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HUMAN TOLERANCE TO ABRUPT ACCELERATION

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INTRODUCTION

Short duration accelerations resulting in injury or death can be inflicted not only on the occupants of vehicles involved in crashes, but also on pedestrians, sportsmen, persons falling from a height, and those exposed to explosions and bomb blast. The injury may be received when a person in motion comes into collision with a solid object or when an object or missile strikes a stationary person. Irrespective of the circumstances surrounding the accident, injury occurs when a person is exposed to forces of some magnitude for a brief period of time, and the degree of injury is related to the magnitude and duration of the applied forces.

Hence, the study of accidental injury can be summarised as what we hit, how we hit it, how long we hit it for, how many times we hit it and which part of the body is subjected to the insult. For effective injury reduction programmes to be introduced, an appreciation must be gained of the way in which accidents cause injuries, the nature of the forces contributing to the injuries and the characteristics of the type of accident under investigation.

SHORT DURATION VS LONG DURATION ACCELERATION

When assessing injuries incurred during aviation or automotive accidents we encounter occupants who have been exposed to high energies for very brief periods of time. The time course of an impact event is extremely short, being completed usually within 0.1 - 0.5 of a second. Early impact and deceleration studies on human and animal subjects, carried out in the 1930s by Siegfried Ruff in Germany, compared prolonged acceleration with impact acceleration and described the pertinent considerations in the study of the effects of impact accelerations to be the magnitude of the peak acceleration, the time of exposure, the momentum, the jolt, the nature of the forces of inertia and the site of application to the body.

The effects of short duration accelerations are related principally to the structural strength of the part of the body upon which they act and to the overall velocity change induced in the body. In contrast, intermediate duration accelerations are forces which persist for 0.5-2.0 seconds, as during ejections from aircraft, catapult launches and deck landings. Human tolerance to intermediate duration accelerations depends not only on the overall velocity change induced, but also upon the time taken to reach peak acceleration and upon the peak acceleration level attained.

Long duration acceleration, which can be experienced in various aircraft manoeuvres, imposes forces which last more than 2 seconds and have a duration of perhaps minutes. The human tolerance to sustained acceleration depends principally on the plateau level of the acceleration imposed on the body, as the response to long duration acceleration is due to the effects of physiological changes arising from distortion of the tissues and organs of the body and from alterations in the flow and distribution of blood and body fluids.

The profile of acceleration forces acting on an aircraft during a crash is determined by the manner in which the aircraft decelerates as its forward momentum is resisted by friction with the ground or by collision with stationary objects. If the structure of a crashing aircraft is crushed or deformed progressively, much of the kinetic energy of the crash is absorbed and the overall deceleration profile is relatively smooth. However, if parts of the crashing aircraft plough into the ground, the aircraft momentum is reduced more rapidly and peaks of abrupt decelerations of high magnitude are produced, with the highest peak values occurring when the aircraft strikes solid objects, such as rocks or buildings.

When an aircraft ditches, the forces acting on the airframe reflect not only the speed of the aircraft and its angle of incidence with the water, but also the orientation of the aircraft with respect to the wave front and the sea state at the time of the accident. There is often little attenuation from airframe deformation during a planned ditching as water tends to produce a uniform load distribution across the lower surfaces of the fuselage.

TERMINOLOGY

The following terms are encountered in the study of short duration acceleration. ,

a) Speed is a scalar system concerned with distance and time, and describes the movement of a body without specifying the direction of travel.

b) Velocity is a vector and denotes speed in a given direction. A change of velocity can be a change in speed, a change of

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direction, or a change of both speed and direction.

c) Acceleration describes the change of velocity of an object and is also a vector quantity with both magnitude and direction. An applied acceleration is often referred to in terms of 'G', the ratio of the applied acceleration to the gravitational constant g ($9.81 m/s^2$).

d) Jolt, the rate of onset of acceleration, is the third derivative of acceleration and has the units of G/sec. Jolt is of particular importance in impact studies.

The direction in which an acceleration or inertial force acts on a human being is described by a three co-ordinate system in which the X axis describes forces acting in the fore and aft direction at right angles to the longitudinal axis of the body, the Y axis indicating laterally applied loads and the Z axis describing accelerations in the long axis of the body (Figure 1). It is important to distinguish between the applied force and the resultant inertial force as these act in opposite directions. For example, an upwards acceleration (applied force) displaces the internal organs and the eyes downwards towards the feet and this resultant (inertial) force is called $+G_Z$.

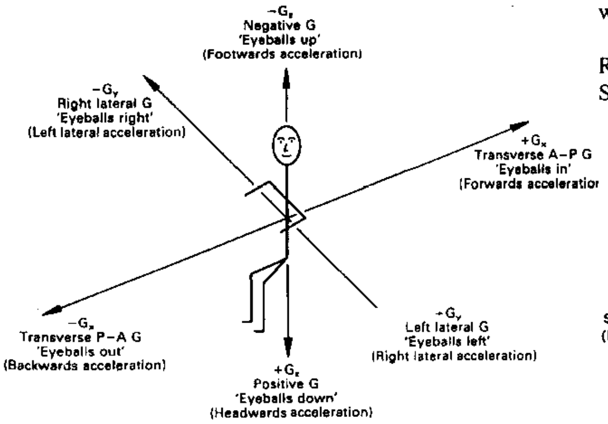

Fig 1. The standard AGARD aeromedical terminology for describing the direction of acceleration and inertial forces. The vectors indicate the direction of the resultant inertial forces.

SHORT DURATION ACCELERATION AND SITING POSITION

The tolerance of the occupant of an aircraft or vehicle seat to backwards acceleration ($-G_X$) depends critically on the effectiveness of the support provided to the front of the body by a restraint harness. If no obstacles are present within the flail envelope, the head will be flung down onto the chest and the arms and legs thrown forwards at right angles to the body.

Significant lateral ($+/-G_Y$) accelerations do not occur under normal flight conditions and in a crash the severity and type of injury received by the occupant is dependent on the restraint provided and the nature of any contact with airframe structures.

Significant $-G_Z$ acceleration can occur in crashes associated with a high sink rate. Tolerance to accelerations in this axis is influenced by the seat back angle, the sitting platform and the posture of the occupant. G_Z acceleration is reacted primarily through the buttocks and spinal column and the position of the occupant and the effectiveness of any restraint harness provided influence the incidence of spinal column injury.

NATURE OF SHORT DURATION IMPACT

Visco-elasticity is a material property whereby a change of stress occurs under constant deformation (stress relaxation) or a change in deformation occurs under constant load (creep). All biological tissues, even hard tissues such as bone have the property of visco-elasticity and will break under different loads depending on the rate of application of the load, the nature of the force and the time over which the force is applied. Figure 2 illustrates the concept of visco-elasticity with respect to human bone and illustrates that bones may sustain, without breaking, a higher force rapidly applied and withdrawn than they may sustain when even a lower force is more slowly applied.

RATE DEPENDENCY OF MAMMALIAN BONE STRUCTURE

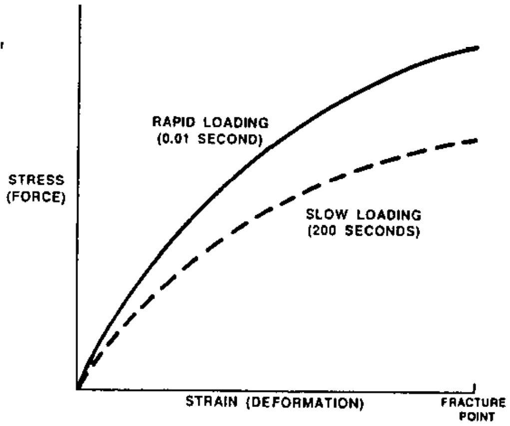

Fig 2

Physical damage incurred during an impact is due to the relative movement of parts of the body coming into contact with an object. The nature of the impact and the configuration of the struck object or surface influence the distribution of the stresses within the body and the damage seen after the impact. The initial velocity change of the body in contact with an accelerative force can be supersonic, subsonic or trans-sonic.

When loads, such as a bullet fired from a gun, travelling at supersonic speeds impact the body, the shock wave set up carries energy that moves through the body faster than the speed of sound in the body. This energy, travelling at supersonic speeds, is concentrated in a shock wave front, and, being concentrated in a thin layer in the body, results in a concentration of strain energy that has a great potential for injury. A fast moving, blunt load that does not penetrate can still cause shock wave damage.

Transonic velocities produces stress waves which move in the body at sonic speeds. These stress waves may be concentrated into a small area and cause concentrated damage in that area. They may also be reflected at the borders of organs and tissues, causing even greater damage. The complex phenomena of shock and elastic wave reflection, refraction, interference and focusing are made more complex in the body by the fact that different organs transmit sound at different speeds.

During the type of impact that may be found in a vehicle or aircraft accident, vibrations can be induced in the internal tissues and organs of the occupants. These vibrations result in a dynamic stress which is higher than the stress that would have existed had the load been applied statically. A force may be applied very slowly and some impact velocities are so slow that they are almost static and all the tissues and organs of the body at every point respond to the static load with static stress. In general terms, the slower the application of the load, the smaller the stress induced, and the greater the rate of application, the larger the stress induced. As the rate of application increases, induced vibration may cause additional damage and even further damage may be sustained from stress concentration of elastic waves.

The input of energy into a system results in stress and its associated strain. The strength of a material, that is, the maximum stress a material can bear without failure, depends on the rate of change of strain. Thus, the limit of safety, where the maximum stress remains below the critical limit of strength, depends on the rate of loading.

When considering the strength and tolerance of the human body to applied loads, the magnitude of the stress and its rate of application must be taken into account. The static stress distribution in the body under external load (e.g. the inertia force due to the deceleration of the aircraft or vehicle) must be determined first, followed by any dynamic amplification due to vibrations within the body or stress concentration due to elastic waves and shock waves. In other words, the strength of an organ or a tissue in the body depends not only on the magnitude of the stress, be it static or dynamic, but also on the type of stress and whether it is uni-, bi-, or tri- axial.

When a vehicle or aircraft crashes, the energy involved is kinetic energy and the vehicle stops once this kinetic energy is used up. However, although the vehicle may stop, the occupants within the vehicle will travel along the same trajectory until they, too, are stopped either by the operation of a restraint system or by contacting part of the interior of the vehicle. The forces acting on the occupant may be significantly reduced in the presence of effective restraints, energy attenuating seats and well-designed occupant space and increased if the occupant experiences little deceleration during the early part of the crash through absent or ineffective restraint or poor seat design.

HUMAN TOLERANCE TO SHORT DURATION ACCELERATION

Tolerance is defined in the OED as "the willingness or ability to tolerate" and "the capacity to tolerate something, especially...environmental conditions without adverse reaction". The definition of the human tolerance levels to short duration accelerations is not a simple task due to the variability of individual response and the need to define the level of injury or discomfort which is considered acceptable. For convenience, short duration acceleration forces are often separated into three broad categories: tolerable, injurious and fatal. In this classification, tolerable forces may produce minor superficial trauma such as bruises and abrasions which do not incapacitate, injurious forces result in moderate to severe trauma which may or may not incapacitate and fatal injuries are self-explanatory.

In a vehicle crash the instantaneous change in velocity, Δv, is the best predictor of injury severity. The probability of an occupant receiving injury or death increases with an increasing Δv, although the relationship between Δv and injury severity is non-linear and influenced by physiological and anatomical variabilities of the occupant.

In 1962 Kornhauser and Gold applied the "impact sensitivity method", developed in the mid-1940s to describe the performance of ballistic devices such as impact switches, to animate beings. This forms the basis of the graph at Figure 3 which plots the logarithm of Δv (ft/sec) against the logarithm of acceleration (G). Fig 3 Inspection of the graph shows that, in general, an acceleration averaging 20G with a velocity change of 80 ft/sec must be exceeded for injury to occur in well restrained humans subjected to accelerations transverse to their long axis (G_X). If the duration of the typical aircraft crash is similar to that of an automobile crash, 0.1 seconds, then inspection of the graph shows that the time epoch of the typical crash occurs at the break between the vertical line of tolerance for acceleration (20G) and the horizontal line of delta v (80 f/s). In other words, at the usual impact duration of 0.1 secs, less than 20G and 80 ft/sec velocity change is probably survivable, or 200G is possibly survivable with a duration of 0.2 secs, with a Δv below 80 ft/sec, 20G is possibly survivable for 10 secs even at velocity changes of 10,000 ft/sec

In general, the following have been accepted as the upper limits of tolerable acceleration forces. However, human variability and differing environmental conditions may significantly alter the ability of an individual to withstand abrupt decelerations in a particular aircraft crash, therefore all estimations of human tolerances to impact must be seen as approximate.

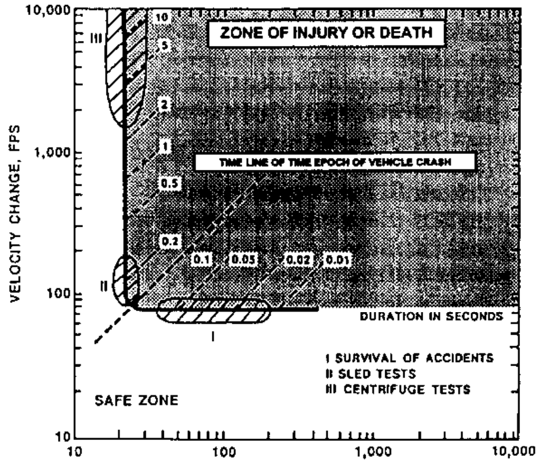

Fig 3 Average Acceleration, G Units
(After Kornhauser and Gold)

$+G_Z$ acceleration. Acceleration in this direction is usually associated with ejection from aircraft and is included here for completion. It has been estimated that an acceleration pulse of approximately 25G for about 0.1 sec is within tolerable limits. Minor injuries, including compression fractures of spinal vertebrae can occur within these limits, but such injuries are not usually incapacitating and should not prevent escape from the aircraft.

$-G_Z$ acceleration. Experimental evidence is that a restrained, seated subject is able to withstand an abrupt $-G_Z$ acceleration of about 15 G for 0.1 sec without serious injury.

$-G_X$ acceleration. For accelerations in this axis, it is considered that 45 G sustained for 0.1 second or 25 G for 0.2 sec are both within tolerable levels for a fully restrained, seated occupant. Some injury may occur, but this should not be incapacitating.

$+G_X$ acceleration. The tolerance limits for occupants seated in this orientation have not yet been accurately defined. It is assumed that, with a suitable headrest and restraint, that the limits for this orientation will be higher than for forward facing occupants.

Gy acceleration. Tolerance limits for lateral impacts are not well defined, but it has been suggested that limits of 11-12 G for 0.1 sec are tolerable and limits of 20 G for 0.1 sec are survivable for an occupant restrained by a harness into the seat.

FACTORS AFFECTING HUMAN TOLERANCE TO SHORT DURATION ACCELERATION

Magnitude and direction of applied force. In general, under similar conditions, the longer the duration of the impact pulse the lower the acceleration level that can be tolerated. For example, a chest-to-back acceleration of 45G can be voluntarily tolerated by some subjects if the pulse duration is less than 0.044 seconds, but only 25G is considered tolerable if the pulse duration is increased to 0.2 seconds.

Rate of onset of applied force. If the conditions of the impact are the same, the lower the rate of onset of the acceleration, the better the impact will be tolerated. For example, if the rate of onset of the acceleration is 1000G/second in a $-G_X$ impact signs of shock will be evident, but if the rate of onset is slowed to 60G/second for an impact of the same magnitude, no signs of shock will be seen. The effects of some rates of onset of acceleration are related to the natural resonant frequency of the whole body, various body organs and to the compliance of the visco-elastic systems of the bones, joints and ligaments.

Direction of applied force. The body can withstand much greater forces applied in the G_X axis due to the larger surface area of the body in this orientation. Accelerations in the G_Z axis place greater strain on the organs suspended in the body cavities and the tolerance to impact is reduced. The limited research on the effects of G_Y impacts indicates these to have the lowest tolerance limits.

Site of application of acceleration. In general, parts of the body, such as the back and buttocks are more able to withstand a given force than the more vulnerable parts like the limbs and head.

OCCUPANT CHARACTERISTICS AND TOLERANCE TO IMPACT

There are a number of problems which must be resolved to identify the limits of human tolerance to impact. Human beings are not only divisible by gender, each with its own set of related characteristics, but are infinitely variable in age, race, build, fitness and freedom from disease. Hence, attempts to quantify impact tolerance limits have resulted in approximations and generalisations making it necessary in any one accident, to analyse occupant injury mechanisms individually.

Not only are human beings infinitely variable, but each crash is also a unique event (as is each ejection from an aircraft). Whilst it can be said in general terms that aircraft tend to crash by flying into the ground, stalling and falling, or impacting buildings or barriers, environmental conditions, impact surfaces and the parameters of the aircraft will differ from accident to accident.

The tolerance limits for fatality and injury causation have been derived from research carried out in a variety of institutions using a multiplicity of experimental devices and techniques. Impacts have been carried out on animal subjects, cadavers, and live volunteers, but the limited numbers of impacts using these scarce resources and the variability of the subjects themselves has allowed only an approximation of tolerance limits. The utilisation of Anthropometric Test Devices (ATDs) to provide repeatable impact conditions has suffered from the employment of a number of ATDs, each with its own characteristic responses and limitations. The protocols, measurements and recording techniques employed in these research programmes have been many and varied, making it extremely difficult to compare the results obtained with either other ATD tests or with tests using biological subjects.

ANATOMICAL AND PHYSIOLOGICAL ASPECTS OF IMPACT TOLERANCE

Injury can result from a direct blow to the body by a solid object, or from an indirectly transmitted force, such as when the humerus or clavicle is fractured from an impact transmitted up the outstretched arm during a fall. Either mechanism of injury can result in damage to the skeletal framework of the body or to the soft tissues and internal organs.

Skeletal Injury. Damage to the bony skeleton of the body, including the joints, is the most common injury seen in the crash environment. Injuries to the upper and lower extremities are particularly common, and these do not appear to be reduced by the provision of effective restraint harnesses. The bones of the skeleton can be classified into four main groups, each of which has a characteristic response to an applied force or load:

a. Long bones are tubular, with dense cortical bone surrounding a medullary cavity filled with trabeculated bone. The trabeculated bony core in the cartilage covered expanded epiphyses of long bones is able to absorb energy when put under load and the hollow tubular shaft resist compression.

b. The short bones of the carpus and tarsus (wrist and foot) are roughly cuboidal in shape, although some may have more than one surface. The short bones permit limited multi-directional motion when under load.

c. Flat bones which have two plates of dense bone either side of a middle layer of softer, marrow filled bone, are represented by the bones of the skull, sternum and scapula. These bones have great stiffness and strength for their weight, both in torsion and bending, and are only be broken by a direct impact.

d. Irregular bones such as those which make up the jaw and the bones of the face.

e. Bones such as the vertebrae which have features common to more than one bony type.

Skeletal fractures may be the result of torsion, tension, shear and compression, or combinations of these forces. The direction of the forces and the rate at which they are applied, together with an estimation of the loads involved, may be obtained from an examination of the fracture type.

Joints. Joint disruption can result in an unstable joint, or one where the range of movement has become either restricted or more than normally mobile. The application of a force which stresses a joint beyond its normal range of motion results in the failure of the ligaments, tendons, and the joint capsule.

The Abdominal Cavity. The peritoneal cavity is the largest cavity in the human body with contents varying in structure and consistency from the highly vascular and easily damaged liver, spleen and pancreas, to the gas containing stomach and intestines. Almost the entire digestive tract and most of the genito-urinary tract is contained within the peritoneal cavity or covered by peritoneum. The major blood vessels, the aorta, iliac vessels and the inferior vena cava course through the abdominal cavity, together with the autonomic ganglia, plexuses and nerves and the splanchnic nerves.

The abdominal cavity reacts to an impact as a fluid-filled or hydraulic cavity and the force of a blow to any part of the abdomen is transmitted to all organs and structures within the abdominal cavity virtually unchanged. Some dampening of the pressure waves generated by an abdominal impact occurs through compression of the air and gas in the intestines and stomach, and some through the action of the muscles of the abdominal wall and the muscular layers of the various viscera. Hence, a potentially rapidly fatal rupture of the diaphragm, liver or spleen can occur from blunt trauma to any part of the abdomen.

Studies to delineate tolerance levels to non-penetrating abdominal trauma are limited. The viscous injury criterion proposed in 1987/1988 by the General Motors Research Laboratories was derived by multiplying the velocity of the abdominal deformation and the amount of abdominal deformation, and relates primarily to the production of liver damage. As the liver can be damaged without injury to other intra-abdominal organs being incurred, and intra-abdominal injuries can occur in the absence of liver damage, this criterion is of limited use as a predictor of abdominal injury thresholds.

Blunt trauma can result in abdominal injury by several mechanisms such as pressure wave transmission, compression and shear forces and the visco-elastic properties of the individual organs influence the tolerance to impact and blast. However, it would appear that intestinal injury in vehicle crashes occurs mainly in response to submarining under a lap belt.

The Chest. In vehicle trauma, the chest is the most commonly injured part of the body after the head and limbs and impact injuries to the chest are either fatal in a short period of time or survivable as all the contents of the chest are vital to life and injury to any one of them may be fatal. The response of the chest to impact is determined by its visco-elastic properties, since the probability of injury to the chest or the thoracic contents is dependant on the time period over which the force is applied as well as to the magnitude of the applied force.

Major life-threatening injuries to the chest compromise either the respiratory or circulatory systems, and can result in hypoxic brain damage or death. Severe decreases in the amount of oxygen available for transport by an intact circulatory system can result from an inhibition of the mechanics of breathing resulting from damage to ribs and diaphragm as well as from the alterations of lung architecture associated with pneumothorax, haemothorax and lung contusions.

Disruption of the circulatory system, with potentially fatal decreases in the blood volume available for oxygen transport, can be the result of blunt trauma to the chest. Non- penetrating cardiac injuries (ruptures of the myocardium, cardiac septa, pericardium and valvular apparatus) and rupture of the aorta are the most frequently seen injuries at post-mortem examination of the victims of vehicle trauma.

Head and Face. The head is the most frequently injured region of the body in vehicle crashes where the occupants have been restrained by a three-point belt, and the predominant cause of death in vehicular crashes. The definition of head injury tolerance is fraught with difficulty and still requires clarification. In pursuing the study of head and brain injury, some researchers have equated head injury with brain injury, whilst others have related head injury to fracture of the skull and as it is possible to have brain injury without a skull fracture, and skull fracture without brain injury difficulties arise in the correlation of the results of observations and experiments. The concept of a single Head Injury Criterion (HIC) derived from a small number of impacts on cadavers and an assessment of head injuries which does not allow for non-contact head injuries and does not distinguish minor head injuries from major brain trauma has been shown to be inappropriate but in the absence of a suitable replacement standard is still referred to in head impact studies.

Head injuries and the mechanisms of injury can be classified as follows.

a. Contact Injuries of the Head. These require a blow to the head, but subsequent motion of the head, if present, is not related specifically to the injuries which are caused by skull deformation.

i. Deformations near the site of the blow can result in skull fracture, extradural haematoma or coup contusion

ii. Deformations distant from the site of impact can result in vault and basilar fractures.

iii. Travelling wave injuries can occur leading to contracoup contusion and/or intracerebral bleeding.

b. Non-contact injuries of the Head. These injuries will only occur if the head is accelerated. They require motion of the head, but do not require the head to strike an object or for the head to be struck by an object. Angular acceleration appears to be more causal than linear acceleration, and lateral motion appears to be more causal than fore and aft motion. These injuries are the result of strains (deformations of the tissues from external force loading) which may be:

i. Surface strains resulting in subdural haematoma, contracoup contusion, "intermediate" coup contusion.

ii. Deep strains resulting in concussional syndromes and diffuse axonal injury. Almost all diffuse axonal injury results from vehicular crash, which has a relatively long acceleration, in contrast to accidental falls and assaults which have an impact the duration of which is more brief than that seen in crashes and therefore more commonly associated with sub-dural haematomata.

Injuries to the brain are exacerbated by concomitant injury elsewhere in the body. The loss of circulating blood volume from haemorrhagic or other shock decreases brain oxygenation and leads to hypoxic-ischaemic damage.

The difficulties encountered in research to derive the tolerance levels for injury to the human brain are legion. Cadaveric studies are limited in their availability, standardisation and repeatability. Animal studies suffer by the need to interpret and scale the results of experiments with respect to human anatomy and physiology, and ATD impact tests are limited by a lack of biofidelity. The development of computer models for the prediction of damage to the brain and tolerance to impact has been hampered by the complexity of the human skull and brain which are not homogeneous, are compartmentalised by the anatomy of the skull and the dividing membranes and subject to pressure fluctuations transmitted by the CSF.

The Spine. Back injuries incurred during an aircraft crash may involve the musculo-skeletal structures of the vertebral column and/or the spinal cord itself. When considering the evidence for the mechanism of injury to the vertebral column, during the inspection of x-ray films and clinical examination of accident victims to determine the mechanism of injury, consideration must be given to the fact that post accident appearances will not indicate the maximum deformation that occurred at the time of maximal loading.

The determination of a mechanism for vertebral column injury in any one accident is further complicated by the variation in response to identical applied loads which arise from individual anatomical and physiological characteristics. The pattern of injury will depend on which of the elements in the vertebral column is the weakest link in a particular individual, such as when intervertebral disc lesions are affected by the degeneration of the disc which occurs with increasing age. Injuries from the same applied loads may be modified in different individuals by the action of the vertebral muscles, especially if pre-tensioning of the vertebral muscles has taken place prior to the impact.

The motion of the spine is complex and occurs as coupled motions. Lateral bending involves rotation about the horizontal and vertical axes as well as translation perpendicular to the horizontal plane, hence lateral bending may cause any combination of transverse shear in the horizontal plane, rotational shear about the vertical axis and tensile and compressive stresses in the vertebral bodies. Furthermore, similar injuries may be produced by a number of different mechanisms, such as anterior lip fracture which may result from either hyperextension or hyperflexion with compression.

The tolerance of the vertebral column to impact in not uniform down its length with, in general terms, fractures of the cervical vertebrae are less stable than those of the lumbar vertebrae. Stability of the vertebral column following impact injury is paramount in determining the overall survival of the casualty. High cervical fractures with instability of the neck are likely to result in injury or transection of the spinal cord and high spinal cord injuries are often fatal or result in quadriplegia.

The majority of the injuries to the vertebral column from vehicle accidents involve the thoraco-lumbar spine. The response of the thoracic vertebrae to impact is modified by the presence of the ribs, whereas the increasing size of the lumbar vertebrae and the orientation of the facet joints of the lumbar vertebrae lead to increased stability of the lower vertebral column. The forces required to cause fractures or fracture dislocations of the thoracolumbar spine are very large due to the size of the vertebral bodies and supporting ligaments.

An awareness of the most likely sequence of events in a particular accident, with some assessment of the probable kinematics of the occupant, will allow the determination of the most likely mechanism of a spinal injury. Consideration must be given to the type of restraints employed as the different belt configurations are associated with characteristic injuries such as hyperflexion over a lap belt or rotation and hyperflexion over a three point harness.

SURVIVABILITY AND TOLERANCE TO IMPACT ACCELERATION

It can be seen from the above that the quantification of survivable levels of impact acceleration is fraught with difficulty. The circumstances surrounding any aircraft accident vary from accident to accident in response to environmental influences, the nature of the emergency and the configuration of the aircraft at the time of impact. The male and female occupants of these aircraft are not "standardised" and cover the full anthropometric range of the human race. The occupants will vary in their pre-accident fitness, freedom from underlying disease or deformity and susceptibility to injury. They may be unrestrained, will be seated on a variety of seats and will be wearing non-standard clothing. Where restraint harnesses are employed, these will come in a many different materials, configurations and attachments, be in varying states of repair and will have been in use for an indeterminate length of time.

Any attempt to standardise human tolerance limits from actual accidents where so many variables exist needs to be circumspect and confined to broad limits only and researchers in the field of human bio-engineering and medicine have been seeking alternative sources of information on human impact tolerances. Information has been gained from human experimentation, cadaver studies, animal studies and impact studies using a diversity of ATDs. However, all these approached have suffered from the limitations inherent in using scarce and costly resources and the lack of standardisation of subjects, impact parameters and test and recording methodology. The development of increasingly sophisticated ATDs and recording devices able to withstand repeated impacts has continued to provide a tool for research into the effects of short duration accelerations but as with live data, the "human tolerance limits" derived from ATD impact research must also be treated with some circumspection.

No experimental programme will be able to fully reproduce the conditions met in an accident and data from all experimental programs requires validation against known injury from painstakingly researched real accidents. Live experimentation is limited to non-injurious levels and ATDs are exactly what they are. Mathematical models are being developed to assisting the understanding of the nature of the forces encountered during accidental impact and although these and the new generation of ATDs are becoming more biofidelic, they are not human beings. Not only do neither mathematical models nor ATDs break in an impact, but they lack the internal structure of the human body and are unable to realistically mimic the result of impact accelerations on organs and body tissues. Most importantly, they do not bleed.

An accident may be considered survivable in terms of the injuries recorded as a result of accelerative forces, but death may ensue from another cause, such as a penetrating injury and internal or external haemorrhage. A survivable accident may become unsurvivable in the presence of a minor head injury causing a short period of unconsciousness and the failure to escape the post crash fire or effect an underwater escape. Relatively minor but incapacitating limb injuries can similarly prevent survivors of the initial event surviving the post crash sequelae.

In other words, the outcome of any accident will depend not only on the nature of the injuries directly resulting from the body' response to impact, but on complicating factors from any injury caused by the deformation of the airframe, penetrating injuries, environmental factors such as fire or water, and the rapidity with which emergency services can respond and the provision of expert medical care. However, research into injury mechanisms has increased the body of knowledge concerning the effects of crashes on occupants, the effectiveness of various configurations of restraint harnesses and the limitation of acceleration level by appropriate seating and airframe construction. The increasing understanding of the way in which abrupt accelerations can distort and damage human beings is leading to improvements in the design of aircraft cabins and seating plans, as well as to the provision of safer cockpits. The interchange of information between researchers in the field of aviation induced accident injury and automotive related accident injury is leading to improvements in the design of safer cars as well as safer aircraft.

However, at present we know a great deal about the performance of certain test dummies and the tolerance levels of these dummies for abrupt accelerations. We also know a great deal about the behaviour of some sophisticated mathematical models when programmed in a crash scenario, but what we still do not know are the tolerance levels of real human beings.

Bibliography