

	SURFACE VEHICLE INFORMATION REPORT	
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Human Tolerance to Impact Conditions as Related to Motor Vehicle Design		

RATIONALE

The members of the SAE Human Biomechanics and Simulations Standards Steering Committee have reviewed J885 and made a conscientious decision to stabilize this Information Report. Extensive research in human tolerance has been conducted since J885 was last revised. Several published papers present Injury Assessment Reference Values (IARVs) that are based on the current human tolerance data. The U.S. auto industry uses these values to assess the restraint performance of their vehicle designs. The committee members see no value in writing a SAE document to summarize these IARVs since their bases are well documented in the literature. J885 has historical value since many of the early IARVs were established from the data it contains.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE Human Biomechanics and Simulations Standards Steering Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

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1. **Scope**—This report reviews current¹ quantitative data on human tolerance levels without recommending specific limits. Data developed on humans (including cadavers) are presented where available; however, in many cases animal data are provided where no suitable human results have been reported. This report confines itself, as much as possible, to information of direct use to the automotive designer and tester. Data of only academic interest are largely omitted; therefore, J885 should not be considered as a complete summary of all available biomechanical data.

Most of the data cited in this report applies to adult males since little information is available on women or children. The summary data provided in the tables should be considered in conjunction with the accompanying descriptive test. This material explains the manner in which the data were obtained and provides an insight as to their limitations.

- 1.1 **Purpose**—The purpose of this report is to assist the automotive safety designer and tester by providing them with quantitative data on the strength of the human body under impact loading conditions.

2. References

- 2.1 **Applicable Publications**—The following publications form a part of the specification to the extent specified herein.

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FMVSS 208

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3. Definitions

- 3.1 Abbreviated Injury Scale (AIS)**—A numerical rating system for quantifying the severity of injuries to an accident victim. The rating scale is:

Code	Category
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical (survival uncertain)
6	Maximum (virtually unsurvivable)
9	Unknown

For further details see the Abbreviated Injury Scale 1980 Revision published by the American Association for Automotive Medicine.

- 3.2 Anterior**—Front.
- 3.3 Anterior-Posterior (a-p)**—Front to back; in humans, directed from the belly surface towards the back surface.
- 3.4 Articular**—Pertaining to a joint.
- 3.5 Avulsion**—Tearing away of a part.
- 3.6 Cancellous Bone**—The spongy or lattice-like structure of a bone occurring towards its inner core.
- 3.7 Cartilage**—Fibrous connective tissue.
- 3.8 Cervical**—Pertaining to the neck.
- 3.9 Comminuted**—Broken into small pieces.
- 3.10 Compact Bone**—The dense structure of the bone which constitutes its outer portion.
- 3.11 Condyle**—A rounded projection on a bone usually associated with a joint.
- 3.12 Contusion**—Bruising from a direct impact.
- 3.13 Cricoid Cartilage**—The ring shape fibrous tissue which encircles the airway passage near the top of the neck.
- 3.14 Distal**—Remote; further away from the point of reference.
- 3.15 Esophagus**—The passageway which carries food to the stomach.
- 3.16 Extension**—Rearward bending when applied to the neck.

- 3.17 **Femur**—Thigh bone.
- 3.18 **Fibula**—The outer and smaller of the two bones of the lower leg.
- 3.19 **Flexion**—Bending; forward bending when applied to the neck.
- 3.20 **Frontal Bone**—The bone constituting the forehead and upper forward portion of the skull.
- 3.21 **Functional Injury**—A trauma which is not readily observable on visual examination but manifests itself as an impairment of normal usage or behavior.
- 3.22 **Hemorrhage**—Bleeding.
- 3.23 **Hemothorax**—A collection of blood in the sac surrounding the lungs.
- 3.24 **Hyperextension**—Extreme or excessive extension of a limb or part; backward overbending when applied to the neck.
- 3.25 **Hyperflexion**—Extreme or excessive flexion of a limb or part; forward overbending when applied to the neck.
- 3.26 **Inferior**—Below.
- 3.27 **Inferior-Superior(i-s)**—Below to above or lower to upper; from the trunk towards the head.
- 3.28 **Injury**—Physical disturbance, damage, or destruction to a biological structure which impairs or prevents its normal functioning.
- 3.29 **Injury Level**—A rating of a trauma's severity relative to its threat to life or degree of physical or functional impairment (cf: Abbreviated Injury Scale).
- 3.30 **Injury Criterion**—A numerical relationship between measurable engineering parameters and injury level.
- 3.31 **In Situ**—In its normal location in the body.
- 3.32 **Intervertebral Disc**—Circular pads of fibrous cartilage situated between adjacent vertebrae in the backbone.
- 3.33 **In Vivo**—Within the living body.
- 3.34 **Laceration**—A wound made by cutting or tearing.
- 3.35 **Larynx (pl. Larynges)**—The muscle/cartilage structure at the front of the neck.
- 3.36 **Lesion**—Any bodily disfunction or damage.
- 3.37 **Ligament**—A band of tissue that connects bone or supports viscera.
- 3.38 **Loading**—See Measurable Engineering Parameter.
- 3.39 **Mandible**—The bone of the lower jaw.
- 3.40 **Maxilla**—The bone which forms the central portion of the upper jaw.

- 3.41 Measurable Engineering Parameter**—Physical behavior of a system detectable by instrumentation which describes the externally applied environment to, or the structural response or, the system or its surrogate. (Examples of measurable engineering parameters are force, acceleration, strain, and pressure).
- 3.42 Mobilized**—Made free to move. (See Surgically Mobilized).
- 3.43 Occipital Condyles**—Rounded prominences on each side of the base of the skull which articulate with the uppermost vertebra of the neck.
- 3.44 Occiput**—The bone forming the rear and lower rear portion of the skull.
- 3.45 Patella**—Knee cap.
- 3.46 Pneumothorax**—An accumulation of air or gas in the sac surrounding the lungs.
- 3.47 Posterior**—Rear.
- 3.48 Process**—A prominence or projection on a bone.
- 3.49 Rotation**—When applied to neck motion refers to the no gesture of the head.
- 3.50 Sagittal**—A plane or section dividing the body into right and left portions.
- 3.51 Spinous Process**—A projection of the rear on a vertebra.
- 3.52 Sternum**—Breastbone.
- 3.53 Subclavian Arteries**—Two of the four major blood vessels arising from the top of the heart; the subclavian arteries pass under the clavicles and supply blood to the upper body.
- 3.54 Subdural Hematoma**—Bleeding between the two layers surrounding the brain.
- 3.55 Superior**—Above.
- 3.56 Supracondylar**—Situated above (superior to) a condyle.
- 3.57 Surgically Mobilized**—Separated by surgery from its surrounding tissues but leaving connecting blood vessels intact.
- 3.58 Suture**—A joint in which the opposed bone surfaces are closely united.
- 3.59 Symphysis**—A line of union; a type of joint in which the opposing bones are firmly united by cartilage.
- 3.60 Temporal Bones**—Two bones which make up the lower sides of the skull.
- 3.61 Temporo-Parietal**—Side of the skull.
- 3.62 Tendon**—A fibrous cord by which a muscle is attached to a bone.
- 3.63 Thorax**—Chest.
- 3.64 Thyroid Cartilage**—A wishbone shaped stiff tissue located in the upper portion of the neck.
- 3.65 Tibia**—The larger of the two long bones of the lower leg.

- 3.66 Tolerance Level**—The magnitude of loading which produces a specific injury level.
- 3.67 Tolerance Specification**—An impact level which is taken as the maximum (or minimum) allowable condition for design purposes.
- 3.68 Trachea**—The windpipe.
- 3.69 Trauma**—See Injury.
- 3.70 Vertebra**—One of the thirty-three bones of the spinal column.
- 3.71 Zygoma**—Cheekbone.

4. Introduction To Biomechanics

- 4.1 Test Subjects**—Of necessity, human tolerance levels must be inferred by indirect means such as testing volunteers (below their injury level), cadavers, or anesthetized animals. Each of these subjects has advantages and shortcomings which influence the applicability of the resultant data.
- 4.1.1 HUMANS**—Volunteers provide the primary source for determining the effects of muscle tone and pre-bracing on the dynamic behavior of humans. Volunteers can also provide some information on the upper boundary of the "no injury" tolerance level. However, true tolerance levels cannot be determined with volunteers since they cannot be tested into the injury range. A further disadvantage is that volunteers are usually young, robust males whose pain and injury tolerance is apt to be considerably higher than that of the general population. Finally, the muscle bracing which volunteers sometimes employ can have an important effect at low levels which cannot necessarily be extrapolated to higher levels.
- 4.1.2 CADAVERS**—Cadavers are normally employed when testing is undertaken at severity levels which would be injurious to volunteers. Cadavers are logical candidates as test subjects since they retain geometric similarity to living humans and many of their structures retain a strength similarity as well. This latter aspect is highly dependent on the treatment of the cadaver and the time duration since death. Recognition of these factors has led to extensive changes in cadaver testing techniques in recent years in an effort to make such test results more representative of living human response. These changes include the use of unembalmed cadavers, inflation of the lungs, and pressurization of portions of the vascular system with dye solutions to assist in trauma diagnosis. It is generally accepted that the mechanical strength of most living human body tissues decreases with age. Consequently data obtained from tests of cadavers of the elderly are likely to be conservative relative to the general population. Other potential shortcomings of cadaver testing revolve around their lack of muscle tone, and differences in some body properties from those of the living.
- 4.1.3 ANIMALS**—Animal testing is generally employed to study the mechanisms of trauma since animals provide the only functioning physiological systems which can be subjected to severe impacts. They also provide the only known bridge for examining the relationships between living and dead subjects. Thus animals may provide the only possibility for evaluating the usefulness of cadaver testing. Unfortunately, the results of animal tests cannot, as yet, be quantitatively scaled with confidence to determine human tolerance levels due to the size, shape, and structural differences between animals and humans.

4.2 Application of Biomechanical Data

- 4.2.1 HUMAN SURROGATES**—The behavior of the human surrogate is an important consideration when the biomechanical data of Section 5 are applied to automotive testing. To be of value, the surrogate must be sufficiently human-like so that its performance will be indicative of human behavior under similar circumstances. The problems of achieving such correlations are discussed in Section 6 of this report.

- 4.2.2 DETERMINATION OF TOLERANCE LEVELS—A comprehensive discussion of the factors involved in the determination of human tolerance levels is beyond the scope of this report. Indeed, such specifications are beyond the state-of-the-art in biomechanics except perhaps for a few academic situations. There are several difficulties which prevent a ready establishment of human tolerance levels. First, there are differences in judgement as to the specific degree of injury severity that should serve as the tolerance level. Second, large differences exist in the tolerances of different individuals. It is not unusual for bone fracture tests on a sample of adult cadavers to show a three-to-one load variation. Presumably, variations of at least this magnitude exist in the living population. Finally, most tolerance levels are sensitive to modest changes in the direction, shape and stiffness of the loading source. The above considerations indicate that complete and precise definitions of human tolerance levels will require large amounts of data based on controlled statistical samples. Only in this way can the influence of age, size, sex, and weight be comprehensively assessed and only in this way can mean loads and statistical measures of scatter be linked to specific tolerance levels.

In the interim, it is necessary to employ various tolerance measures in the development and evaluation of safety features. Probably the most widely used of such measures is the tolerance specification. This is an impact level taken somewhat arbitrarily as a boundary condition for design purposes. The tolerance specification should not be confused with the tolerance level which is the magnitude of loading that produces a specific degree of injury. As explained above, complete definitions of tolerance levels properly should be statistical measures relating probabilities of injury and degrees of injury to impact histories.

- 4.3 **Biomechanical Materials**—The body is composed of hard and soft materials which can occur together in composite body structures such as the rib cage and vertebral column. The presence of soft tissue as a bone connector allows for large structural deflections.

- 4.3.1 BONE—In addition to being non-homogeneous and anisotropic, a given bone often varies in shape from individual to individual. Therefore, it is not generally convenient to employ conventional stress analysis techniques for estimating the strength of a bone from its material properties. To overcome this difficulty, bones are generally tested in situ to determine their load carrying capacity as a structure. As with any structure, a variety of failure modes is usually possible depending on the distribution and location of the applied forces and, for impact situations, time duration effects may be important as well. Accordingly it is important to understand the mode of load application (that is, torsion, bending, shear) for the situations presented in Section 5; these tolerance levels should only be applied under similar conditions.

The bones of the skull and knee cap are uniquely sensitive to punch through (bearing load) failures. This is due to their anatomical construction as well as to their physical prominence and lack of soft tissue covering to provide a padding effect. The bones of the skull and knee cap are of a sandwich construction. Their innermost and outermost layers are shells of compact bone which embrace a middle zone of porous bone between them. Excessive bearing loads can punch through the outer shell at force levels that would not cause failure of the overall bone structure. Examples of this bearing load effect are given in Section 5.

- 4.3.2 SOFT TISSUES—The development of injury criteria for soft tissue trauma is an extraordinarily complex subject which is only in its early development stage. Progress in this field is likely to be slow for the following reasons:
- A wide variety of possible injury mechanisms exist.
 - Small differences in the location or level of injury can have vastly different consequences to the injured person.
 - The capability to analyze and model the organs is very limited.

4.3.2.1 *Skin*—Skin has been studied more than any other soft tissue insofar as automotive collision trauma is concerned. The state-of-the-art in assessing skin injuries is summarized in SAE Information Report J202. One test procedure is to expose a synthetic skin material to a standardized impact test and then to evaluate the injury level either by subjective observation or measurement of the resultant damage to the synthetic material. This appears to be a practical method to evaluate skin injury levels when the multiplicity of skin injury mechanisms are considered. Skin trauma includes:

- a. Avulsion (tearing away).
- b. Contusion (bruising from direct impact).
- c. Laceration (cutting).
- d. Puncturing.
- e. Splitting.
- f. Abrasion.

4.3.2.2 *Internal Soft Tissues*—Internal soft tissues are vulnerable to all of the above types of trauma except abrasion. In addition, they can be injured by excessive displacement which may detach an organ from its vascular or ligamentous connections. In the brain, rapid displacement may result in injury due to cavitation. Unfortunately, little quantitative data exist on force, penetration, or displacement levels that are injurious to soft tissues. No synthetic internal organs are currently in common use for impact testing.

5. **Data**—The human body can be subjected to a broad variety of trauma caused by a number of injury mechanisms; certain of these predominate for each zone of the body. Therefore, this information report discusses each body zone separately. They are considered in body order from head to legs.

5.1 Fracture Loads for the Cranium

5.1.1 **FRACTURE MODES**—The bones of the cranium are not homogeneous throughout their thickness, but are of a sandwich construction. The sandwich consists of a core of cancellous (low density) bone between two layers of compact (high density) bone. This arrangement allows two different types of bone fractures to occur, each arising from a different failure mode.

5.1.1.1 *Linear Fractures (failure of the structure as a whole due to bending stresses)*—When the impact is well distributed, the skull will be bent inwardly at the site of the blow, and outwardly in some regions remote from the blow. The tensile stresses (or strain energy densities according to one theory) arising in the latter regions can precipitate a crack. The crack usually originates at some point of stress concentration and propagates towards the site of the blow along an essentially direct path. The bone on each side of the crack remains in alignment in this type of fracture. A linear fracture is not life threatening per se since it does not in itself precipitate brain injury. However a linear skull fracture is a cause for concern since the integrity of the skull has been lost.

5.1.1.2 *Depressed Fractures (localized failure of a cranial bone due to concentrated forces)*—If the impact force is sufficiently concentrated, it may break through the structure locally even though the magnitude of the force might be insufficient to over-stress the bone structure as a whole. A contact area of approximately 2 in² (13 cm²) is considered here to represent the transition between distributed and concentrated loading. As the contact area diminishes below this threshold size, depressed fractures are likely to occur as a result of localized stresses at the impact site. This produces a cave-in mode of failure. If the contact area is further diminished, to less than approximately 3/4 in² (5 cm²) the depressed fracture takes the form of a clean punch-through with a hole size which matches the size of the struck object. This behavior is thought to be due to two concurrent failures: compression of the core of cancellous bone and shearing of the compact bone. Both the cave-in and punch-through types of depressed fractures result in an inward displacement of the bone which can lead to mechanical impingement against the brain and allow the entry of foreign bodies. Depressed fractures are potentially life threatening injuries.

- 5.1.2 FRACTURE DATA—Table 1 presents a summary of fracture load data for the cranium. Some of the anomalies found there can be explained by considering the impactor shape and the cranial bone properties; however, most are likely due to the large variations that are inherent in any cadaver population. The likelihood of inconsistencies is compounded by the small number of test specimens employed in many of the test series cited. These considerations suggest the need for caution in the use of this table.

**TABLE 1—DYNAMIC FRACTURE FORCES FOR CRANIAL BONES
RIGID SURFACE IMPACTS**

Type of Impact Surface	Fracture Forces ⁽¹⁾ Mean lb	Fracture Forces ⁽¹⁾ Mean N	Fracture Forces ⁽¹⁾ Range lb	Fracture Forces ⁽¹⁾ Range N	Sample Size	Fresh or Embalmed	Ref
Frontal Bone							
flat plate ⁽²⁾	1430	6360	880–2650	3910–11 790	12	fr	1
flat plate	1440	6400	1220–1770	5420–7870	6	em	2
longitudinal surface of cylinder							
1 in (2.5 cm) rad. aligned transversely	1260	5600	950–1650	4220–7340	7	em	3
1 in (2.5 cm) rad. aligned sagittally	1600	7120	940–2000	4180–8900	5	em	2
5/16 in (0.79 cm) rad. aligned transversely	1230	5470	700–1730	3110–7700	5	em	3
sphere, 8 in (20.3 cm) rad.	1180	5250	830–1530	3690–6810	5	em	2
small area flat surfaces							
1 1/8 in (2.9 cm) dia	1130	5030	848–1600	3770–7120	5	em	4
1 1/8 in (2.9 cm) dia	1390	6180	980–1990	4360–8850	5	fr	4
1 1/8 in (2.9 cm) dia	1310	5830	930–2220	4140–9880	7	em	5
0.61 in (1.55 cm) dia	1710	7610	920–2200	4090–9790	5	em	6
0.43 in (1.09 cm) dia	1030	4580	470–2000	2090–8900	5	em	6
small area rounded surface							
0.67 in (1.70 cm) dia ⁽²⁾	1000	4450	620–1820	2760–8100	6	fr	1
Temporo-Parietal Bones							
flat plate ⁽²⁾	1140	5070	770–1760	3430–7830	13	fr	1
flat plate	1910	8500	1050–3360	4670–14 950	7	em	2
small area flat surfaces							
1 1/8 in (2.9 cm) dia	846	3760	550–1330	2450–5920	7	fr	5
1 1/8 in (2.9 cm) dia	702	3120	302–1330	1340–5920	8	em	5
0.61 in (1.55 cm) dia	1290	5740	500–2200	2220–9790	10	em	6
0.43 in (1.09 cm) dia	780	3470	140–1500	620–6670	10	em	6
small area rounded surface							
0.67 in (1.70 cm) dia ⁽²⁾	766	3410	400–1100	1780–4890	7	fr	1
Occiput Bone							
small area rounded surface							
0.67 in (1.70 cm) dia ⁽²⁾	1440	6410	1150–2150	5120–9560	5	fr	1
Padded Surface Impacts							
Frontal Bone							
rubber padded rigid surface							
flat sheet, 90 durometer	2530	11 260	1200–3400	5340–15 100	7	em	2
1 in (2.5 cm) rad. cyl. 90 durometer aligned sagittally	1650	7340	1100–1960	4890–8720	6	em	2

1. These forces produced a variety of fracture patterns: see the source material referenced for a description of the fractures produced by each surface.
2. Static tests.