

Table V shows the coefficient, error, and *P* values in predicting rib fracture from regression analysis in each scenario. The most important morphomics variable was *Prox. end inner angle*. *Age* was most important when combined with the vehicle and demographic variables. However, when morphomics were combined with both demographic and vehicle variables, *Age* became less important. The age decrease in importance can be explained by collinearity between age and morphomic variable such as *Prox. end highest curvature* and *Prox. end inner angle*.

Figures 6 and 7 show the scatter plot of without and with rib 5 fracture occupants of *Prox. end highest curvature* and *Prox. end inner angle* with respect to the age. Triangles indicate 34 occupants with rib 5 fracture and circles indicate 68 occupants without rib 5 fracture. The occupants with rib 5 fracture are distributed in large *Prox. end highest curvature* and *Prox. end inner angle* and it also increases with age.

TABLE V
ESTIMATION OF COEFFICIENTS FOR VARIABLES DIFFERENT SCENARIO

Variables	Estimate	SE	p-Value
Scenario 1			
Vehicle			
(Intercept)	0.034	0.584	0.954
Severity	-0.008	0.019	0.689
Intrusion count	-0.211	0.120	0.080
Scenario 2			
Vehicle			
(Intercept)	-3.417	1.669	0.041
Severity	0.013	0.022	0.557
Intrusion count	-0.088	0.137	0.521
Demographics			
Age	0.043	0.015	0.003 *
BMI	0.000	0.029	0.999
Gender	0.465	0.472	0.325
Scenario 3			
Vehicle			
(Intercept)	-82.428	31.783	0.010
Severity	0.004	0.025	0.870
Intrusion count	-0.228	0.140	0.103
Morphomics			
Spiral Peak Location (X)	76.660	33.091	0.021 *
Prox end highest curvature	-1.132	0.611	0.064
Prox end post-most curvature	9.742	4.129	0.018 *
Dist end inner angle	-0.008	0.036	0.824
Prox end inner angle	0.281	0.096	0.003 **
Scenario 4			
Vehicle			
(Intercept)	-128.535	39.026	0.001
Severity	0.017	0.028	0.545
Intrusion count	-0.272	0.171	0.111
Demographics			
age	0.041	0.018	0.024 *
bmi	0.015	0.037	0.678
gender	1.702	0.656	0.009 **
Morphomics			
Spiral Peak Location (X)	119.385	39.566	0.003 **
Prox end highest curvature	-2.038	0.755	0.007 **
Prox end post-most curvature	14.698	4.898	0.003 **
Dist end inner angle	0.012	0.040	0.773
Prox end inner angle	0.419	0.120	0.000 **

* p<0.05 **p<0.01

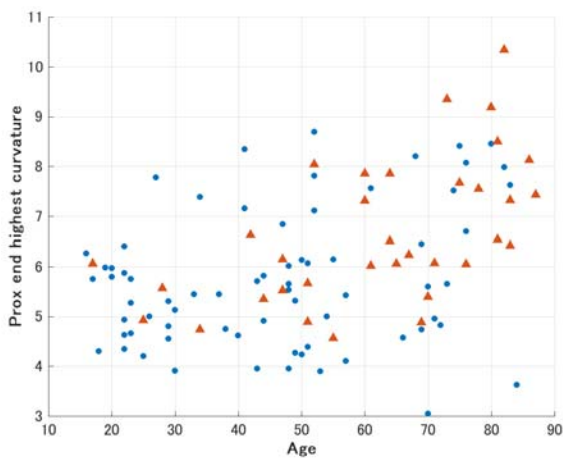


Fig. 6 Fractured Rib 5 prox. end highest curvature with respect to the age

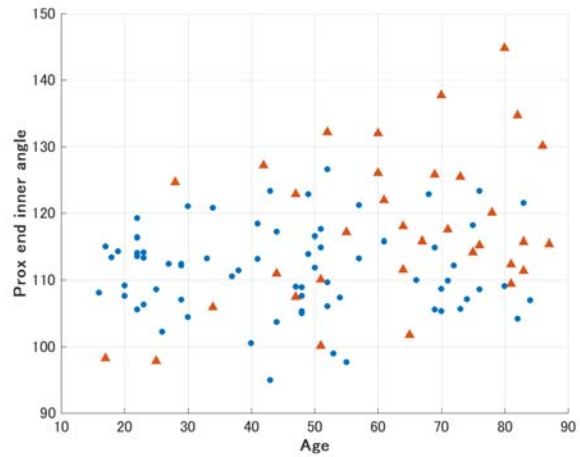


Fig. 7 Fractured Rib 5 prox. end inner angle with respect to the age

IV. DISCUSSION

The ICAM crash data collection system is based on the identification and documentation of injury causation, and this system can define all the factors that are believed to be necessary for the occurrence and/or severity of injury. The advantage of crash data collection in a trauma center is to integrate data that includes medical imaging such as CT, X-ray, and MRI, which indicate the location of the fracture or the tissue damage constituting the injury. In addition, the image data provide effective information for predicting injury patterns related to the particular type of loading or mechanical response that can estimate not only the strength of the bone but also the geometry change with age. In this study the elderly variables involved in frontal crashes and causation of rib fracture are summarized by using real-world crash cases.

According to the univariate analysis with MAIS_{thx} 3+ and rib fracture incidence ratio, older occupants sustained more fractured ribs at lower crash severity and with less intrusion compared to the younger occupants. This result indicates that the seat belt is the main involved physical component (IPC) of MAIS_{thx} 3+ older occupants. This phenomenon is consistent with prior studies [18-19] which show the common IPC of elderly (older than 75) occupants is the seat belt.

The ICAM database captures the location of rib fractures with much more detail and precision than previously available. Utilizing this system to analyze the rib cages of ICAM study subjects who have sustained chest wall injuries shows clear variation in the pattern of rib fracture observed in younger versus older occupants. Older occupants' rib fractures tend to occur more anteriorly while younger occupants' fractures occur more laterally. This result shows a similar trend along with rib fracture patterns in various restraint statuses, when compared to the CIREN database [19]. The age related changes increase the risk of rib fracture due to the geometry or material changes along the ribs [20]. According to the study of analytic morphomics with ribs [11], rib shape change has a potential to affect fracture location and loading path from seatbelt in frontal crashes. For this reason, the logistic regression analysis is applied to clarify the effect of rib shape by using morphomics variables linked to the crash case.

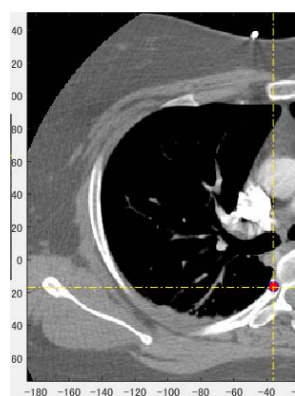
The results obtained in this study highlight the importance of morphomics variables in predicting rib fracture risk. The effect of two vehicle, three demographic, and five morphomics variables on the risk of rib fracture in frontal crashes are assessed by using ROC curve. The results indicated that the effect of morphomics variables improved the prediction of occupant rib fracture risk. The AUC, obtained in Scenario 4 where morphomics data was added to the vehicle and demographic data, was greater than the AUC obtained when using vehicle and morphomics data (Scenario 3), significantly greater than when using vehicle and demographic data (Scenario 2), and when using vehicle data alone (Scenario 1).

Prox. end inner angle, *Prox. end highest curvature*, *Prox. end post most curvature*, and *Spiral peak location* were among the most significant morphomics variables of rib fracture in frontal impact in the multivariate models. In addition, *Prox. end inner angle* and *Prox. end highest curvature* were significant in the univariate analysis as shown in Table IV. This indicates that these two factors are good surrogates for rib fracture risk and

provide rib shape information in the prediction model. Figure 8 indicates the sagittal image at the start point of rib 5 for younger and older occupants. The rib shape of younger occupants who have small *Prox. end inner angle* and *Prox. end highest curvature* shows a round shape and the rib shape of older occupants who have a large *Prox. end inner angle* and *Prox. end highest curvature* shows a vertically long elliptic shape. *Prox. end inner angle* is the exit angle at the proximal end of the rib and *Prox. end highest curvature* is related to the curvature of the rib shape. These factors could change the boundary conditions with respect to frontal load with a belt as well as change the rib fracture location. These results suggest the rib shape is also important as well as material properties when we discuss rib fracture. The next step of this study with finite element models clarifies these effects when compared to material properties. In this study, gender difference is not discussed due to the limited sample size. However, the effect of gender is important for chest injury. Scenario 4 where morphomics data is added to the vehicle and demographic data, the effect of gender is important to predict rib fracture, which was not significantly important only by using vehicle and demographic variables (Scenario 2).

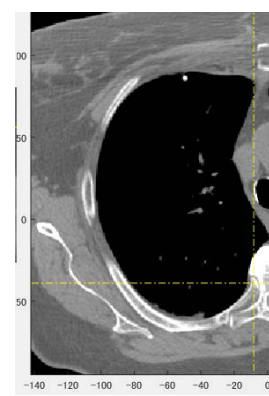
Prox. end inner angle and *Prox. end highest curvature* which tended to increase the rib fracture risk are age-related shape changes. Therefore, rib shape change is important factor when we consider the risk of rib fracture in real-world crashes.

In this study, the statistical model selected the parameterization of a rib's in-plane shape from morphomic variable and rib's out-of-plan factors such as pump-handle angle, lateral swing angle and bucket-handle angle[10] are not included. To avoid the problem of over-fitting caused by the extra terms corresponding to the size of the model, the model presented focuses only in-plane shape. In addition, the model did not include the effect of changes in material and thickness of cortical bone to predict the rib fracture due to the limited sample size. By increasing the number of crash cases, these analyses will have more statistical power to investigate the contribution of these factors compared to geometry.



(a) 40 yr.

Prox. inn angle 100.5 deg
Prox. end highest curvature 4.6



(b) 82 yr.

Prox. inn angle 134.6 deg,
Prox. end highest curvature 10.3

Fig. 8. Sagittal plane image at start point of rib 5

V. CONCLUSIONS

This study used detailed injury and crash data in conjunction with medical imaging from the ICAM and morphomics databases to evaluate the effect of rib shape in frontal crashes. Results, confirmed with real-world crash cases, demonstrate that rib fracture patterns in older occupants were more anterior compared to younger occupants. Multivariate analysis with vehicle, demographic, and morphomics variables predicted the rib fracture risk and assessed the importance of individual predictors. Morphomics variables in this study showed that elderly rib shape is important when predicting rib fracture risk. This paper introduced a method to quantify elderly rib fractures using analytic morphomics in an accurate and systematic manner. The characterization of the elderly can then be used as a data source to provide relevant geometric data to inform tailored human finite element ribcage models.

VI. ACKNOWLEDGEMENT

The authors are grateful for the assistance of the Morphomic Analysis Group (MAG) image processing team in the University of Michigan.

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