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COMPUTATION OF THORACIC INJURY PREDICTORS USING CHESTBAND INFORMATION

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Objective

The objective of the present study will be to demonstrate the use of the chestband data in computing secondary variables, such as the injury predictor according to the Neathery equation, normalized chest deformation and deformation velocities at the upper and lower thoracic levels, and the viscous criterion. A comparative evaluation is made of these parameters with previous studies along with the applicability of the injury indices to seatbelt loading in a frontal impact situation.

Methods

Unembalmed human cadavers were used in the study. The specimens were selected based on radiography and review of medical records to exclude metastatic disease and other disorders. They were also tested for the presence of antibodies to Human Immunodeficiency Virus and Hepatitis by drawing blood before subject selection. Suggested precautions during handling and biomechanical testing of human cadavers were followed in the study (2,3). Physical data according to NHTSA specifications were taken. All specimens were prepared and tested according to standard procedures. Briefly, the surrogate was pressurized to approximate the *in vivo* vascular and pulmonary characteristics. Triaxial accelerometer arrays (Endevco model 7264, San Juan Capistrano, CA) were mounted on the head and spinous process of T1 vertebra to measure the accelerations. Two chestbands were mounted on the surrogate: the upper band was placed at the mid sternum region approximately at the anterior level of the fourth rib and the lower band was placed over the xyphoid process approximately at the sixth

rib level. Thoracic deformation contours were derived for upper and lower levels using the information from the two chestbands. Chestband signals were filtered at SAE class 1000.

All tests were conducted by placing the subject in a driver seat restrained by a three-point belt. A horizontal crash simulator (MTS Systems Corporation, Minneapolis, MN) was used to simulate frontal impact at approximately 50 kph. The test was photographed at 1000 frames/second using an onboard camera (Model 16mm-1B, Instrumentation Marketing Corporation, Burbank, CA). Following the test, the specimen was palpated, radiographed, and a detailed autopsy was performed. Chestband signal data processing included a transformation of the individual curvature histories to deformation contours. The temporal deformation contours were computed using the RBAND_PC program (4-6). This software has the ability to interpolate and provide deformations at numerous discrete locations. An algorithm was developed to calculate the chest compression along the anterior region of the thorax. The software computes the chest contours at one ms intervals using the chestband data. Approximately 70 - 100 discrete locations in the anterior region were selected and the compression histories were computed at each of these locations. A pulse duration of approximately 150 ms encompassing the entire deceleration event was used for these computations. Normalized chest compression (C) was computed by dividing the compression by the surrogate anteroposterior chest depth. The velocity of compression (V) and viscous response (VC), defined as the product of normalized chest compression (C) and the velocity of compression (V) were computed according to suggested

procedures (10). Peak magnitudes of these variables, i.e., C_{max}, V_{max} and $(VC)_{max}$, and the corresponding time of occurrence and location for each specimen were obtained.

The following criterion corresponds to a 25% probability of serious (AIS > 3) injury (10): (a) when the velocity of compression is below a threshold of 3.0 m/s, the compression criterion (C_{max} =0.35), i.e., anteroposterior chest deflection normalized with respect to the initial chest depth, most reliably describes the thoracic response, and (b) when the velocity of compression is above 3 m/s, the viscous criterion, i.e., a $(VC)_{max}$ of 1.0 m/s, governs the injury mechanism (10).

A comparative evaluation was conducted between the AIS rating of thoracic injuries documented at autopsy (in the present study) according to the 1990 revision (1) and the predicted AIS according to the Neathery equation (given below). Neathery, using the data from the earlier studies of Kroell et.al., 7,8) examined the interrelationship between physical parameters such as subject mass, age, chest depth, and chest compression (9). Based on a multiple regression analysis, they derived the following relation:

$$AIS = -5.1508 + 17.4338\ C + 0.03128\ (AGE).$$

Where C represents the maximum normalized chest compression.

Results and Discussion

While the time of occurrence of the peak varied among the compression, velocity and the viscous criterion variables, their location on the thorax remained approximately the same. However, for a particular specimen, compression data at the upper thoracic

level often varied considerably from the lower thoracic level, indicating regional differences in the biomechanical response of the chest. The peak compressive velocity for two specimens was above 3 m/s. In two specimens, C_{max} as well as $(VC)_{max}$ were above the suggested threshold at the upper or lower thoracic levels. However, three out of four specimens had injuries with a severity of AIS > 3. In the two specimens wherein C_{max} and $(VC)_{max}$ were below the threshold, serious thoracic injuries (AIS = 4) occurred. Peak V_{max} always preceded the occurrence of peak $(VC)_{max}$, followed temporally by C_{max}.

All specimens demonstrated multiple rib fractures at autopsy. However, plain x-rays did not reveal all injuries because of the anatomy of the rib cage and the difficulty in viewing rib fractures with x-rays. There was a mean of 17 rib fractures. The overall average AIS of 3.7 determined at autopsy compared favorably with the predicted AIS from Neathery's equation (9) although differences between the two were found on a specimen to specimen basis. It should be noted that Neathery's analysis uses the mid sternum deflection between the fourth and fifth intercostal space to obtain normalized chest compression; in contrast, we used the maximum chest compression irrespective of the anatomic level or location on the surrogate to predict injury.

Because the compression histories were obtained along the entire cross section of the thorax at two anatomical levels, we developed an algorithm to identify the location and the time of occurrence of the maximum chest deflections at each of the two levels based on the contours. Consequently, the location of

maximum chest compression was not identical in all cases. The time of occurrence was also not the same in all cases, presumably due to biological variations. However, data from the chestbands were easily amenable to compute these parameters thus providing an opportunity to investigate the regional differences in the thoracic response. This eliminated the inherent bias in identifying a single location *a priori* to represent the response of the human thorax. These studies demonstrate that the chestband is capable of measuring dynamic chest deformations which can be used to compute velocities and other pertinent variables which may predict thoracic trauma.

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TABLE 1

Specimen Population

Specimen Number	Sex	Age(yrs)	Height (cm)	Weight (kg)	Cervical Unit	Strain Gauged Level
1	M	71	180	73	C5-C7	C6
2	M	54	191	86	C5-C7	C6
3	M	69	178	79	C6-T1	C7
4	F	78	160	36	C4-C6	C5
5	M	65	180	96	C4-C6	C5
6	M	52	191	52	C6-T1	C7
7	M	69	183	100	C6-T1	C7
8	M	69	180	70	C6-T1	C7

TABLE 2

Summary of Change in Strain during Failure Runs

Specimen	Location of Vector	Failure Force (kN)	$\mu\varepsilon$ $\Delta\varepsilon$ V.B.	$\mu\varepsilon$ $\Delta\varepsilon$ FAC
3	1.0 cm post.	3.5	-1600	+350
4	1.0 cm ant.	1.9	-710	+150
5	0.5 cm post.	3.8	-300	+200
6	Uniform Compression	2.5	-900	+3500
8	Uniform Compression	2.7	-200	+150

DISCUSSION

PAPER: **Computation of Thoracic Injury Predictors using Chest Band Information**

PRESENTER: N. Yoganandan

FELLOW AUTHORS: R. Morgan, F. Pintar, D. Skrade, A. Sances, Jr.

QUESTION: Pat Kaiker, Chrysler Corporation

You have both men and women subjects in your study, did you do any assessment of differences between them in terms of what's been called before the bone condition factor or did you notice any differences based on ages?

ANSWER: As part of this presentation, we have not included the assessment of bone mineral or bone condition factor or anything, but in general, all the specimens were of a similar age. None of them were over 80 or 65 years or so.

Q: Right. I noticed that. Did you feel that they were all reasonably healthy.

A: They were all reasonably healthy and none of them had a long period of bed rest before death. Those kind of standing positions were typical.

Q: OK

A: Thank you.

Q: Guy Nusholtz, Chrysler Corporation

Can you explain two of the slides? They went by too fast for me to catch them, but it looked like on one of the slides, action was stable and didn't come back when you went to a certain level. It just stayed there. Did I see that correctly?

A: You did see it correctly and it is probably due to the rib fracture.

Q: OK. So there is no recovery. It just flat topped. Second one was in the VC slide, you showed one set where you had two, one was 0.8 something and the other was 0.9 and then the next slide, the VC was 1.36. Could you explain how you got a larger number?

A: Yes. In the first slide where I showed the peak values from the nine specimens, one set was for the lower chestband and the other set was for the upper chest band. When you take the absolute maximum values for each cadaver, you disregard whether it is upper or lower, you just pick the peaks. So when you pick the maximum one set of numbers for each cadaver, the average turns out to be higher.

Q: That still doesn't make sense. You had an average of 0.8 and an average of 0.9. How can

the maximum be greater than either of those two numbers?

A: I'll give you a simple example. You have an upper chestband giving you one max C. You will have two specimens. You'll have C1 and C2. The lower chestband will give you C3 and C4. If it happens that C4 and C1, if you pick, the mean of Cl and C4 could be more than the mean of C1 and C2 and C2 and C3. I'll repeat again. C1 and C2 are the two numbers you get for two specimens in the upper chestband. C3 and C4 are the two numbers you get from the lower chestband. So from C1 and C2 will give a mean. C3 and C4 will give you a mean. Now if you happen to pick the maximum of the maximum sledge, C1 is the maximum in the first cadaver and C4 is the maximum in the second cadaver. In other words, you pick the upper chestband in one or the lower chestband in the other one because it worked out like that. So the max and the mean of C1 and C4 could be more than the mean of C1 and C2 and the mean of C3 and C4. I can show you a couple of numbers.

No. I understand. It just sounds hokey.