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A Method to Acquire Non-censored Rib Fracture Data During Dynamic Belt Loading Tests

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ABSTRACT

The purpose of this paper is to present a method to determine the timing of all rib fractures individually during dynamic chest compression tests on human cadavers. The technique utilizes a total of 47 strain gages placed throughout each thorax. Using a combination of single and rosette gages, ribs one and nine through 12 have single gages, while ribs two through eight have multiple gages in order to isolate fracture timing in the case of multiple fractures per rib. For this study, two human cadavers (1 male, 1 female) were instrumented with the 47 strain gage array and tested. In order to simulate thoracic loading from a severe car crash, a table-top belt loading device was developed that utilizes a servo-hydraulic test machine to apply a dynamic input. The belt was positioned diagonally across each thorax in a passenger side orientation. For each cadaver, the belt load pulse was configured to result in 40% chest compression through a 150 ms load and unload cycle. Potentiometers and accelerometers measured the chest compression and acceleration at three locations, load cells in line with the belt provided belt loads, and load cells on the posterior side of the thorax measured the reaction loads. The time histories of each strain gage were analyzed to determine the time of fracture which could then be compared directly to the reaction loads and chest displacements at that exact time, thereby creating a non-censored data set. In both cadavers, all fractures (20 for female and 12 for male) occurred within the first 35% compression of the thorax. As a general trend, the first series of fractures were on the left side of the thorax where the belt passed over the abdominal region. The peak strain at failure ranged from 1.1 % to 2.5 %. By utilizing this technique, the exact timing of an injury level can be characterized relative to the mechanical parameters. For example, using rib fractures as the parameter for AIS scores in the female test, it is shown that AIS 1 injury occurs at a chest compression of 21%, AIS 2 at 22%, AIS 3 at 24 %, and AIS 4 at 34%. It is expected that this information will augment and clarify the foundation of thoracic injury risk functions.

INTRODUCTION

All previous studies aimed at determining thoracic injury criteria generally rely on the same set of cadaver impact tests. These tests all provide censored injury data. In other words, it is not possible to determine the exact loads, accelerations, or displacements at the time of fracture. Rather, one only knows that an injury occurred at some point during the impact test. In order to reduce this limitation, this study presents a method to generate non-censored rib fracture data. Although previous studies have shown the ability to detect selected rib fractures, no method has been successful at mapping the exact fracture timing of the entire thorax during dynamic belt loading.

METHODS

The tests were performed on two cadavers (one male, one female) instrumented with 47 single axis and rosette strain gages on the ribs, sternum, and clavicle. The primary components of the belt loading system were a tensile testing machine (MTS 810, 22 kN, Eden Prairie, MN) and rigid loading table (Figure 1). The thorax of each cadaver was placed over a rigid plate that distributed the applied load over four load cells to measure the reaction loads of the thorax which were used to compensate for inertial effects. The 5 cm wide nylon loading belt was situated 40° from the sagittal plane of the body. The orientation of the belt simulated a passenger-side seat belt, going over the right clavicle and left side of the abdomen. A series of wire cables and pulleys connected the hydraulic piston to a Material Testing System (MTS 810, 22 kN, Eden Prairie, MN) used to load the cable/belt system at the desired rate. The locations of the pulleys were adjustable to accommodate cadavers of various sizes as well as to alter the angle of the belt relative to the table top. A slack reducer, connecting the primary wire rope to two secondary wire ropes, served to displace the ends of the loading belt equally, as well as remove slack from the system.

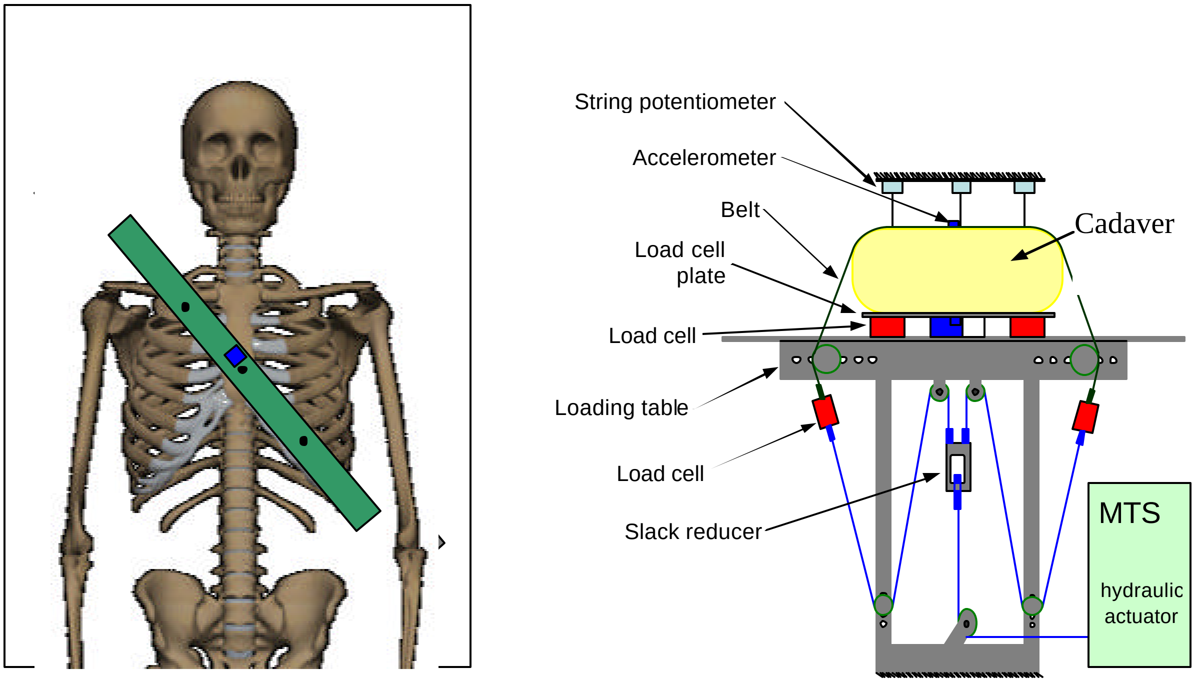

Figure 1: Top and Oblique View of Belt Loading System.

Once all the cables and instrumentation were connected, each cadaver was preconditioned prior to each test. This was done by placing a large flat 9.07 kg mass on the thorax five times for 10 seconds at one minute intervals. Before each test the MTS was used to pretension slightly the belt (75-80 N for the male, 58-75 N from the female). In order to model *in vivo* conditions, the test subjects' pulmonary systems were inflated to 14 kPa immediately prior to each test, which corresponded to the mean inspiration pressure, with a tracheostomy connected to a pressure regulator. The depth of the inflated chest was then measured and recorded. Finally, the MTS machine loaded the cable system at a rate of 1.5 m/s in order to simulate a severe car crash.

Instrumentation

Each cadaver was instrumented with a total of 47 strain gages; 26 single axial strain gages (Vishay Measurements Group, CEA-06-062UW-350, Malvern, PA) and 7 rectangular rosette strain gages (Vishay Measurements Group, CEA-06-062UR-350, Malvern, PA). The deflection of the thorax was measured using three string potentiometers (Space Age Control, 160, Palmdale, CA) that were attached to the belt at the sternum and situated approximately 90 mm apart along the length of the belt (Figure 1). Additionally, an accelerometer (Endevco, 7264B, 2000 g, San Juan Capistrano, CA) was mounted on the belt at the sternum and load cell plate to acquire chest acceleration and table vibration. Belt tension was measured with two load cells (Interface, SSM-AJ, 13kN, Scottsdale, AZ). Four additional load cells (Denton, 5768, 11 kN, Rochester Hills, MI), (Denton, 1968, 22 kN, Rochester Hills, MI), (Denton, 1716A, 13 kN, Rochester Hills, MI) located between the cadaver and loading table, measured the force response of the body.

Test Subject Information

Two fresh frozen human cadavers were used in these tests (Table 1). It should be noted that chest depth measurements were taken from the middle of the sternum to the back of the thorax. Also, the percent compression was defined as the ratio of chest depth during the test to the chest depth measured prior to the test.

Table 1. Subject Anthropometric Data.

Cadaver Number	**SM35**	**SF33**
Sex	Male	Female
Age	73	73
Weight	84.36 kg	45.35 kg
Height	154 cm	154 cm
Height (head to heal)	1730 mm	1540 mm
Sternum Length	210 mm	150 mm
Chest Circumference (Largest part)	1140 mm	700 mm
Chest Circumference (Center of Sternum)	1070 mm	740 mm
Linear Breadth (Center of Sternum)	370 mm	280 mm
Chest Depth (Center of Sternum)	230 mm	165 mm
Chest Circumference (Center of Thorax no Superficial Tissue)	840 mm	610 mm

Stain Gage Locations

The strain gages were located on the lateral sides of ribs 2-10 as well as the anterior side of ribs 3, 4, and 5 (Figure 2). The only difference between the two is the orientation of the rosettes on the left 7th and 9th ribs. The first "R" in the rib strain gage labels stand for "Rib". Similarly, the first letters on the clavicle and sternum strain gage labels "CR", "SU", and "SL" stand for clavicle, upper sternum, and lower sternum respectively. The first number represents the number of the rib. The second letter "R" or "L" stands for the right side or left side of the thorax, respectively. The first letter after the dash, "S" or "R", stands for single axis or rosette strain gage. The gages were numbered one to three bilaterally for ribs containing multiple gages. The number "1" gage corresponded to the gage closest to the sternum on each side, and the number "3" gage was the most distal gage from the sternum. The last letter "A", "B", or "C" only concerned the rosette strain gages and identifies the gage position within the rosette. For example, the strain gage label R3R-R3A stands for gage A of a rosette on the lateral right side of rib 3.

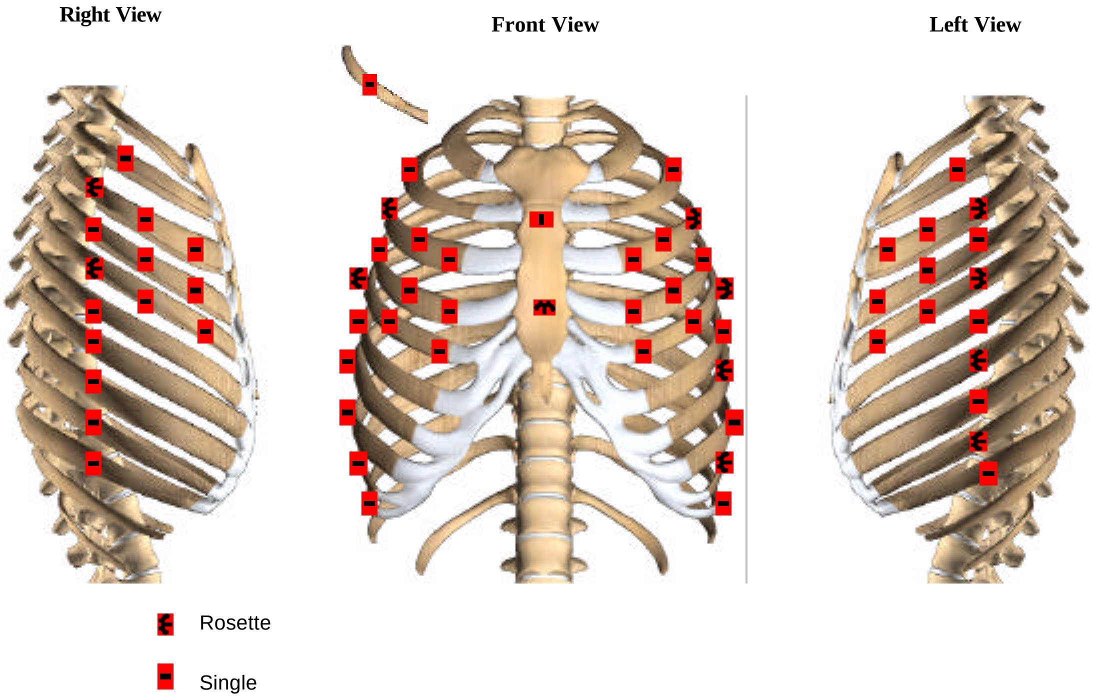

Figure 2: Strain Gage Positioning on the Thorax.

Strain Gage Attachment

Once the location of each strain gage was determined the surface of the bone was then swabbed with ether and allowed to dry. Upon drying, Conditioner A, an acidic solution, was applied to the surface with a clean piece of gauze in order to etch the surface of the bone. Then, Neutralizer 5A, a basic solution, was applied to the surface in order to neutralize the acidic solution. The gage was removed from its case and prepared by applying M-Bond Catalyst to the underside of the gage. Next, M-Bond 200 Adhesive was applied to the bone and the gage was quickly pushed over the adhesive in a rolling manner. The strain gage covered with a small piece of latex was held with firm pressure for 3 minutes. Special care was taken to align each gage so that it was in line with the axis of the rib. The strain output from the three gages that composed each rosette was used to calculate the first and second principle strains and the angle Phi (F). Phi was defined as the angle from the gage reference axis (labeled X-Y) to the first principal axis.

RESULTS

In order to validate that these tests were representative of an actual severe crash, the data was compared to data obtained from an actual sled test preformed (Figure 3). It can be seen that the compression rates produced from these tests closely match those seen in an actual sled test. The full travel of the MTS (15 cm) was used to fully compress the chest, causing 55% compression of the female thorax and 37% of the male thorax. This corresponded to 91.39 mm for the female and 100.36 mm for the male. The MTS was actuated at 150 cm/s, which compressed the thorax of the female at a rate of 94 cm/s and the male at 97 cm/s. The difference in the rate of the MTS and the rates seen by the cadavers was due to inertial effects and friction in the cable system.

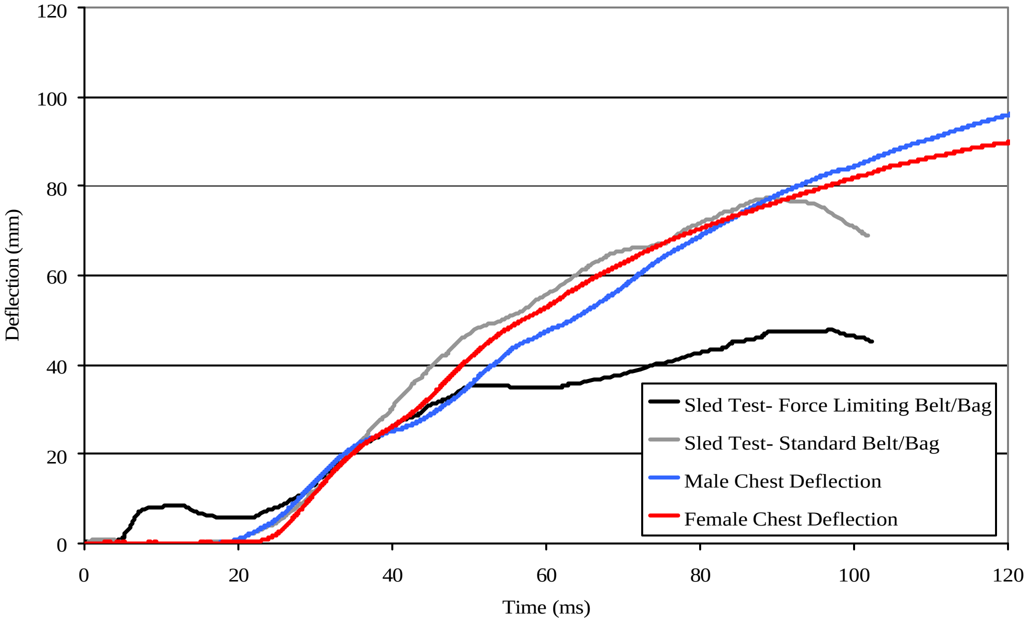

Figure 3: Chest Compression Rate of Cadavers in a 48 km/hr Sled Test (Kent, 2001) versus Presented Belt Loading Data.

The peak strains and strain rates vary from gage to gage for both the male and female cadavers (Table 2, Table 3). The highest absolute value for each gage was reported as the peak strain. The strain rate was determined from the most linear portion of the initial strain loading. The majority of the gages reported tensile loading. The male cadaver had peak strain ranging from 1,533 to 39,812 (μ strain) in tension and from 1,612 to 15,332 (μ strain) in compression. The female cadaver had peak strain ranging from 1,716 to 33,614 (μ strain) in tension and from 1,223 to 17,193 (μ strain) in compression. The rib strain rates seen by the male cadaver ranged from -0.376 to 0.880 (strain/s), while strain rates seen by the female cadaver ranged from -0.468 to 0.547 (strain/s).

Table 2. Peak Strains and Strain Rates for all Strain Gages on Male Cadaver.

Strain Gage Number	**Thorax Location**	**Rib Number**	**Gage Type**	**Rib Location**	**Peak Strain (μ strain)**	**Time (ms)**	**Strain Rate (strain/s)**
R2R-S3	Right Side	2	Single	3	13680	79.3	0.243
R3R-S1	Right Side	3	Single	1	11353	89.5	0.134
R3R-S2	Right Side	3	Single	2	11595	89.2	0.209
R3R-R3A	Right Side	3	Rosette	3	1941	89.3	0.071
R3R-R3B	Right Side	3	Rosette	3	22111	88.9	0.459
R3R-R3C	Right Side	3	Rosette	3	12574	88.9	0.225
R4R-S1	Right Side	4	Single	1	5083	95.6	0.143
R4R-S2	Right Side	4	Single	2	13758	95.2	0.268
R4R-S3	Right Side	4	Single	3	12561	95.3	0.179
R5R-S1	Right Side	5	Single	1	4848	82.6	0.243
R5R-S2	Right Side	5	Single	2	7252	82.6	0.267
R5R-R3A	Right Side	5	Rosette	3	3335	82.9	0.054
R5R-R3B	Right Side	5	Rosette	3	8165	82.6	0.145
R5R-R3C	Right Side	5	Rosette	3	3577	82.6	0.055
R6R-S3	Right Side	6	Single	3	10480	136.2	0.095
R7R-S3	Right Side	7	Single	3	7014	132.3	0.080
R8R-S3	Right Side	8	Single	3	4557	132.7	0.062
R9R-S3	Right Side	9	Single	3	1286	118.2	0.015
R10R-S3	Right Side	10	Single	3	2810	121.5	0.079
CR-S3	Right Clavicle	N/A	Single	N/A	-6577	95.5	-0.122
SU-S	Upper Sternum	N/A	Single	N/A	-7711	69.1	-0.376
SL-RA	Lower Sternum	N/A	Rosette	N/A	13331	69.4	4.098
SL-RB	Lower Sternum	N/A	Rosette	N/A	39812	77.2	3.256
SL-RC	Lower Sternum	N/A	Rosette	N/A	7960	76.7	0.581
R2L-S3	Left Side	2	Single	3	11589	53.9	0.535
R3L-S1	Left Side	3	Single	2	10478	56.1	0.413
R3L-S2	Left Side	3	Single	3	13328	55.9	0.577
R3L-R3A	Left Side	3	Rosette	3	4624	55.9	0.172
R3L-R3B	Left Side	3	Rosette	3	5936	55.8	0.267
R3L-R3C	Left Side	3	Rosette	3	1839	56.1	0.144
R4L-S1	Left Side	4	Single	1	9290	51.4	0.449
R4L-S2	Left Side	4	Single	2	15576	51.4	0.880
R4L-S3	Left Side	4	Single	3	7948	51.5	0.410
R5L-S1	Left Side	5	Single	1	11741	47.3	0.603
R5L-S2	Left Side	5	Single	2	14128	47.3	0.706
R5L-R3A	Left Side	5	Rosette	3	3674	47.6	0.204
R5L-R3B	Left Side	5	Rosette	3	6499	47.6	0.342
R5L-R3C	Left Side	5	Rosette	3	1533	47.7	0.059
R6L-S3	Left Side	6	Single	3	6961	44.7	0.385
R7L-R3A	Left Side	7	Rosette	3	3772	42.6	0.215
R7L-R3B	Left Side	7	Rosette	3	6618	42.7	0.451
R7L-R3C	Left Side	7	Rosette	3	1822	117.1	0.117
R8L-S3	Left Side	8	Single	3	5080	136.0	0.318
R9L-R3A	Left Side	9	Rosette	3	2310	35.9	0.183
R9L-R3B	Left Side	9	Rosette	3	3026	35.8	0.251
R9L-R3C	Left Side	9	Rosette	3	-1673	52.7	-0.086
R10L-S3	Left Side	10	Single	3	-15332	126.1	-0.287

Table 3. Peak Strains and Strain Rates for all Strain Gages on Female Cadaver.

Strain Gage Number	**Thorax Location**	**Rib Number**	**Gage Type**	**Rib Location**	**Peak Strain (μ strain)**	**Time (ms)**	**Strain Rate (strain/s)**
R2R-S3	Right Side	2	Single	3	-5504	111.2	0.138
R3R-S1	Right Side	3	Single	1	5508	85.8	0.300
R3R-S2	Right Side	3	Single	2	8000	111.1	0.191
R3R-R3A	Right Side	3	Rosette	3	2410	78.3	0.104
R3R-R3B	Right Side	3	Rosette	3	5246	57.2	0.225
R3R-R3C	Right Side	3	Rosette	3	4755	57.2	0.179
R4R-S1	Right Side	4	Single	1	3338	62.7	0.345
R4R-S2	Right Side	4	Single	2	7076	62.5	0.202
R4R-S3	Right Side	4	Single	3	5490	95.1	0.175
R5R-S1	Right Side	5	Single	1	2709	52.5	0.111
R5R-S2	Right Side	5	Single	2	4846	58.6	0.137
R5R-R3A	Right Side	5	Rosette	3	-1223	56.8	-0.044
R5R-R3B	Right Side	5	Rosette	3	7391	108.0	0.146
R5R-R3C	Right Side	5	Rosette	3	n/a	n/a	n/a
R6R-S3	Right Side	6	Single	3	10642	105.5	0.153
R7R-S3	Right Side	7	Single	3	7785	133.1	0.094
R8R-S3	Right Side	8	Single	3	4633	111.1	0.144
R9R-S3	Right Side	9	Single	3	2971	118.2	0.062
R10R-S3	Right Side	10	Single	3	1716	107.3	0.123
CR-S3	Right Clavicle	N/A	Single	N/A	-9020	74.4	-0.248
SU-S	Upper Sternum	N/A	Single	N/A	-2947	115.4	-0.195
SL-RA	Lower Sternum	N/A	Rosette	N/A	-2109	70.1	-0.058
SL-RB	Lower Sternum	N/A	Rosette	N/A	-7683	132.7	-0.316
SL-RC	Lower Sternum	N/A	Rosette	N/A	7729	84.2	0.300
R2L-S3	Left Side	2	Single	3	20681	72.8	0.531
R3L-S1	Left Side	3	Single	2	-8174	61.7	0.520
R3L-S2	Left Side	3	Single	3	33641	92.2	0.682
R3L-R3A	Left Side	3	Rosette	3	2593	119.7	0.034
R3L-R3B	Left Side	3	Rosette	3	3095	111.0	0.058
R3L-R3C	Left Side	3	Rosette	3	-3954	93.7	-0.069
R4L-S1	Left Side	4	Single	1	-7257	50.2	-0.301
R4L-S2	Left Side	4	Single	2	9028	49.1	0.385
R4L-S3	Left Side	4	Single	3	9139	49.2	0.350
R5L-S1	Left Side	5	Single	1	-17193	50.3	-0.468
R5L-S2	Left Side	5	Single	2	3008	45.5	0.129
R5L-R3A	Left Side	5	Rosette	3	6326	47.6	0.218
R5L-R3B	Left Side	5	Rosette	3	10109	47.5	0.460
R5L-R3C	Left Side	5	Rosette	3	7025	47.0	0.364
R6L-S3	Left Side	6	Single	3	12211	46.9	0.547
R7L-R3A	Left Side	7	Rosette	3	-3124	61.4	0.252
R7L-R3B	Left Side	7	Rosette	3	11357	46.1	0.491
R7L-R3C	Left Side	7	Rosette	3	8260	45.4	0.547
R8L-S3	Left Side	8	Single	3	-5254	51.7	0.275
R9L-R3A	Left Side	9	Rosette	3	n/a	n/a	n/a
R9L-R3B	Left Side	9	Rosette	3	-6217	621	0.320
R9L-R3C	Left Side	9	Rosette	3	3523	54.5	0.184
R10L-S3	Left Side	10	Single	3	9297	73.1	0.316

Rib Fracture Identification

The rib fracture locations were determined by performing a post-test injury analysis on each cadaver using a detailed necropsy of the thorax. The fracture locations were photographed and documented for each cadaver. The time of facture was determined from the plots of strain gage output vs. time (Figure 4). The male cadaver sustained 12 fractures on 12 ribs [8 on the left, 4 on the right], as well as one fracture on the right clavicle (Figure 5). For the female cadaver, 20 rib fractures were detected on 12 ribs [14 on the left, 6 on the right] as well as one fracture to the sternum (Figure 6). The strain rates seen by the ribs of the male cadaver that fractured varied from 0.133 to 0.648 (strain/s), and from -0.581 to 0.559 (strain/s) for the female cadaver. The male cadaver sustained two fractures directly under strain gages, and the female sustained 7. The fractures that occurred directly under gages are of particular interest because the peak strain at the time of fracture could be obtained from these gages.

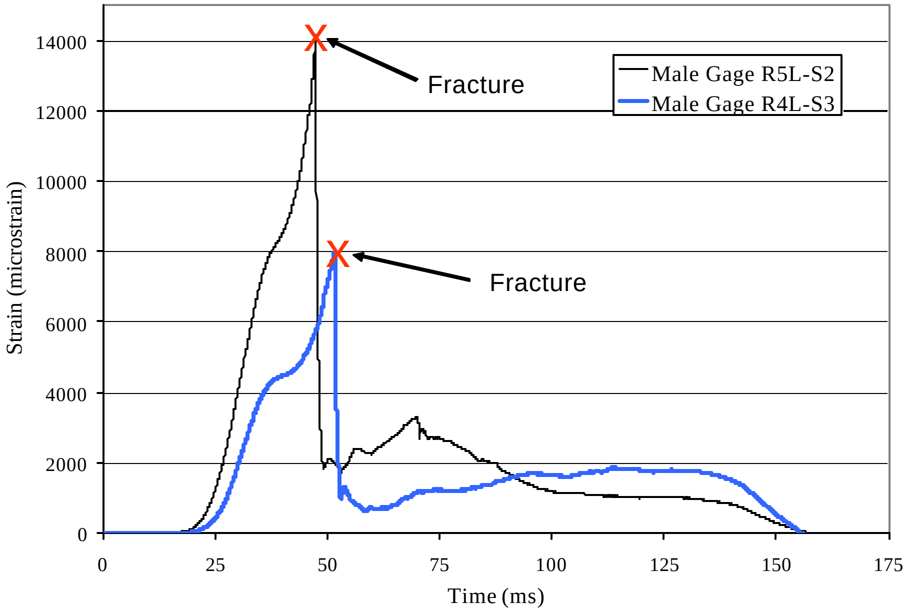

Figure 4: Determination of Rib Fracture Timing.

Male Rib Fracture Identification

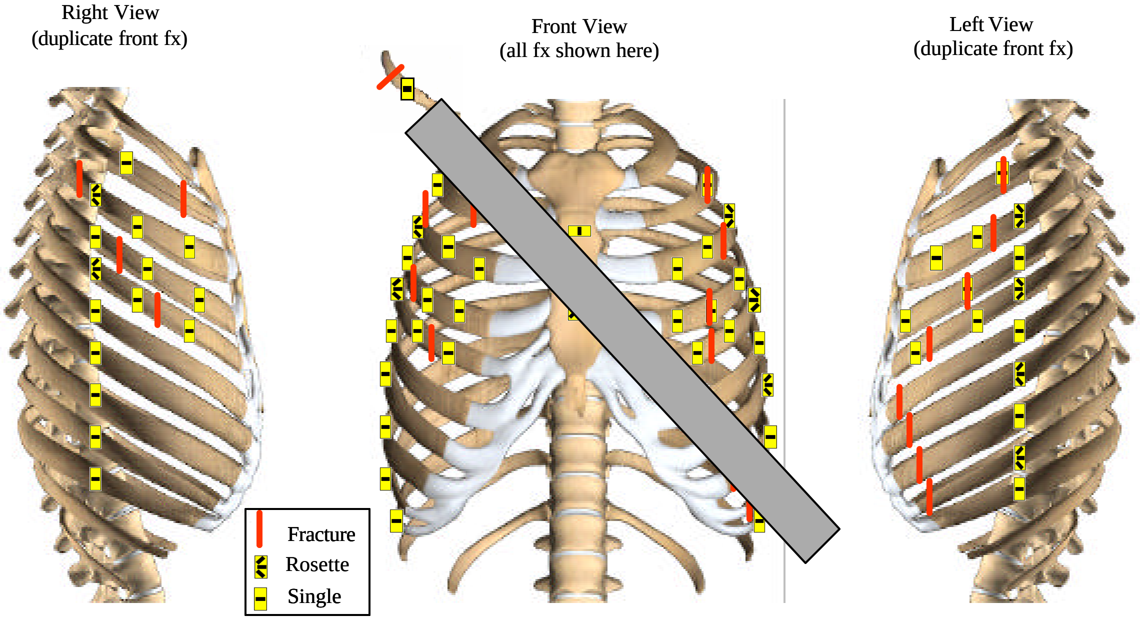

Figure 5: Location of Strain Gages and Fractures for Male Cadaver.

Female Rib Fracture Identification

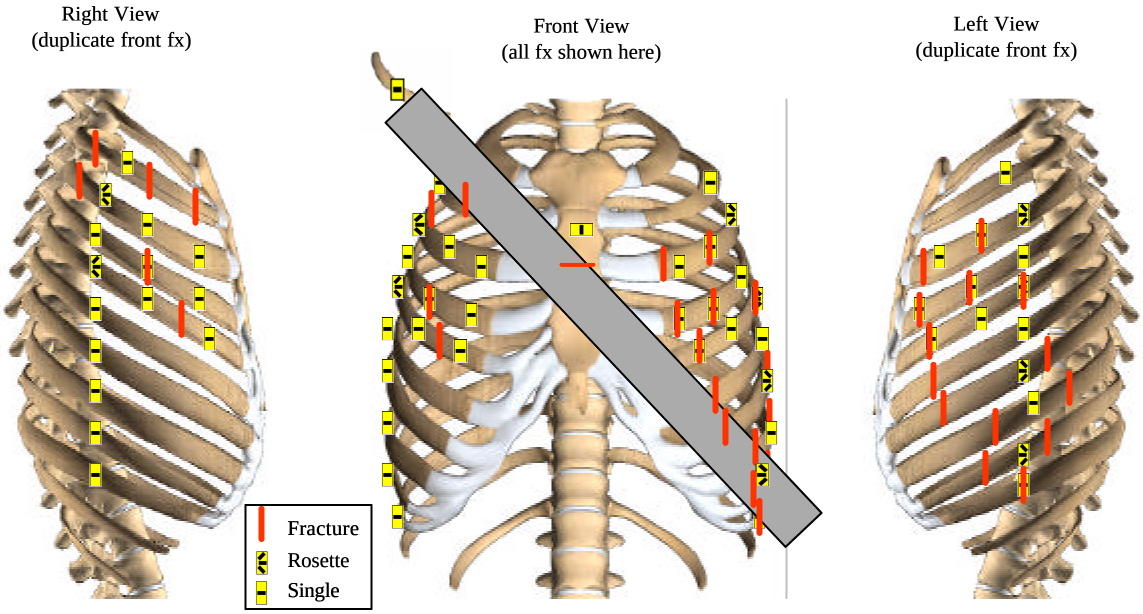

Figure 6: Location of Strain Gages and Fractures for Female Cadaver.

DISCUSSION

In both cadavers, all rib fractures occurred within the first 35% compression of the thorax. As a general trend, the first series of fractures were on the left side of the thorax where the belt passed over the abdominal region. The ribs in the upper thoracic region on the right side fractured next. In order to illustrate the usefulness of the non-censored data, the reaction force data was plotted vs. percent chest deflection data for these tests with the fracture timing and corresponding Abbreviated Injury Scale (AIS) score (Figures 7 and 8). This was used to compare the definition of an AIS=3 for the human rib cage as defined by NHTSA to the injury criteria for an AIS=3 for the 50th percentile male and 5th percentile female hybrid III dummies. An AIS=3 for the rib cage was defined to be greater than 3 rib fractures on one side of the rib cage and no more than 3 on the other side. NHTSA has defined the injury criteria of the 50th percentile male dummy as a chest deflection of 63 mm, which corresponds to a 28%-30% chest deflection. The injury criteria for the 5th percentile female hybrid III dummy has been defined as a chest deflection of 52 mm, which corresponds to a 22%-24% chest deflection. The range of percent chest deflections is due to the variations in dummy chest thickness as a result of tolerances set by the manufacturer, Denton ATD. As seen in Figures 7 and 8, an AIS= 3 occurred at 13% chest deflection for the male and 23% chest deflection for the female.

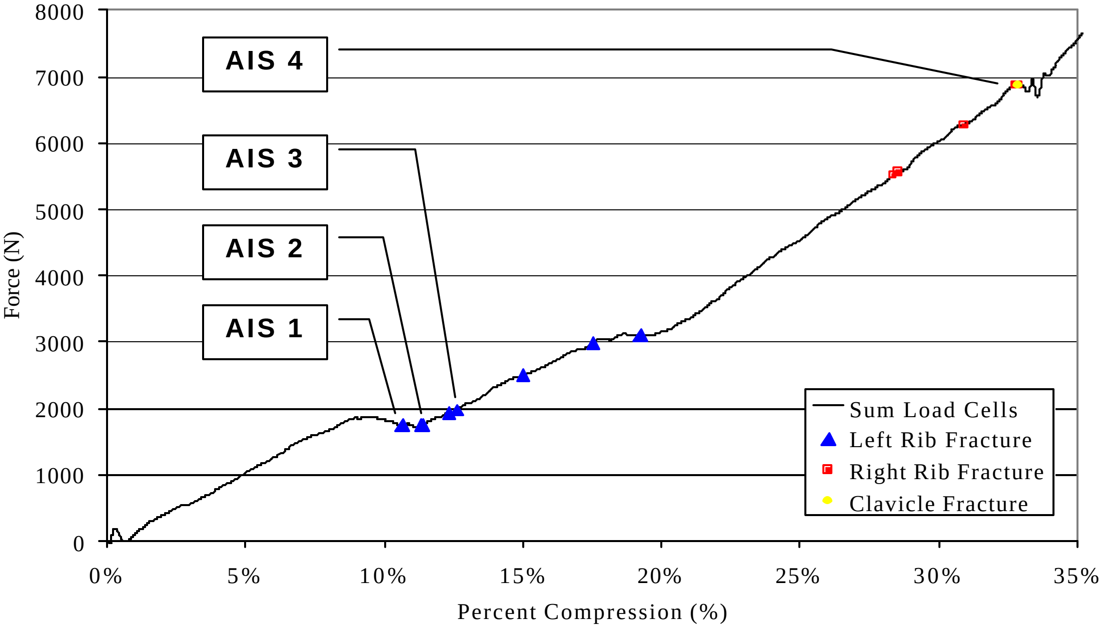

Figure 7: Rib Fracture Progression of Male Cadaver with AIS Levels.

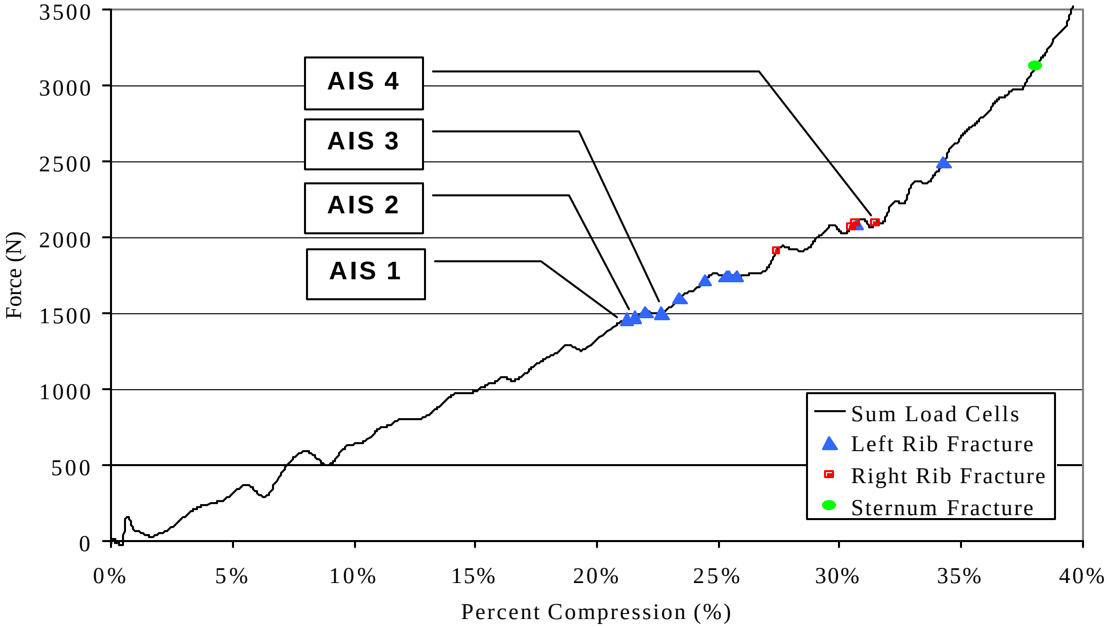

Figure 8: Rib Fracture Progression of Female Cadaver with AIS Levels.

CONCLUSIONS

The novel strain gagging technique presented in this report, in which the thorax was instrumented with 47 single axis and rosette strain gages, has allowed for the precise determination of the time of fracture for each rib for the first time in the history of thoracic research. In addition, for the first time the exact point at which the different thoracic AIS scores occurred could be identified with the time of rib fracture data. All rib fractures occurred within the first 35% compression of the thorax for both cadavers, and were side dependant for both cadavers. The first series of fractures were on the left side of the thorax where the belt passed over the abdominal region. The ribs on the upper right hand side of the thorax fractured second. Finally, the strain gage data showed that the majority of the ribs sustained tensile loading until the time of fracture. The male and female cadaver had peak tensile strains ranging from 1,533 to 39,812 (μ strain) and 1,716 to 33,614 (μ strain), respectively.

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DISCUSSION

PAPER: **A Method to Acquire Non-censored Rib Fracture Data During Dynamic Belt Loading Tests**

PRESENTER: ***Dr. Stefan Duma, Virginia Tech – Wake Forest Center for Injury Biomechanics and Toyota Motor Corporation***

QUESTION: *Erik Takhounts, NHTSA*
I don't think, Stefan, that you can directly look at the injuries and compare them to AIS scale because of your boundary condition in the spine, because you don't allow the ribs to rotate. That contributes to extra chest deflection. So, are you planning to do something about that in the future?

ANSWER: Exactly, and that's the caveat of these tests. Basically, these two were proof of concept. We want to do a series of sled tests with the same instrumentation package and see what we get. But you're right, you do have this what I call this posture, but you do have that fat condition that can affect these results.

Q: Okay. Thanks.

QUESTION: *Jason Kerrigan, University of Virginia*
Just a quick question: You noted that the linear or, sorry, the single axis strain gauges and the rosettes were pretty much giving you the same information. Most of the strains were linear along the bone there. I was curious. Did you see a good correlation in maximum strain for the rib fractures or have you looked at that at all, like, you know, the upper ribs or the right-side ribs were failing at a lower strain or--?

A: We looked at that. We don't have enough data to make a comparison. In general, the failure strain was between 1 and 3.

Q: But, pretty widely varying between those two?

A: It is widely varying.

Q: Okay. Thank you.

QUESTION: *Guy Nusholtz, DaimlerChrysler*
You got double fractures on the females and single fractures on the male. You seem to be attributing that to male and female-ness. Or most likely, I think it's just you had two specimens that happen to behave that way. Is that a better estimate?

A: That's certainly a big part of the estimate, and there is a little difference in the BMD content. So maybe with the lower BMD, we'll get double fractures; but you can't make these conclusions based on these few tests. It's just an interesting, very different fracture pattern between these two.

Q: Okay. So it wouldn't be part of male-ness or female-ness.

A: I wouldn't say that.

Q: Yeah. Okay. The next question is sort of an instrumentation one. Did you have any problems with the strain gauges floating off the ribs because you've got water that comes up underneath there and--?

A: Right. Typically—Well, we had no problems. Like I said, of the 90, 94 gauges, we had 100% read through the test. Now we do make sure we limit the time. So it takes us about five hours to get these on and then we try to test within two to three hours from that point. But certainly, the longer you wait, the more you'll have these bonding-type issues.

Q: And, one more question which is more an opinion than anything else: The primary advantage of getting uncensored data is that you can reduce the number of test subjects. If you try and develop a risk curve off of censored, you can need anywhere from about four to five to twice, depending on how many samples. And the question is: Do you think all this effort—In addition, you have to have all the instrumentation processing. Is all that effort—Would all that effort be worth it as opposed to running additional cadavers? I mean there's certain advantages to running the additional cadavers because you also get a statistically wider estimate of a population.

A: Right. Well, I would say I would do both: I would run more tests and I would do the—Certainly, there's a lot of extra time. There's a lot of extra personnel and analysis. But if you look—You know, we'll have other papers today. The complexity of these cadaver tests, in general, is escalating so much and you know, I gave you the example using three chest bands on these tests now, and you know, this is—This is what I would consider in the magnitude of complexity, and I think we should do it if we can; but also, do that with the additional tests. So keep the sample high, but do this. If you can do it, why not?

Q: Well, I think what you can probably do is cut the number of samples in half and that may be the value to it even with the additional complexity. Okay. Thank you.

QUESTION: *Sean Ji, Center for Applied Biomechanics - University of Virginia*

I just have a comment on this certain study and on the basis of the limited experience that I have. What I was trying to do is to load the thorax in a CT machine and the idea was that you could see the rib fractures. I mean, it's not exactly as non-censored as it is in your study, but I mean, what I was doing was, like, say if you compress the thorax from 0 to 10% and then take the CT and then you can see, you know, give it to a radiologist, and he'll give the rib fractures record between that compression. And then, do the compression again from 10-20% and, you know, do the CT again and then you can see the fractures record between 10 and 20%. So the only difference that I noticed, you know, in this study and that study is that in my case under dynamic belt loading, the rib fractures seemed—I had two test, two subjects tested and in both cases, anterior and lateral fractures I got first, then posterior fractures. So, this is something that is different, you know, from this study. So, just wanted to make a comment on that.

A: Well, you said anterior and lateral show up first before posterior.

Q: Yeah.

A: I wouldn't say that's different. I would say that is consistent with what we did although we don't see the posterior. Maybe you have a different back condition.

Q: Okay.

A: But the other obvious big difference is dynamic versus static. And if you step down, you're doing a static test.

Q: Yeah, mine was almost like quasi-static or a static test. But I mean, but it did show a similar fracture pattern, you know, along, along the belt path. Thank you.

QUESTION: *Richard Kent, University of Virginia*

First, let me commend you on a good study and a heck of a lot of patience. We—We put strain gauges on ribs before and it's extremely tedious work. And so, good job sticking through that process. I was interested in to see you put failure strain numbers up there because when we've done this sort of thing before, we basically sort of gave up on trying to get that out and pretty much went to timing, which is what, clearly, the focus of your study is. And so, I'm wondering: How did you get to that failure strain given that the fractures are generally going to occur away from where the strain gauges are mounted? And so, it seems like that would be, sort of, a lower estimate. The failure strain must be at least as high as what you're measuring. How are you estimating the failure strains from the data you're getting?

A: Right, that's a good point. So, these are gonna be on the lower estimate. The range I gave was from about seven cases where we had the fracture, and this is a little messed up because I had to put the blue on there so you could see it because it's not kind of dark in here. But, we had seven cases, seven of these, you know, 32 fractures where the fracture was right on top of the gauge. So, the 1-3 is from those cases. But certainly as you move away, the strain drops off and you can't really say that.

Q: Okay. So, maybe that's at least some justification use that you use 47 though maybe not worth it.

A: Well, you don't have to use all those. Yeah.

Q: Okay. Great. Thanks, Stefan.