MULTIVARIATE INJURY RISK CRITERIA FOR FRACTURES TO THE DISTAL RADIUS

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INTRODUCTION

- The number and severity of forward fall related distal radius fractures has remained high and consistent over the last 20 years [1].
- Previous attempts to develop distal radius injury criteria have not considered the dynamic multidirectional nature of forward fall initiated loading [2].
- Accurate failure probability models are needed to assess the effectiveness of injury prevention strategies (*e.g.* wrist guards, protective flooring and fall prevention training).

PURPOSE

- Develop a multivariate distal radius injury risk prediction model that incorporates dynamic loading variables in multiple directions.
- Utilize the Weibull distribution to interpret the failure data and establish distal radius injury probability thresholds.

METHODS: INJURY CRITERIA DEVELOPMENT

- A custom designed pneumatic impactor (Figure 1) [3,4] was used to impact eight cadaveric radius specimens, potted to match the impact surface/radius angle commonly reported.
- Impacts were applied at increasing energy levels, starting at 20 J (*i.e.*, pre-fracture) and increasing in 10 J increments, until a crack (*i.e.*, non-propagating damage) and fracture (*i.e.*, specimen separated into at least two fragments) were recorded.

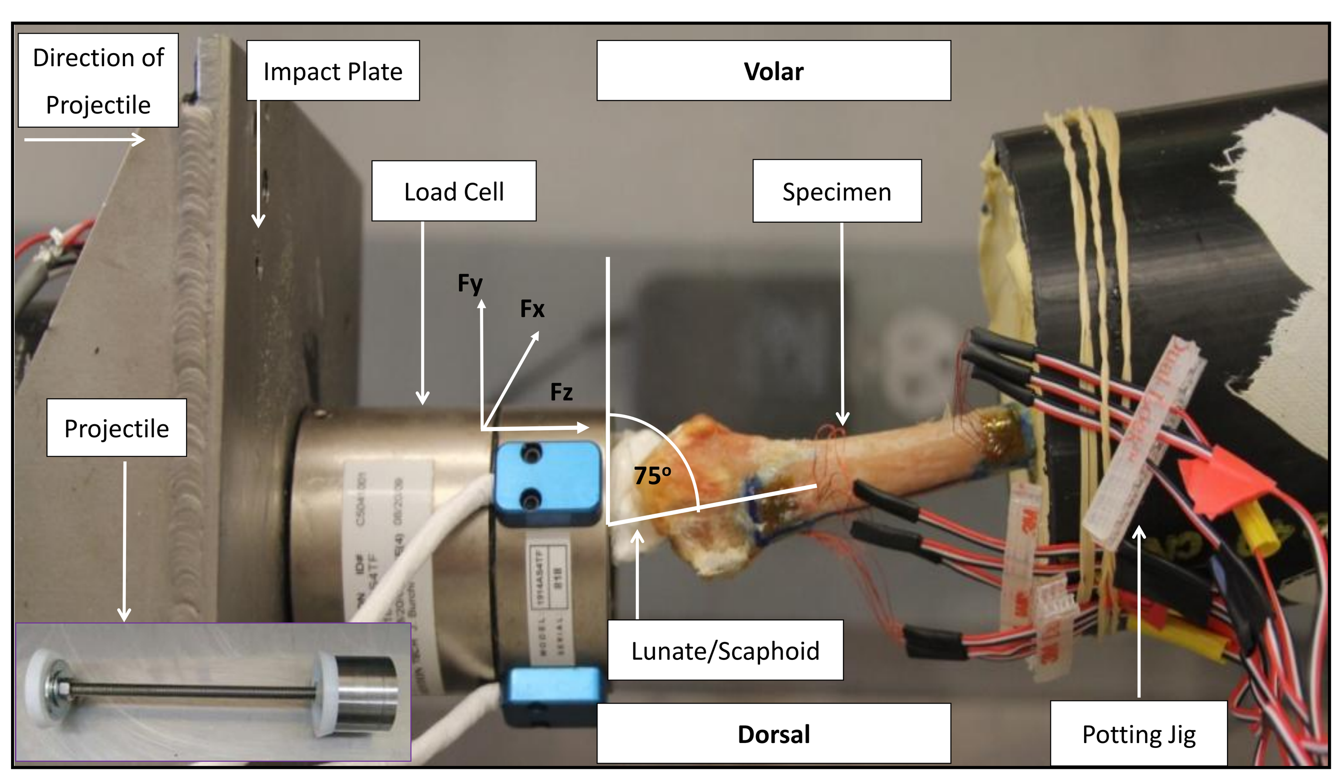

Figure 1: *Components of the pneumatically-controlled impactor including the projectile (inset). Also shown are the three force axes and the impact surface/radius impact angle.*

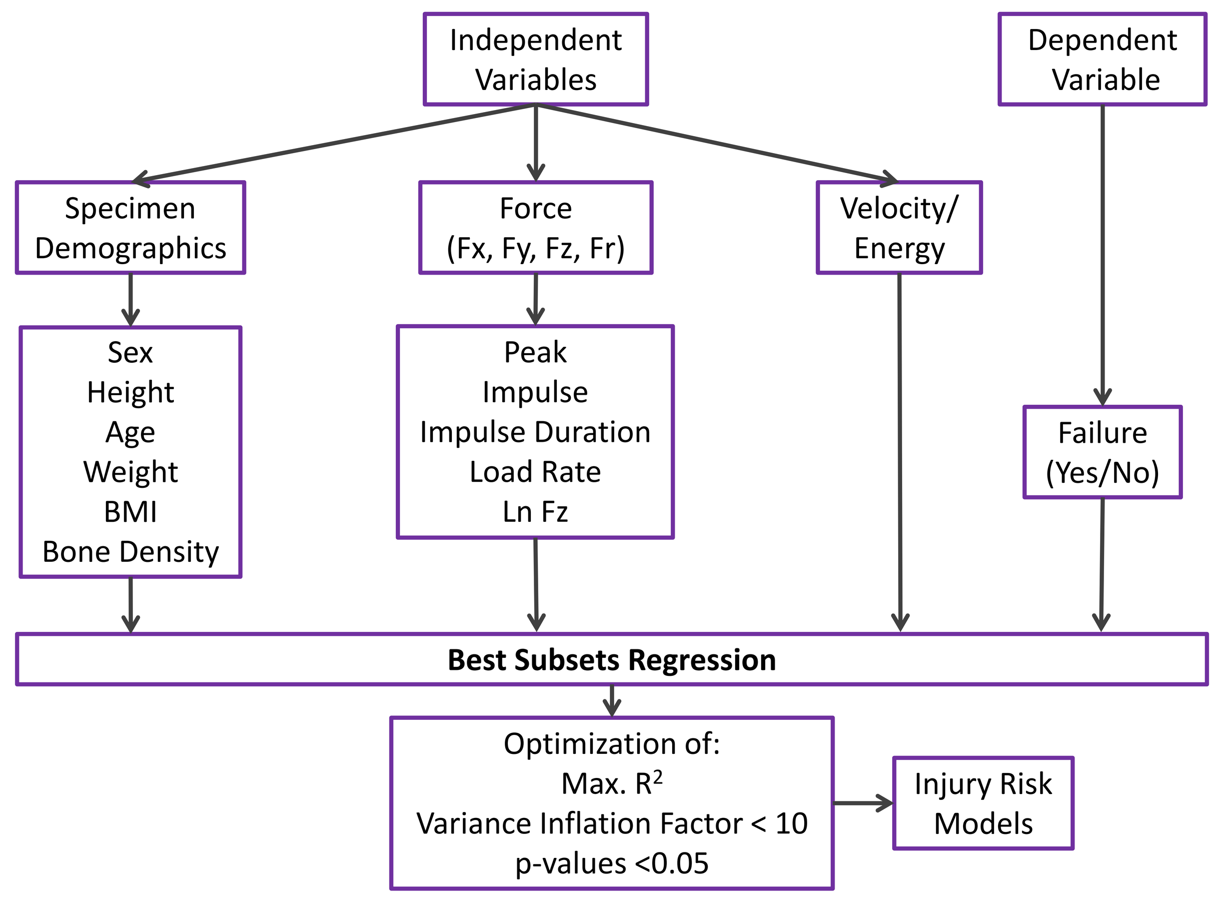

Figure 2: *Diagram showing the best subsets regression protocol and flow of data.*

- Best subsets regression analyses were used to determine the best combination of variables that predicted the risk of a crack and fracture event separately (Figure 2).
- Force-only models were also created for comparison.

METHODS: WEIBULL ANALYSIS

- Weibull analysis[5]:
  - Assessment of failure and survivability data
  - Provides evidence of the underlying failure mechanism
  - Robust to small sample sizes
- Weibull parameters are calculated from Weibull plots (Figure 3); Eq. (1) versus Eq. (2).
  - Shape parameter (β) - Slope of the best fit line (Figure 3)
  - Scale Parameter (α) - Calculated from Eq. (3)

$$y = \ln\left(\ln\left\{\frac{1}{1-P_f}\right\}\right) \quad (1)$$

P_f = median rank of each failure criteria (Fz or risk score)

$$x = \ln(z) \quad (2)$$

z = Fz or the risk score

$$\alpha = e^{-\left(\frac{b}{\beta}\right)} \quad (3)$$

b = intercept of the Weibull plot (Figure 3)

$$F(x,\alpha,\beta) = 1 - e^{-\left(\frac{r}{\beta}\right)^{\alpha}} \quad (4)$$

r = risk scores calculated from model or Fz

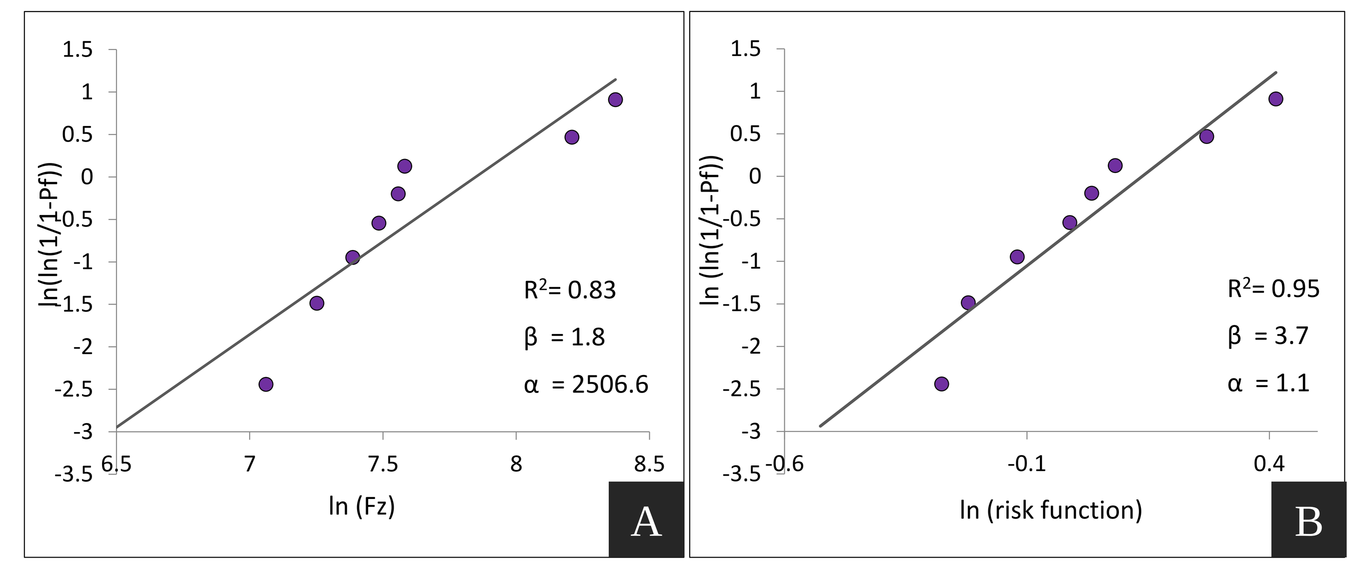

Figure 3: *Force-only crack (A) and Multivariate fracture (B) event Weibull plots showing the R^2, and the α and β parameters.*

- Cumulative distribution functions (CDF) were produced (Eq. 4), the shape of which are dependent on the alpha and beta coefficients; risk scores at 10% probability of injury were calculated .

RESULTS

- The mean (SD) fracture velocity was 3.4 (0.7) m/s resulting in a mean (SD) fracture force of 2142.1 (1228.7 N).
- The damage incurred by the distal radius was consistent and clinically relevant in terms of severity and location (Figure 4).
- Crack (R^2=0.69) and fracture (R^2=0.85) models were developed containing dynamic multidirectional variables (Table 1).
- In contrast, peak Fz alone accounted for only 55% and 29% of the variance in the crack and fracture outcomes, respectively.
- There is a 10% probability of crack and fracture at risk scores of 0.45 and 0.61, respectively (Figure 5).

Table 1: *Summary of the multivariate crack and fracture event prediction models*

Model and Variables	Model R^2	Beta Coefficients	p-values	Variance Inflation Factor
Multivariate Crack	0.698			
Intercept		5.0	0.087	0
Fy Impulse		0.2	0.007	1.05
Fz Load Rate		5.0E-7	0.013	2.57
Velocity		0.1	0.020	4.33
Ln Fz		-0.9	0.047	5.41
Multivariate Fracture	0.852			
Intercept		-1.196	0.001	0
Fz Peak		-0.00027	0.015	2.46
Fy Impulse		0.18	0.005	1.24
Velocity		0.665	0.001	2.23

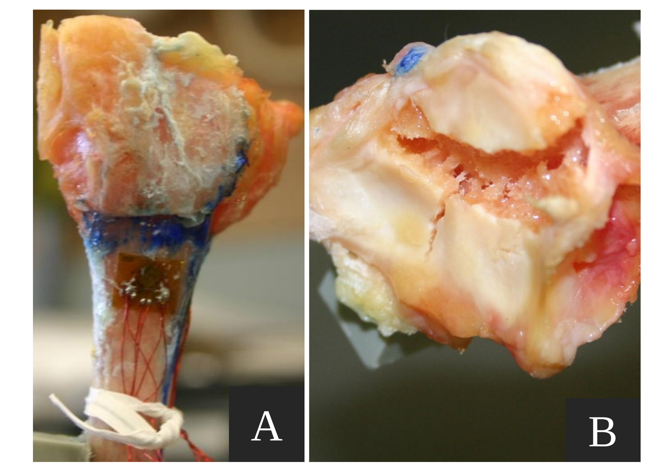

Figure 4: *Dorsal (A) and intra-articular (B) views of the radius showing the locations and severity of fracture.*

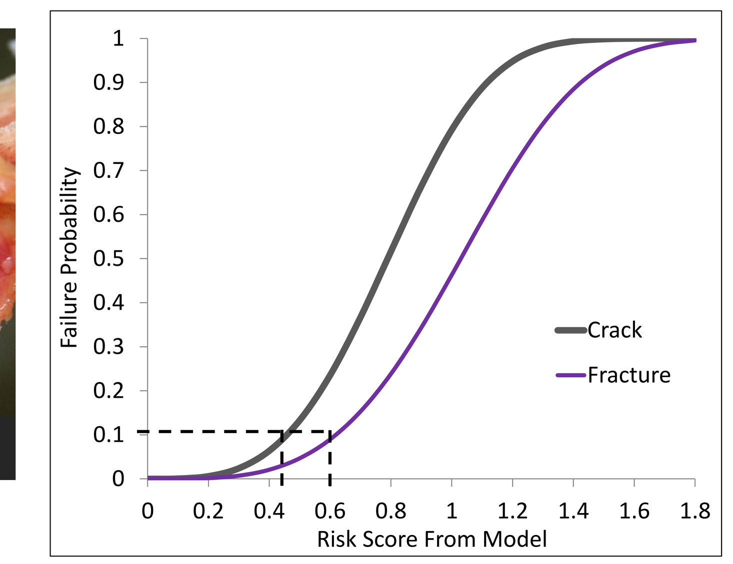

Figure 5: Crack and fracture impact event CDFs. The dotted lines show risk scores at 10 % *probability of injury.*

DISCUSSION

- Overall, the multivariate models provided better failure predictions (based on R^2) compared to the axial (Fz) force-only models.
- The results suggest that force directions and rates must be considered, along with force magnitudes when attempting to predict the risk of distal radius fractures.
- The force-only beta coefficients are suggestive of a "constant failure" mechanism while multivariate beta coefficients are representative of a "wear out" failure mechanism [4].

CONCLUSION

- The current study highlights the importance of considering all impact force components and dynamic measures that predict distal radius fracture risk. An injury probability threshold of 10% has been presented and should assist researchers in the assessment and development of injury prevention interventions.

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