The Effect of Fall-Related Factors on Colles’ Fracture

INTRODUCTION

Distal forearm fracture is one of the most frequently observed osteoporotic fractures which may occur as a result of low energy falls such as falls from a standing height and may be linked to the osteoporotic nature of the bone especially in the elderly. In order to improve both the diagnosis of high fracture risk individuals and the fracture prevention methods, the influence of extrinsic and intrinsic factors during a fall needs to be identified in detail.

In this study, fracture mechanics-based cohesive finite element method, which was shown to successfully predict the effect of intrinsic bone properties on Colles’ fracture load [1], is used to assess the combined effect of the extrinsic and intrinsic factors on radius fracture. The current study (i) evaluates the influence of the load orientation and the load distribution between the scaphoid and lunate on the Colles’ fracture load (ii) establishes a robust fracture risk assessment method that combines the effects of intrinsic properties of bone (age-related change in fracture properties and bone geometry) with extrinsic factors (load orientation and load distribution) associated with a fall, and (iii) determines the strongest predictive factor for Colles’ fracture load.

METHODS

Seven idealized three-dimensional radius geometries (Fig.1a) were created using the finite element program, ABAQUUS, based on the measurements provided in the literature [1]. A crack plane that simulates Colles’ fracture was created by inserting cohesive elements in the model (Fig.1a). Cohesive finite elements are based on a traction-crack opening displacement relationship (Fig.1b) and form a crack when there is no transfer of traction between the opening surfaces.

The load was applied at the top surface of the model with 11 different orientations based on experimentally measured fall configurations [2,3]. The loads were applied following the five load distribution ratios between the lunate and scaphoid ranging from 0.25 to 1 [4,5]. The age-related changes in fracture properties were investigated for 50, 70 and 90 years by modifying the cohesive parameters [1]. Multiple regression analyses were performed including both intrinsic and extrinsic factors to identify the best explanatory variable for the Colles’ fracture load.

RESULTS

The fracture load decreased by 3 to 4 times with increasing and decreasing angle with respect to the axial and the dorsal axis of the bone, respectively (Fig. 2a,b). The lowest correlation was observed between the fracture load and the angle with respect to the lateral (Fig 2c). The fracture load increased by about 1.3 times for all geometries as the load ratio between the lunate and scaphoid decreased from 1 to 0.25 (Fig. 3a). The variation of fracture load with cortical polar moment of inertia (CJ) was linear for all load distribution and load ratio cases with correlation values varying between $r^2 = 0.95$ to 0.99 (Fig. 3b). The variation in the load orientation had a more significant influence on the fracture load compared to the load ratio for all geometries. The combined variation in the load distribution and load orientation lead to the largest change in the fracture load (Fig. 3b).

Stepwise multiple regression analysis showed that (Table 1) neither the intrinsic bone properties (M1) nor the extrinsic factors (M2) provided a good prediction of the fracture load when they were considered separately. However, combining the intrinsic and extrinsic factors improved the fracture load predictions significantly (M3, M4). When only the strongest predictors among the intrinsic and extrinsic factors were used (M3) the fracture load predictions resulted in a correlation value that was very close to the predictions including all factors (M4). The addition of the load ratio to any of the models did not change the predictions. The fracture properties based on age did not have a strong contribution to the fracture load.

![Figure 1: (a) A 3D distal radius finite element mesh and the cross section of the crack plane tiled with cohesive elements (b) Traction-displacement relationship defining the cohesive zone model.](image)

![Figure 2: Fracture load vs. load angle with respect to the (a) axial axis (b) dorsal axis (c) lateral axis for two representative geometries under uniform load ratio with fracture properties of 50 years.](image)

![Figure 3: (a) Fracture load vs. load ratio for two geometries under a constant load orientation for 50 years. (b) Fracture load vs. CJ for two different load ratios and angles with respect to the longitudinal axis using fracture properties for 50 years (AL=axial angle, LR=load ratio).](image)

Table 1: Multiple regression models and the corresponding $r^2$ values for predicting the fracture load (F(N)) using extrinsic (LR = load ratio, AL, AD = axial, dorsal angle (degrees)) and intrinsic factors (Age (years), CJ (mm$^3$)). Note that $p < 0.0001$ for all models.

<table>
<thead>
<tr>
<th>Multiple Regression Models</th>
<th>$r^2$</th>
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<tbody>
<tr>
<td>M1: F = -24.72 Age + 1.32 CJ + 1525</td>
<td>0.41</td>
</tr>
<tr>
<td>M2: F = -723.72 AL-1076.37 LR - 220.26 AD + 32408</td>
<td>0.44</td>
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<tr>
<td>M3: F = 1.24 CJ - 522.43 AL + 9064</td>
<td>0.44</td>
</tr>
<tr>
<td>M4: F = -34.19 Age + 1.32 CJ - 630.68 AL-262.18LR-10494AD+20744</td>
<td>0.83</td>
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</table>

DISCUSSION

The current study focused on the combined effect of extrinsic and intrinsic factors and provided additional insight into the contribution and interaction of these factors in determining the Colles’ fracture load using cohesive finite element modeling.

The results showed that the fracture load increased with smaller (larger) angles with respect to the axial (dorsal) axis. The fracture load also varied as a function of the load ratio between the lunate and scaphoid, however, not as drastically as with the load orientation. Multiregression analysis showed that the bone geometry and the load orientation are the most significant components that contribute to the prediction of the fracture load. These findings indicate that evaluating the geometrical properties of an individual’s bone using advanced imaging techniques, and developing fracture intervention approaches that focus on protective fall response strategies can be valuable for fracture assessment and prevention.

In summary, this study established a computational fracture risk assessment method that combined the effects of intrinsic properties of bone with fall-related extrinsic factors and may be elemental in diagnosis of high fracture risk individuals as well as in the development of fracture prevention methods including protective falling techniques.