Prediction of distal radius fracture redisplacement: a validation study

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ABSTRACT

Objective: To externally validate the Edinburgh Wrist Calculator (EWC) in a population of patients with distal radius fractures at risk for loss of threshold alignment.

Design: A retrospective cohort study.

Setting: One academic hospital.

Patients/participants: All consecutive adult patients with a displaced distal radius fracture with initial dorsal angulation >10° and/or an ulnar variance of >3 mm who were treated with closed reduction and cast immobilisation between 2009 and 2014.

Main Outcome measurement: The sensitivity and specificity for diagnosis of loss of threshold alignment within 2 weeks of injury was calculated at the 10%, 40% and the original 70% probability thresholds. The Area under Receiver Operating Characteristics Curve (AUC) was calculated using two different thresholds for loss of alignment: Mackenney and colleagues and the Dutch consensus standards.

Results: The EWC predicted a greater than 70% chance of redisplacement for only 3 fractures. Redisplacement within 2 weeks occurred in 61 of 99 (62%) fractures according to the thresholds of Mackenney et al. and in 18 of 99 (18%) fractures according to the Dutch thresholds. The sensitivity increased and the specificity decreased using a lower probability threshold for redisplacement. The AUC of the EWC was poor for Mackenney’s thresholds (0.47; 95% CI: 0.36 – 0.59) and adequate for the Dutch thresholds (0.71; 95% CI: 0.58 - 0.84).

Conclusions: The EWC was a poor predictor of fracture redisplacement greater than threshold in displaced distal radius fractures in our patient population.
INTRODUCTION

Non and minimally displaced fractures tend to heal in acceptable position when managed non-operatively.\textsuperscript{1,2} Patients with a displaced distal radius fracture are at some risk of losing alignment with non-operative treatment and might consider operative treatment. The probability of redisplacement of reduced and immobilised fractures of the distal radius can inform patients considering surgery.\textsuperscript{3,4}

There are several proposed predictors of loss of alignment after closed reduction.\textsuperscript{3,5-9} Mackenney et al. studied more than 4000 fractures of the distal radius and developed a formula to estimate the probability of fracture redisplacement with non-operative treatment.\textsuperscript{4} An online calculator, the Edinburgh Wrist Calculator (EWC), is available for use in clinical practice and research. Evaluating the performance of a prediction model in various patient populations can help determine where it is most useful.\textsuperscript{10} One recent study of 168 patients with displaced distal radius fractures treated non-operatively to union found that the probability of malunion using Mackenney’s equation correlated with final ulnar variance and radial height and inclination, not dorsal tilt, but diagnostic performance characteristics were not calculated.\textsuperscript{11} Mackenney’s thresholds for loss of alignment are stricter than the Dutch guidelines developed by the Dutch work group for distal radius fractures.\textsuperscript{12} Therefore, in addition to measuring the performance of the EWC in our population of patients, we also evaluated the effect of the threshold used to define loss of alignment.

The aim of this study was to test the performance of the EWC among patients with a displaced fracture of the distal radius, treated with closed reduction and cast or splint immobilisation, using two different thresholds for unacceptable alignment: the thresholds according to Mackenney et al. and the Dutch consensus thresholds.

MATERIALS AND METHODS

Source of data and participants

For this retrospective cohort study, we included all consecutive adult patients with a displaced distal radius fracture treated with closed reduction and immobilisation who visited the outpatient clinic between January 1\textsuperscript{st}, 2009 and August 4\textsuperscript{th}, 2014.
Patients were retrospectively identified using the hospital administration code (in Dutch: DBC, Diagnosis and Treatment Combination) for distal radius fractures. Ethics approval was not required at our institution.

We used the following radiographic definitions consistent with Mackenney and colleagues. Fractures were considered displaced when there was dorsal angulation of $>10^\circ$ and/or a positive ulnar variance of $>3$ mm. Acceptable reduction was defined according to Mackenney et al. as a fracture with dorsal angulation of $\leq 0^\circ$ and a positive ulnar variance of $\leq 3$ mm. An unacceptable reduction was defined as a position with dorsal angulation of $>0^\circ$ and/or a positive ulnar variance of $>3$ mm following closed reduction. The exclusion criteria were similar to Mackenney’s protocol: (1) skeletal immaturity; (2) primary operative treatment; (2) prior fracture malunion; and (4) missing data. Patients with missing radiographic data from the evaluation after reduction were excluded from the analyses.

**Study outcomes measures**

The primary outcome was radiographic redisplacement of the fracture greater than threshold within 2 weeks of reduction. The threshold for unacceptable loss of alignment used by Mackenney et al. was a dorsal angulation of $>10^\circ$ and/or a positive ulnar variance of $>3$ mm. According to Dutch guidelines, the threshold for unacceptable loss of alignment is $\geq 15^\circ$ dorsal angulation or $\geq 20^\circ$ volar angulation of the distal fracture fragment, $\geq 5$ mm radial shortening, or $<15^\circ$ radial inclination.

**Predictors**

According to hospital protocol, patients were evaluated clinically and radiographically at presentation, following closed reduction, and at approximately two weeks and six weeks after injury. Radiographic evaluation comprised standard posteroanterior and lateral radiographs. The following were determined from radiographs by one observer (a clinician with extensive experience in distal radius fracture research): AO/OTA fracture classification, angulation of the articular surface on a lateral radiograph, inclination of the articular surface on a posteroanterior radiograph, radial height, ulnar variance and radial shift (in millimetres), and the presence of any comminution. Comminution was a purely qualitative assessment and included either volar or dorsal comminution or both.
Mackenney et al. expressed ulnar variance as the difference between the injured side and the normal (uninjured) side. However, since we do not regularly image the uninjured wrist, ulnar variance was calculated as the difference between the injured side and a reference value (0.49 mm positive ulnar variance). All radiographs were measured using the functions available on the computerized radiographical system with a calibrated digital ruler and protractor.

**Analysis**

We reported medians and interquartile range (IQR) for non-normally distributed variables, and means and standard deviations (SD) for normally distributed variables. Normality was determined by visually inspecting the histograms.

For each patient, the probability of fracture redisplacement greater than threshold was calculated according to the published EWC formula: \( X = 0.03 \times \text{age} + 0.38 \times (\text{if comminution is present}) + 0.21 \times \text{pre-reduction ulnar variance} - 3.12 \). The probability of redisplacement greater than threshold equals \( \frac{e^X}{1 + e^X} \) * 100. We dichotomized this probability as 70% or greater or less than 70%, as proposed by Mackenney. The sensitivity, specificity, and positive and negative predictive value of these thresholds were calculated. Because only three fractures met this criterion, we were asked during the peer-review process to calculate the sensitivity and specificity using cut-off values of 10% and 40%.

To estimate the ability of the model to discriminate between patients with and without fracture redisplacement, we calculated the Area under the Receiver Operating Characteristics Curve (AUC) for the probability of redisplacement greater than threshold. Higher AUC scores indicate better discrimination. A score of ≤0.5 is considered equal to a coin toss and therefore holds no diagnostic value.

**RESULTS**

During the study period we treated 515 patients with a fracture of the distal radius. A total of 99 patients met the inclusion criteria and were analysed (Figure 1, Table 1).
The probability of redisplacement according to Mackenney’s formula was greater than 70% for only 3 fractures and only one actually lost alignment (Table 2). Sixty-one patients (62%) had fracture redisplacement greater than the Mackenney threshold within 2 weeks. The AUC for the ability of the EWC to discriminate between patients with and without development of fracture redisplacement was 0.47 (95% CI: 0.36 – 0.59). The sensitivity was 1.6% (95% CI: 0.9% – 9.9%) and the specificity was 95% (95% CI: 81% – 99%) (Table 2). The positive predictive value was 33% (95% CI: 4% – 84%) and the negative predictive value 38% (95% CI: 36% – 39%). After decreasing the cut-off value of the predicted probability to 40% and 10%, the sensitivity increased to 36%
Table 1. Characteristics of study population (N=99)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (median, IQR)</td>
<td>63 (54 – 74)</td>
</tr>
<tr>
<td>Sex (female), No. (%)</td>
<td>73 (74)</td>
</tr>
<tr>
<td>AO/OTA fracture classification, No. (%)</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>55 (56)</td>
</tr>
<tr>
<td>B</td>
<td>20 (20)</td>
</tr>
<tr>
<td>C</td>
<td>24 (24)</td>
</tr>
<tr>
<td>Early redisplacement Mackenney et al.*, Number (%)</td>
<td>61 (62)</td>
</tr>
<tr>
<td>Early redisplacement Dutch**, Number (%)</td>
<td>18 (18)</td>
</tr>
</tbody>
</table>

*Redisplacement according to Mackenney et al.: >10° dorsal angulation and/or an ulnar variance of >3 mm.  **Redisplacement according to the Dutch guidelines: ≥15˚ dorsal angulation or ≥20˚ volar angulation of the distal fracture fragment, ≥5mm shortening or <15˚ radial inclination.

Table 2. Performance of the model according to thresholds of Mackenney et al. to when different cut-off values were applied (N=99)

<table>
<thead>
<tr>
<th>Fracture with redisplacement</th>
<th>Early redisplacement occurred</th>
<th>Early redisplacement did not occur</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥70%</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>≥40%</td>
<td>22</td>
<td>14</td>
<td>36</td>
</tr>
<tr>
<td>≥10%</td>
<td>57</td>
<td>38</td>
<td>95</td>
</tr>
<tr>
<td>Fracture without redisplacement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;70%</td>
<td>60</td>
<td>36</td>
<td>96</td>
</tr>
<tr>
<td>&lt;40%</td>
<td>39</td>
<td>24</td>
<td>63</td>
</tr>
<tr>
<td>&lt;10%</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>61</td>
<td>38</td>
<td>99</td>
</tr>
</tbody>
</table>

Sensitivity (95% CI)

- Predicted probability 70%: 1.6% (0.9% – 9.9%)
- Predicted probability 40%: 36% (24% – 49%)
- Predicted probability 10%: 93% (83% – 98%)

Specificity (95% CI)

- Predicted probability 70%: 95% (81% – 99%)
- Predicted probability 40%: 63% (46% – 78%)
- Predicted probability 10%: 0% (0% – 11%)

*Fractures with redisplacement according to Mackenney’s formula using different percentages for the predicted probability.  **Fractures without redisplacement according to Mackenney’s formula using different percentages for the predicted probability. Abbreviations: CI, Confidence Interval
According to the more forgiving Dutch consensus thresholds, only 18 patients (18%) developed fracture redisplacement within 2 weeks of reduction. The AUC of the model was 0.71 (95% CI: 0.58 - 0.84). The model had a sensitivity of 0% (95% CI: 0% - 19%), and a specificity of 96% (95% CI: 90% - 99%) (Table 3). The negative predictive value was 81% (95% CI: 81% - 82%). After decreasing the cut-off value of the predicted probability to 40% and 10%, the sensitivity increased to 56% (95% CI: 31% - 78%) and 100% (95% CI: 78% - 100%), respectively. The specificity decreased to 68% (95% CI: 56% - 78%) and 4.9% (95% CI: 1.6% – 12.8%), respectively (Table 3).
DISCUSSION

The Edinburgh Wrist Calculator was not a good predictor of loss of threshold alignment in our selected population of patients with initially displaced fractures and adequate evaluation time. Since only 3 fractures met the 70% probability criterion, most of the other statistics are relatively meaningless. Lowering the probability threshold did not result in a better diagnostic performance of the prediction model.

This study has several limitations. Because of its retrospective nature, selection of patients for surgery did not follow a protocol. The study population is therefore less clearly defined which limits the generalizability of our results. We also had to exclude a considerable number of patients due to missing radiographs. Our hospital is situated in a city that is frequently visited by tourists who do not continue care with us. It’s possible that prospective application to consecutive patients mimicking the population of patients used to create the EWC would lead to better performance of the model. Another possible reason for the model’s poor performance is the method we used to determine the ulnar variance. Mackenney et al. calculated the ulnar variance as difference between the injured side and the normal (uninjured) side. However, because we do not regularly image the uninjured wrist, we used the published normal value for ulnar variance.

Predictors of loss of reduction or instability in distal radius fractures are well studied.\textsuperscript{5,6,8,15-20} However, the definition of acceptable reduction varies across studies. In general, the Dutch consensus standards are more forgiving, allowing up to 15° of dorsal angulation or 20° of volar angulation, and 5 mm of radial shortening. The EWC performed better when it was used to predict fracture redisplacement according to the Dutch thresholds, so it’s possible that more forgiving thresholds might perform better in clinical prediction rules.

The poor performance of the model could be explained by our local practices. Our surgeons may be less likely to recommend primary operative treatment, leading to a higher rate of redisplacement. The higher percentage of patients with fracture redisplacement in our sample (62% versus 43% for Mackenney et al.) supports this contention. If the initial prediction rule excluded most of these fractures due to primary operative treatment, it may have affected the statistics, resulting in a low number of fractures meeting the 70% threshold. Moreover, in our study sample 44% of the fractures were intra-articular, while it’s unclear how many intra-articular fractures were included by Mackenney and colleagues.
A prediction model for redisplacement greater than threshold, and thus a tool to select patients pre-emptively for operative treatment, may be of less value in patients with intra-articular fractures. This because other factors such as gap and step-off play an important role and surgeons might be more likely to recommend operative treatment.

**Conclusions**

The Edinburgh Wrist Calculator had poor discrimination in our patient population. This suggests that the model is not helpful for decision making for the subset of patients we studied. We recommend clinicians to validate the model in their own population before using it in clinical practice. Additional research is merited to determine how closely the practice setting must mimic the setting used to create a clinical prediction rule.
REFERENCES


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