

Submitted for recognition as an American National Standard

**Human Mechanical Impact Response Characteristics—  
Dynamic Response of the Human Abdomen**

**Foreword**—Human mechanical impact response is defined as the reaction of a body segment in terms of measurable engineering parameters such as forces, accelerations, and deflections due to direct or indirect impact loading. The impact response of a body region can depend upon the test conditions used to generate the data (such as impactor shape, stiffness, mass, and body region boundary conditions) and thus, in most cases, can only be defined in terms of those conditions. Accordingly, the impact response of a test dummy component must be evaluated under test conditions similar to those used to obtain the defined response data.

A number of problems need to be addressed in defining human impact response characteristics, since most impact response studies use cadaver or animal surrogates to obtain data at severe impact levels. The impact response of surrogates can differ from that of living humans due to lack of physiological effects, such as muscle tone in the cadaver subject, and lack of geometric similitude with animal subjects. In cases where sub-injury tests are conducted with volunteers, there are also problems with extrapolation of the response data to represent the response at higher impact severities. Some studies only include response of the body region up to the injurious level while others include response well beyond the initiation of tissue structural failure associated with injury.

In addition, the human form is not of unique size, shape, and proportion. There are significant geometric differences between and among adults and children, and males and females. The available response data in the literature dictates that treatment of this topic be constrained essentially to guidelines for average adult male responses, with scaling used to define equivalent responses for the small adult female and the large adult male.

Finally, there may be response variability introduced by age, physical conditioning, and other factors not discussed here. This variability is discussed for those body regions where such information is available.

1. **Scope**—This series of reports provides response characteristics of the head, face, neck, shoulder, thorax, lumbar spine, abdomen, pelvis, and lower extremities. In each report, the descriptions of human impact response are based on data judged by the subcommittee to provide the most appropriate information for the development of human surrogates.
- 1.1 **Purpose**—This is one of a series of reports which define human mechanical impact response characteristics for specific body regions. These reports update SAE J1460 which is intended for use by anthropomorphic test dummy designers and analytical modelers who need quantitative definitions of human mechanical impact behavior. These reports do not discuss criteria for assessing human impact injury potential, which are the subject of a separate SAE Information Report SAE J885. Each document in the series covers material specific to a body region and will be independently updated when new response data become available.

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## SAE J1460-1 Reaffirmed NOV2000

### 2. References

**2.1 Applicable Publications**—The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J885—Human Tolerance to Impact Conditions as Related to Motor Vehicle Design

SAE J1460 MAR85—Human Mechanical Response Characteristics

SAE 840884—A Procedure for Normalizing Impact Response Data, Mertz, H. J.

SAE 861878—Lower Abdominal Tolerance and Response, Proceedings of the 30th Stapp Car Crash Conference, Cavanaugh, J. M., Nyquist, G. W., Goldberg, S. J., and King, A. I.

SAE 892432—Biomechanical Response and Injuries in Blunt Lateral Impact, Viano, D. C.

SAE 892440—Assessing Submarining and Abdominal Injury Risk in the Hybrid III Family of Dummies, Proceedings of the 33rd Stapp Car Crash Conference, Rouhana, S. W., Viano, D. C., Jedrzejczak, E. A., and McCleary, J. D.

SAE 902317—Assessing Submarining and Abdominal Injury Risk in the Hybrid III Family of Dummies: Part II Development of the Small Female Frangible Abdomen, Proceedings of the 34th Stapp Car Crash Conference, Rouhana, S. W., Jedrzejczak, E. A., and McCleary, J. D.

2.1.2 IRCOBI PUBLICATION—Available from IRCOBI Secretariat, ONSER, 109 Ave Salvador Allende, 69500 Bron France.

IRCOBI—Designing of a Dummy's Abdomen for Detecting Injuries in Side Impact Collisions, Proceedings of the 5th International Research Conference on Biokinetics of Impacts, Walfisch, G., Fayon, A., Tarriere, C., Rosey, J., Guillon, F., Got, C., Patel, A., and Stalnaker, R.

2.1.3 ISO/TR PUBLICATION—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO/TR 9790-5—Road vehicles—Anthropomorphic side impact dummy—Part 5: Lateral abdominal impact response requirements to assess biofidelity of dummy

2.1.4 MVMA PUBLICATION—Available from MVMA, American Automobile Manufacturers Association, 7430 Second Avenue, Suite 300, Detroit, MI 48202.

MVMA Report UMTRI-88-19—Steering System Abdominal Impact Trauma, Nusholtz, G. S., Kaiker, P. S., and Lehman, R. J.

2.1.5 UMTRI PUBLICATION—Available from University of Michigan, Transportation Research Institute, 2901 Baxter Avenue, Ann Arbor, MI 48109.

UMTRI Report 83-53-1/NHTSA Reports DOT HS 806 715-806 717—Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family, Schneider, L. W., Robbins, D. H., Pflug, M. A., and Snyder, R. G., Vols. 1-3

2.1.6 OTHER PUBLICATIONS

2.1.6.1 Anatomy, Descriptive and Surgical, Gray, H., Bounty Books, New York, 1977

2.1.6.2 The Biomechanical Response of the Lower Abdomen to Belt Restraint Loading, Miller, M. A., Journal of Trauma, Vol. 29, No. 11, 1989

**3. Dynamic Response of the Human Abdomen**

**3.1 Introduction**—Occupant kinematics in automotive collisions can result in loading of the abdominal region for the unbelted or belted occupant. In either case, abdominal response may affect kinematics of the other body regions and human-like abdominal response is vital to realistic assessment of risk of abdominal injury. This section provides an overview of studies performed to determine abdominal response to impact loading conditions. It includes a brief discussion of abdominal anatomy, and frontal and lateral impact response under various loading conditions. This is new material not contained in SAE J1460 MAR85.

**3.2 Anatomy**—Some organs of the abdomen are “solid” while others are “hollow”, and some are located within the lower parts of the rib cage while others are surrounded only by soft tissue. Classical anatomy separates the abdomen into nine parts, consisting of three rows and three columns as in Figure 1 (2.1.6.1). The top row includes the organs beneath the diaphragm and above the tip of the ninth rib (liver, stomach, spleen, pancreas, duodenum, part of the kidneys). The second row includes organs from the tip of the ninth rib to the highest point on the pelvis called the iliac crest (ascending, descending, and transverse colon, part of the small intestine, the pancreas, and the rest of the kidneys). The bottom row includes all the abdominal organs below the iliac crests (cecum, sigmoid colon, bladder, the rest of the small intestine, and, in females, the uterus).

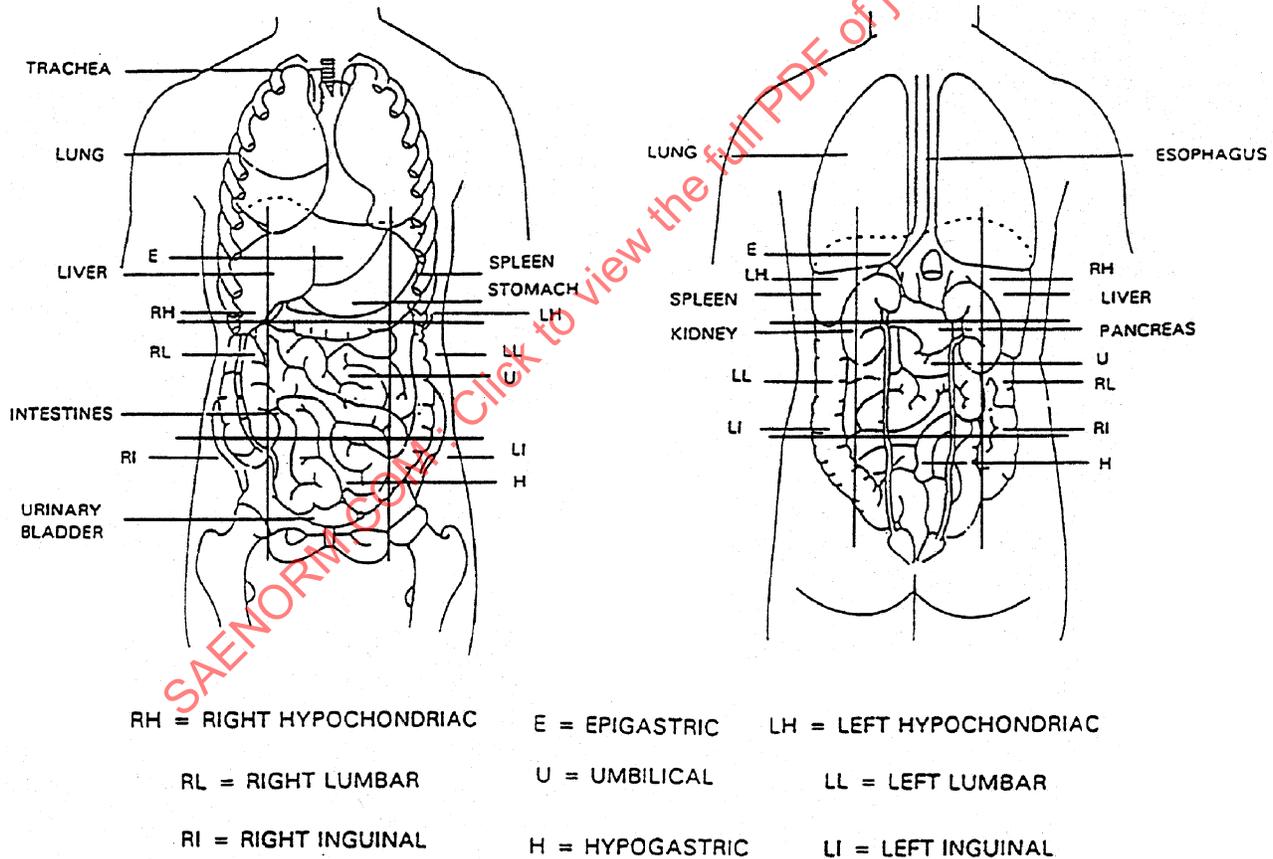


FIGURE 1—THE CLASSICAL SEPARATION OF THE ABDOMEN

In terms of impact response, it is noteworthy that the majority of the organs within the abdomen are, unlike the thorax, not surrounded by bony structures. However, the organs of the top row are partially surrounded by the lower rib cage which can affect the response of this region. Also, the bottom row is partially flanked by the pelvis, hence the lateral abdominal response for this row is undefined.

In general, response data pertaining to the classical separation of the abdomen are not available. For frontal impacts, all of the abdominal response data in the literature are from experiments which have loaded across the entire width of the abdomen. Therefore, while there may be unique frontal response corridors for the three columns of the abdomen (the right, left, and central regions), for the purposes of this document, the abdomen is considered as a single column with three rows. While there are no published data on the frontal response of the bottom row of the abdomen, its response should be similar to that of the middle row for which data are available. Therefore, this document refers to the frontal impact response of only two regions: the upper abdomen (top row) and the lower abdomen (middle and bottom rows).

In lateral impact, there may be unique response corridors for the right and left regions of the upper abdomen due to the presence of the liver on the right side and the stomach and spleen on the left side. The lateral impact response of the middle row probably differs from that of the top row, but the right and left regions of the middle row are expected to have similar response characteristics. Lateral impact abdominal response data in the literature are only available for the top row. Therefore, this region, which is called the upper abdomen, is the only region of the abdomen for which lateral impact data are presented. However, until more data are available, it is considered reasonable to use the frontal impact response of the lower abdomen for the lateral impact response of the middle row.

The studies that have been reported in the literature involve the use of different loading surfaces, loading rates, regions of the abdomen, and loading directions. For these reasons, multiple response corridors corresponding to these different test conditions are presented.

### 3.3 Frontal Impact Response

3.3.1 LOWER ABDOMEN—Cavanaugh et al, (SAE 861878) performed studies of frontal impact to the lower abdomen of unembalmed human cadavers using a rigid cylindrical impactor. The impactor was an aluminum bar, 381 mm long and 25.4 mm in diameter which was oriented with the long axis parallel to the width of the subject at the level of the third lumbar vertebra (L3). The subjects were seated, upright on a table, in the free-back condition with their legs on the table and straight out at 90 degrees to the torso. The subjects' torsos were held upright by straps under the arms which were released at the time of impact. The table was covered with a plastic sheet to minimize frictional effects during impact. A 32 or 64 kg mass impactor was accelerated by a pneumatically accelerated piston, and translated 250 mm before striking the subject. Impact velocities were measured immediately prior to impact by a magnetic pick-up and varied from 4.9 to 13.0 m/s. The deflection data were obtained by film analysis. Deflection was not controlled in the experiments since the impactor was "free-flying". Figure 2 shows the low and high velocity rigid impactor, force-deflection response from Cavanaugh's tests ( $|v|=6.1 \text{ m/s} \pm 1.1 \text{ m/s}$  and  $10.4 \text{ m/s} \pm 1.5 \text{ m/s}$ , respectively).

Nusholtz et al, (MVMA Report UMTRI-88-19) also performed frontal impacts to the lower abdomen of unembalmed human cadavers using a "rigid lower rim of a steering wheel attached to a rigid column support" as the impact surface. This was mounted to a 25 kg pendulum which was driven by a pneumatically accelerated piston, and was free-flying at the time of impact. The subjects were seated on a table in the free-back condition with their legs hanging down. An upright posture was established by suspending the subjects from the ceiling using a parachute harness which was released at the time of impact. The table was covered with plastic sheets to minimize frictional effects during impact. The impactor was positioned so that the bottom of the rim was "halfway between the most inferior point on rib 10 and the iliac crest" (approximately L3). Impact velocities varied from 3.9 to 10.8 m/s. Deflection was measured using accelerometers, high-speed photogrammetry and string potentiometers affixed to T12 and to the rigid impactor. Figure 3 shows the rigid impactor, force-deflection response from Nusholtz' tests ( $|v|=8.0 \text{ m/s} \pm 2.6 \text{ m/s}$ ).

LOWER ABDOMINAL RESPONSE  
Rigid Bar Impacts

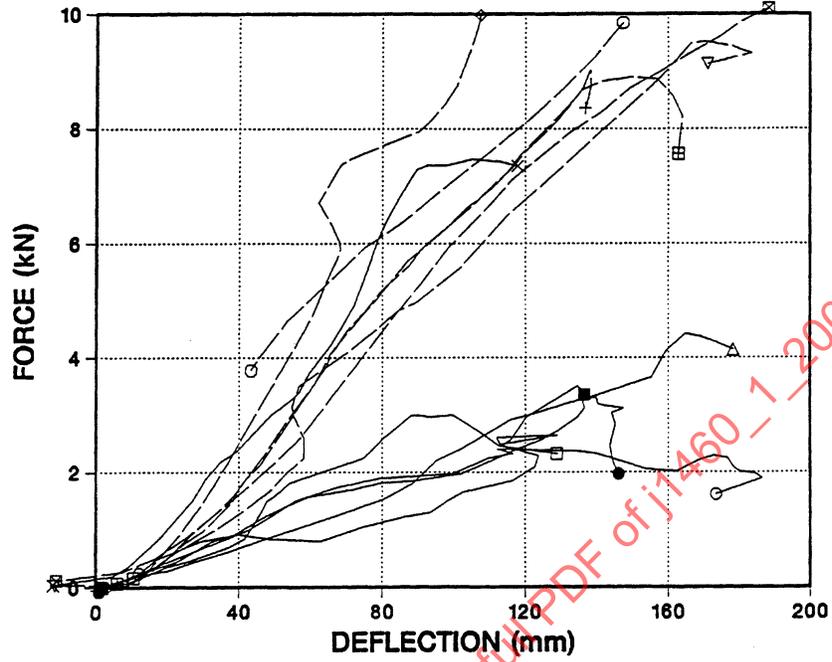


FIGURE 2—LOWER ABDOMINAL RESPONSE CURVES FILTERED AT 100 Hz FROM LOW (AVG = m/s) AND HIGH (AVG = 10.4 m/s VELOCITY RIGID BAR IMPACTS (SAE 861878)

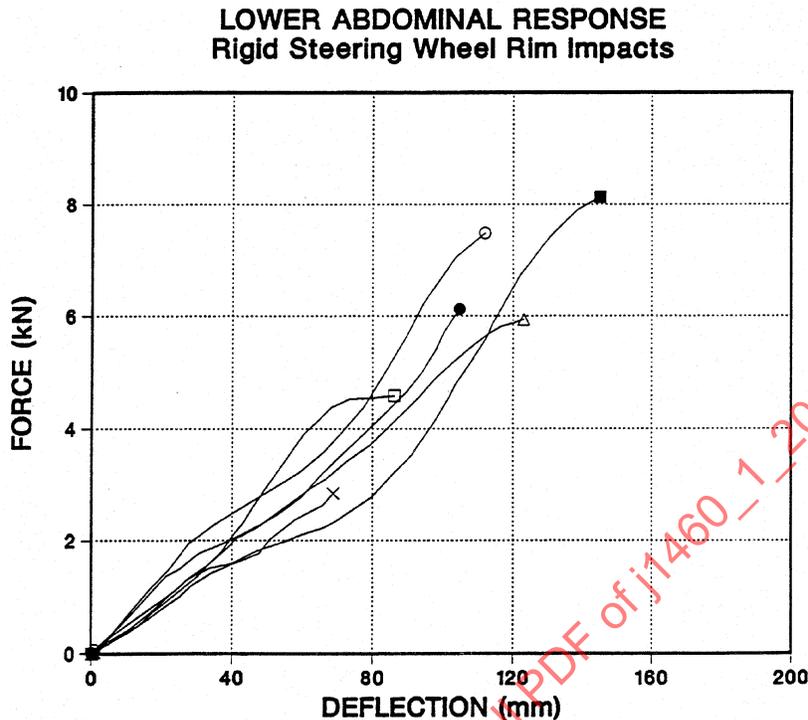


FIGURE 3—LOWER ABDOMINAL RESPONSE CURVES FILTERED AT 100 Hz FROM RIGID STEERING WHEEL RIM IMPACTS AT 8.0 m/s (MVMA REPORT UMTRI-88-19)

Miller (2.1.6.2) performed dynamic experiments with anesthetized porcine subjects lying supine in a fixed-back condition using a 50 mm wide lap belt as the impact surface. The tests were done on a closed-loop, controlled-stroke, hydraulic test machine with an inverted yoke-like fixture attached to a piston above the test subject. The belt was attached to the ends of the yoke and initially positioned in contact with the abdomen. The impact consisted of downward motion of the piston through a preset distance and with a prescribed velocity profile. Miller reported the axial piston force and piston stroke data. Since belt stretch was not taken into account, the actual deflection of the abdomen may have been different from the piston stroke reported by Miller. The impact location was at the level of the fourth lumbar vertebra on the porcine subject, which is approximately the same relative location as the level of the third lumbar vertebra on the human, and is approximately the midpoint between the top of the pelvis and the bottom of the rib cage.

To determine force-deflection curves, Rouhana et al, (SAE 892440) normalized Miller's data to account for differences in subject mass and physical dimensions. Miller's experiments were performed at many different velocities, but Rouhana et al, separated them into "low" (3.7 m/s) and "high" (6.3 m/s) velocity groups, based on the stiffness of the force-deflection curves. Rouhana et al, (SAE 902317) also used scaling to obtain abdominal force-deflection corridors based on the small female and mid-sized male dimensions from Schneider et al, (UMTRI 83-53-1, NHTSA Reports DOT HS 806 715-806 717). Figures 4 and 5 show the low velocity force-deflection response using a seat belt impact interface for the mid-sized male (determined by Rouhana from Miller's tests with  $|v|=3.7 \text{ m/s} \pm 0.84 \text{ m/s}$ ) and for the small female (determined by scaling from the mid-sized male corridor), respectively.

### MID-SIZED MALE LOWER ABDOMINAL RESPONSE Seat Belt Loading

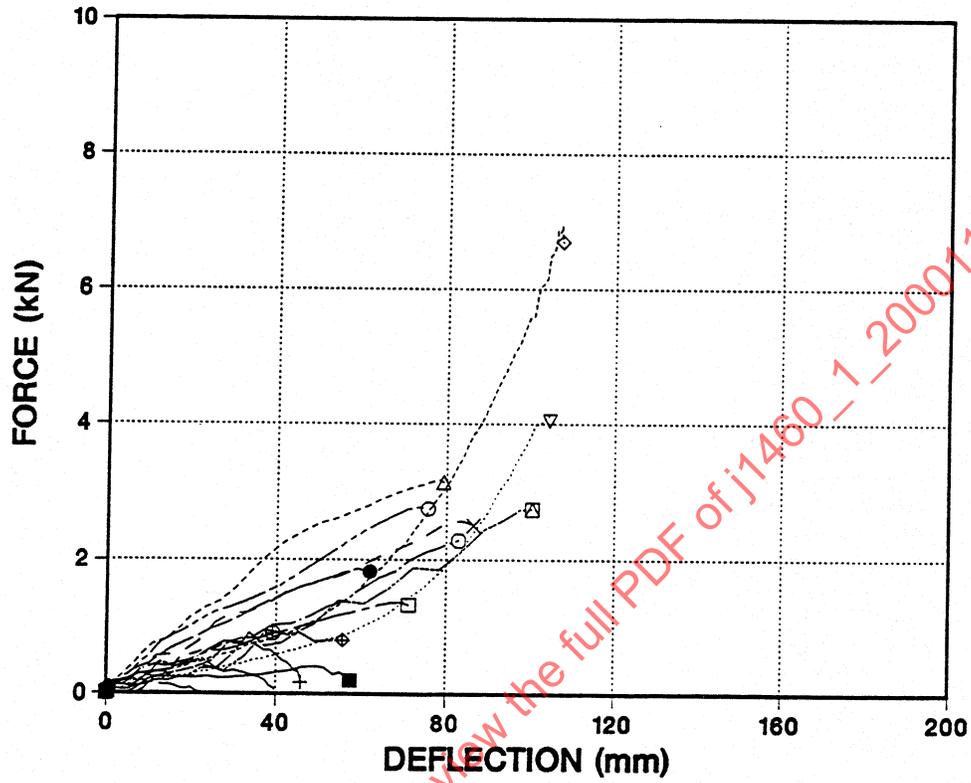


FIGURE 4—MID-SIZE MALE LOWER ABDOMINAL RESPONSE CURVES FILTERED AT 2 kHz  
SCALED FROM LOW VELOCITY (AVG = 3.5 m/s), SEAT BELT LOADING RESPONSE  
DATA FROM PORCINE SUBJECTS (SAE 892440)

### SMALL FEMALE LOWER ABDOMINAL RESPONSE Scaled From Mid-Sized Male Belt Loading By Seat Belt

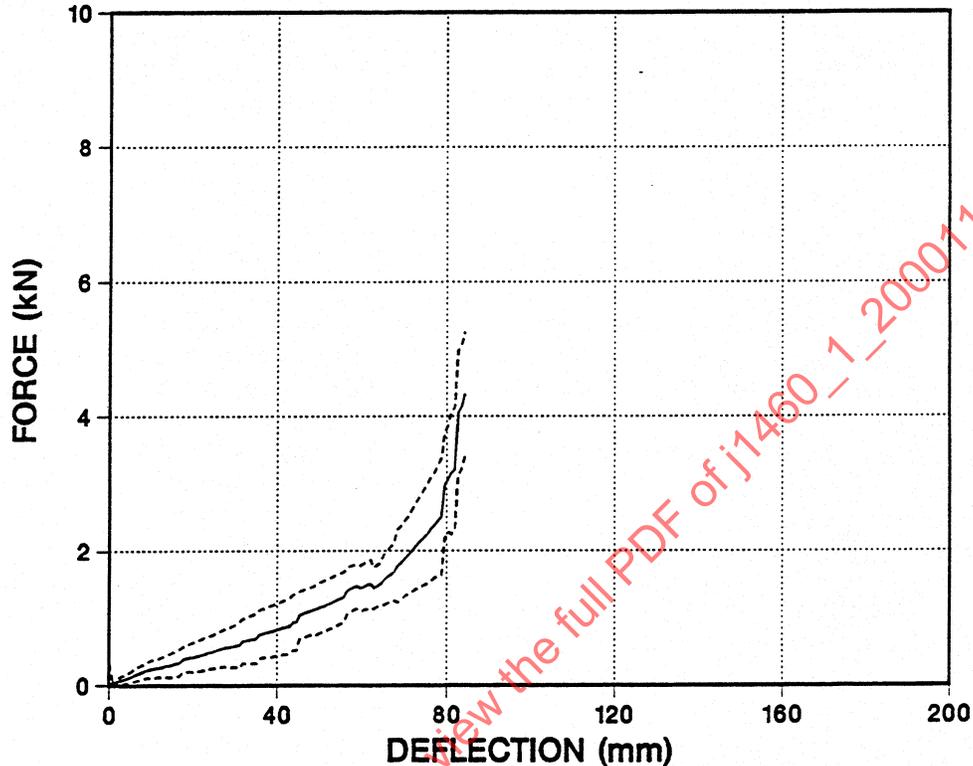


FIGURE 5—SMALL FEMALE LOWER ABDOMINAL RESPONSE CURVES  
(SOLID LINES = MEAN, DASHED LINES = MEAN  $\pm$  1 s.d.)  
SCALED FROM MID-SIZED MALE RESPONSE CURVES (SAE 902317)

### 3.4 Lateral Impact Response

#### 3.4.1 NINETY DEGREE LATERAL IMPACT

- 3.4.1.1 *Upper Abdomen*—Walfisch et al, (see 2.1.2) dropped unembalmed human cadaver subjects from heights of one and two meters so that the right side at the level of the ninth rib struck a rigid or deformable rectangular block simulating the general shape of an armrest. The height of the “armrest” block was 70 mm, the depth varied between tests from 31 to 55 mm, and the length is assumed to have been longer than the antero-posterior dimension of the abdomen at the contact point. Contact velocities were 4.5 m/s for the one meter drop and 6.3 m/s for the two meter drop. Deflection data were determined by film analysis, and deflection was defined as intrusion of the armrest relative to the spine (not relative to the opposite side of the subject). Nevertheless, due to difficulties in defining an appropriate measure of deflection, force-time data, rather than force-deflection data, were used to define the lateral abdominal response for the upper abdomen. Figures 6a and 6b show the force-time curves for the rigid armrest data from Walfisch's tests after being normalized using Mertz's method (SAE 840884). The corridors are those proposed for lateral impact response by ISO (ISO/TR 9790-5) with the upper and lower bounds represented by the average of all the curves plus or minus 25%, respectively.

**CADAVER RESPONSES AND CORRIDOR FOR THE 50th %ile MALE  
1 Meter Drop**

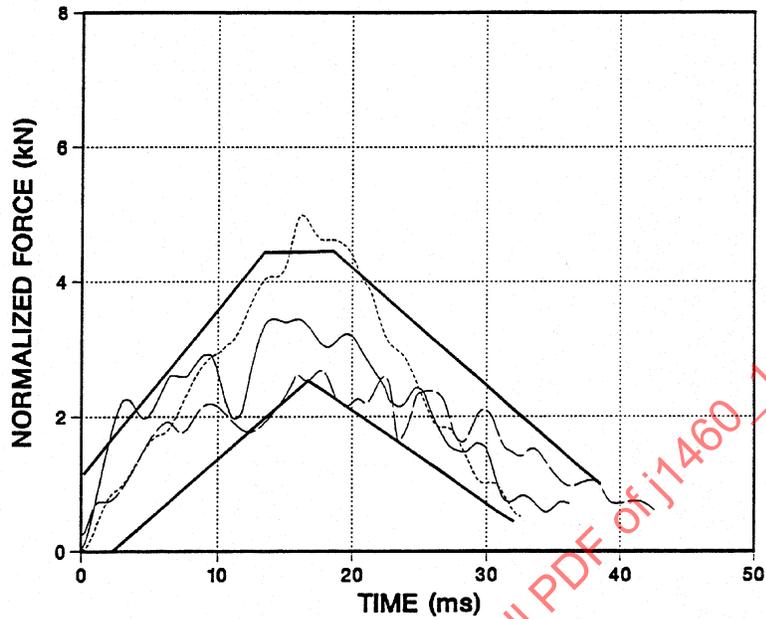


FIGURE 6A—NORMALIZED LATERAL ABDOMINAL RESPONSE CORRIDOR FOR 1 m DROP TESTS ONTO RIGID SIMULATED ARMRESTS OR VARYING DEPTHS (ISO/TR 9790-5)

**CADAVER RESPONSES AND CORRIDOR FOR THE 50th %ile MALE  
2 Meter Drop**

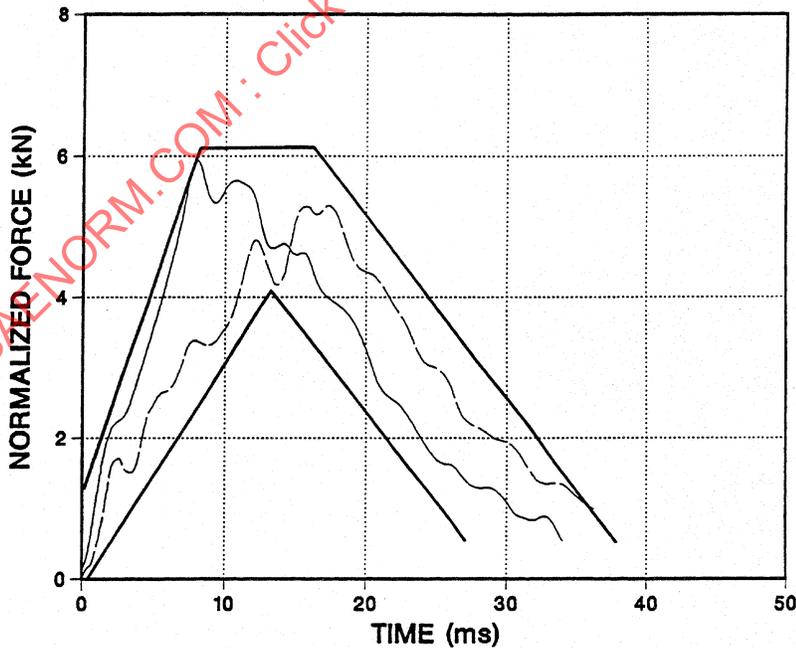


FIGURE 6B—NORMALIZED LATERAL ABDOMINAL RESPONSE CORRIDOR FOR 2 m DROP TESTS ONTO RIGID SIMULATED ARMRESTS OF VARYING DEPTHS (ISO/TR 9790-5)