Frailty and Injury Causation

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ABSTRACT – Purpose: The current study will attempt to elucidate whether frailty has a role in motor vehicle crash injury causation.

Methods: The association between frailty and injury was studied among Crash Injury Research Engineering Network (CIREN) cases. The baseline "physical functioning" (PF) score of the SF-36 was used as a marker of frailty (i.e., PF score <75). Frailty associations with ISS and occupant, vehicular and crash factors were explored. Frailty association with delta V was analyzed among injured (i.e., brain, rib, or femur) belted occupants in frontal crashes to establish whether frailty confers a different risk of each particular injury.

Results: Frailty occurred in 13.7 % of the cohort (n=1,747). Median (q1-q3) ISS was 14.0 (10-22) among the frail and 17.0 (10-24) among the non frail (p=0.40). Frailty was significantly associated with advanced age, male gender, the presence of co-morbidities, extreme BMIs, frontal and near-side crashes and delta V < 45 km/h. Seat belt use and ISS<16 were not associated with frailty. Multiple linear regressions, adjusting for age, gender and BMI revealed a negative association between frailty and log delta V (coefficient -0.188, p=0.04) among those with rib fractures but not among those with brain injuries or femur fractures.

Conclusion: PF score, a marker of frailty, is associated with similar ISS and lower delta V and is independently linked to lower delta V thresholds for some injuries (i.e. rib fractures) but not for others (i.e. brain injuries and femur fractures). These associations suggest a potential role of frailty in injury causation.

INTRODUCTION

With the aging of the U.S. population, there is increasing interest in the role of frailty in injury and illness. Despite the conceptual and clinical overlap between disability, co-morbidity and functional decline due to aging, researchers over the last 20 years have attempted to arrive at a clear operational definition of frailty.

While there may not be a complete consensus on the definition of frailty, it is commonly understood that frailty predisposes individuals to poor clinical outcomes (Abellan van Kan et al, 2010). In general, frailty has been considered a syndrome independent of normal aging and the result of impairments in multiple biological systems (Fried et al, 2004). Impairments present in frailty include sarcopenia (i.e. loss of skeletal muscle mass), functional decline (weakness, slowed reflexes, impaired vision, etc), neuroendocrine dysregulation, and immune impairments (Fried et al, 2004). Frailty has been framed in two different phenotypical conceptualizations: 1) a physical phenotype characterized by declines in lean body mass, strength, endurance, balance, walking performance, and low activity, and 2) a multidimensional phenotype also includes cognitive impairments, mood disorders, sensory impairments, poor social conditions and support, chronic diseases, and disability (Abellan van Kan et al, 2010).

For the purpose of measuring the physical phenotype of frailty, Fried et al categorized frailty as having three or more of the following

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characteristics: shrinking (weight loss), weakness (grip strength), poor endurance and energy (exhaustion), slowness (time to walk), and low physical activity level (Fried et al, 2001). Patients with none of these characteristics were considered robust and those with one or two characteristics were considered intermediate/possibly pre-frail.

Woods, et al (2005) validated the use of SF-36 self-reported measures as a surrogate for the weakness, slowness, and exhaustion metrics identified by Fried. That work used the physical functioning category of the SF-36 as a measure of slowness/weakness and the vitality category as a measure of exhaustion. A link between SF-36 and other measures of frailty (i.e. frailty index) have also been shown in different populations (Saxton and Velanovich, 2011).

Frailty has been linked to higher rates of death, disability, institutionalization, and falls in the general population of older adults [Cardiovascular Health Study and the Women's Health and Aging Study, and the Women's Health Initiative Observational Study (WHI-OS)] (Abellan van Kan et al, 2010) and more frequent postoperative complications after elective surgery (Saxton and Velanovich, 2011). In a previous study it was shown that, independent of chronological age, markers of frailty were predictive of injury recovery after moderate and severe vehicular crashes (Andersen et al, 2010). That study used pre-injury physical functioning, vitality and mental health scales from the SF-36 as markers of frailty.

The current study will attempt to elucidate whether frailty has a role in injury causation among occupants of vehicles involved in crashes. Given the link between frailty and diminished tissue strength the expectation would be that given the occurrence of a crash, individuals with markers of frailty, will experience a higher frequency and severity of injuries in general. On the other hand, frailty related decrease in muscle function (i.e., delayed muscular responses to stimuli and decreased strength of muscle contraction) could affect the occurrence of injuries during a crash in a less predictable way. Several studies have suggested that muscle bracing, by modifying the pre-collision occupant position, may influence the occurrence of injuries in different ways for different body regions. Typically, braced individuals would exhibit increased forces to the lower extremities and decreased forces to the thorax (Bose 2008, 2010).

Hence, it was also hypothesized that, due to the effect of frailty on bracing, vehicular occupants with markers of frailty will experience a higher risk of certain injuries (chest) and lower risk of injuries to the femur region when involved in frontal crashes.

The primary research questions: 1) Are the crash, occupant, and injury characteristics among those who are frail different than among those who are not frail; and 2) Is frailty associated with specific injuries (femur and multiple rib fractures, and traumatic brain injury (TBI)).

METHODS

Data from the Crash Injury Research Engineering Network (CIREN) database were used for this analysis, which includes trauma patients with one Maximum Abbreviated Injury Severity (MAIS) score of 3+ or two MAIS 2+ injuries who were occupants of a vehicle less than eight years old. All cases with baseline Short Form-36 (SF-36) scoring, the psychosocial outcome test incorporated into CIREN, were included in this analysis.

The baseline SF-36 was administered in an interview format in-person at the baseline assessment. The baseline assessment queried the respondent regarding the four weeks prior to the injury, hence reflects the pre-injury functioning. The SF-36 is a widely used and validated tool to assess self-perceived health status (Ware and Shelbourne, 1992). Further description of the tool is given elsewhere (Andersen et al, 2010).

The physical functioning (PF) score from the baseline SF-36, reflecting the PF score prior to the motor vehicle crash (MVC) was used as a marker of frailty because CIREN is not able to quantify standard measures of frailty, such as weight loss, low physical activity, or grip strength. Questions used to score physical functioning assess the degree of limitation [i.e., none, little or a lot) in performing vigorous activities (heavy lifting), moderate activities (moving a table), carrying groceries, climbing stairs, bending/kneeling /stooping, walking more than a mile, walking a block, and bathing or dressing.

Previous studies have used both the vitality (VS) and PF metrics from the SF-36 as markers of frailty. The WHI-OS (Woods, et al., 2005) used VS<55 and PF score < 75 as markers of frailty. However, preliminary analyses comparing patients with low PF only, low VS only, low PF and low VS, and all normal scores (Table 1) showed that PF but not VS was linked to the populations that typically exhibit higher prevalence of frailty. Those with "low VS only" resemble those with "normal VS and PF" in regard to age, abnormal weight, and presence of comorbidity while those with "low PF only" resemble those with "both low VS and PF". Hence, for this study we used PF alone as a frailty marker. Those with a PF score less than 75 were considered to be frail (consistent with the WHI-OS and previous CIREN research).

To ascertain the presence of co-morbidity, medical history information was obtained from the patient, their proxy respondent, or the patient's medical record. Sixteen disease categories were considered (obesity, cardiac, diabetes, gastrointestinal, psychiatric, immune suppressed, liver, malignancy, musculoskeletal, neurological, pulmonary, renal, hematological, general, and other). Cases showing evidence of comorbidities in 3 or more disease classes were classified as having "comorbidity" (Andersen et al, 2010).

Body mass index (BMI) was categorized as "underweight" (< 18.5 kg/m2), "normal" (18.5-24.9 kg/m2), "overweight" (25.0-29.9 kg/m2) "obese" (30.0-39.9 kg/m2) and "extremely obese" (> 40.0 kg/m2).

Cases, 18 years of age or older, with baseline SF-36 scores captured within two weeks of admission were included in the study. Injury Severity Score (ISS) (AAAM, 1985), the occurrence of MAIS3+ injuries in each body region, as well as occupant, vehicular, and crash factors' associations with pre-injury frailty (i.e., baseline PF score <75) were explored using contingency tables. The Mantel-Haenszel chi-square tests was used for statistics. Median (q1-q3) ISS was compared in relation to the presence of frailty using the Wilcoxon tests.

Since CIREN contains only injured cases (all cases must have one MAIS 3+ or two MAIS 2+ injuries to enter CIREN), comparisons of the prevalence of injuries between particular subgroups are not good markers of injury risk. Therefore, in order to establish whether frail individuals experienced a different risk of brain injury, multiple rib fractures or femur fractures, the association of frailty and delta v among injured (i.e., brain injuries, femur or multiple rib fractures) belted occupants in frontal crashes was analyzed using linear regression. The assumption behind this approach was that if frailty is associated with a particular injury, that injury would occur at a lower delta v among those with frailty markers. Under the same assumption the mean delta V among frail and non-frail cases was compared using the Student's t-test

Adjusted risk was determined using multiple linear regression analyses. Regression models

Table 1 – Occupant characteristics Associated with Abnormal PF and VS in CIREN Cases (N=1,736)

	PF<75 Only (%)	VS<55 Only (%)	Both Less (%)	Both Normal (%)
Age <50	32.8	76.4	34.7	68.2
Male Gender	34.5	43.7	34.7	48.6
Underweight BMI	0.9	1.2	3.3	2.0
Normal BMI	31.0	38.5	31.4	42.3
Overweight BMI	30.2	23.6	23.1	33.0
Obese BMI	30.2	27.0	27.3	18.2
Extremely Obese BMI	6.9	9.8	11.6	3.8
Comorbidity Count 3+	56.9	34.5	62.8	20.5

were constructed to include variables that potentially influenced the occurrence of injuries or confounded the effect of frailty with outcome (i.e., age, comorbidity, gender, BMI). To assess the contribution of an individual's frailty, multivariate analysis was conducted with and without frailty as a factor in the model. Statistical significance was defined as having a p-value for association below 0.05.

RESULTS

Of the 4,380 cases in the CIREN database at the time of analysis, only 1,747 had baseline PF data reflecting their pre-injury functional status. Of those, 237 (13.7%) had a baseline PF score less than 75.

As expected, frailty (PF<75) was associated with age > 55, weight extremes (underweight, obese, and morbidly obese) and a higher comorbidity count. It was also linked with male gender (Table 2). With regard to crash factors, frailty (PF<75) was more common among occupants of crashes of delta V <45km/h and less common among occupants of rollover crashes. There was no association between seatbelt use and frailty (Table 3).

Frailty (PF<75) prevalence was not different among those with moderate (ISS<16) vs. those with severe (ISS 16+) injuries. Median (q1-q3) ISS was 14.0 (10-22) among the frail and 17.0 (10-24) among the non frail (p=0.40). With regard to injured body regions, frailty (PF<75) was less prevalent among those with MAIS 3+ head, neck and spine injuries (Table 4).

Multiple linear regression models were built to analyze the association of frailty (PF<75) and delta V adjusting for comorbidity count (0-2 vs. 3+), age group (<55 vs. 55+), gender (men vs. women), and BMI (normal/overweight vs. other) among belted occupants in frontal crashes with particular injuries (brain, multiple rib fractures and femur fractures). Delta V was log-transformed in the regression models because delta V has a non-normal distribution.

Univariate analysis among those with femur fractures (n=120) revealed no association between frailty (PF<75) and log delta v (Table 5). However, the association between frailty and log delta V was statistically significant for those with brain injuries (n=57) and among those with multiple rib fractures (n=128) (Tables 6 and 7).

Table 2 –Frailty Prevalence by Occupant factors (N=1,747)

	PF<75 (%)	p-value
Age		
<55	8.5	
55+	27.1	<0.01
Gender		
Male	16.8	
Female	10.3	<0.01
Comorbidity Count		
0-2	11.6	
3+	46.7	<0.01
BMI		
Normal/Overweight	11.0	
Underweight/Obese /Extremely Obese	20.1	<0.01

Table 3 – Frailty Prevalence by Crash Factors (N=1,747)

	PF<75 (%)	p-value
Delta V (km/h)		
<45	17.4	
45+	9.0	<0.01
Crash Type		
Frontal	15.9	
Near Side	11.6	
Far Side	14.6	
Rollover	6.9	0.02
Belt Use		
Yes	13.5	
No	14.0	NS

*NS – not significant

Multivariate analyses among those with brain injuries (n=57) and those with femur fractures (n=120) showed no adjusted association between frailty (PF<75) and log delta v (Tables 5 and 6). However, the adjusted association between frailty and log delta V was significant (p=0.04) among those with multiple rib fractures (n=128) (Table 7), suggesting that frail occupants suffer multiple rib fractures at lower log delta Vs.

Table 4 –Frailty Prevalence In Relation To Injury Type (PF<75) (N=1,747)

	PF<75 (%)	p-value
Injury Severity Score (ISS)		
<16	14.6	
16+	12.9	NS
MAIS 3+ Injuries		
No Head	14.6	
Head	10.1	0.04
No Face	13.9	
Face	9.3	NS
No Neck	14.0	
Neck	0.0	0.03
No Thorax	13.0	
Thorax	15.0	NS
No Abdomen	14.2	
Abdomen	10.7	NS
No Spine	14.4	
Spine	9.3	0.04
No Upper Extr.	13.8	
Upper Extremity	13.4	NS
No Lower Extr.	13.1	
Lower Extremity	14.6	NS

*NS – not significant

Upon further exploration, it was found that, among those occupants with multiple rib fractures, the mean delta V among the frail was significantly lower than the mean delta V among the non-frail (39.1 km/h vs. 47.1 km/h, p=0.03). Similar, but not significant, differences in delta V between frail and non-frail occupants were observed among those with brain injuries and femur fractures.

DISCUSSION

Previous CIREN research has shown that recovery from injury after vehicular crashes was more dependent on frailty than chronological age (Andersen et al, 2010). The aim of this study was to explore a possible link between frailty and injury causation among those involved in vehicular crashes. In other words, the purpose of the analysis was to establish whether frail vehicular occupants involved in crashes are at a different risk of injury than their non-frail counterparts.

The univariate analyses revealed that, while ISS distribution was not different, delta V was lower among the frail cases, suggesting that it takes lower delta V (energy) to cause injuries of similar severity.

Additionally, after adjusting for age, comorbidity, gender and BMI, a negative association was found between frailty and delta V among those with multiple rib fractures. This, again, suggests that it takes less energy to cause multiple rib fractures among frail occupants. No association was found, however, for femur fractures.

Our findings suggest an increased risk of multiple rib fractures linked to frailty. This is compatible with frailty mediated negative effects on tissue strength and bracing. Furthermore, in our analysis frailty is a better predictor of multiple rib fractures than the combinations of other risk factors (i.e. age, gender, comorbidity and BMI).

On the other hand we did not find any effect in relation to femur fracture risk, challenging the postulated effects of decreased bracing described by others (Bose 2008, 2010).

For brain injuries an association was found in the univariate analyses for both frailty and age, however, these associations become non-significant in the multivariate models suggesting the possibility of multicollinearity. The small number of cases, however, limits the validity of any conclusions with regard to brain injuries.

Although it is not possible to identify all components of the frailty syndrome in occupants in the CIREN database using standard measurements (i.e. weight loss, grip strength, exhaustion, time to walk and low physical activity level), the physical functioning score in the SF-36 survey was used as a marker. Previous studies have validated the use of physical functioning and vitality scores as frailty markers. Preliminary analyses of CIREN data for this study showed a high correlation between low physical functioning scores (but not low VS), and known frailty risk factors (i.e. age, extreme BMI, and comorbidites).

Table 5 – Frailty Association with Log Delta V among cases with Femur Fractures (N=120)

	Univariate		Multivariate ±		Multivariate + frailty	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Frailty	-0.137	0.16			-0.099	0.35
Age >55	-0.045	0.57	-0.034	0.69	-0.032	0.71
Male Gender	-0.053	0.43	-0.046	0.52	-0.047	0.51
Comorbidity	0.067	0.68	0.087	0.60	0.119	0.47
High BMI*	-0.044	0.55	-0.039	0.60	-0.020	0.79

* BMI normal and underweight used as reference.

± Multivariate includes comorbidity count (0-2 vs. 3+), age group (<55 vs. 55+), gender (men vs. women), and BMI (normal/overweight vs. other)

Table 6– Frailty Association with Log Delta V among cases with Head MAIS 3+ (N=57)

	Univariate		Multivariate ±		Multivariate + frailty	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Frailty	-0.415	0.03			-0.245	0.26
Age	-0.213	0.06	-0.192	0.10	-0.175	0.14
Male Gender	-0.126	0.25	-0.101	0.35	-0.097	0.37
Comorbidity	-0.096	0.62	0.018	0.93	0.048	0.81
High BMI*	-0.066	0.65	-0.094	0.54	-0.116	0.45

* BMI normal and underweight used as reference.

± Multivariate includes comorbidity count (0-2 vs. 3+), age group (<55 vs. 55+), gender (men vs. women), and BMI (normal/overweight vs. other)

Table 7 – Frailty Association with Log Delta V among cases with Multiple Rib Fractures (N=128)

	Univariate		Multivariate ±		Multivariate + frailty	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Frailty	-0.214	0.01			-0.188	0.04
Age	-0.119	0.10	-0.120	0.11	-0.002	0.21
Male Gender	-0.033	0.64	-0.033	0.65	-0.018	0.79
Comorbidity	-0.051	0.65	-0.053	0.66	-0.002	0.99
High BMI*	-0.002	0.98	-0.010	0.86	0.001	0.99

* BMI normal and underweight used as reference.

± Multivariate includes comorbidity count (0-2 vs. 3+), age group (<55 vs. 55+), gender (men vs. women), and BMI (normal/overweight vs. other)

CIREN's main strength is its wealth of information in relation to occupant, vehicular and crash factors, and detailed injury outcome descriptions. Besides the large number of cases without SF-36 data, the main limitation of CIREN use as a database for this type of study is the non-random nature of case sampling and the lack of non-injured controls. This latter limitation makes it very difficult to properly interpret injury risk results within this cohort.

With the aging U.S. population, increased focus should be directed to mitigating crash and injury characteristics that will more likely occur among the growing number of frail vehicular occupants. There is a need to develop more objective anatomic/physiologic correlates of frailty that could better account for putative association in vehicular injury research.

SF-36 metrics are widely available, but physical functioning scores, while correlated with frailty characteristics, may not properly capture the entire scope of the frailty syndrome making it difficult to identify associations with particular biomechanical mechanisms. It is also critical to understand the effect of frailty on injury outcomes, but necessary information is not collected in most databases. Systems with detailed injury and kinematics data should capture frailty markers that better reflect the indices outlined by Fried et al. (2001) for evaluation of this relationship.

CONCLUSION

There is an association between a marker of frailty and lower delta V among injured MVC occupants, particularly among those with multiple rib fractures. This association suggests a link between frailty and injury causation. Further studies should better and more directly characterize this link.

DISCLAIMER

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