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Controlling Boundary Conditions and Specimen Preparation for Testing Human Ribs: Effects of Periosteum, Hydration, and Strain Gages

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ABSTRACT

The purpose of this study was to evaluate the effects of boundary conditions and specimen preparation on human rib testing. This was done by performing 48 three-point bending tests on 24 matched human rib specimens. The rib specimens were dissected from anterior and lateral regions of ribs 8-10 of three male human thoraces. Both specimens of each matched set were then potted side by side in a polyvinyl chloride (PVC) square pot filled with PMMA fast cast compound while using a custom jig to ensure the matching orientation. Once the specimens were potted, a microCT was used to obtain a detailed cross-sectional image of each specimen at the point of the impactor blade contact. The cross-sectional image was then thresholded and a custom Matlab code was used to calculate the area moment of inertia and distance to the neutral axis. Next, the matched specimens were randomly divided into three test groups. In the first test group, matched specimens were tested to determine the effects of leaving the periosteum intact versus removing the periosteum. In the second test group, matched specimens were tested to determine the effects of placing a strain gage on the tension side of the specimen. In the third test group, matched specimens were tested to determine the effects of immersing the specimens in saline for five days versus wrapping the specimens in saline soaked gauze. The soft tissue and periosteum were not removed in the second test group. The specimens were tested using a servo-hydraulic material testing machine (MTS) and a three-point bending setup, in which the potted specimen end was pinned and the other end was simply supported. Specimens were oriented so that the specimen was bent inside-out by the impactor blade. The impactor displacement rate of 7 in/s yielded a strain rate of approximately 0.5 strain/s, which is similar to that seen in a belted 35 mph automotive crash. In the first test group, a paired t-test showed that there was no statistical difference in the area moment of inertia (p=0.60), distance to the neutral axis (p=0.29), peak moment (p=0.31), peak stress (p=0.42), or peak impactor displacement (p=0.14) between specimens with an intact periosteum versus no periosteum. In the second test group, a paired t-test showed that there was no statistical difference in the area moment of inertia (p=0.76), distance to the neutral axis (p=0.20), peak moment (p=0.68), peak stress (p=0.34), or peak impactor displacement (p=0.91) between specimens with a strain gage versus no strain gage. In the third test group, a paired t-test showed that there was no statistical difference in the area moment of inertia (p=0.35), distance to the neutral axis (p=0.42), peak moment (p=0.45), peak stress (p=0.98), or peak impactor displacement (p=0.75) between specimens immersed in saline for five days versus specimens wrapped in saline soaked gauze. In summary, this procedure proved to be a very accurate means of preparing matched rib specimens and showed that neither the presence of the periosteum, strain gage, nor the two hydration conditions have a significant influence on the biomechanical properties of human rib specimens.

INTRODUCTION

In automotive accidents, chest injuries rank second only to head injury in overall number of fatalities and serious injuries (Cavanaugh, 1993). Mulligan (1996) reported that thoracic injury is a principle causative factor in 30% of automotive deaths. In addition, Gabler et al. (2005) reported that the thorax is the most frequent body region incurring serious injury in far side impact. Previous studies using restrained cadavers in impact sled tests have frequently found rib fractures to be the most common skeletal injury (Crandall et al., 1997; Kallieris et al., 1998; Cromack and Ziper, 1975; Patrick, 1976; Ramet and Cesari, 1979). Finite element models of the human thorax are becoming an integral tool in the reduction of these injuries, thereby improving crashworthiness. However, the correct biomechanically-based material properties must be applied in order for these models to accurately predict injury. A number of studies have performed three-point bending tests on whole rib sections to evaluate the properties of the ribs (Granik and Stein, 1973; Yoganandan and Pintar, 1998; Cormier et al., 2005). However, none of these studies have evaluated the effects of specimen preparation and testing methodology on the response of whole rib sections. Therefore, the purpose of this study was to evaluate the effects of boundary conditions and specimen preparation on isolated whole human rib sections in three-point bending.

METHODS

A total of 48 dynamic three-point bending tests were performed on 24 matched fresh frozen human cadaver rib specimens. Three boundary condition test groups were evaluated for significance: the effect of the presence of the periosteum versus no periosteum, the effect of placing a strain gage on the tension side of a three-point bending specimen versus not placing a strain gage on the specimen, and the effects of immersing the specimens in saline for five days versus wrapping the specimens in saline soaked gauze.

Subject Information

Matched pair rib specimens were obtained from male fresh frozen post mortem human subjects ranging from 42 to 72 years of age. For comparison with the normal population, Osteograms were performed on the left hand of each cadaver. The left hand of the cadavers were x-rayed and scanned by CompuMed incorporated (Los Angeles, CA). The global BMD results are reported with respect to the normal population (Table 1). The T-score represents the number of standard deviations away from the average the subject's bone mineral content is compared to the average healthy individual between 25 and 50 years. The positive or negative T-score value denotes greater or lower bone mineral density respectively. T-scores at -1.0 or greater are considered normal, between -2.5 and -1.0 indicates a low bone mineral density, and below -3.0 is considered osteoporotic. The Z-score is the number of standard deviations away from the average bone mineral density at the subject's age.

Table 1. Test Subject Information.

Subject ID	Gender	Age (years)	Mass (kg)	Race	BMD	T-score	Z-score
sm52	M	42	85.91	Caucasian	92.1	-1.7	-1.3
sm48	M	45	53.18	Caucasian	120.1	0.9	0.9
sm37	M	56	81.36	Caucasian	105.3	-0.5	0.3
sm40	M	66	66.36	Caucasian	79.4	-2.9	-1.4
sm50	M	72	75.91	African American	105.1	-0.5	1.2

Specimen Procurement and Preparation

First, matched left and right rib specimens were dissected from anterior and lateral regions of ribs 8-10 of the five human thoraces (Figure 1). The specimens were approximately 11.43 cm long. It should be noted that anterior specimens were taken at least 10 mm from the costal cartilage joint. The soft tissue and periosteum were removed from the anterior end of each specimen and a one inch plastic pin was inserted through the prepped region. This was done in order to provide a rigid fixation in the potting compound. Both specimens of each matched set were then potted side by side in a polyvinyl chloride (PVC) square pot filled with PMMA fast cast compound while using a custom jig to ensure the matching orientation.

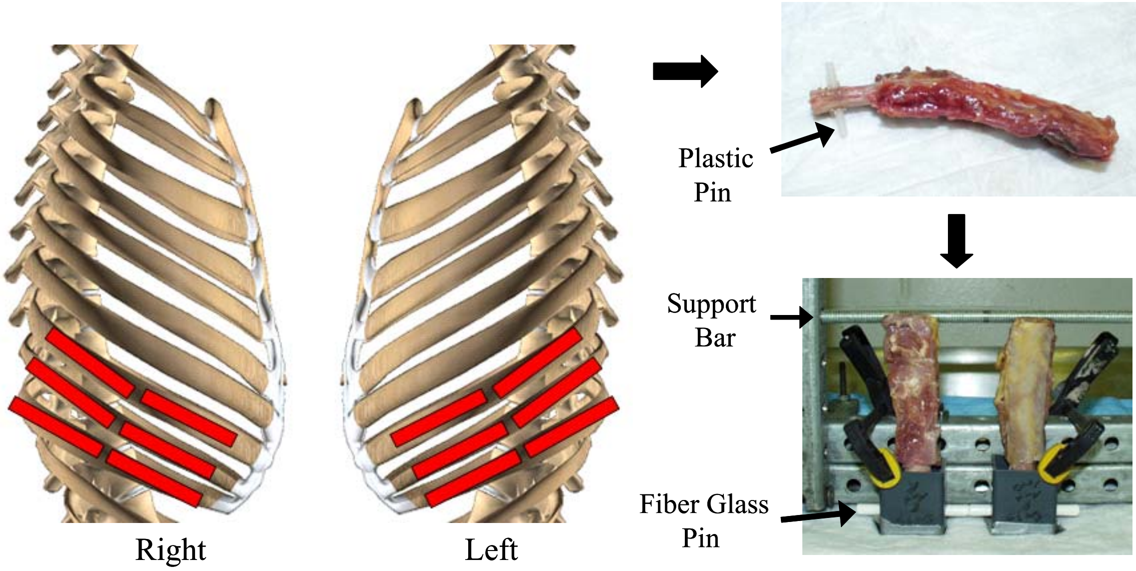


Figure 1: Specimen Procurement, Preparation, And Matched Potting.

Once the specimens were potted, a microCT (VivaCT 40, Scanco Medical, Switzerland) was used to obtain a detailed cross-sectional image, 38 micron isentropic resolution, of each specimen at the point of the impactor blade contact. This was done by first obtaining a scout image of the potted specimen. A cross-sectional image at the exact location of the impactor blade contact could then be obtained by performing the CT scan 50.8 mm from the center of a fiber glass pin placed through the PVC square pot to act as a pivot on the test setup (Figure 2). Potting the specimens using non-metallic materials prior to scanning ensured that the CT slice was taken at the exact location and specimen orientation as that seen in the initial testing conditions. The cross-sectional microCT image was then thresholded to obtain the shape of the cortical shell (Figure 3). Finally, the image was converted to black and white, and a custom Matlab code was used to calculate the area moment of inertia (I_{xx}) and the distance from the tension side to the neutral axis (c).

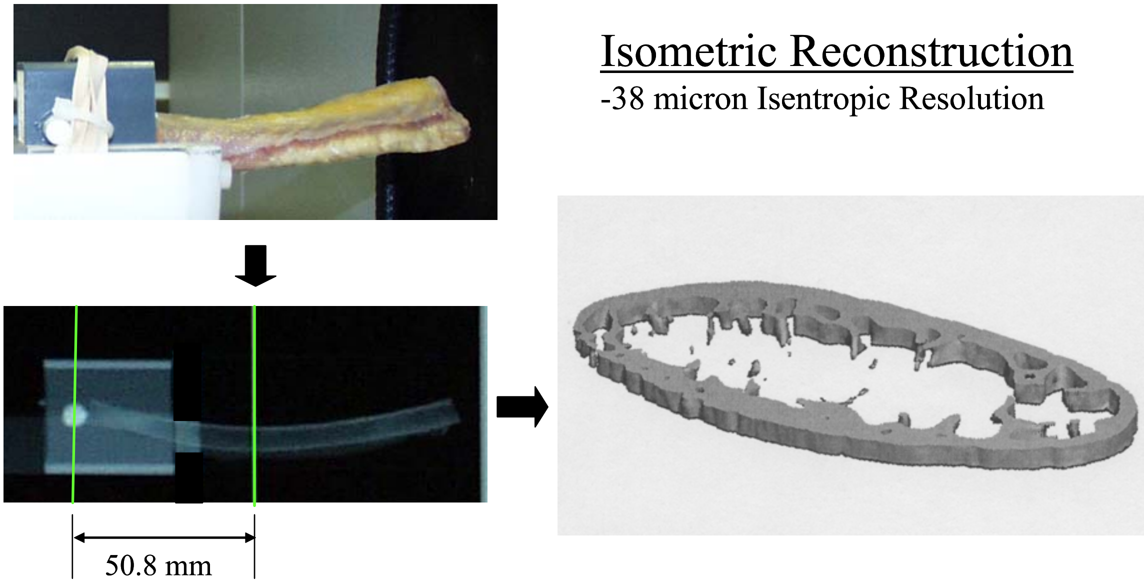


Figure 2: Obtaining The Cross-Sectional Image At The Exact Location Of The Impactor Blade Contact Point Using MicroCT.

Figure 3: Rib Cross-Section Before And After Thresholding.

Test Matrix

The matched rib pairs were randomly divided into three groups (Tables 2-4). In the first test group, matched specimens were tested to determine the effects of leaving the periosteum intact versus removing the periosteum and soft tissue. In the second test group, matched specimens were tested to determine the effects of placing a strain gage on the tension side of the specimen. The soft tissue and periosteum were removed only at the location of the strain gage. In the third test group, matched specimens were tested to determine the effects of immersing the specimens in saline for five days versus wrapping the specimens in saline soaked gauze. The soft tissue and periosteum were not removed in the third test group. For the first and second test group, specimens were kept hydrated by wrapping the specimens in saline soaked gauze.

Table 2. Group 1 Test Matrix – Periosteum Versus No Veriosteum.

Test ID	Subject Number	Side of Thorax	Rib Number	Location	Periosteum
PNP_1	sm37	Right	9	Lateral	**Yes**
PNP_2	sm37	Left	10	Anterior	**Yes**
PNP_3	sm48	Left	8	Lateral	**Yes**
PNP_4	sm48	Left	9	Anterior	**Yes**
PNP_5	sm52	Right	8	Anterior	**Yes**
PNP_6	sm52	Left	9	Lateral	**Yes**
PNP_7	sm52	Left	10	Anterior	**Yes**
PNP_8	sm37	Left	9	Lateral	No
PNP_9	sm37	Right	10	Anterior	No
PNP_10	sm48	Right	8	Lateral	No
PNP_11	sm48	Right	9	Anterior	No
PNP_12	sm52	Left	8	Anterior	No
PNP_13	sm52	Right	9	Lateral	No
PNP_14	sm52	Right	10	Anterior	No

Table 3. Group 2 Test Matrix – Strain Gage Versus No Strain Gage.

Test ID	Subject Number	Side of Thorax	Rib Number	Location	Strain Gage
GNG_1	sm40	Right	8	Anterior	**Yes**
GNG_2	sm40	Left	8	Lateral	**Yes**
GNG_3	sm40	Right	9	Anterior	**Yes**
GNG_4	sm40	Left	9	Lateral	**Yes**
GNG_5	sm40	Right	10	Anterior	**Yes**
GNG_6	sm50	Left	8	Lateral	**Yes**
GNG_7	sm50	Right	8	Anterior	**Yes**
GNG_8	sm50	Left	9	Lateral	**Yes**
GNG_9	sm50	Right	9	Anterior	**Yes**
GNG_10	sm40	Left	8	Anterior	No
GNG_11	sm40	Right	8	Lateral	No
GNG_12	sm40	Left	9	Anterior	No
GNG_13	sm40	Right	9	Lateral	No
GNG_14	sm40	Left	10	Anterior	No
GNG_15	sm50	Right	8	Lateral	No
GNG_16	sm50	Left	8	Anterior	No
GNG_17	sm50	Right	9	Lateral	No
GNG_18	sm50	Left	9	Anterior	No

Table 4. Group 3 Test Matrix – Soaked Versus Not Soaked.

Test ID	Subject Number	Side of Thorax	Rib Number	Location	Soaked
SNS_1	sm37	Right	8	Lateral	**Yes**
SNS_2	sm37	Left	10	Lateral	**Yes**
SNS_3	sm48	Left	8	Anterior	**Yes**
SNS_4	sm48	Left	9	Lateral	**Yes**
SNS_5	sm48	Right	10	Anterior	**Yes**
SNS_6	sm52	Right	8	Lateral	**Yes**
SNS_7	sm52	Left	9	Anterior	**Yes**
SNS_8	sm52	Left	10	Lateral	**Yes**
SNS_9	sm37	Left	8	Lateral	No
SNS_10	sm37	Right	10	Lateral	No
SNS_11	sm48	Right	8	Anterior	No
SNS_12	sm48	Right	9	Lateral	No
SNS_13	sm48	Left	10	Anterior	No
SNS_14	sm52	Left	8	Lateral	No
SNS_15	sm52	Right	9	Anterior	No
SNS_16	sm52	Right	10	Lateral	No

Experimental Setup

The primary component of the three-point bending test setup was a servo-hydraulic Material Testing System (MTS 810, 13.3 kN, Eden Prairie, MN). The three-point bending setup was designed so that the potted specimen end was pinned and the unpotted end was simply supported (Figure 4). The testing span was fixed at 10.16 cm. Specimens were oriented so that the specimen was bent inside-out by the impactor blade. The impactor displacement rate of 17.78 cm/s yielded a strain rate of approximately 0.5 strain/s, which is similar to that seen in a belted 35 mph automotive crash (Duma *et al.*, 2005). The impactor and reaction support assembly were instrumented with single axis load cells (Interface, INC., 1210, 2,224 N, Scottsdale, Arizona). An accelerometer (Endevco 7264B, 2000 G, San Juan Capistrano, CA) was attached to the impactor head to allow for inertial compensation. Displacement was measured using the MTS internal LVDT. Data from the load cells and accelerometers were recorded at a sampling frequency of 30 kHz (Iotech WBK16, Cleveland, OH).

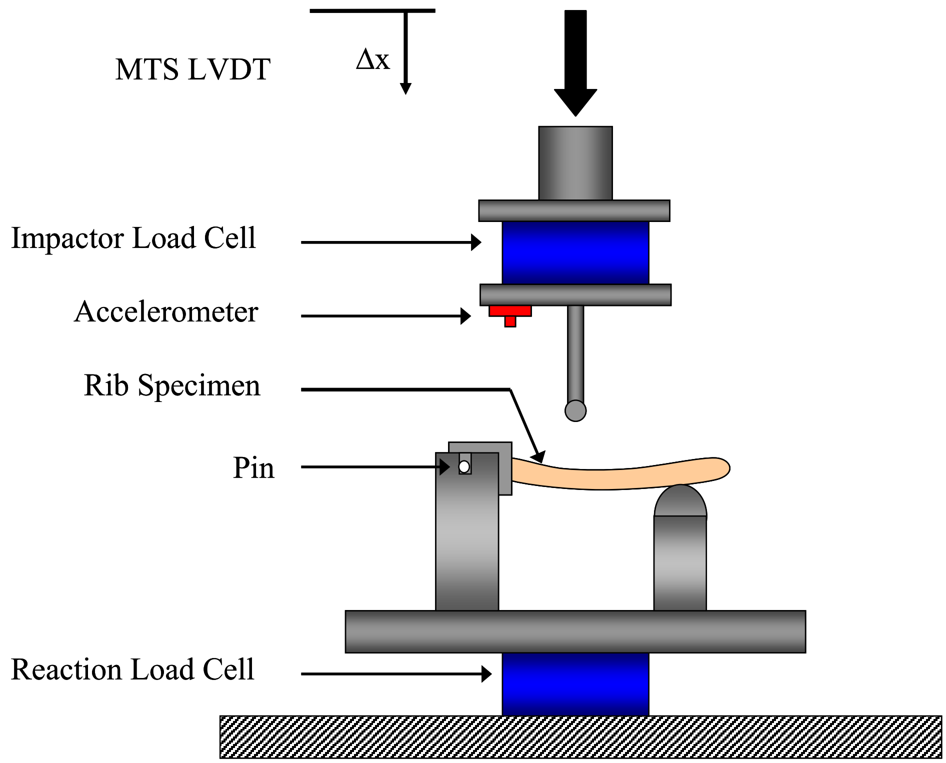


Figure 4: Rib Three-Point Bending Test Setup.

RESULTS

The peak moment, peak bending stress, peak impactor deflection, area moment of inertia, and distance from the tension side to the neutral axis for each matched pair within each test group, as well as the statistical analysis are presented in this section. The peak values were defined at the point at which structural yielding occurred. Due to limitations in specimen length for certain bodies or pre-existing fractures, some tests were omitted from the structural response comparisons. However, the omitted samples were included in the geometrical comparisons. All load cell and accelerometer data was filtered at CFC 180 in order to eliminate the noise while not affecting the signal.

Statistical Analysis

In order to determine if there were significant differences between the two test conditions within each group, a paired two-sample t-test was used to compare the means. Significance was defined as a p-value of ≤ 0.05. The resulting two tail p-values are reported (Table 5). For all test groups, the paired t-test showed that there was no statistical difference in the area moment of inertia, distance to the neutral axis, peak moment, peak stress, or peak impactor displacement between specimens for the two test conditions within each group.

Table 5. Statistical Analysis For All Three Test Groups - Paired Two Sample T-Test For Mean.

Comparison Group	p-values				
	Ixx (mm^4)	c (mm)	Peak Moment (N)	Peak Stress (MPa)	Peak Displacement (mm)
Periosteum vs. No Periosteum	0.60	0.29	0.31	0.42	0.14
Strain Gage vs. No Strain Gage	0.76	0.20	0.68	0.34	0.91
Soaked vs. Not Soaked	0.35	0.42	0.45	0.98	0.75

Periosteum versus No Periosteum

The subject, rib number, and anatomical location for the matched pairs used in the periosteum versus no periosteum statistical analyses were recorded (Table 6). The average peak values and corresponding standard deviations for the periosteum test group are reported (Table 7). In addition, the peak moment, peak bending stress, and peak deflection for periosteum versus no periosteum matched pairs were plotted for visual comparison (Figures 5-7).

Table 6. Left And Right Matched Pair Specimens For Periosteum Test Group.

Matched Pair	Subject Number	Rib Number	Location
1	sm37	9	Lateral
2	sm37	10	Anterior
3	sm48	8	Lateral
4	sm48	9	Anterior
5	sm52	8	Anterior
6	sm52	9	Lateral
7	sm52	10	Anterior

Table 7. Averages And Standard Deviations For Periosteum Test Group.

		Ixx (mm^4)	c (mm)	Peak Moment (Nm)	Peak Stress (MPa)	Peak Displacement (mm)
Periosteum	AVG	100.29	3.41	5.73	222.20	5.77
	STDEV	90.32	1.13	3.77	42.25	1.34
No Periosteum	AVG	103.97	3.25	6.06	213.94	5.07
	STDEV	96.29	0.81	3.98	35.22	1.49

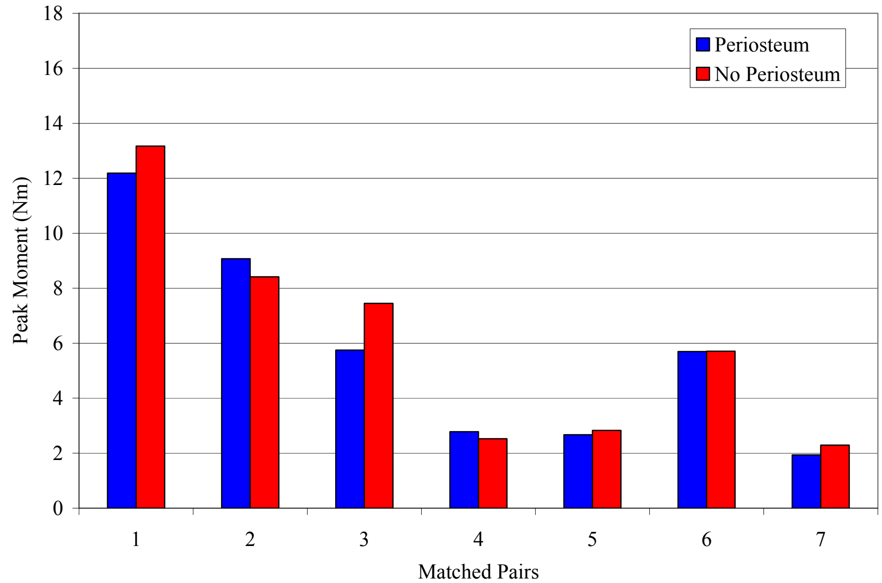


Figure 5: Peak Moment For Periosteum Versus No Periosteum Matched Pairs.
(p=0.31)

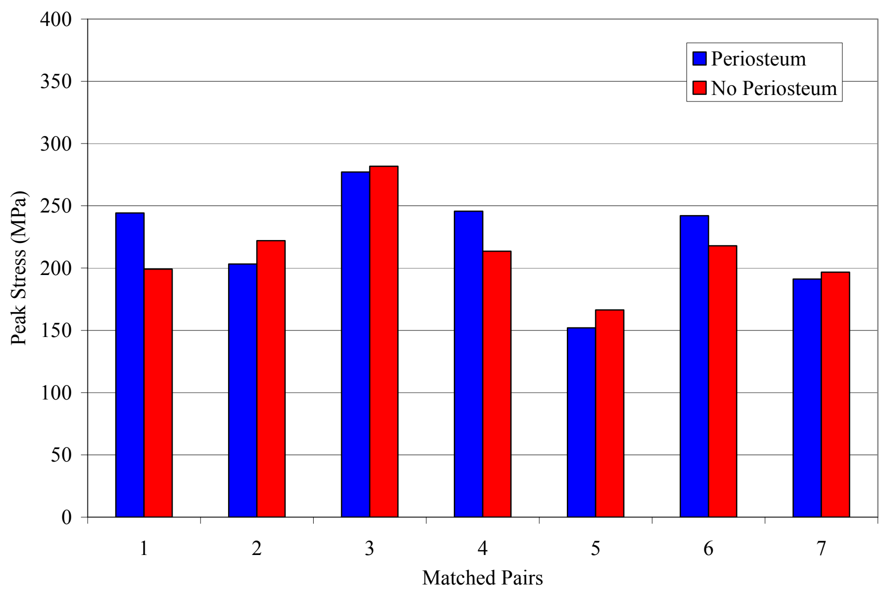


Figure 6: Peak Bending Stress For Periosteum Versus No Periosteum Matched Pairs.
(p=0.42)

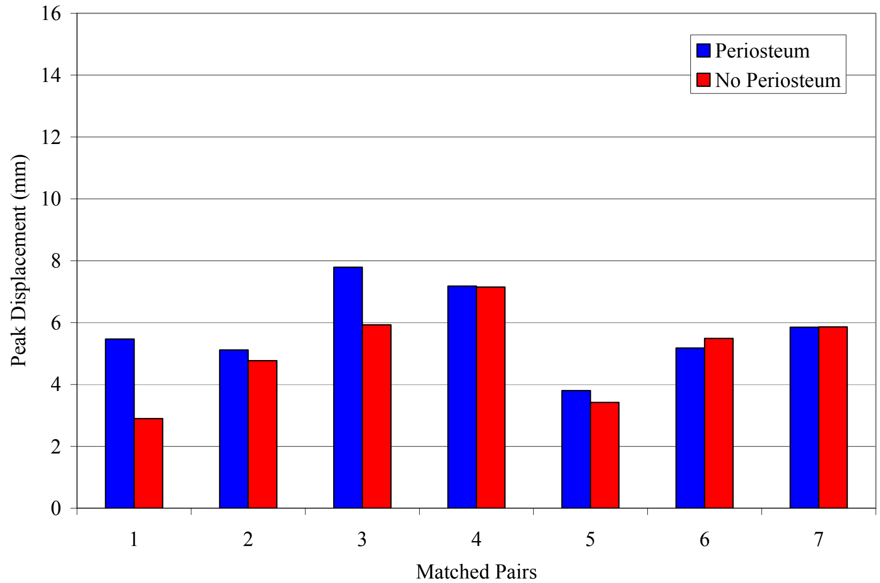


Figure 7: Peak Deflection For Periosteum Versus No Periosteum Matched Pairs.
(p=0.14)

Strain Gage versus No Strain Gage

The subject, rib number, and anatomical location for the matched pairs used in the strain gage versus no strain gage statistical analysis were recorded (Table 8). Average and corresponding standard deviations for the strain gage test group are reported (Table 9). In addition, the peak moment, peak bending stress, and peak deflection for strain gage versus no strain gage matched pairs were plotted for visual comparison (Figures 8-10).

Table 8. Left And Right Matched Pair Specimens For Strain Gage Test Group.

Matched Pair	Subject Number	Rib Number	Location
1	sm40	8	Anterior
2	sm40	8	Lateral
3	sm40	9	Anterior
4	sm40	9	Lateral
5	sm40	10	Anterior
6	sm50	8	Lateral
7	sm50	8	Anterior
8	sm50	9	Lateral
9	sm50	9	Anterior

Table 9. Averages And Standard Deviations For Strain Gage Test Group.

		Ixx (mm^4)	c (mm)	Peak Moment (Nm)	Peak Stress (MPa)	Peak Displacement (mm)
Strain Gage	AVG	96.27	3.34	4.38	147.78	3.89
	STDEV	0.43	11.74	2.35	53.98	1.08
No Strain Gage	AVG	100.49	3.12	4.58	138.93	3.85
	STDEV	63.31	0.61	2.97	49.14	1.38

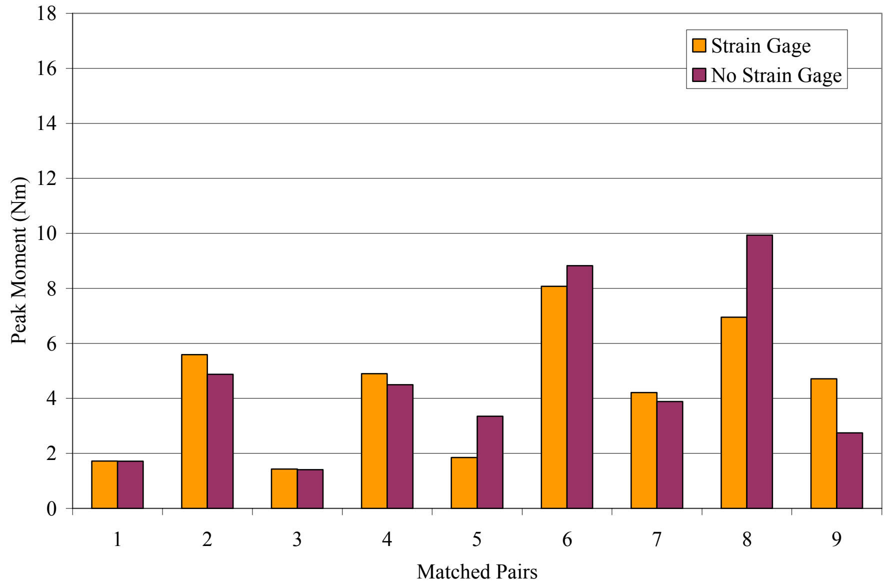


Figure 8: Peak Moment For Strain Gage Versus No Strain Gage Matched Pairs.
(p=0.68)

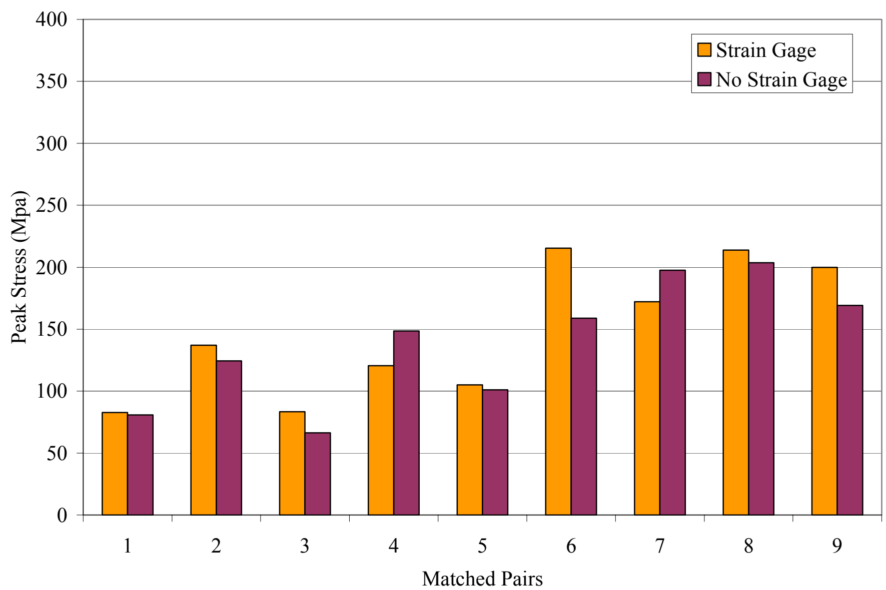


Figure 9: Peak Bending Stress For Strain Gage Versus No Strain Gage Matched Pairs.
(p=0.34)

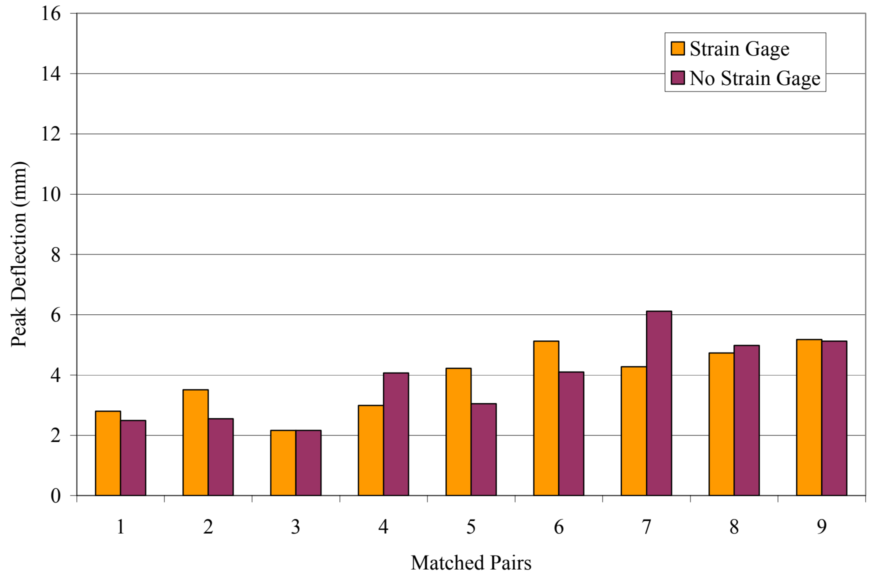


Figure 10: Peak Deflection For Strain Gage Versus No Strain Gage Matched Pairs. **(p=0.91)**

Soaked versus Not Soaked

The subject, rib number, and anatomical location for the matched pairs used in the soaked versus not soaked statistical analysis were recorded (Table 10). Average and corresponding standard deviations for the hydration test group are reported (Table 11). In addition, the peak moment, peak bending stress, and peak deflection for soaked versus not soaked matched pairs were plotted for visual comparison (Figures 11-13).

Table 10. Left And Right Matched Pair Specimens For Hydration Test Group.

Matched Pair	**Subject Number**	**Rib Number**	**Location**
1	sm37	8	Lateral
2	sm37	10	Lateral
3	sm48	8	Anterior
4	sm48	9	Lateral
5	sm48	10	Anterior
6	sm52	8	Lateral
7	sm52	9	Anterior
8	sm52	10	Lateral

Table 11. Averages And Standard Deviations For Hydration Test Group.

		Ixx (mm^4)	**c (mm)**	**Peak Moment (Nm)**	**Peak Stress (MPa)**	**Peak Displacement (mm)**
Soaked	AVG	114.29	3.57	6.01	223.45	6.43
	STDEV	87.66	0.96	3.11	50.35	2.32
Not Soaked	AVG	127.89	3.69	6.57	223.74	6.59
	STDEV	110.28	0.90	3.84	38.41	2.40

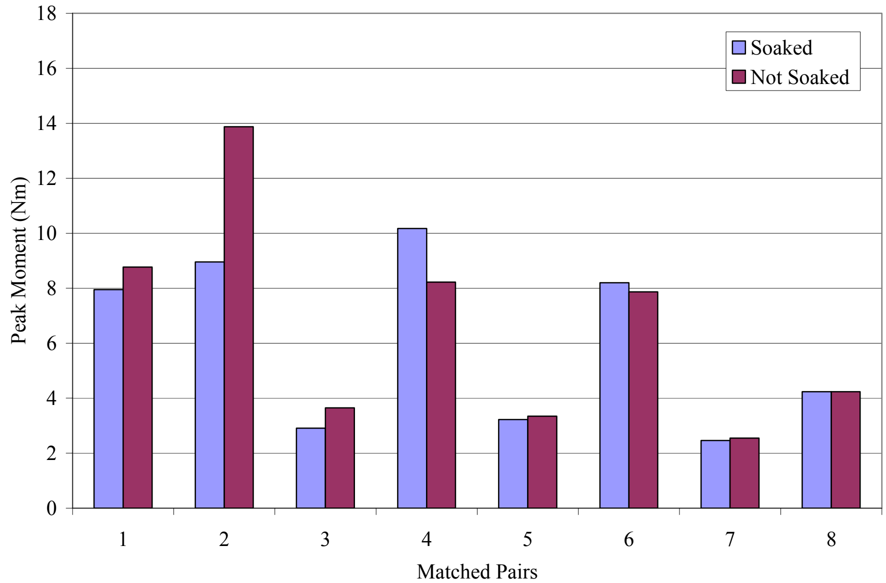


Figure 11: Peak Moment For Soaked Versus Not Soaked Matched Pairs.
(p=0.45)

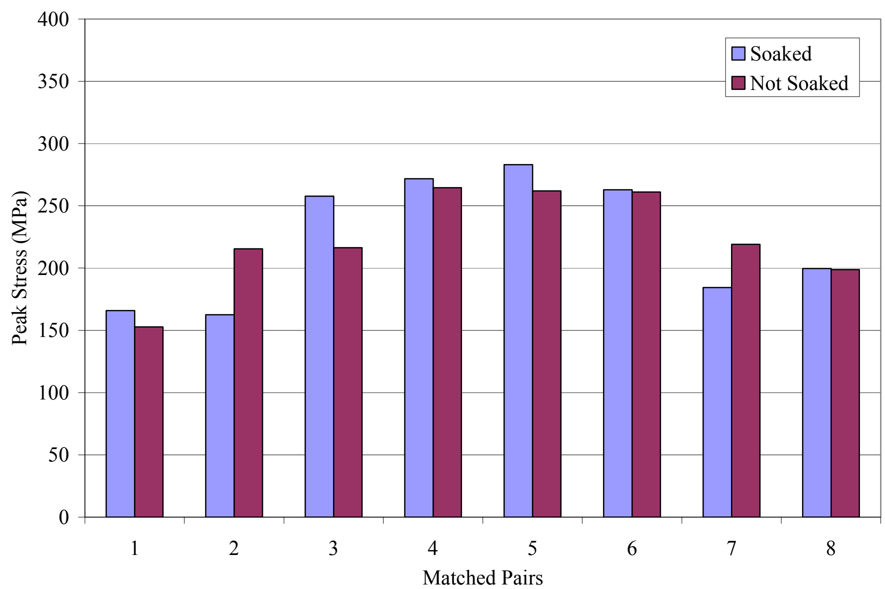


Figure 12: Peak Bending Stress For Soaked Versus Not Soaked Matched Pairs.
(p=0.98)

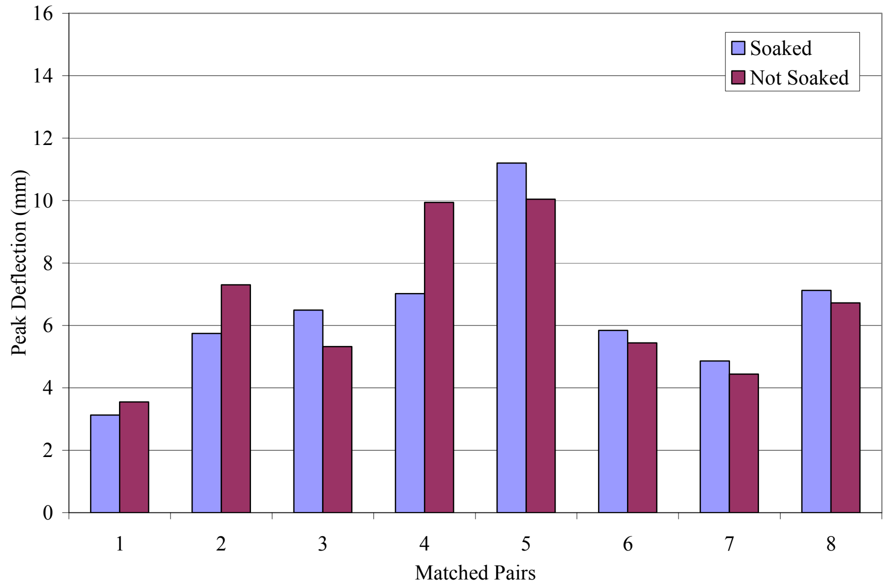


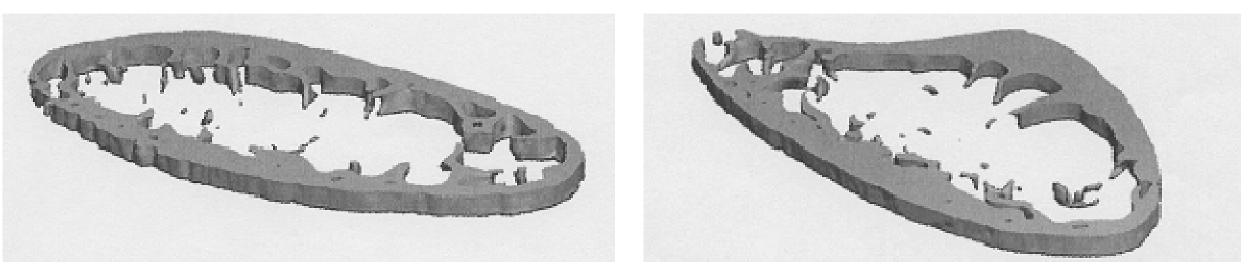
Figure 13: Peak Deflection For Soaked Versus Not Soaked Matched Pairs.
(p=0.75)

Regional Differences: Anterior versus Lateral

Cross-Sectional Properties

The statistically significant differences in the structural response of matched anterior versus lateral specimens could be due to the differences in the cross-sectional properties of anterior versus lateral specimens (Figure 14). The average values for cross-sectional properties and corresponding standard deviations for the anterior and lateral specimens are reported (Table 12).

A paired two-sample t-test showed that there were significant differences, $p \leq 0.05$, in the cross-sectional geometry of the anterior specimens versus the lateral specimens. Specifically, lateral specimens had a significantly larger area moment of inertia ($p<0.01$), distance to the neutral axis ($p<0.01$), and area ($p<0.01$) than the anterior specimens. The finding that both the moment of inertia and distance to the neutral axis decrease when moving from the posterior region to the anterior is consistent with that of Cormier (2005).



Anterior **Lateral**

Figure 14: Isometric Reconstruction For Matched Anterior Versus Lateral Specimens.

Table 12. Average Geometric Properties And Standard Deviations Of Anterior And Lateral Specimens.

Region		Ixx (mm^4)	c (mm)	Area (mm^2)
Anterior	AVG	74.54	3.09	14.75
	STDEV	56.27	0.71	5.74
Lateral	AVG	158.11	3.97	21.55
	STDEV	73.61	0.66	6.05

CONCLUSIONS

In conclusion, the testing and preparation methods presented in this report proved to be a very accurate means of preparing matched rib specimens. The results showed that the presence of the periosteum, the presence strain gage, or the two hydration conditions do not have a significant influence on the structural response of human rib specimens ($p>0.05$). In addition, there were also considerable differences in the cross-sectional geometry of the anterior specimens versus the lateral specimens. This was shown by a significantly larger area moment of inertia ($p<0.01$), distance to the neutral axis ($p<0.01$), and area ($p<0.01$) in the lateral specimens versus the anterior specimens. Based on the experience gained testing three-point bending rib specimens and the additional data strain gages provide while not significantly affecting on the structural response, it is recommended to store specimens in saline soaked gauze and test specimens with a strain gage on the tension side of the bone while leaving the remaining soft tissue and periosteum intact.

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DISCLAIMER

The conclusions presented in this report are those of the authors and not necessarily those of the sponsor, Ford Motor Company.

REFERENCES

CAVANAUGH, J. M. (1993). The biomechanics of thoracic trauma. In Accidental Injury Biomechanics and Prevention, ed A. M. Nahum and J. W. Melvin, 362-390. Springer- Verlag, New York.

CORMIER, J. M., STITZEL, J. D., DUMA, S. M., and MATSUOKA, F. (2005). Regional variation in the structural response and geometrical properties of human ribs. Proc. 49th Association for the Advancement Automotive Conference, Boston, MA.

CRANDALL, J. R., BASS, C. R., PILKEY, W. D., MILLER, H. J., SIKORSKI, J., and WILKINS, M. (1997). Thoracic response and injury with belt, driver side airbag and force limited belt restraint systems. International Journal of Crashworthiness, 2(1): 119-132.

CROMACK, J. R., and ZIPER, H. H. (1975). Three-point belt induced injuries: a comparison between laboratory surrogates and real world accident victims. Proc. 19th Stapp Car Crash Conference, pp.1-22. Society of Automotive Engineers.

DUMA, S. M., STITZEL, J. D., KEMPER, A. R., MCNALLY, C., KENNEDY, E. A., and MATSUOKA, F. (2005). Non-censored rib fracture data from dynamic belt loading tests on the human cadaver thorax. Proc. 19th International Technical Conference on the Enhanced Safety of Vehicles. NHTSA, Washington, D.C.

GABLER, H. C., DIGGES, K., FILDES, B. N., and SPARKE, L. (2005). Side Impact Injury Risk for Belted Far Side Passenger Vehicle Occupants. SAE Transactions, Journal of Passenger Car - Mechanical Systems, v.114, Section 6, Paper No. 2005-01-0287.

GRANIK, G., and STEIN, I. (1973). Human ribs: static testing as a promising medical application. J. of Biomechanics. 8: 237-240.

KALLIERIS, D., ZERIAL, P. D., RIZZETTI, A., and MATTERN, R. (1998). Prediction of thoracic injuries in frontal collisions. Proc. 18th International Technical Conference on the Enhanced Safety of Vehicles, pp. 1550-1563.

KEMPER A., MCNALLY C., KENNEDY E., RATH A., MANOOGIAN S., STITZEL J., and DUMA S. (2005). Material Properties of Human Rib Cortical Bone From Dynamic Tension Coupon Testing. The Proc. of the 49th International Stapp Car Crash Conference. 49, 199-230.

PATRICK, L. M. (1976). Frontal force impact tolerance of the human thorax. The Human Thorax- Anatomoy, Injury, and Biomechanics, SAE P-67, Dearborn, MI. 37-48.

RAMET, M., and CESARI, D. (1979). Behavior of restrained dummies and cadavers in frontal impacts. Proc. 7th International Research Council on the Biomechanics of Impact, pp. 210-219.

YOGANANDAN, N., and PINTAR, F. A. (1998). Biomechanics of human thoracic ribs. J. of Biomechanical Engineering. 120: 100-104.

DISCUSSION

PAPER: **Controlling Boundary Conditions and Specimen Preparation for Testing Human Ribs: Effects of Periosteum, Hydration, and Strain Gages**

PRESENTER: ***Stephen Duma, Virginia Tech – Wake Forest Center for Injury Biomechanics***

QUESTION: *Guy Nusholtz, Daimler Chrysler*
Okay. Needs to get his thoughts together. You notice a large difference in the geometry between posterior and anterior. Did you consider looking at the material properties also being different? That would shoot out another level of complexity of the problem.

ANSWER: Right. That's a great question. So that's the overall purpose of this project, and that's where we are now is looking at that. But before we could do that and looking at some of the previous research, we had to develop basically these techniques and how we're affecting that geometry and if any of these things will matter. It's a good question. I don't have the answer for your right now, but that's the overall purpose and the next step.

Q: Because if you're going to go after the material properties, you're going to have to somehow figure out how to compensate for the differences in geometries, as well.

A: Sure.

Q: Because those could easily be contaminated. Okay. Thank you.

A: And if you look at some of the previous work: I think what we're going to find is, obviously the overriding parameter here is geometry and the material—from what we know so far—doesn't vary nearly as much, but the geometry's going to be a dominant factor.

Q: We'll see.

Q: *Narayan Yoganandan, Medical College of Wisconsin*
Thought I'd give Guy a first chance all the time. Did you find any different with an 8, 9 and 10 ribs because and what is the reason you selected 8, 9 and 10?

A: The reason we selected those, primarily, was the specimen availability. We were using the other ribs in a different study and some of the questions that Guy was talking about: We had them available to do these kind of control boundary condition questions. No other reason.

Q: Because we found a whole bunch of ribs after we did all the friendly cadaver tests. About 10 years ago, I published a paper—general biomechanical engineering—where we did not find any difference between T6 and T7. Frank is probably going to correct me. We tested T6 and T7 and we didn't find any differences between the two ribs. We had a good numb—a good sample, probably 30 or 40 samples. In terms of either the morbid inertia or the stress of the strain—I don't want to call it—of the defluxion to failure or the moments to failure. Perhaps you'll find the same thing if you test more 8, 9 and 10 as well. Maybe 10 is different because it's a transitional one.

A: Right. I'm familiar with that study and I think—We're not seeing a huge difference. I didn't go into the analysis here between the vertical levels. It's more of a regional, front to back, that we're seeing as you go from the anterior lateral posterior. That's where we start to see the bigger, the bigger result and effects.

Q: That is probably due to the geometer connector, rib shield, I guess.

A: Yeah. Absolutely.

Q: Thank you.