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## CHESTBAND MEASUREMENT OF HUMAN UPPER TORSO DYNAMIC RESPONSE

***Paper was presented at the 20th Annual Workshop on Human Subjects for Biomechanical Research. This paper has not been screened for accuracy nor refereed by any body of scientific peers and should not be referenced in the open literature.***

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**Abstract**
This paper discusses a study designed to review the feasibility of using the chestband to measure the response of the human thorax to dynamic belt loading conditions. The subjects were two fiftieth percentile male volunteers with physical characteristics matched to those of the Hybrid III. The test methods and apparatus used are reviewed. Experimental results are presented and compared with previous studies and with the results of similar testing of the Hybrid III.

## 1.0 Introduction

The understanding of the response of the human thorax to impact has been the focus of many biomechanical research projects. Most of these studies have used a circular impactor to dynamically load the thorax, following work by Gadd and Patrick (1968). This early work was carried out in order to achieve a better understanding of the interaction between the upper torso and energy absorbing steering columns. Nahum et al (1970), and Kroell et al (1971) conducted further cadaver tests to investigate thoracic tolerance to sternal loading. The cadavers were impacted at mid-sternum using a rigid faced impactor. The impactor was 152mm in diameter (the size of the steering wheel hub used by Gadd and Patrick and the mass was that of the average thorax, 23.4kg. They concluded that thoracic compression was the most important injury parameter.

When the Hybrid III anthropometric test dummy (ATD) was being developed to have response characteristics based on available biomechanical data, the primary thoracic performance objective for the ATD was thus to assess the efficiency of energy absorbing steering columns (Mertz et al, 1991). So the thorax was developed to have appropriate responses to these blunt sternal impacts (Foster et al, 1977). The cadaver chest response corridors used in this development were adjusted by 667N to account for the lack of muscle tone (Mertz et al, 1991). The thoracic instrumentation included in the Hybrid III was intended to reflect this loading pattern. The Hybrid III thorax was not designed to reproduce human thoracic response to the type of asymmetric strip loading applied by a shoulder belt.

A study comparing the thoracic deflection of human male volunteers and the Hybrid III under dynamic belt loading conditions was carried out by L'Abbé et al, (1982). The test conditions did not fully replicate seat belt loading to the chest. The load mechanism chosen for the tests dynamically squeezed the thorax of the subject between the diagonally positioned belt and a flat back plane. Some problems were found with the test apparatus and test conditions. It was concluded that the Hybrid III and the volunteers in a tensed state were similar in mid sternal response but that the Hybrid III did not reproduce the volunteers responses adequately in the other areas of the chest.

The apparatus was redesigned to allow higher load levels and to improve measurement of the chest deflection (St-Laurent, 1988). This apparatus was used to extend the test program to include higher level Hybrid III and cadaver impacts (Cesari and Bouquet, 1990). The study found that the Hybrid III thorax undergoing this type of loading was almost twice as stiff as the average of the tested cadavers.

Since the original human subject study, many changes have been made in test apparatus and instrumentation. The aim of the work reported here was to investigate the feasibility of further work with male volunteers. Significant changes in community attitudes have occurred since the previous human subject testing and

these changes have had bearing on the approval and procedures required for this type of experiment. Furthermore, developments in available instrumentation, specifically the External Peripheral Instrument for Deformation Measurement (EPIDM) or chest band (Eppinger, 1989), required some investigation.

## 2.0 Test Apparatus

The test apparatus used for this test series was developed during previous work with Transport Canada (St. Laurent, 1988) and has also been used in the test programs carried out at INRETS (Cesari and Bouquet, 1990). This apparatus is illustrated in Figure 1.

The apparatus is designed to deliver either a static or dynamic load to either an ATD or human subject thorax by means of the shoulder portion of a seat belt. Instrumentation attached to the subject is able to monitor the chest deformation.

The support structure consists of tubular steel held together with Kee Klamps and securely bolted to the laboratory floor. A galvanized steel table rests on top of the structure. There are two slots in the table through which the belt passes. The belt is supported by roller bearings. A platform surrounding three sides of the table permits access to the test subject and instrumentation.

For this testing dynamic loading was generated using a standard ATD chest calibration pendulum. This pendulum was attached directly to webbing which was directed around a roller fixed to the support frame. The other end of the webbing was connected to a yoke which linked the ends of the shoulder belt, as the belt was draped across the subject's chest.

The static loading test employed a manual hydraulic pump. The cylinder was fixed to the support frame as seen in Figure 1. The same webbing as used for the dynamic procedure was attached to the end of the piston. As the piston retracted into the cylinder, the webbing pulled downward on the yoke which was attached to the ends of the shoulder belt.

The transducers used for the testing consisted of 9 displacement transducers (LVDTs) to monitor chest deflection, a pair of belt load cells to monitor belt loading during testing and an external peripheral instrument for deformation measurement (EPIDM) or chest band, was used to measure the thoracic profile. The pendulum peak velocity was also measured. The internal potentiometer was used to monitor the Hybrid III chest deflection.

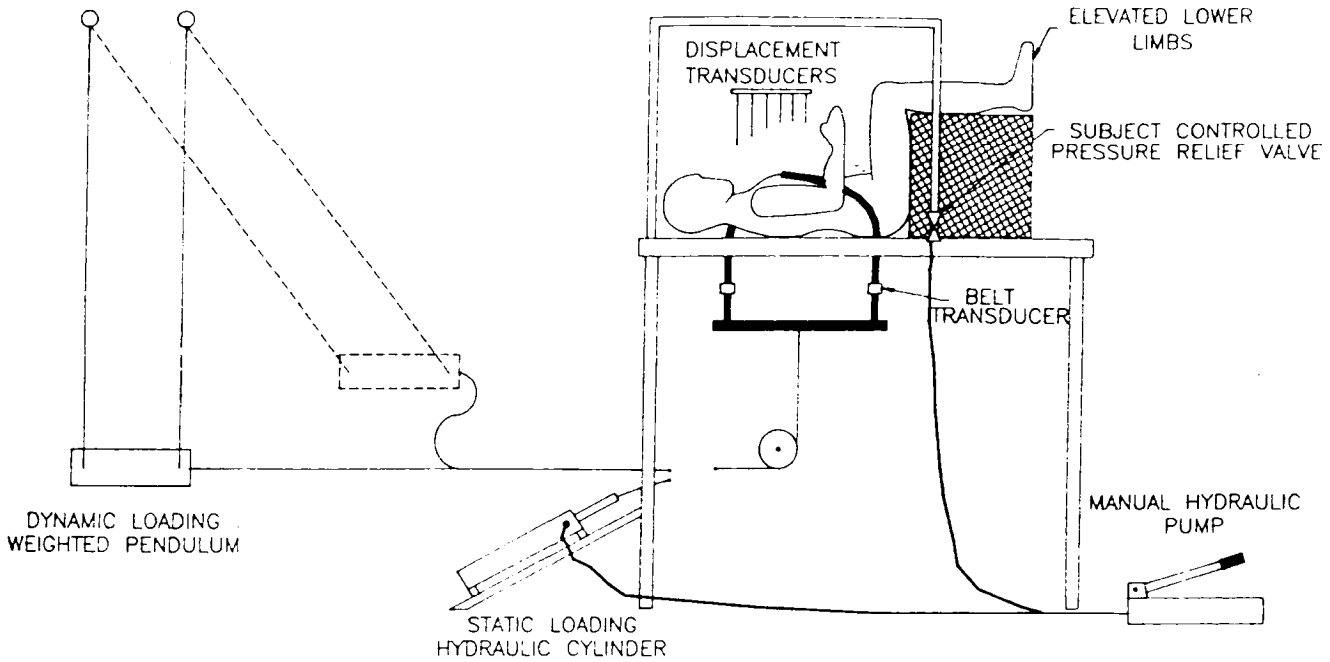


**Figure 1:** The test apparatus used for this test series.

With the participation of human subjects in this test program, it was necessary that a number of safety features be introduced into the test device. A positive stop limit was incorporated into the column structure to limit the displacement of the yoke to a predetermined amount. Prior to each test, this was positioned so that the maximum travel of the yoke assembly was limited to 35mm. In addition, a safety release valve was connected into the hydraulic line between the pump and the hydraulic cylinder used for the static load testing. The release valve permitted the subject to release the hydraulic pressure if he felt that the load was becoming too great. A stiff spring located beneath the collar of the cylinder rapidly released the load.

The LVDT signals were sampled at a frequency of 10,000 Hz and filtered at SAE Class 180. Triggering was initiated from the velocity meter.

The chest band was wrapped around the test subject between the LVDT probes. Twenty-four channels were monitored from a single chest band. This is considered the minimum acceptable number to use (Hagedorn et al, 1991). During dynamic testing, all channels were sampled at 2500 Hz while static tests were sampled at 1,200 Hz. The data reduction software package (RBAND-PC) was used to produce a cross sectional profile of the thoracic deformation at selected time intervals using the strain gauge readings.

The positioning of the LVDTs was based on the previous testing (St-Laurent, 1988) and (Cesari and Bouquet, 1990). Figure 2 illustrates the anatomical locations of the 9 LVDT units. Eight LVDTs were aligned vertically and supported by a structure separate from the load table (see Figure 3). One LVDT was positioned horizontally to the right side of the subject's torso. All LVDTs were centred directly over their respective landmarks.

The LVDT cores were connected to flexible fibreglass rods which extended down to the level of the subject's thorax. A snap button was secured to the end of the rod to allow attachment of the rod to an electrocardiograph (EKG) lead pad which was placed directly on the subject's chest. A similar process was used for securing the LVDTs to the chest of the Hybrid III; except, an opening had been previously made in the chest skin to allow direct measurement of rib motion.

Due to the seat belt covering several of the desired measurement locations, three LVDTs (1, 6, 8) were secured directly to the webbing.

Belt load cells were secured to the seat belt webbing assembly and positioned below the level of the table. Alignment was chosen to ensure that there would be no possibility of having the belt load cell contact the table.

The chest band was fitted to the test subject immediately prior to final positioning of the LVDTs. The band was draped around the subject's chest at the level of the fifth rib. A measurement was taken of the circumference of the chest band prior to all tests and following any changes to the test conditions (eg. expanded or relaxed chest). The ends of the chest band were then secured with tape in order to prevent any change in circumference. It had been found that having continuous adhesion of the band to a live subject's chest was too uncomfortable.

## 3.0 Test Procedures

The testing was carried out in conjunction with Dr. C. Cotton from the University of Ottawa and the subjects were his students. Hence the project had to receive the approval of the University Human Research Ethics Committee before carrying out the testing. During the time that the submission was passing through this process, an ice hockey player died of injuries received from an impact to the chest from another player's hockey stick. As a result the medical advisors to both the Ethics Committee and the project itself became extremely cautious in their approach.

The concern about the medical effects of the testing led to several restrictive requirements being placed on the testing, including the attendance of a medical practitioner.

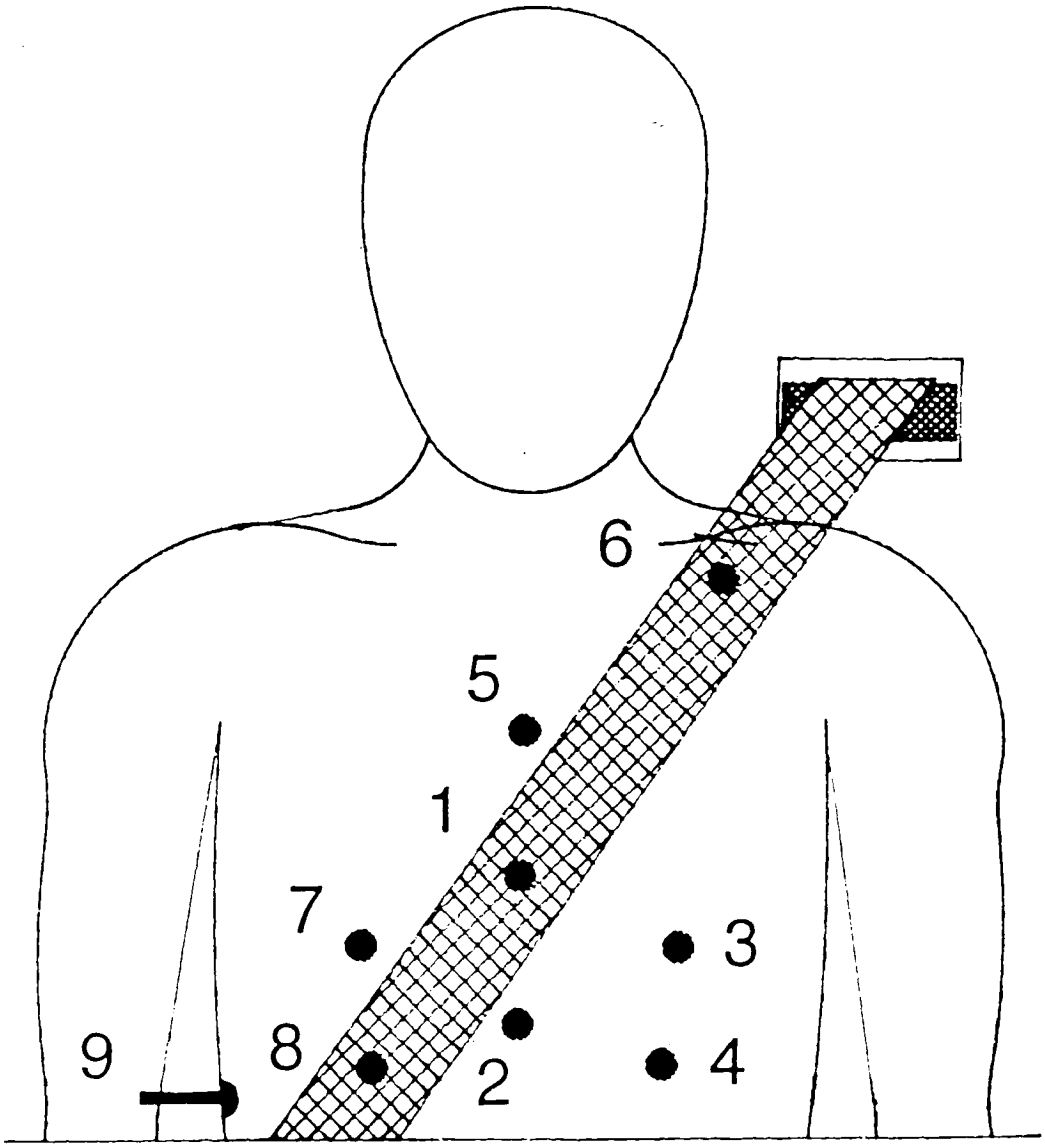


**Figure 2:** The LVDT positions on the thorax of the test subject.

The concerns carried over to the testing staff and the subjects. As a consequence there was a distinct lack of enthusiasm by the subjects for the higher load levels in the testing. All of this had the effect of restricting the testing to low levels in comparison to the previous volunteer results (L'Abbé et al, 1982).

Initial subject selection was based upon anthropometric resemblance to the Hybrid III test dummy. A total of nine measurements were taken for each subject who wished to participate in this research study. A score was calculated based on the difference between four anthropometric measurements relative to those for the

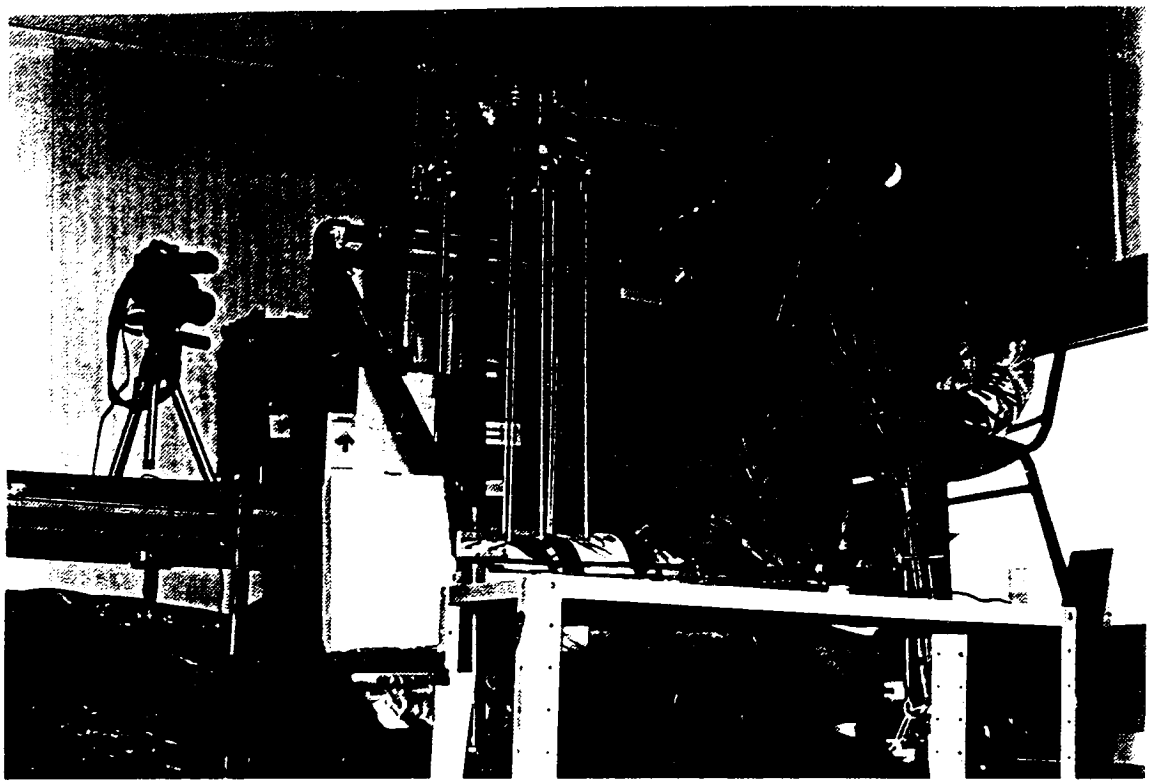

**Figure 3:** A test subject with the LVDTs attached to the thorax and the chest band positioned at the fifth rib.

Hybrid III. The measurements used were chest circumference, sternum length, chest depth and chest width. A total of 15 subjects were pre-screened. The two subjects with the best combined measurement scores were asked to continue with the test program. Table 1 presents the measurements of the two subjects who participated in this study. Those for the Hybrid III are included for comparison.

The state of subject readiness was either relaxed (ie. unprepared for impact) or tensed (ie. prepared for impact). The tensed subject state was accompanied by a verbal countdown to the release of the impact pendulum. The subject was instructed to prepare for the oncoming force through tensioning of the thoracic musculature.

The subjects were tested with their chests in a normal relaxed position (eg. normal breathing) or in an expanded chest mode, meaning that they inspired a full breath of air and kept their chest expanded over the duration of static load or impact pulse.

For the initial set up of the test apparatus, a calibrated Hybrid III was used to test the range of likely impact conditions for the human subjects. Upon completion of all human subject testing, the test matrix was repeated for the Hybrid III. The same instrumentation was used for all tests, except for the internal chest potentiometer.

Table 1: Physical characteristics of the two volunteers compared with those of a Hybrid III ATD.

| Subject | Height (cm) | Weight (kg) | Chest Circum. (cm) | Trunk Length (cm) | Sternum Length (cm) | Chest Depth (cm) | Chest Width (expanded) (cm) | Chest Width (relaxed) (cm) | Acromion Width (cm) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 178.0 | 82.7 | 101.0 | 40.3 | 22.6 | 23.7 | 32.9 | 31.2 | 36.9 |
| 2 | 175.0 | 75.0 | 99.0 | 40.1 | 20.3 | 23.6 | 31.6 | 29.2 | 37.5 |
| Hybrid III | 170.0 | 85.5 | 101.0 | 40.0 | 13.8 | 24.1 | 28.2 | 28.2 | 32.5 |

Identical static test procedures were used for the Hybrid III testing. Following each test, sufficient recovery time was given to allow the ribs to return to their pre-test state. In addition to the low level dynamic tests described above, the Hybrid III was subjected to higher level impact tests in order to evaluate thoracic response both within the human subject corridor and beyond. Impact energy was varied by changing either the pendulum mass or the pendulum drop height.

The test results are summarized in Table 2.

## 4.0 Data Analysis

### 4.1 Comparison of Current to Previous Hybrid III Tests

Figure 4 is a scattergraph of peak combined belt load versus mid-sternum displacement for both the current set of tests and previous tests on the Hybrid III.

1. There are several observations to be made regarding the relationship of the current data to previously published data. The current test loading is far less than in previous tests. The peak loads and displacements for the current tests are within 4kN and 40mm, while the peaks from previous tests go as high as 15kN and 70mm.

2. The previous tests used significant amounts of preload to remove slack from the system and to improve energy transfer. St-Laurent (1988) used 300N preload, other test preloads are unknown but were definitely used by Cesari and Bouquet (1990) and L'Abbé et al (1982). No preload was used in this test series as the changes to the apparatus made it unnecessary.

**Table 2:** Chest impact test results summary.

| Test No | Subject | Condition | Pendulum Mass [kg] | Drop Height [mm] | Impact Energy [J] | Combined Belt Load [N] | Internal Pot [mm] | LVDT 1 [mm] | LVDT 2 [mm] | LVDT 3 [mm] | LVDT 4 [mm] | LVDT 5 [mm] | LVDT 6 [mm] | LVDT 7 [mm] | LVDT 8 [mm] | LVDT 10 [mm] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 1 | Dynamic Relaxed Unexpanded | 29.1 | 50 | 12.6 | 558 | - | -17.2 | -3.0 | -3.0 | -1.4 | -12.9 | -20.8 | -16.4 | -15.0 | 3.9 |
| 27 | 1 | Dynamic Relaxed Unexpanded | 29.1 | 100 | 26.1 | 1021 | - | -23.6 | -13.2 | -5.1 | -1.8 | -20.2 | -27.5 | -23.6 | -22.1 | 6.8 |
| 30 | 1 | Dynamic Relaxed Expanded | 29.1 | 50 | 13.1 | 643 | - | -16.4 | -8.1 | -5.5 | -0.7 | -14.6 | -22.8 | -11.1 | 11.2 | * |
| 31 | 1 | Dynamic Relaxed Expanded | 29.1 | 100 | 26.2 | 1023 | - | -25.9 | -13.9 | -9.3 | -2.1 | -24.1 | -32.1 | -22.0 | -21.1 | 5.2 |
| 28 | 1 | Dynamic Tensed Unexpanded | 29.1 | 50 | 12.8 | 657 | - | -14.9 | -6.1 | -2.7 | -1.2 | -11.8 | -19.1 | -13.5 | -10.9 | 1.7 |
| 29 | 1 | Dynamic Tensed Unexpanded | 29.1 | 100 | 26.2 | 1039 | - | -20.1 | -11.0 | -4.1 | -1.6 | -16.0 | -21.9 | -20.1 | -19.3 | 5.7 |
| 32 | 1 | Dynamic Tensed Expanded | 29.1 | 50 | 13.0 | 669 | - | -16.5 | -8.3 | -4.5 | -1.6 | -12.1 | -17.7 | -14.0 | -13.5 | 3.3 |
| 33 | 1 | Dynamic Tensed Expanded | 29.1 | 100 | 26.7 | 1103 | - | -21.5 | -11.9 | -6.5 | -1.5 | -17.6 | -23.6 | -20.4 | -19.9 | 5.3 |
| 40 | 2 | Dynamic Relaxed Unexpanded | 29.1 | 50 | 13.6 | 611 | - | -16.4 | -9.7 | -1.3 | -3.1 | -13.5 | -21.7 | -17.9 | -16.3 | 3.3 |
| 41 | 2 | Dynamic Relaxed Unexpanded | 29.1 | 100 | 26.8 | 1062 | - | -26.4 | -17.9 | -3.3 | -7.9 | -25.2 | -31.0 | -27.0 | -22.7 | 2.4 |
| 42 | 2 | Dynamic Relaxed Unexpanded | 29.1 | 150 | 40.9 | 1344 | - | -29.1 | -19.6 | -4.4 | -7.0 | -28.3 | -36.2 | -28.7 | -23.4 | 2.8 |
| 34 | 2 | Dynamic Relaxed Expanded | 29.1 | 50 | 12.1 | 600 | - | -16.7 | -7.5 | -2.6 | -0.8 | -11.9 | -20.5 | -13.7 | -12.2 | 2.7 |
| 35 | 2 | Dynamic Relaxed Expanded | 29.1 | 100 | 25.5 | 1007 | - | -24.4 | -13.1 | -5.1 | -1.4 | -19.9 | -28.7 | -21.0 | -19.6 | 4.2 |
| 36 | 2 | Dynamic Relaxed Expanded | 29.1 | 150 | 40.7 | 1349 | - | -30.7 | -17.9 | -6.3 | -2.1 | -27.6 | -37.7 | -26.6 | -24.1 | 6.7 |
| 43 | 2 | Dynamic Tensed Unexpanded | 29.1 | 50 | 13.6 | 639 | - | -19.6 | -11.7 | -2.0 | -2.7 | -18.3 | -25.4 | -19.5 | -16.1 | 1.5 |
| 44 | 2 | Dynamic Tensed Unexpanded | 29.1 | 100 | 26.9 | 1093 | - | -25.4 | -14.7 | -2.6 | -1.7 | -24.5 | -33.2 | -22.9 | -19.8 | 2.9 |
| 45 | 2 | Dynamic Tensed Unexpanded | 29.1 | 150 | 40.8 | 1470 | - | -28.8 | -17.6 | -3.7 | -2.9 | -27.6 | -37.0 | -26.9 | -22.9 | 4.8 |
| 37 | 2 | Dynamic Tensed Expanded | 29.1 | 50 | 12.3 | 630 | - | -15.7 | -7.9 | -3.0 | -0.6 | -11.2 | -19.0 | -12.4 | -11.5 | 3.3 |
| 38 | 2 | Dynamic Tensed Expanded | 29.1 | 100 | 25.5 | 1014 | - | -24.6 | -13.5 | -5.0 | -1.0 | -20.8 | -32.1 | -20.9 | -19.6 | 5.1 |
| 39 | 2 | Dynamic Tensed Expanded | 29.1 | 150 | 40.6 | 1410 | - | -30.0 | -16.7 | -5.7 | -1.1 | -22.4 | -38.7 | -24.9 | -25.0 | 5.9 |
| 46 | Hyb III | Dynamic - - | 21.5 | 68 | 13.2 | 748 | 3.6 | -12.0 | -5.3 | -3.2 | -3.4 | -5.4 | -14.0 | -4.7 | -6.7 | 1.7 |
| 49 | Hyb III | Dynamic - - | 21.5 | 135 | 25.9 | 13 | 5.4 | -13.8 | -7.0 | -4.8 | -5.1 | -8.3 | -18.2 | -7.3 | -10.4 | * |
| 50 | Hyb III | Dynamic - - | 21.5 | 203 | 40.2 | 1606 | 7.8 | -18.5 | -9.7 | -6.9 | -6.9 | -11.6 | -22.4 | -10.1 | -14.1 | * |
| 56 | Hyb III | Dynamic - - | 21.5 | 500 | 102.5 | 2728 | * | -26.1 | -15.6 | -12.8 | -8.5 | -21.7 | -16.1 | -32.9 | -20.3 | 2.9 |
| 51 | Hyb III | Dynamic - - | 21.5 | 943 | 186.6 | 3813 | 19.0 | -37.3 | -23.0 | -15.4 | -14.8 | -22.6 | -35.5 | -24.3 | -33.4 | * |
| 52 | Hyb III | Dynamic - - | 29.1 | 50 | 14.6 | 970 | * | -9.4 | -4.8 | -3.2 | -3.5 | -5.9 | -12.6 | -5.0 | -7.9 | 2.2 |
| 54 | Hyb III | Dynamic - - | 29.1 | 100 | 26.4 | 1265 | 4.1 | -11.4 | -6.1 | -5.3 | -4.7 | -8.6 | -19.8 | -8.0 | -9.0 | 1.2 |
| 51b | Hyb III | Dynamic Initial - | 29.1 | 100 | 26.3 | 1356 | 5.7 | -13.7 | -6.9 | -4.5 | -4.8 | -8.5 | -17.1 | -7.7 | -11.6 | 3.2 |
| 50b | Hyb III | Dynamic Initial - | 29.1 | 150 | 40.8 | 1751 | 7.8 | -17.9 | -9.4 | -6.0 | -6.3 | -11.7 | -21.0 | -10.3 | -15.6 | 4.3 |
| 52b | Hyb III | Dynamic - - | 29.1 | 200 | 53.8 | 1746 | 6.8 | -16.4 | -9.8 | -8.5 | -6.9 | -12.3 | -26.6 | -11.8 | -14.5 | 2.3 |
| 53 | Hyb III | Dynamic - - | 29.1 | 250 | 66.7 | 2069 | 8.6 | -19.4 | -12.1 | -10.7 | -7.6 | -15.4 | -29.5 | -12.4 | -17.0 | 2.3 |
| 55 | Hyb III | Dynamic - - | 29.1 | 500 | 134.7 | 3325 | 14.4 | -28.7 | -17.6 | -13.6 | -10.2 | -20.5 | -30.9 | -27.3 | -25.5 | 4.0 |
| 59 | Hyb III | Dynamic - - | 44.1 | 67 | 27.6 | 1303 | 5.0 | -10.9 | -6.6 | -4.6 | -4.5 | -9.0 | -21.0 | -6.1 | -10.7 | 1.8 |
| 58 | Hyb III | Dynamic - - | 44.1 | 168 | 68.8 | 2343 | * | -19.6 | -11.9 | -6.0 | -7.5 | -15.6 | -37.7 | -1.4 | -12.5 | 3.0 |
| 57 | Hyb III | Dynamic - - | 44.1 | 335 | 138.5 | 3310 | 14.3 | -27.2 | -16.9 | -12.5 | -10.7 | -19.1 | -31.4 | -16.4 | -25.4 | 4.7 |

* data loss due to hardware/software difficulties

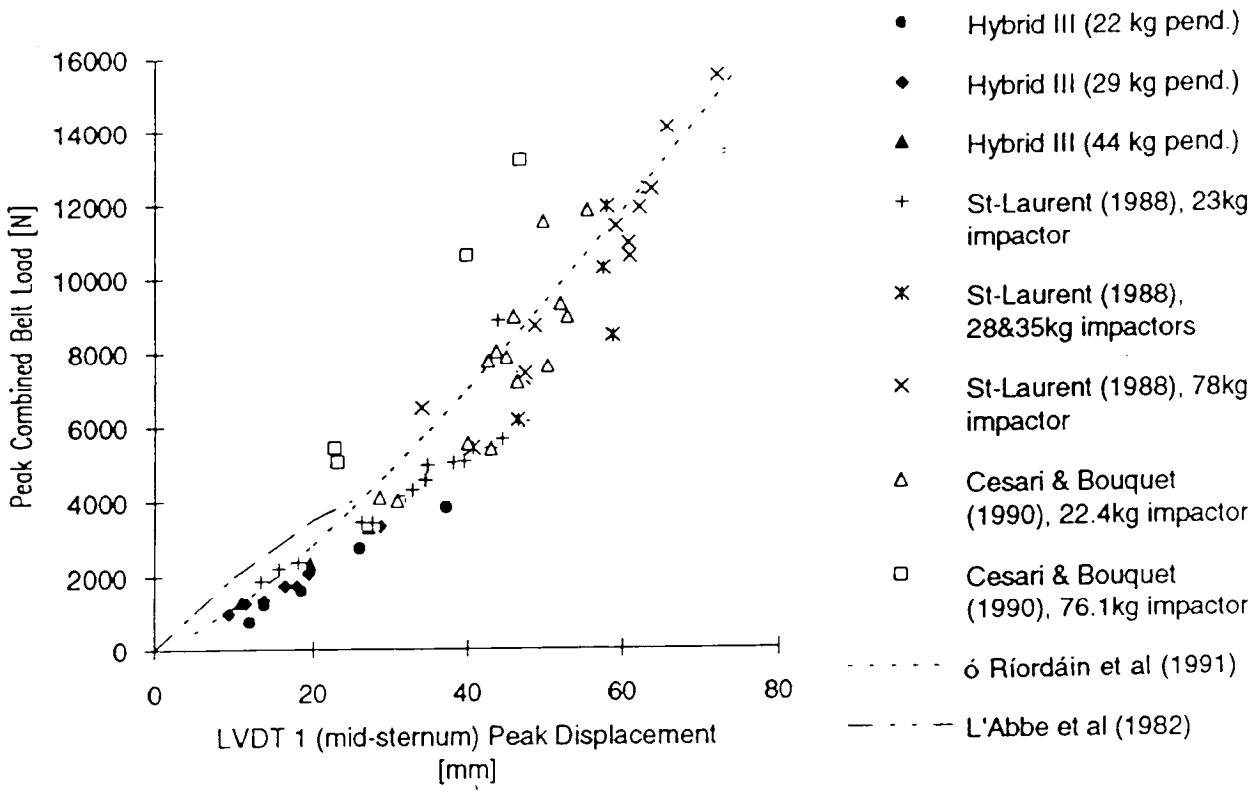


**Figure 4:** Comparison of Hybrid III mid-sternum displacement (LVDT1) with previous tests

3. The pendulum/impactor mass had an effect on the observed mid-sternal stiffness. As with tests done by Cesari and Bouquet (1990) and by St-Laurent (1988), the current tests indicate that increasing the mass of the pendulum increases the effective stiffness of the Hybrid III chest. The effect of pendulum mass on the stiffness of other areas of the thorax is not as evident. Part of the mass relationship may be attributable to the vinyl flesh with which the mid-sternum LVDT was in contact while the lower and upper sternum LVDT's were connected directly to the sternum plate through the flesh.

   When the above factors are taken into account, especially the lack of preload and the lower pendulum mass, the current Hybrid III test data forms a group at the lower end, but consistent with the aggregated test results.

## 4.2 Comparison of Current to Previous Volunteer/Cadaver Tests

The lack of actual data points for the L'Abbé (1982) and the ó Ríordáin (1991) studies on volunteers and cadavers limited comparison and analysis methods to graphical means. Figure 5 shows peak belt load against peak mid-sternum

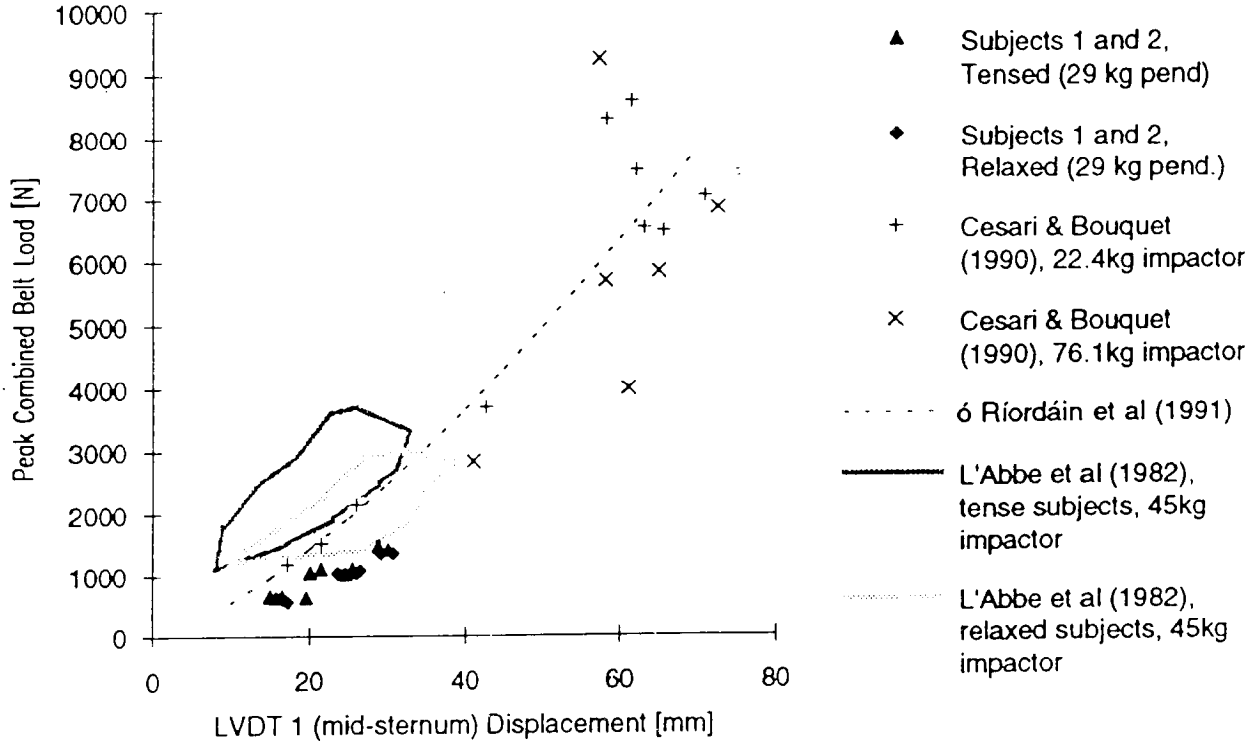


**Figure 5:** Comparison of volunteer and cadaver mid-sternum displacement (LVDT1).

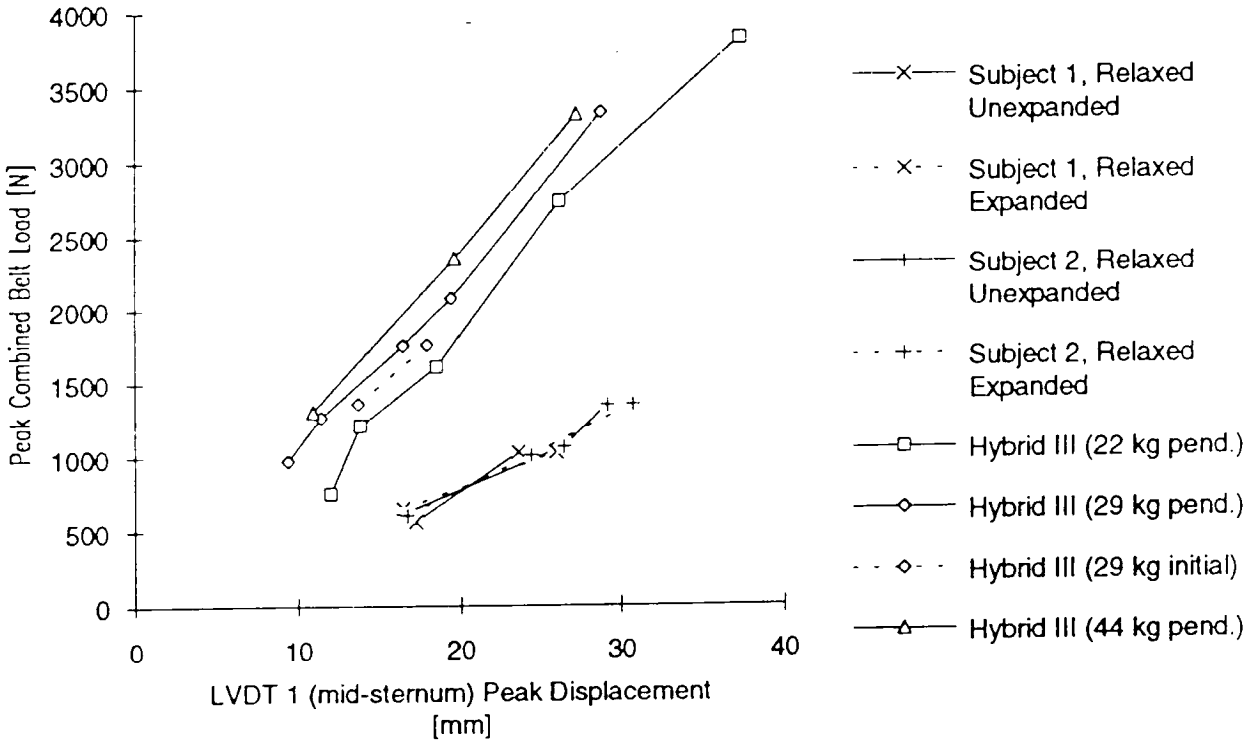


**Figure 6:** Comparison of Hybrid III and relaxed volunteers mid-sternum displacement.

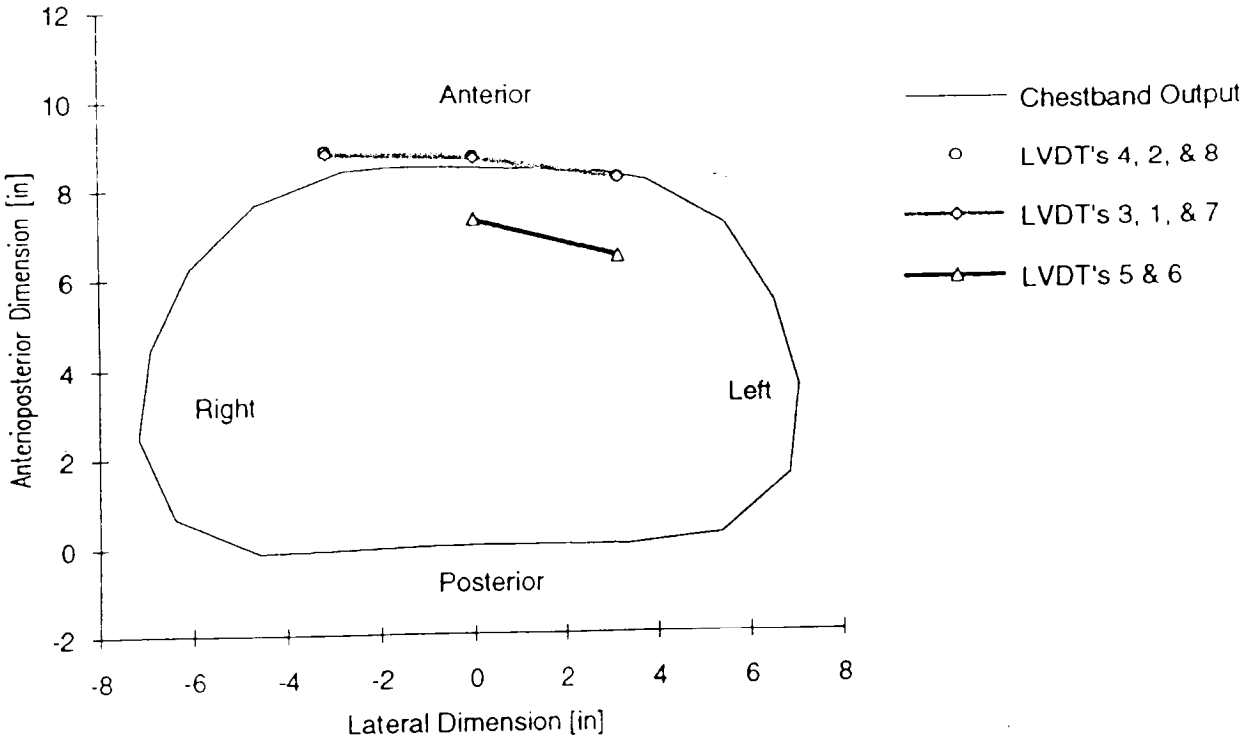


**Figure 7:** Undeformed chest contour, Subject 1 (100 mm drop, 29 kg pendulum)

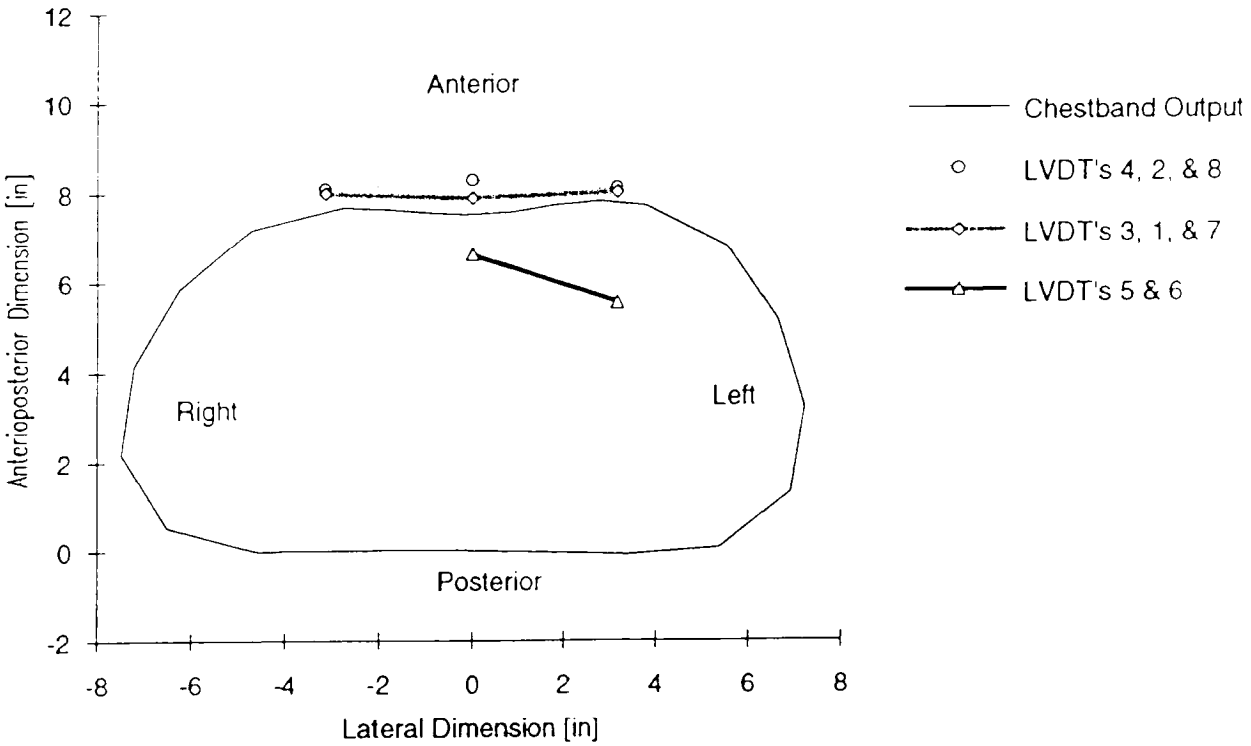


**Figure 8:** Maximum deformation chest contour, Subject 1 (100 mm drop, 29 kg pendulum).

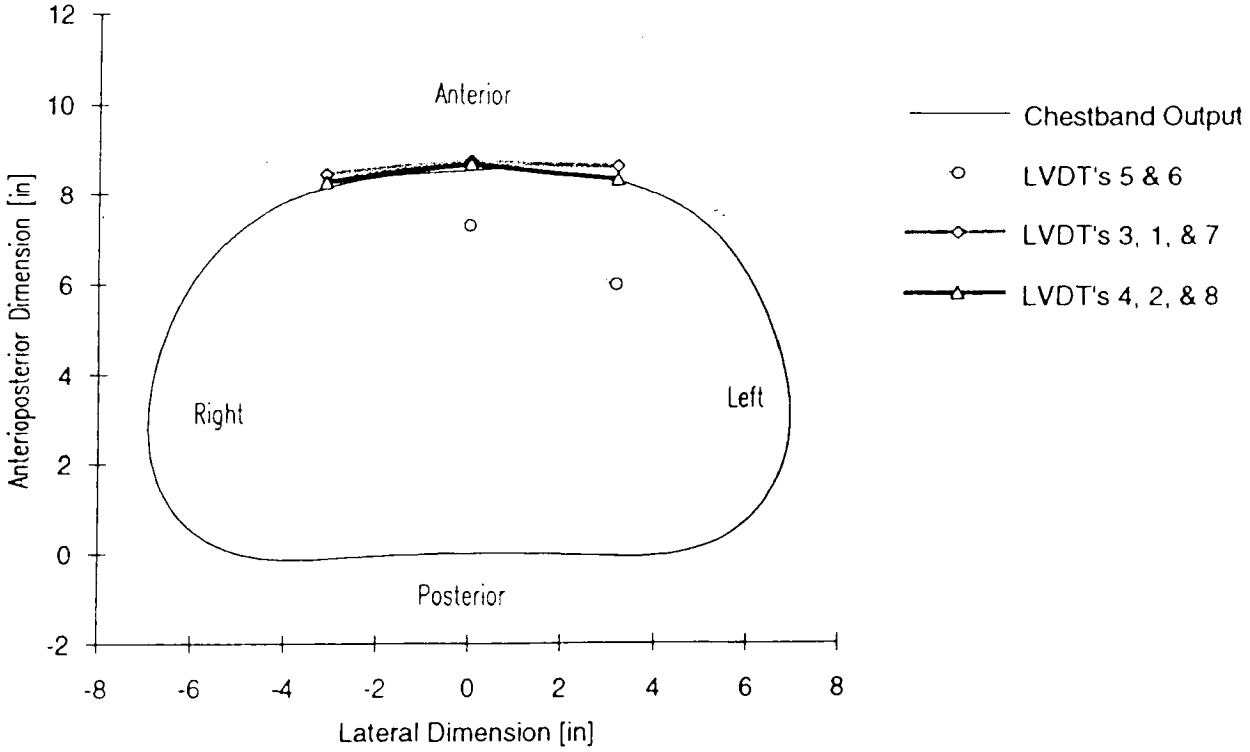


**Figure 9:** Chest contour at t=0 ms, Subject 2 (relaxed-unexpanded, 100 mm drop, 29 kg pendulum)

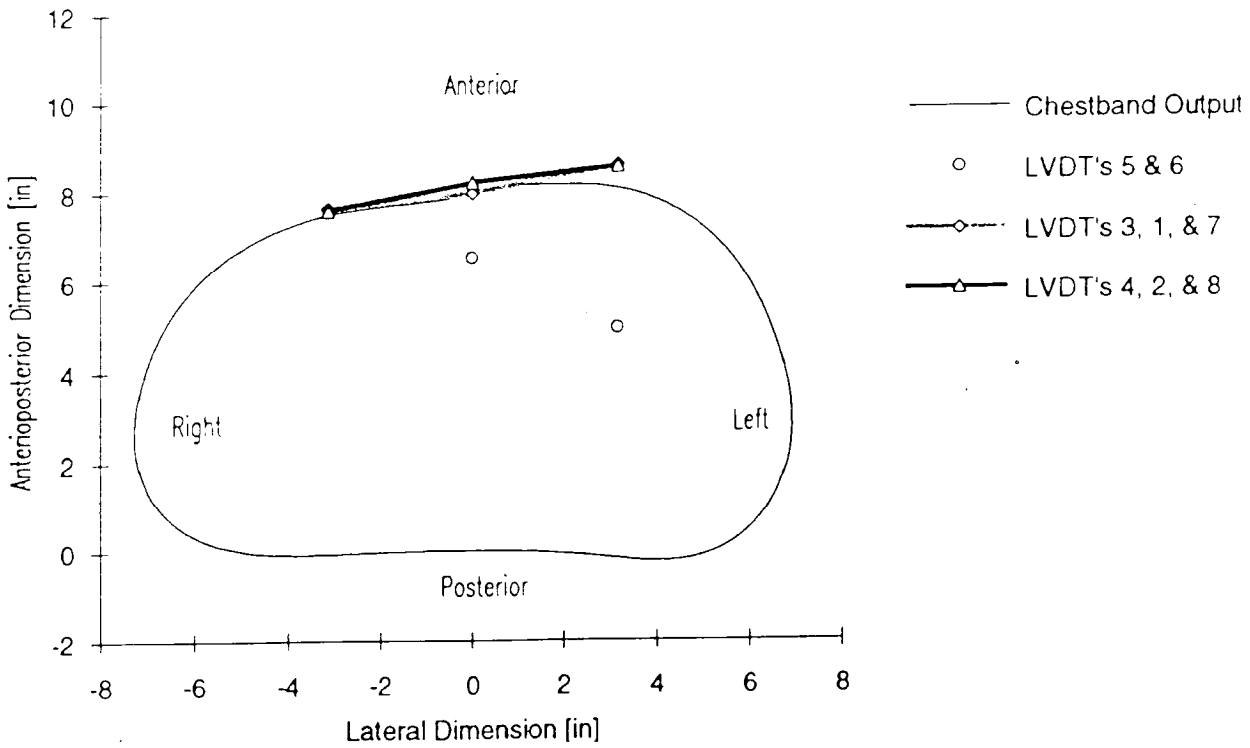


**Figure 10:** Chest contour at t=135 ms, Subject 2 (relaxed-unexpanded, 100 mm drop, 29 kg pendulum).

RBANDPC always positions the sternum directly above the spine, any lateral motion of the sternum is masked and can only be inferred from an apparent rotation of the posterior of the thorax. Referring to Figure 11, it can be seen that the right posterior chest appears to move anteriorly while the left posterior chest appears to move posteriorly (or less anteriorly in the case of the Hybrid III). Since the posterior of the chest is held to the table, which is fixed in space, the apparent rotation is actually a product of the sternum moving laterally to the right (by an amount which is not directly measurable from these plots) over the course of the impact. Later discussions with Richard Morgan suggested that it was possible to overcome some of these problems by using different reference axes.

The chest band is only able to give accurate quantitative information on the position of any particular point on the chest contour. From that, it yields valuable qualitative information on the overall shape of the undeformed and deformed chest. For example, the asymmetry characteristic of Subject 2, evident in Figure 12, would be attributed to non-zero offset if the LVDT's were the only measurement of chest dimension/shape. Also, the relative movement of the ribs of the Hybrid III as the test proceeds, in Figure 13, would not be noticed at all if only LVDT data were examined.

## 5.0 Summary and Conclusion

This project began with the aim of testing a sufficient number of live subjects to complete the Hybrid III and cadaver work of St-Laurent (1988) and Cesari and Bouquet (1990). This work was required because of the uncertainties with the previous work with live humans (L'Abbé et al, 1982) and changes to the test equipment and procedures. However, the project became beset by a series of problems.

The start of testing was delayed by the requirement to obtain Ethics Committee approval from the University of Ottawa. Obtaining this approval consumed much of the project budget. The structures imposed by the Ethics Committee with respect to the human subject testing made the test procedure more complex. As a result the testing was reduced to two subjects and became a pilot to test the future direction of the project. The requirements of the Ethics Committee led to a distinct lack of enthusiasm on the part of the test subjects and limited the test loading to low levels.

The range of loads and displacements used in this testing was much less than in the previous testing of cadavers and the Hybrid III. It was again found that the stiffness of the Hybrid III thorax was very dependent on the impactor mass used, the higher the mass the higher the effective stiffness.

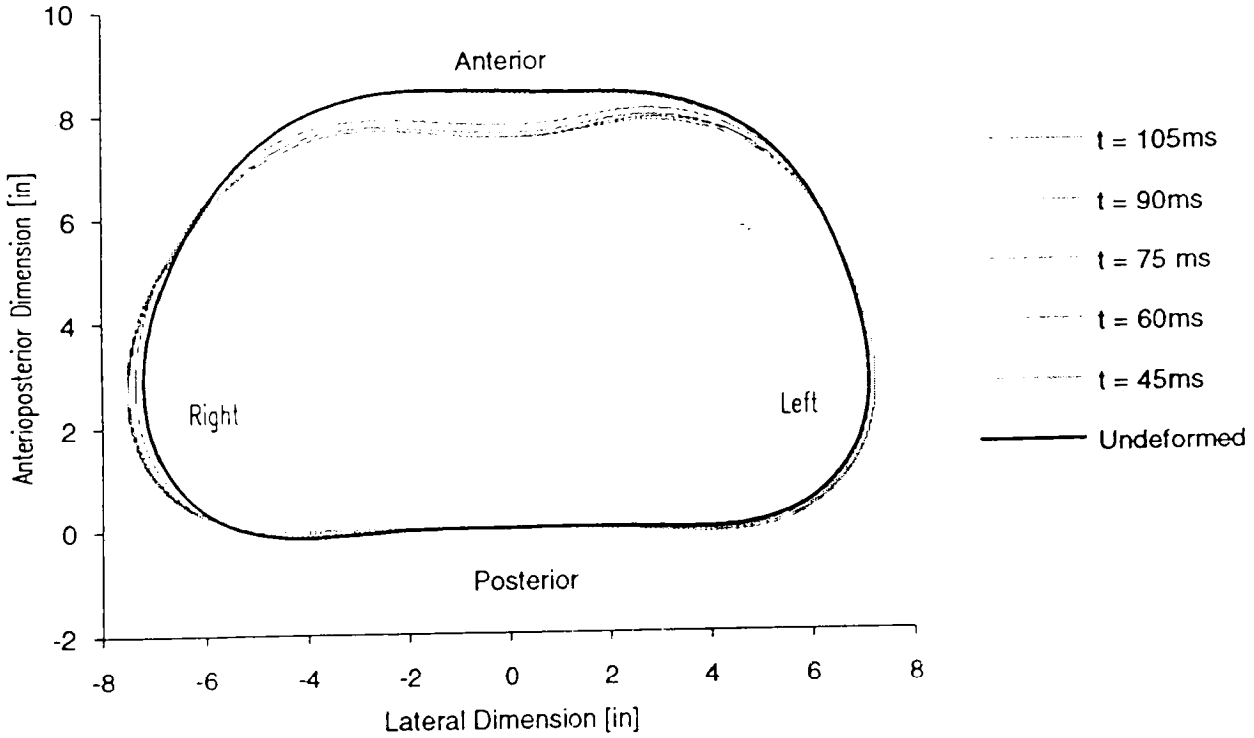


**Figure 11:** Chestband contours for Subject 1 (tensed unexpanded, 100 mm drop, 29 kg pendulum).

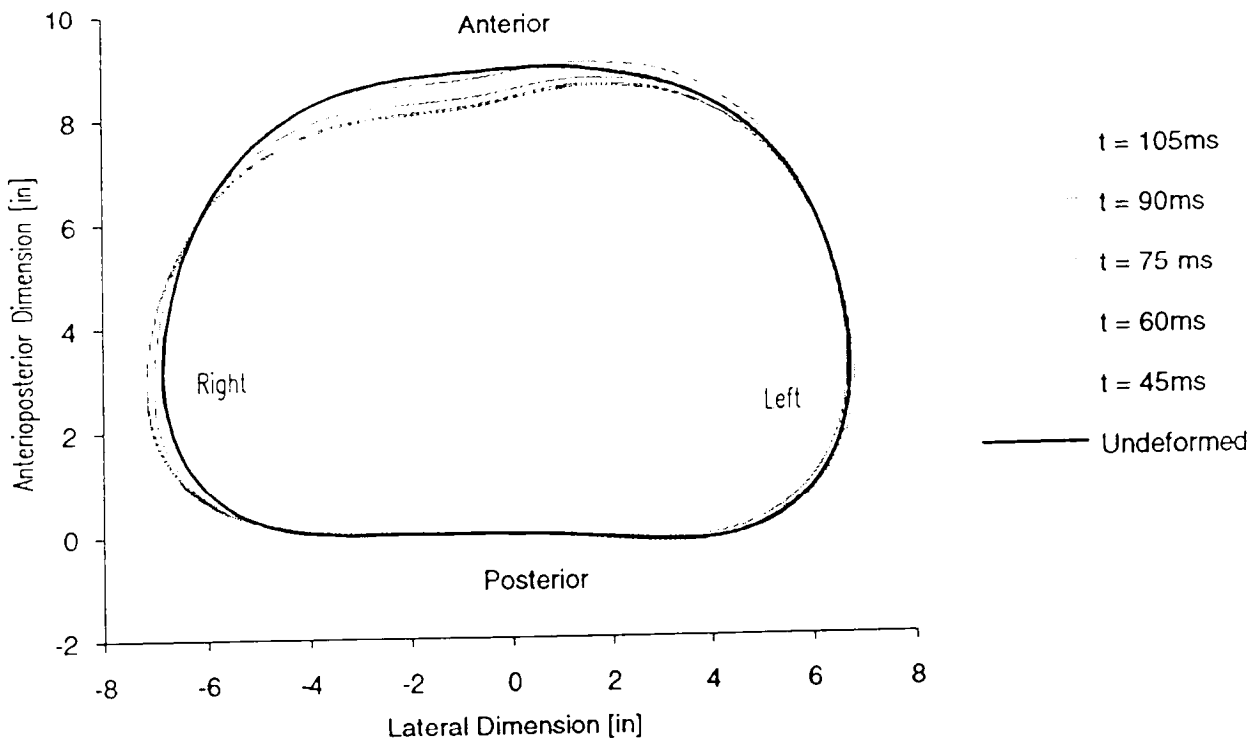


**Figure 12:** Chestband contours for Subject 2 (tensed unexpanded chest, 100 mm drop, 29 kg pendulum).

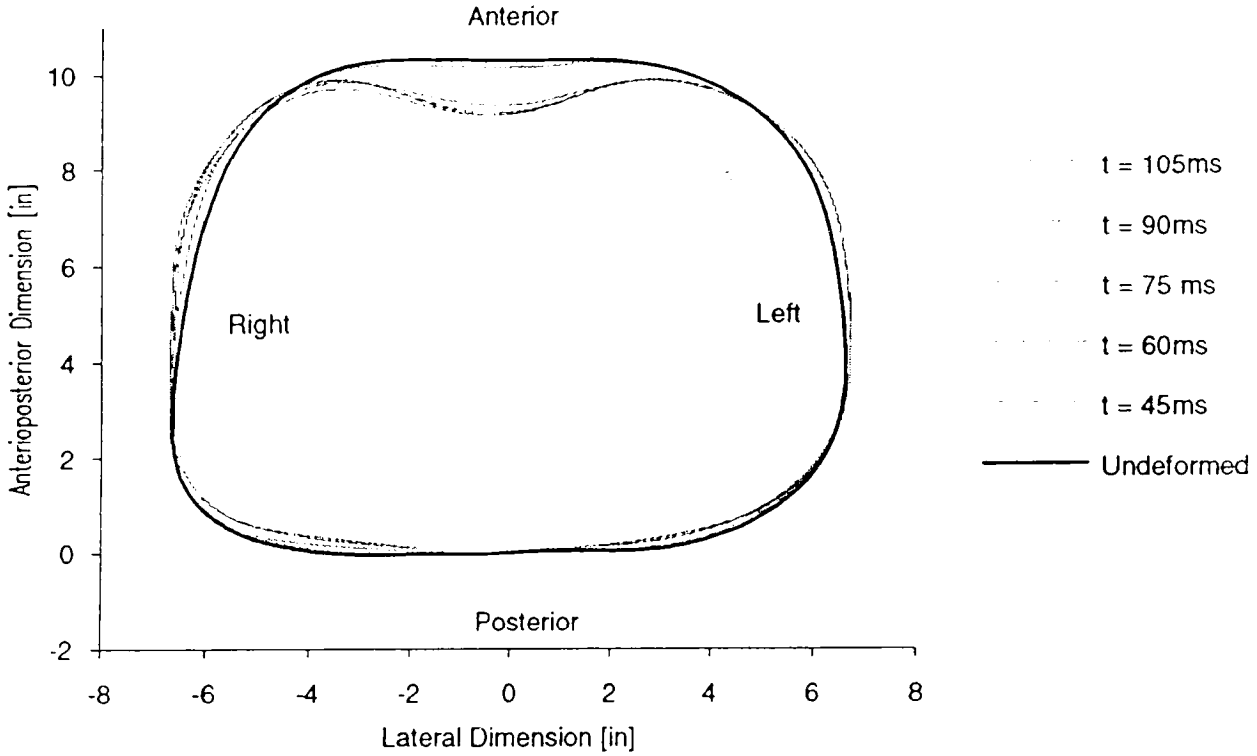


**Figure 13:** Chestband contours for Hybrid III (300 mm drop, 29 kg pendulum)

The stiffness of the Hybrid III measured in this study fell at the lower end of the aggregated results from previous tests. Not only was the impact severity lower in the tests but the measured thorax stiffness was lower. This was partially accounted for by the preload which was applied in the previous testing (St-Laurent, 1988).

Similarly, the volunteers were less stiff than in previous testing (L'Abbé et al, 1982). This is partially explained by the lack of preload in this test series. Other causes are the changes in apparatus and experimental procedure, plus the difference between living and dead subjects. These two volunteers did not have as great a difference between tensed and relaxed condition as did the previously tested volunteers, (L'Abbé et al, 1982). The lack of difference was most probably due to differences in test procedure.

The use of the chest band made testing considerably more complicated. Due to space constraints, only a single band could fit among the LVDT probes. The chest band does not give high quality quantitative information on positions, but it was able to demonstrate details of the deformed shape of the chest. The band is difficult to use on volunteers because of the need to allow chest motion for breathing. The processing of the output of the strain gauges is slow and lacks flexibility. The biggest difficulty would appear to be with the smoothing required to produce the final contour shape.

This testing was conducted as a pilot for a more extensive program. The results are similar to the previous volunteer testing, but with some discrepancies. The severity of the testing for the volunteers fell at the low end of the previous range, mainly due to changes in procedure required by the Ethics Committee. Some increase in severity would be possible if further testing was carried out, but not to the level previously reached.

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DISCUSSION

PAPER: **Chest Band Measurement of Human Upper Torso Dynamic Response**

PRESENTER: Tom Gibson

FELLOW AUTHORS: James Surowiak and Charles Pierce

Q: John Cavanaugh, Wayne State University

You had one plot where you compared Hybrid III mid-sternum deflection to volunteer mid-sternum deflection. They were forced deflection plots. Do you have any similar data for LVDT's on ribs comparing Hybrid III compliance to volunteer.

ANSWER: Yes, we do. It's just a matter of picking it out of the data that we've actually got, because we have got all the data for the LVDT's and it is just a matter of making a comparison between the Hybrid III and the volunteers. I think at mid-sternum it worked at around about a factor of two, the difference in stiffness and that was for the relaxed volunteers to the Hybrid III. It is not exactly two but it was of that order. In the other areas, there is less discrepancy between the strip lighting that we actually undertook for the Hybrid III's and the volunteers, but I don't have any figures for you.

Q: Joe Balser, General Motors

I believe part of the reason why the response curve for the Hybrid III was looked to be stiffer is that in your human testing, you have flesh deformation. In the Hybrid III, your forced deflection is based upon only the rib deflection. You have a rib versus borus. Another words, you are attached to the sternal area whereas in your test with your LVDT's, you are including the flesh displacement in addition to the rib displacement.

A: Not for LVDT-1 because LVDT-1 was attached to the actual belt, so it had the standard Hybrid III flesh skin underneath it. We looked in a couple of other areas where we actually put the LVDT's through the skin of the Hybrid III to insure that there weren't buckling effects, but on the belt itself, it was not attached to the belt.

Q: But I believe that you got flesh displacement that actually physically makes a measurement. Whereas, the Hybrid III, you are internal, you don't have any flesh displacement measured. In other words, you press on the flesh of the Hybrid III, you get no output.

A: But the LVDT was from the outside.

Q: Yes, it was on the outside.

It was on the belt and it is looking at the motion of the belt.

A: Well that is true, but also there is flesh underneath and that is deflecting and giving you the impression that your impact response is softer because you had the flesh deflecting beneath the

strap. Thank you.

Q: Larry Schneider, University of Michigan

I had a similar question about the flesh. Your stiffnesses, it looked like what you were showing were low compared to what LaBay showed a few years ago both for tensed and relaxed. Is that correct?

A: For the volunteers, yes, they were low and the Hybrid III ones, do you want to look at the curves again?

Q: Well, you didn't preload so I wondered how much of the compression or stroking that you were getting might be just flesh and that might be the difference. The reason why you didn't see a lot of difference between tense and relaxed and all the factors is that a lot of the compression that you were seeing maybe was just the flesh of the volunteer and some of that is on the back as well, because you are compressing the back also.

A: It certainly would have had a lot considering the level of preload which appeared to be applied; it would have been quite uncomfortable for the volunteers in the first lot of testing, so there was a significant amount of displacement before they even did the test and, if you look at the experimental data, there was quite a significant amount of chest deflection because the loading went up fairly high. It went up above three coonyans which is reasonably high, I think, for volunteers.

Q: And in your case, you were looking at 20 to 30 millimeters, it looked like a deflection total which, a large part of which, may have been the flesh on both the back and the front of the torso.

A: Yes, I agree. That would have been.