LOWER EXTRIMITY FRACTURE IN PATIENTS WITH OBESSITY IN REAL-WORLD CRASH DATA

Susumu Ejima, PhD
Carla Kohoyada-Inglis, MPA
Sven Holcombe, PhD
Brian Derstrin, MS
Peng Zhang, PhD
Rebecca Goulson
Joel MacWilliams
Stewart Wang, MD, PhD
University of Michigan, International Center for Automotive Medicine
USA

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ABSTRACT
The purpose of this study was to use detailed medical information to evaluate lower extremity fractures of obese patients in real world frontal crashes. In this study, we used analytic morphomics to understand the effect of abdominal and hip body shape on lower extremity fracture for occupants in frontal crashes. Analytic morphomics extracts body features from computed tomography (CT) scans of patients. Lower extremity fractures were examined in front row occupants involved in frontal crashes from the International Center for Automotive Medicine (ICAM) database. Among these occupants, two BMI groups (BMI < 30 kg/m^2 [Nonobese] and BMI ≥ 30 kg/m^2 [Obese]) who suffered from severe lower extremity fractures (AIS2+) were analyzed. The severity of lower extremity fracture was compared between the groups. Regression analyses were conducted to investigate fracture outcomes considering variables including those for vehicle, demographics, and morphomics.

Compared to the nonobese group, the obese group sustained more lower extremity fractures. Logistic regression models were fitted with different configurations of variables predictive of the summation of injury severity score of lower extremity fractures AIS (LEXAIS). The model developed based solely on vehicle data (Scenario 1) had an area under the receiver operating characteristic curve (AUC) of 0.72. When demographic data was combined with vehicle data (Scenario 2), the model prediction improved to an AUC of 0.75. The AUC associated with vehicle and morphomics data (Scenario 3) was increased to 0.78 and increased to 0.79 when combining vehicle, demographic, and morphomics variables (Scenario 4). The important morphomics variable was vertebra-to-front skin which represents fat thickness in the anterior trunk. BMI was important when combined with the vehicle and demographic variables as well. However, morphomics variables such as fat distribution can be precisely adjusted in a finite element human body model or anthropomorphic testing device to represent occupants of different body shapes and sizes and are thus more valuable in assessing injury during vehicle crashes. The current results for fat distribution can highlight the importance of considering these morphomic characteristics when assessing lower extremity injury and creating obese models.

Morphomic data, specifically vertebra-to-front skin, showed a strong association in the severity of lower extremity fractures among obese patients in frontal crashes. These data are useful measurement that can be provided in human models to assess occupant response.

INTRODUCTION
According to the Centers for Disease Control, more than one-third (36.5%) of US adults are obese [14]. The trends in US adult obesity have increased every year from 1999-2014. One recent study [7] stated that while numbers seem to be currently leveling off, by 2030, 42% of US adults could be obese.

Based on several studies which examined the relationship between body habitus and injury rate or fatality grounded in the crash data, the consequence of obesity related to motor vehicle crashes is problematic. Mock et al. [13] found that obese occupants were more at risk of fatal injuries compared to nonobese occupants. Zhu et al. [27] showed that obese male drivers were more likely to die due to their injuries than obese female drivers and found an increased risk for death with increasing BMI. Viano et al. [22],[23] concluded that obesity influences the risk of serious and fatal injury in motor vehicle crashes (MVCs). These studies suggest that while the 50th percentile male is best protected in the current vehicle fleet, occupants whose bodies differ from that baseline are at greater risk for injury or death.

Obesity may also affect the distribution of body regions injured in MVCs. Boulanger et al. [4]

reported that the obese were more likely to have rib fractures, pulmonary contusions, pelvic fractures, and extremity fractures and less likely to receive head trauma and liver injuries. Austin et al. [3] studied the correlation between intrusion and lower extremity in frontal crash and reported that the drivers with higher BMIs are more likely to experience lower extremity injuries than those with lower BMIs. A group of investigators [8],[10],[11] conducted laboratory test that simulated frontal impact crashes with mid-sized and obese post-mortem human subjects (PMHS) to understand the potential injury mechanisms by the kinematics of subjects. The authors documented the crash mechanics in depth and noted that obese occupants experienced greater excursion of lower extremities which increases the risk of a hard contact and resulting injury.

In previous work at ICAM, Arbabi et al. [2] and Wang et al. [24] noted an increase in lower extremity injuries and fewer abdominal injuries for obese occupants when compared to their lean counterparts. These results led to the hypothesis that not all regions of the body sustain severe injuries as a result of obesity and highlight the potential importance of body size and composition in influencing injury severity. Analytic morphomics was developed by ICAM to objectively measure body geometry and composition. Parenteau et al. [15],[17] used analytic morphomics to measure body shape and size for all patients. That study showed that torso and abdominal body shape changes were associated with altered serious abdominal injury risk. Wang et al. [26] identified additional morphomic factors that were predictive of injury risk in MVCs. Based on these previous findings, this study uses analytic morphomics to analyze potential mechanisms of lower extremity fracture for obese occupants in frontal crashes.

Analytic morphomics extracts body geometry and composition data from computed tomography (CT) scans of people involved in vehicle crashes. Based on these images, the features of body shape, such as body width/depth, fascia area, subcutaneous fat area, dorsal muscle groups, vertebra-to-front skin, spine-to-back skin, cortical bone density, trabecular bone density, and pelvis width/height were measured. This morphomics data was combined with crash and medical data to analyze lower extremity fractures in obese occupants using a logistic regression model.

METHOD

Crash Database

In this study, the crash data from the ICAM database for calendar year 1996 to 2016 was used to evaluate the pattern of lower extremity fractures for obese occupants in frontal crashes. Inclusion criteria for the current study were based on the following vehicle and crash parameters: the general area of damage of highest location was frontal (Collision Deformation Code: CDC_3=F) and the principal direction of force (PDOF) was between 11 to 1 o'clock. In cases with multiple impacts, only the primary impact was considered. Vehicles that sustained a non-horizontal event, such as a rollover, were excluded. Occupant inclusion was based on the following criteria: older than 15 years and seated in the right or left front outboard seating position, an Abbreviated Injury Score (AIS) of each body region, and available CT scans. The vehicle data included:

- Crash severity: Change in vehicle velocity (delta V), miles per hour or barrier equivalent speed (BES), miles per hour.
- Intrusion: The longitudinal intrusion in the lower floor including toe pan, foot control, and knee bolster; centimeters
- Belt use: Belt restraint condition were categoriesed into two: belted or unbelted.
- Body Mass Index (BMI): Calculated by dividing the patient's mass in kilograms by the square of his or her height in meters
- Length of Stay (LOS) : Length of stay at the hospital in days

Severity of Lower Extremity Fracture

Severity of lower extremity fracture was assessed using AIS coding. In the ICAM data collection system, medical records are examined to find all lower extremity fractures as well as side of fractures (left or right) previously identified by a board-certified radiologist; all injuries were coded by the ICAM team using AIS2005 [1]. The Maximum Abbreviated Injury Score (MAIS) of lower extremity region ($MAIS_{LEX}$) was assessed separately for each occupant.

Lower extremity fractures in this analysis were categorized with AIS coding. Using this categorization, lower leg fractures involve the foot (AIS code prefix 857***, 858***) and the leg below the knee (AIS code prefix 8540**, 8541**, 8542**, 8543**, 8544**); upper fractures involve the knee (AIS code prefix 8545**), thigh (AIS code prefix 853***) and the acetabulum fracture (AIS code prefix 8562**) for pelvis. The major hip injuries for the occupant in frontal crash were acetabulum fractures which occur from a Knee-Thigh-Hip (KTH) loading path [20],[21]. Therefore, we only included acetabular fractures rather than all pelvic fractures in this analysis. In addition, the location of lower extremity fractures for the passenger side was mirrored to the opposite side and these were categorized as inboard (driver's right side) or outboard (driver's left side), in order to combine driver and passenger data. Since AIS represents the assessment of life-threatening injuries at the time of first medical evaluation, the severity of lower extremity fractures measured on AIS may not fully reflect the long-term consequence of lower extremity injuries [19]. For this reason, the summation of injury severity score of lower extremity fractures AIS (LEXAIS) was proposed to assess in this study for each occupant to represent the severity of lower extremity fracture. Compared to the $MAIS_{LEX}$, the summation of skeletal injuries considers the number of the lower extremity fracture locations as well as injury severity.

Analytic Morphomic

Analytic morphomics processing was performed according to the methods previously described [9],[12],[16] and results from each individual was placed in the context of the Reference Analytic Morphomics Population (RAMP) [18]. The University of Michigan Internal Review Board approved the use of the standard CT scans available for each occupant for this study (HUM00043599 and HUM00041441). CTs were obtained from the University of Michigan radiology archive. The scans were processed semi-automatically using custom algorithms written in MATLAB 2015a (The Mathworks Inc., Natick, MA, USA). By using semi-automated processing of CT scans, analytic morphomics measures detailed geometry and material characteristic for tissue, organ, and bone. The following morphomic variables were assessed based on the need to represent the shape and material properties of abdomen and pelvis components. Data at the L5 was used for the body depth, body width, fascia area, subcutaneous fat area, vertebra-to-front skin, spine-to-back skin, and cortical bone density, trabecular bone density and L2 was used for the dorsal muscle group. Measurements are illustrated in Figure 1.

- Body depth: Front-to-back body distance at L5 (aligned to body habitus) ; millimeter
- Body width: Left-to-right body distance at L5 (aligned to body habitus) ; millimeter
- Fascia area: The cross-sectional area within the fascia at L5; squaire millimeter
- Subcutanous fat area: The cross-sectional area between skin and fascia at L5 meeting fat density thresholds -205 and -51 Hounsfield units (HU).
- Muscle density: The ratio of low density (HU) to high density (HU) dorsal muscle group at L2
- Vertebra-to-front skin: Distance between front of vertebra body to skin at L5; millimeter
- Spine-to-back skin: Distance between the posterior tip of the spinous process to the back skin at L5; millimeter
- Cortical bone density: The maximum cortical bone signal peak at L5 ; Hounsfield units (HU).
- Trabecular bone density: Average pixel intensity within a circular core sample at the mid-level of each vertebral at L5; Hounsfield units (HU)
- Pelvis width: Distance between left and right lateral most point on the pelvic wings; millimeter
- Pelvis height: Average of left/right vertical distance between the ischial tuberosity to the most superior point on the iliac wing; millimeter.

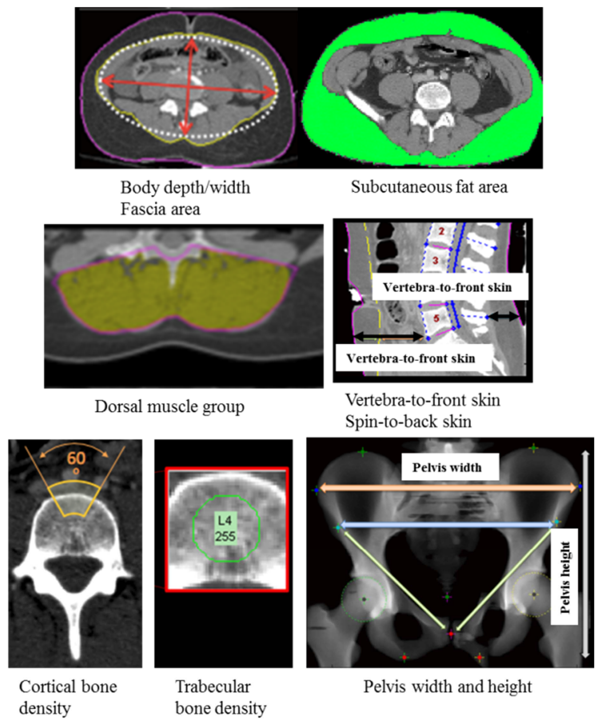

***Figure 1 Morphomics measurement obtained from CT scans*.**

Statistical Analysis for Lower Extremity Fracture

Occupants were categorized by BMI in either the nonobese group (BMI < 30 kg/m^2) or obese group (BMI ≥ 30.0 kg/m^2). Utilizing frontal crash occupants in the ICAM database, univariate and multivariate regression analyses were conducted to investigate the association between occupant factors and lower extremity fracture. According to the univariate analysis in this study as shown in Table 1, mean value of LEXAIS for obese group (5.8) shows a high lower extremity fracture (multiple site) compare to the nonobese group (4.1). The concept of using a statistical approach is to predict the lower extremity fracture and the importance of each variable defined with a predictive model [6],[17],[28].

Logistic regression models were fitted to investigate LEXAIS injuries with different configurations of crash, demographic, and morphomic variables. There are 380 ICAM cases available with occupants involved in frontal crashes, among which there are 228 cases with complete processed morphomic data. LEXAIS was calculated for occupants involved in frontal crashes who also had morphomics data and separated into two groups: LEXAIS≤3 and LEXAIS≥4 to distinguish single fracture and multiple fracture at lower extremity. The data analysis was conducted using MATLAB2015a statistical tool box.

Selection of variables for inclusion in the predictive models was done using forward and backward stepwise regression to determine a final model. At each step, the criteria to add or remove the term are defined with Akaike information criteria (AIC). AIC is an information criterion that addresses the trade-off between the goodness of fit of the model and the complexity of the model. The performance of regression models was assessed with AIC and receiver operating characteristic (ROC) which plots the model sensitivity as a function of specificity. The performance of the models was compared using area under the curve (AUC).

There were 17 covariate variables examined: three vehicle (Crash severity, Belt, Intrusion), three demographic (Age, BMI, Gender), and eleven morphomic (body depth, body width, fascia area, subcutaneous fat area, muscle density, vertebra-to-front skin, spine-to-back-skin, cortical bone density, trabecular bone density, pelvis width, pelvis height). The models were characterized into four different scenarios to assess each variable that contributes to lower extremity fracture. Scenario 1 used vehicle variables; Scenario 2 vehicle and demographic variables; Scenario 3 vehicle and morphomics variables; and Scenario 4 used all variables. We then used AIC and AUC to compare the performance of predictive models developed with the four different scenarios.

RESULT

There were 228 occupants who met the inclusion criteria of this study. By using vehicle and demographic data, obese features were compared with the nonobese group. Among 228 occupants, there were 141 nonobese occupants and 87 obese occupants. Average BMI for the nonobese and obese group is 24.5 and 36.3 respectively. Table 1 shows the result of the univariate analysis for the vehicle and demographic variables and injury severity. The table includes mean, standard errors, and *P* value obtained from two-sample *t* tests for continuous variables. It also provides the counts and the percentage for categorical variables (Belt and Gender) of each group, the *P* value from the Fisher's exact tests. While the obese group had a higher age and weight compared to the nonobese group, there are no significant differences in the vehicle variables (crash severity, belt, intrusion) between the groups. The obese group had a higher LEXAIS than the nonobese group. Comparison of nonobese (LEXAIS=4.1) and obese (LEXAIS=5.8) fractures indicates a significant difference. For the obese group, the number of fractured locations seems multiple. These might attribute to an increase in the length of stay (LOS) in the hospital for the obese group compare to the nonobese group.

Table 1 Summary of statistical for $MAIS_{LEX} \geq 2$ occupants by BMI group.

Variables	Nonobese (n=141)		Obese (n=87)		*P* value	
	Mean or count	Std error or	Mean or count	Std error or		
Vehicle						
Model year	2002.1	5.1	2002.1	5.3	0.996	
Crash severity	31.2	12.5	28.3	11.2	0.071	
Belt	109	77.3%	65	74.7%	0.660	
Intrusion	15.4	16.8	16.9	20.4	0.558	
Demographics						
Age	45.9	20.5	49.0	17.8	0.218	
Height	171.0	10.1	168.7	10.0	0.096	
Weight	72.2	14.6	103.9	24.9	0.000	**
BMI	24.5	3.3	36.3	7.2	0.000	**
Male	67	47.5%	38	43.7%	0.574	
Injury						
$MAIS_{LEX}$	1.8	1.1	2.2	1.0	0.017	*
LEXAIS	4.1	6.0	5.8	6.1	0.041	*
Length of stay	9.2	9.5	11.8	10.8	0.061	

* $p<0.05$ **$p<0.01$

Examining the lower extremity fracture incidence and injury severity using LEXAIS criteria, the obese group had significantly more fractures and multiple sites. From this analysis, LEXAIS4+, which showed the difference between nonobese and obese occupants, was chosen as a predictor for multivariate analysis with vehicle, demographic, and morphomics variables. For the 228 occupants with available morphomics variables, a logistic regression model was applied to quantify the contribution of body shape to lower extremity injury. Table 2 presents a univariate analysis of the 17 variables. It includes mean, standard errors, and *P* value obtained from two-sample t tests for continuous variables. It also provides the counts and the percentage for categorical variables (Belt and Gender) of each group. Various features were compared between the groups of occupants with LESAIS≤3 and LEXAIS≥4. Crash severity and intrusion was the significant variable in the vehicle variables. Among the demographic variables, age and BMI were the significant variables. This result suggests that an increase in BMI was significantly associated with LEXAIS whereas an increase in age was opposite. Among the various morphomics variables, subcutaneous fat and spine-to-back skin were significantly different between the two groups.

Table 2 Summary of statistics between the groups of occupants between LEXAIS≤3 and LEXAIS≥4

Variables	LEXAIS≤3 Mean or count	LEXAIS≤3 Std error or percent	LEXAIS≥4 Mean or count	LEXAIS≥4 Std error or percent	*P* value	
Vehicle						
Crash severity	27.6	10.7	33.7	13.0	0.000	**
Belt	105	79.5%	69	71.9%	0.188	
Intrusion	10.3	14.5	23.8	19.9	0.000	**
Demographics						
Age	50.1	20.9	42.9	16.8	0.005	**
BMI	27.8	6.6	30.6	8.8	0.009	**
Male	60	45.5%	45	46.9%	0.833	
Morphomics						
Body depth	249.0	49.3	259.9	53.7	0.119	
Body width	349.8	43.4	357.9	44.4	0.172	
Subcutanous fat area	26542.3	13148.5	30267.6	14030.1	0.043	*
Vertebra-to-front skin	123.3	35.0	128.5	36.4	0.284	
Spin-to-back skin	44.0	18.9	50.8	21.3	0.013	*
Fascia area	41957.1	12405.1	41846.3	11041.8	0.943	
Muscle density	0.3	0.5	0.2	0.2	0.069	
Cortical bone density	278.3	88.2	280.8	68.2	0.809	
Trabecular bone	203.6	81.8	209.6	53.1	0.504	
Pelvis width	278.9	19.7	277.6	18.6	0.591	
Pelvis height	211.3	13.5	210.2	12.7	0.513	

* p<0.05 ** p<0.01

The logistic regression models were fitted with different configurations of variables predictive of lower extremity fractures and were evaluated by the AIC in the multivariate analysis of the 17 variables. Table 3 summaries the selection of independent variables to be applied in the regression models for each scenario weighted by AICs. Within each scenario, AICs were decreased by removing the variable except Scenario 1. Age and gender was removed in scenario 2 and trabecular bone density, body depth/width, pelvis width, subcutaneous fat area, and spin-to-back skin were removed in scenario 3. In scenario 4, pelvis height was removed in addition to the variables removed in scenario 2, and 3.

Table 3 AICs in selecting the respective model (LEXAIS ≥ 4) in each scenario.

Scenarios	Removed variables	AIC
1: Vehicle	None	281.0
2: Vehicle and Demographic	Age	274.6
	Gender	274.3
3: Vehicle and Morphomic	Trabecular bone density L5	277.3
	Body width L5	275.4
	Body depth L5	273.5
	Pelvis width	271.7
	Subcutanous area L4	270.4
	Spin-to-back skin L4	270.1
4: Vehicle Demographic and Morphomic	Body depth	277.7
	Body width	275.7
	Trabecular bone density L4	273.8
	Age	271.9
	Spine-to-back skin L4	270.4
	Pelvis width	268.7
	Gender	267.7
	Subcutanous area L4	267.0
	Pelvis height	266.8

Table 4 shows the coefficient, error, odds ratio, and 95% confidence intervals in predicting LEXAIS≥4 from stepwise regression analysis in each scenario. The important morphomics variables identified in the current analysis were vertebra-to-front skin and fascia area. BMI was important when combined with the vehicle and demographic variables. However, when morphomics were combined with both demographic and vehicle variables, BMI became less important. The decrease in importance can be explained by strong correlation (Pearson correlation: 0.74) between BMI and morphomic variable such as vertebra-to-front skin.

Figure 2 shows the progression of ROC curves from the statistical model of lower extremity fracture rate using vehicle, demographic, and morphomic data. The model developed based solely on vehicle data had an AUC of 0.72. The model prediction improved when combining vehicle and demographic data with an AUC of 0.75. The AUC associated with vehicle and morphomics data was 0.78 and increased to 0.79 when combining vehicle, demographic, and morphomics variables.

Table 4 Estimation of coefficient, odds ratio, their 95% confidence intervals and p-value for variables from different scenarios.

Variables	Coeff.	SE	Odds Ratio	95% CI Lower	95% CI Upper	*P* value	
Scenario 1							
Vehicle							
(Intercept)	-1.078	0.466		-1.997	-0.160	0.021	
Severity	0.021	0.014	1.021	-0.007	0.048	0.141	
Belt	-0.692	0.345	0.501	-1.372	-0.012	0.045	*
Intrusion	0.041	0.010	1.042	0.022	0.060	0.000	**
Scenario 2							
Vehicle							
(Intercept)	-2.959	0.832		-4.598	-1.320	0.000	
Severity	0.026	0.014	1.027	-0.002	0.055	0.067	
Belt	-0.620	0.353	0.538	-1.315	0.076	0.079	
Intrusion	0.040	0.010	1.041	0.021	0.060	0.000	**
Demographics							
BMI	0.057	0.020	1.059	0.017	0.097	0.005	**
Scenario 3							
Vehicle							
(Intercept)	3.528	3.169		-2.717	9.773	0.266	
Severity	0.035	0.016	1.036	0.004	0.066	0.025	*
Belt	-0.813	0.371	0.444	-1.544	-0.082	0.028	*
Intrusion	0.051	0.011	1.052	0.029	0.073	0.000	**
Morphomics							
Vertrbra-to-front skin	0.029	0.009	1.029	0.010	0.047	0.002	**
Facia area	-6.E-05	3.E-05	1.E+00	-1.E-04	0.E+00	0.050	*
Muscle density	-0.845	0.601	0.430	-2.029	0.340	0.160	
Cortical bone density	-0.005	0.002	0.995	-0.009	0.000	0.052	
Pelvis height	-0.022	0.015	0.978	-0.058	-0.052	0.134	
Scenario 4							
Vehicle							
(Intercept)	-1.375	1.187		-3.713	0.964	0.247	
Severity	0.035	0.016	1.035	0.004	0.066	0.027	*
Belt	-0.690	0.376	0.502	-1.431	0.052	0.067	*
Intrusion	0.047	0.011	1.048	0.026	0.069	0.000	**
Demographics							
BMI	0.073	0.032	1.076	0.010	0.137	0.023	*
Morphomics							
Vertrbra-to-front skin	0.022	0.010	1.023	0.003	0.042	0.026	*
Facia area	-9.E-05	3.E-05	1.E+00	-1.E-04	0.E+00	0.002	**
Muscle density	-0.739	0.597	0.478	-1.916	0.438	0.216	
Cortical bone density	-0.005	0.002	0.995	-0.009	0.000	0.051	

* $p<0.05$ **$p<0.01$

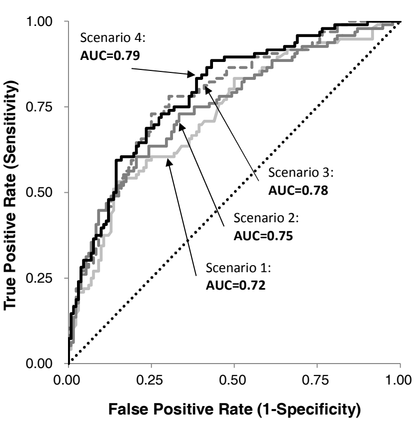

Figure 2 Progression of receiver operating characteristic curves of difference scenarios

DISCUSSION

By 2030, approximately 42% of the population will be obese according to the estimation of demographic shifts in the US. This shift in the population will likely increase the societal burden from MVCs. Wang [25] remarks that obesity is highly associated with cardiovascular disease, hypertension, diabetes, and poor wound-healing which complicate post-injury treatment and rehabilitation. It is known that increase in mass increases the forces exhibited to the occupant. The effect of these inertia forces, and this study showed obese occupants have an increased rate of more severe lower extremity fractures. Also it was shown with similar crash condition the obese still sustained lower extremity fractures. It is noted that the current crash testing is tuned for nonobese occupants and with the increase in obesity in the US more should be addressed to examine and protect the obese occupants. This study integrated crash and medical data that includes analytic morphomics and showed an increase in lower extremity fracture of obese occupants using real world crash cases.

Utilizing LEXAIS to analyze the study subjects who have sustained lower extremity injures shows clear variation in the pattern of fracture observed in nonobese versus obese occupants. According to the univariate analysis with LEXAIS, obese occupants sustained more fractures at lower extremity compared to the nonobese occupants. Moreover, mean value of LEXAIS of obese group in Table 1 indicated lower extremity fracture at multiple sites and this might attribute to an increase in the LOS. Based on this observation the obese group sustains more severe lower extremity fractures than the nonobese group and lower extremity injuries lead to a long-term physical cost from MVCs as already described in prior studies [5],[19].

The phenomenon of lower extremity fracture of the obese is also supported with prior studies by Kent et al. [11]. The authors indicated that the obese subjects experienced greater maximum forward displacement. The primary difference was a larger hip-point excursion in the obese subject which may subsequently show an increase in lower extremity injury. In addition, "unfavorable kinematics" that results from increased hip excursion is observed in the obese PMHS. This crash mechanism helps to predict the possibility of lower extremity fracture due to greater interaction between lower extremities and components such as knee bolster or floor pan.

The results showed an increase in LEXAIS when including the morphomic variable in the model. The effect of vehicle, demographic, and morphomic variables on the lower extremity fracture in frontal crashes were assessed by using a ROC curve. The results indicated that morphomic variables when included in the model strengthened and showed significance in evaluating lower extremity fractures among the obese when compared to the nonobese. The AUC, obtained in Scenario 4 where morphomics data was added was 1.05 times greater than when using only vehicle and demographic data (Scenario 2), and 1.10 times greater than when using vehicle data alone (Scenario 1).

Overall intrusion was among the significant variables of frontal impact at lower extremity fracture (LEXAIS) in the multivariate models. It has shown that occupants who are involved in crashes with more integrity loss and multiple components of intrusion reflect more severe crashes. From Scenario 2 (vehicle and demographic), BMI is the significant demographic variable of LEXAIS. These results are consistent with prior study [3] with multivariate statistical models. Vetebra-to-front skin depth was the significant morphomic variables of lower extremity fracture in frontal impact. This indicates that this factor was important in assessing the increased severity of lower extremity fracture. Obesity related changes appear to correlate with lower extremity fracture. Parentenu et al. [15] quantified the amount of fat at each vertebral level using representative parameters based on the CT scan measurement of 10,952 individual's data and the obese occupants have large amounts of fat distributed in the abdomen and pelvis regions. The obese occupants with large volumes of mass around the hip region demonstrate that current restraint systems are challenged in trying to arrest forward motion, especially for obese occupants. Increased fat depth anteriorly (vertebra-to-front skin) moves the hip point up off the seat and further forward from the seat back. These results suggest the fat distribution is also important as well as material properties when discussing lower extremity fracture. Our next steps investigating the effect of obesity will utilize finite element models to test the effects of morphomic variations.

The ICAM database involves vehicle crashes whose occupants have been treated at University of Michigan, a Level-1 trauma center and is therefore the cohort used in this study is not representative of national sample or occupant exposure. Gender difference is not discussed due to the limited sample size. However, gender is important for lower extremity injury. Vertebra-to-front skin which tends to increase the lower extremity fracture is obviously a BMI-related shape change, but also appears to be related to gender. Fat distribution change appears to be an important factor when we consider the lower extremity fracture in real-world crashes.

CONCLUSIONS

Morphomic variables in this study showed that vertebra-to-front skin depth was important in assessing lower extremity fractures of obese occupants and intrusion were the most significant variables of front impact LEXAIS in the multivariate models. The lower extremity fracture more likely occurred in obese occupants even with similar intrusion as compare to nonobese occupants. This paper introduced a method to quantify obese lower extremity fractures using analytic morphomics in an accurate and systematic manner. The characterization of the obese can then be used as a data source to provide relevant geometric data to inform tailored human finite element models.

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