Humerus and Forearm Fracture Bending Risk Functions for the 50th Percentile Male

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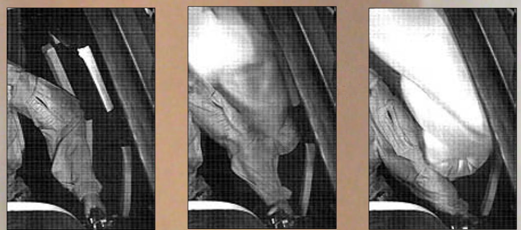
Introduction

The advent of airbags in automobiles has reduced fatal injuries in automobile crashes, but have increased the incidence of some non-fatal injuries especially those in the upper extremities. Jernigan et al. investigated severe upper extremity injuries resulting from frontal automobile crashes and showed that occupants exposed to an airbag deployment were statistically more likely to sustain a severe upper extremity injury (2.7%), than those occupants not exposed to an airbag deployment (1.6%) (p=0.01) [1]. Two modes of injury have been suggested to explain the increased incident of upper extremity injuries with airbag deployment. The first type is an indirect type of injury in which the airbag propels the upper extremity into an object in the vehicle such as the roof. The second type is called primary contact which is attributed to contact with the airbag or airbag flap. The purpose of this study was to combine experimental data from tests that calculated mean humerus and forearm failure bending moment and produce humerus and forearm injury risk functions for the 50th percentile male by using mass, orientation, and rate scaling factors.



High Speed Video frames of an Upper Extremity struck by a side airbag

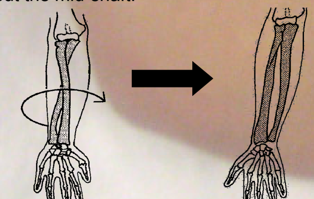
Methods

DATA COLLECTION

Published data from a total of 25 three point bending experiments on male cadaver humeri and 28 three point bending experiments on male cadaver forearms were gathered [2] [3] [4] [5].

SCALING PROCESSES

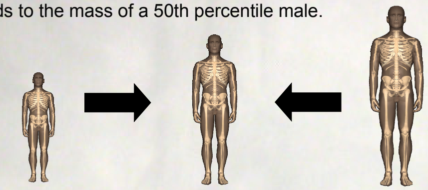
Depending on the application three different scaling techniques were utilized. First, the forearm moments were scaled based on orientation because the forearm is 14% weaker in the supinated position than in the pronated position; however, orientation scaling was not needed for the humerus because the symmetry about the mid-shaft.



$$M_{\text{Orientation Scaled}} = M_{\text{Supinated}} * 0.86$$

$$M_{\text{Orientation Scaled}} = M_{\text{Pronated}}$$

Next, the moment was mass scaled, using the entire cadaver, to 77kg which corresponds to the mass of a 50th percentile male.



$$\lambda = \left(\frac{77}{m}\right)^{1/3}$$

$$M_{\text{Orientation and Mass Scaled}} = M_{\text{Orientation Scaled}} * \lambda^3$$

Given the widely varying impact rates between humerus tests, the humerus moments were scaled to an equivalent loading rate of 3.63 meters/second because it matches the humerus loading rates as measured in the cadaveric subjects under side airbag loading. A limit was placed on this scaling in that everything below 0.005m/s was treated as 0.005m/s because if the test get infinitely slower the bone does not get infinitely weaker. The forearm experiments were all preformed at dynamic rates so rate scaling was not needed.

$$M_{\text{Orienation and Mass and Rate Scaled}} = M_{\text{Orienation and Mass Scaled}} * \left(\frac{3.63^{0.06}}{V_{test}^{0.06}}\right)$$

CREATION OF RISK FUNCTION

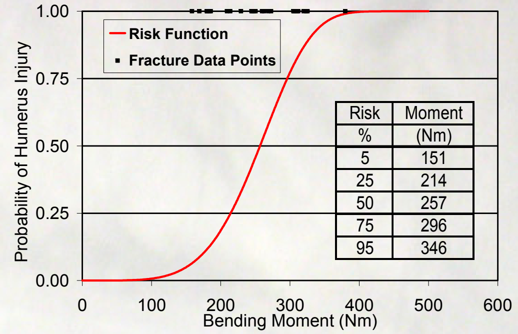
Survival analysis was utilized to develop the risk functions. A Weibull model was chosen because of its increasing hazard model with severity and the closed form solution of its Cumulative Distribution Function (CDF). The Weibull CDF is given by, (Equation 1), where λ and γ are the scale and shape parameters respectively and x is the measured bending moment. This function provides an estimate of risk of injury using the maximum likelihood estimate of the scale and shape parameters.

$$\text{Risk of Fracture} = 1 - e^{-(\lambda * x)^{\gamma}}$$

Results

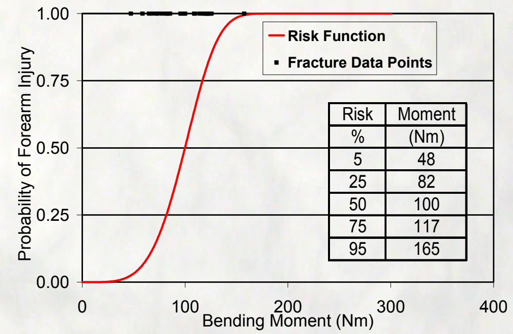
$$\text{Humerus Risk of Fracture} = 1 - e^{-(0.0036 * x)^{4.871}}$$

$$\text{Forearm Risk of Fracture} = 1 - e^{-(0.0092 * x)^{4.409}}$$



Risk %	Moment (Nm)
5	151
25	214
50	257
75	296
95	346

Humerus fracture risk function for the 50th percentile male.



Risk %	Moment (Nm)
5	48
25	82
50	100
75	117
95	165

Forearm fracture risk function for the 50th percentile male.

Conclusion

Based on the experimental data collected from previous primary studies risk functions were computed for forearm and humerus fracture for the 50th percentile male. The results show that a 50% risk of injury corresponds to 257Nm for the humerus and 100Nm for the forearm. It is believed that the risk function can be utilized with an instrumented upper extremity during vehicle testing.

References

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[2] Kallieris, D., Rizzetti, A., Jost, S., Priemer, P., Unger., M., "Response and Vulnerability of the Upper Arm Through Side Airbag Deployment," *Proc. 41st Stapp Car Crash Conference*, pp. 101-100, Society of Automotive Engineers, Warrendale PA, 1997

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