well the teardrop angle and AP distance measured on radiographs relate to actual anterior lunate facet displacement. After injury, the teardrop angle is associated with anterior lunate facet displacement, but not after surgery. Increased AP distance is mainly associated with articular incongruity after anterior plate fixation. A reliable measure of articular displacement on plain radiographs could potentially reduce the number of CT scans obtained and is useful in situations when CT is impractical, for example operatively or during follow-up.

This study has some limitations. First, we selected cases based on CT scans that demonstrated a separate anterior lunate facet. This limits generalizability of our results to fractures with an unclearly separated anterior lunate facet. Second, we included 36 fractures. A larger sample size may have found smaller correlations significant. Third, this study was powered on our primary null hypothesis. All other analyses are hypothesis generating and should be reassessed in future study. Fourth, although rotation is part of anterior lunate facet displacement as well, our methods could not assess it.

Teardrop angle and AP distance were not associated with overall 3D displacement of the anterior lunate facet after injury or surgery. Overall displacement is the vector of displacement on three axes: proximal-distal, posteroanterior and ulnar-radial. Since the teardrop angle and AP distance are measured on lateral radiographs, they do not include ulnar-radial displacement. Because ulnar-radial displacement makes up part over the overall 3D vector, it dilutes the strength of any correlation with overall 3D displacement.

After injury, greater teardrop angle is associated with greater distal and anterior displacement of the anterior lunate facet, which makes it a valid measure of anterior lunate facet displacement in new distal radial fractures. We found a postoperative nearly normal mean teardrop angle. During anterior locking plate fixation, great care is taken to reduce and secure the anterior lunate facet. Any residual articular incongruity can probably no longer be gauged from the (restored) teardrop angle. After surgery, the teardrop angle seems no longer to be a reliable measure to gauge articular incongruity.

Greater AP distance was only associated with greater distal anterior lunate facet displacement after fracture. After surgery, AP distance was not associated with proximal-distal, posteroanterior and ulnar-radial anterior lunate facet displacement. AP distance after injury and after surgery does not

| Radiographic characteristics | Pearson correlation [r] between characteristic and teardrop angle | Pearson correlation [r] between characteristics and anteroposterior distance |
|-----------------------------|--------------------------------------------------|-------------------------------------------------|
|                             | After fracture | After surgery | After fracture | After surgery |
| Overall 3D anterior lunate facet displacement | −0.18 0.28 | 0.065 0.71 | 0.024 0.89 | 0.31 0.064 |
| Q3DCT displacement | Surface area of the anterior lunate facet fragment* | 0.27 0.11 | 0.22 0.24 | 0.28 0.10 | 0.13 0.49 |
| Proximal-distal displacement | 0.49 0.003 | 0.25 0.18 | 0.39 0.019 | 0.23 0.21 |
| Posterior-anterior displacement | 0.54 <0.001 | 0.006 0.97 | 0.25 0.14 | 0.32 0.088 |
| Ulnar-radial displacement | −0.19 0.26 | −0.021 0.91 | −0.19 0.27 | −0.22 0.23 |
| Gap surface area | 0.33 0.059 | 0.060 0.73 | 0.32 0.063 | 0.65 <0.001 |
| CT displacement | CT sagittal step-off | 0.45 0.006 | −0.032 0.85 | 0.17 0.32 | 0.36 0.031 |
| | CT sagittal gap | 0.26 0.13 | 0.0086 0.96 | 0.24 0.15 | 0.61 <0.001 |

Bold p-value indicates statistically significant correlation.
Q3DCT: quantitative three dimensional computed tomography.

Table 3. Pearson correlation between radiographic characteristics and teardrop angle or anteroposterior distance.
seem to be a very accurate measure of anterior lunate facet displacement. Teardrop angle after injury was associated with CT sagittal step-off. A larger sample size might have resulted in an association with CT gap and Q3DCT gap surface area. A previous study reported a correlation of the teardrop angle with CT articular gap and step-off after fracture (Fujitani et al., 2012). After injury, a greater teardrop angle resembles step-off measured on CT and potentially measures gap. The association of teardrop angle with CT gap could be confirmed by future study with a larger sample size. After surgery, the teardrop angle no longer reflects articular incongruity, probably due to near-to-normal teardrop angle restoration after anterior plating.

After injury, AP distance was not associated with CT measures of articular incongruity. However, after surgery, greater AP distance was associated with greater articular gap surface area, and CT sagittal gap and step-off. Therefore, after surgery, AP distance could be used to gauge articular incongruity, when the teardrop angle loses its validity. Future study could assess the effect of teardrop angle and AP distance on functional outcome.

Declaration of conflicting interests The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: T. Teunis declares grant support from from ZonMw and CZ, consultancy payments from VCC, PATIENT+, and DePuy Synthes and non-financial support from Stryker outside the submitted work. S. Meijer has nothing to disclose. J. Jupiter declares consultancy payments from Aptis Co and Trimed company outside the submitted work. D. Rikli declares financial relationship to DePuy Synthes outside the conduct of the study. All authors certify that there are no other financial or personal conflicts of interest with regards to the material discussed in the manuscript.

Funding The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: T. Teunis declares grant support from the AO Foundation via the AO TK Trauma Network during the study for study design, analysis and manuscript preparation.

Ethical approval This study was approved by each participating hospital’s ethical committee.

References
AO Clinical Investigation and Documentation. 2.4 mm Variable Angle LCP Two-Column Anterior Distal Radius (VALCP2010), 2010. https://clinicaltrials.gov/ct2/show/NCT01103297 (accessed 16 October 2016).
Cole RJ, Bindra RR, Evanoff BA, Gilula LA, Yamaguchi K, Gelberman RH. Radiographic evaluation of osseous displacement following intra-articular fractures of the distal radius: reliability of plain radiography versus computed tomography. J Hand Surg Am. 1997, 22: 792–800.
Fujitani R, Omokawa S, Iida A, Santo S, Tanaka Y. Reliability and clinical importance of teardrop angle measurement in intra-articular distal radius fracture. J Hand Surg Am. 2012, 37: 454–9.
Medoff RJ. Essential radiographic evaluation for distal radius fractures. Hand Clin. 2005, 21: 279–88.
Teunis T, Bosma NH, Lubberts B, Ter Meulen DP, Ring D. Melone’s concept revisited: 3D quantification of fragment displacement. J Hand Microsurg. 2016, 8: 27–33.
Teunis T, Joeris A, Schaser KD et al. Evaluation of radiographic fracture position one year after variable angle locking anterior distal radius plating. A prospective multicentre case series. J Hand Surg Eur. 2017, 42: 493–500.