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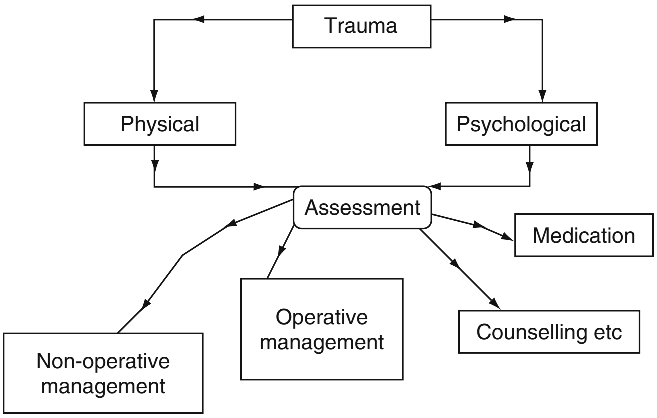
Trauma and Traumatic Injuries: General Introduction

1.1 Trauma Types and Management

Trauma is a wound or injury caused by mechanical or physical factors. It can also occur due to a negative psychological effect such as an emotional shock caused by a stressful event eventually leading to neurosis or psychosis. Flowchart 1.1 gives a full picture of types and the assessment of the trauma. Doctors and clinicians assess patients after traumatic injuries and further treatments are arranged and finally carried out. The function of the trauma engineers is to carry out analytical-cum-numerical analyses fully backed-up by computer softwares to assess injuries and fractures. In addition, the trauma engineers evaluate the causes and effects of traumatic injuries and fractures, and finally assist the medical profession in medico-legal cases if ever arise. The computer-aided results will also give a clear picture of the trauma scenario. In order to understand this subject fully, it is important to grasp a minimum knowledge of the components constituted in the human body. The major ones related to trauma are fully illustrated in Sect. 1.1.1.

1.1.1 Human Body Systems

The plates offer in parts a detailed description of various human systems. They can be looked at specifically for any kind of trauma affecting within the entire system related to a specific field of interest. Every area of interest is labeled thus giving a clear and vivid view of the body component under each system. It will be easier to isolate and identify areas in each system under trauma for major analytical and numerical study, yet it can be viewed as an element operating in the global environment. For the engineering system analyst, both elemental and global modelings are needed so that the results can be processed for localized and global case studies having sophisticated and nonrigorous finite element meshes. Even in medico-legal arguments both refined and nonrefined mesh schemes will be needed to impress upon the legal system, the kind of results derived from the finite element techniques.



Flowchart 1.1. Trauma and trauma management

They also give a clear overall vision to a clinician upon whom he/she will plan medical assessment and provide a clear cut report on short- and long-term management criteria and management execution. The psychologist or psychiatrist will frame an objective opinion on medication and/or counseling. The engineering results will offer a basis of interaction between a surgeon and a psychologist.

For this purpose the text incorporates smaller case studies such as *hand and wrist, hand and neck, hip and knee, and foot and ankle.* They are the highest pressure areas which most likely take a higher percentage of traumatic injuries in the human system. They are fully dealt within the text. In order to assist the analyst, many X-rays and photographs are included which have been examined using well-established numerical techniques and computer softwares, thus paving the way in applying the principles of applied mechanics successfully to human biological system. Therefore the engineering trauma approach is related in this text.

The analysis of the effects caused by impact to the body. This is then known as biomechanical response of the body. The *Engineering Analysis of Trauma* addresses injuries due to mechanical impact and can be treated as a multidisciplinary research field uniting engineering sciences and medicine. The engineering analysis of trauma is extremely useful in the field of epidemiology. Epidemiology is a fundamental science for studying the occurrence, causes, and prevention of injury. The term includes the tools to identify the injury risk, analyze positive possible causative factors with respect to possible intervention, and develop methodology and its effectiveness of counter measures. In the field of "Engineering Analyses of Trauma," the accident data are definitely a pre-requisite. Although major limitation exists on the applicability of statistics, field studies and data bases, one should be aware of the problems associated with the collection, classification and interpretation techniques. The engineering analysis requires a sound statistical evaluation and can simply fail owing to the insufficient number of cases available at the time. It is, therefore, essential to have input a complete data base inclusive of experimental and site monitoring. Injury criteria are important tools to assess the severity of mechanical impact occurring from all sources. The injury criterion correlates a function of the engineering parameters such as force, velocity, acceleration, etc., with a probability of certain body regions to be on the receiving end of trauma. The trauma as a result of injury can be understood and generally must be evaluated and thus finally validated on the basis of experimental and site monitoring studies. Since the advent of advanced computers, numerical methods and computer programs have been developed to evaluate and to examine the trauma meted out in the human infrastructure. Depending on the type of analysis, it is now easy to differentiate between injury criterion, damage criterion with and without living tissues. In such circumstances, a threshold value is established in order to detect anatomical or physiological human structures as and when the limit is exceeded. A damage criterion is then postulated, using human cadavers as surrogates for the live human beings. The analytical methods such as hybrid finite element and finite/discrete element analyses can also become valid, as described later on in this text for a protection criterion. A comparative study can be carried out using these numerical techniques and anthropomorphic test devices (dummies) for establishing protection criterion. In such cases, the relation to human trauma and injury tolerance levels is derived from these investigations. It is, therefore, taken that level to be a bottom line for an adult of not sustaining injuries of the kind addressed by this particular criterion when exposed to loading conditions defined in this protection criterion. Hence the actual risk of this traumatic injury can then be estimated with a risk function which relates the probability to be injured to the criterion underlying mechanical properties measured. A threshold value in this case will be defined such that given a certain loading scenario, represented by a certain value for the criterion, the risk of sustaining injury does not exceed a chosen percentage. The medical profession considers this to be not more than 50%. It is to be noted that scales to classify the type of injury are generally based on medical diagnosis. In trauma research, the most widely used injury scale is the Abbreviated Injury Scale (AIS) which is a system to define the severity of injuries through out the body, regularly being revised and updated (AAAM 2004). The AIS classification is given in Table 1.1. Each category represents a certain threat-to-life associated with an injury.

Table 1.1 is a standardized system and is an anatomically based, global severity scoring system that classified each injury in every body region by assigning a code (AISO-AIS6). The AIS severity code is a single time-dependent value for each injury and every body region. As stated, the severity is clearly defined in Table 1.1. It must be remembered that blindness or life-threatening complication, including infections occurring after certain period are not generally coded as severe injury. Thus resulting trauma since they do not represent an initial threat. Generally the AIS is not a linear scale. For example the differences between AIS1 and AIS2 is the same as between

Table 1.1. The AIS classification

AIS code	injury
0	noninjured
1	minor injury
2	moderate injury
3	serious injury
4	severe injury
5	critical injury
6	untreatable injury

AIS5 and AIS6. Hence, mean value calculation becomes senseless. It is recommended that for one person the overall trauma severity shall be treated maximum AIS known as MASI; the highest ASI code sustained by one occupant on any part of the body, even if the same occupant sustained several injuries of the same severity level at different body parts. This means that for an occupant with an injury AIS2 on head and legs with no injuries classified higher, MAIS will still be MAIS2.

People with multiple injuries producing trauma of unusual nature, the Injury Severity Score (ISS) can easily be updated and the latest version serialized as AAAM (2001). For each region, the highest code is determined. As a result the ISS is calculated as the sum of the $\sum^3 (\text{AIS})^2$, i.e., the squares of AIS codes of at least three severely body regions. The minimum ISS = 0 to the maximum ISS = 75 = 3 AIS injuries. For AIS6, the ISS shall be 75. The major trauma is when the ISS value is >15. This assessment is related to mortality (Baker and O'Neil 1976) and long-term impairment (Campbell et al. 1994). Other scales are also recommended such as involving scaling scheme for categorizing soft tissue and neck injuries. This work is noted in detail later in many areas in the text. This is noted against QTF, the Quebec Task force (Spitzer et al. 1995). There are other scales which are cost scales addressing impairment, disability and societal loss throughout the ratings of long-term consequences by assigning an economic value. Some of the major ones are given below have been adopted by the US government.

- Injury Cost Scale (ICS) (Zeidler et al. 1989)
- Injury Priority Rating (IPR) (Carsten and Day 1988)
- Harm (Malliaris 1985)

One of the most crucial problems in "Trauma Engineering" is the assessment of the relationship between injury severity and mechanical load including impact loading which causes this injury. It is therefore necessary to find a relationship that allows the probabilities that a certain load will cause a particular injury. Such correlations are vital without which it will become useless to interpret or to carry out a comparative study of any results obtained from experimental tests or existing patients monitoring data. This theme in the text will be highlighted in detail using computerized analyses based on well-known numerical techniques.

Hence it becomes necessary for the trauma to be assessed to

- Develop a comprehensive analytical tool
- Perform well equipped laboratory experiments using human surrogates for determining the biomechanical response and corresponding injury tolerance levels
- Establish injury risk functions and risk curves, perhaps, statistical methods, cumulative frequency distribution, and the Weibull distribution methods

Despite certain limitations, decades of trauma engineering research have provided a sufficiently large number of sources that allow to establish several well-founded relationships thus linking mechanical loads to injury probability and injury mechanisms. The latest research has been utilized to extend this kind of relationship.

1.2 Definitions

Abrasion. Wearing away of tissue by sustained or heavy friction between surfaces.
Acetasulum. The socket in the side of the bony pelvis into which the spherical head of the thigh bone (femur) fits.
Acoustic trauma. The often damaging effect of loud nose on the inner ear.
Acomioclaviclar joint. The joint between the outer end of the collar bone and the acromion process on the shoulder blade.
Acromion. The outer most extremely of the spine of the shoulder blade.
Adduction. Movement towards the center line of the body.
Adrenal Glands. The small internally secreting organs that sit on top of each kidney producing various steroid hormones.
Alveolus. One of the many million tiny thin-walled, air sacs in the lungs.
Amnesia. Loss of memory as a result of physical or mental disease or injury.
Anatomy. The structure of the body or the study of the structure.
Aneurysm. A berry-like or diffuse swelling or an artery, usually at or near a branch, and caused by localized damage or weakness to the vessel wall.
Anterior. In front of anus short terminal portion of the alimentary canal which contains two sphincters by means of which the contents of the section are retained until they can be discharged as faeces.
Aorta. The main and largest artery in the body originating from the left side of the heart and gives off branches to the heart and rest of the body.
Apex. The tip of an organ with a painted end.

Aphasia. An acquired speech disorder resulting from brain damage which affects the understanding and production of language rather than the mechanical aspects of articulation.
Appendix. A worm-like structure attached to the caecum (start of the large intestine).
Apraxia. Disorder of the cerebral cortex leading to loss of the ability to perform skilled movements with control and accuracy.
Arachnoid. Middle layer of the three meninges covering the spinal cord and brain.
Arrythmia. Any abnormality in the regularly of the heart beat.
Ataxia. Unsteadiness in standing and walking from a disorder of the control mechanisms in the brain or from inadequate information input to the brain from the skin, muscles, and joints.
Atrial fibrillation. Irregularity of heart rate due to a defect in upper chambers in the heart.
Atrium. One of the thin-walled upper chambers of the heart that receives blood from the veins and passes it down to the lower powerful pumping chambers (ventricles).
Auditory. Pertaining to hearing or to the organs of hearing.
Avascular. Lacking blood vessels.
Avascular necrosis. Death of a tissue due to lack of blood supply.
Axial skeleton. The skull and spine.
Axilla. Armed Biceps Prominent and powerful muscles on the front of the upper arm allowing the elbow to bend and the forearm to rotate outwards.
Bile. Fluid provided by liver and stored in gall bladder and secreted into the duodenum to aid fat absorption.
Bile duct. Narrow tube carrying bile from the liver to the bowel.
Biomechanical engineering. The application of the principles of mechanical engineering to improve the results of surgical treatment, e.g., design of prosthetic parts.
Biomedical Engineering. Principles of both engineering and medicine are used to broaden the scope of medicine.
Bionic. Relating to a living or life-like system enhanced by or constructed from electronic or mechanical components.
Bone. The main structural material of the body consisting of protein scaffolding (collagen) and calcium phosphorous salts.
Bowel. The intestine.
Bradycardia. Slow heart rate.
Bronchiole. One of the many thin-walled, tubular branches of the bronchi which extend the airway to the alveoli.
Bronchus. A breathing tube which is a branch of the wind pipe (Trachea).
Burns. Damage respire of the skin and underlying tissues to high temperatures from any source.
Bursa. Small fibrous sacs lined with a membrane that secretes lubricating fluid which occur around joints and in areas where tendons pass over bone.

Caecum. Beginning of the large intestine (colon).
Calcaneus. Heel bone.
Callus. A collection of partly calcified tissue formed in the blood clot around the site of a healing fracture.
Capitellum/capitulum. Any small round prominence or ending on a bone.
Carpal. Pertaining to the wrist or wrist bones.
Cartilage. A dense form of connective tissue performing various functions in the body, e.g., Bearing surfaces in joints.
Cauda equina. Collection of spinal nerves hanging down in the spinal canal below the termination of the spinal cord.
Caudal. Pertaining to the tail end of the body.
Cephalad. Situated towards the head.
Cephalic. Relating to the head or in the direction of the head.
Cerebellum. Small part of the brain lying below and behind the cerebrum which aids coordination of information concerned with posture, balance and fire voluntary movement.
Cerebral cortex. Grey outer layer of the cerebral hemisphere.
Cerebrospinal fluid. Fluid that bathes the brain and spinal cord and also circulates within the ventricles of the brain and central canal of the cord.
Cerebrum. Largest and most highly developed part of the brain containing several structures for various functions, e.g., memory, vision, etc.
Cervical. Pertaining to the neck.
Cervix. The neck of the womb (uterus).
Choroid. Densely pigmented layer of blood vessels lying just under the retina of the eye supplying nutrition.
Ciliary body. Thickened ring of muscular and blood vascular tissue that forms the root of the Iris and contains the focusing muscle of the eye.
Clavicle. Collar bone.
Clot. Thick, coagulated viscous mass especially of blood elements.
Coccyx. Rudimentary tail bone beneath sacrum.
Cochlea. The structure of the inner ear containing the coiled transducer that converts sound energy into nerve impulse information.
Coeliac. Pertaining to the abdominal cavity.
Colon. Large intestine.
Concussion. "Shaking up" of the brain from violent acceleration or deceleration of the head causing unconsciousness lasting for seconds to hours.
Conjunctiva. Transparent membrane attached around the cornea.
Connective tissue. Loose or dense collections of collagen fibres and many cells in a liquid, gelatinous, or solid medium.
Contralateral. Pertaining to the opposite side.
Contrecoup. Damage occurring at a point opposite the point of impact especially injury to the brain against the inside of the skull.
Confusion. Bruise.
Convulsion. Fit or seizure.
Cornea. Outer and principal, lens of the eye helping to focus latter.

Coronal. Relating to the crown of the head.
Coronal plane. An anatomical plane lying vertically and dividing the body into front and rear halves.
Coronary arteries. Two important branches of the aorta that supplies the heat muscle.
Cranium. Skeleton of the head without the jaw bone.
Cricoid. Ring shaped.
CT scanning. Computer-assisted tomography.
Cuboid. One of the bones of the foot lying on the outer size immediately in front of the heel bone.
Cuneiform. Wedge-shaped bone of the foot.
Cutaneous. Pertaining to the skin.
Cuticle. Outer layer of the skin.
Decerebellate. Suffering the effects of loss of cerebellar function.
Decerebrate. Suffering from the effects of loss of cerebral activity.
Deformity. State of being misshape or distorted in body.
Deltoid muscle. Large, triangular "shoulder-pad" muscle which raises arm sideways.
Dental. Pertaining to the teeth.
Dentine. The hard tissue that makes up the bulk of the tooth.
Dermis. Layer of skin deep to epidermis.
Diaphragm. Dome-shaped muscular and tendinous partition that separates the cavity of the chest from that of the abdomen.
Doppler effect. Change in the frequency of waves, e.g., sound/light, received by doserver when the source is moving relative to the doserver.
Duodenum. The C-shaped first part of the small intestine into which the stomach empties.
Dura mater. Tough fibrous membrane, the outer of the three layers of meninges that cover the brain.
Ear drum. Lympanic membrane that separates the inner end of the external auditory canal from the middle ear.
Ecchymosis. Bleeding or bruising in the skin or a mucous membrane in the form of small, round spots or purplish discoloration.
Electrocardiography. Recording of the rapidly varying electric currents which can be detected as varying voltage differences between different points on the body surface, as a result of heat muscle contraction.
Embolism. Sudden blocking of an artery by solid, semisolid or gaseous material brought to the site of the destruction in the blood stream.
Enamel. Hard outer covering of the crown of a tooth.
Endocrine system. A group of hormone-producing glands, controlled by different parts of the brain, consisting of pituitary, pineal, thyroid, parathyroid, pancreas, adrenal, testes/ovaries, and placenta glands during pregnancy.
Enzyme. A biochemical catalyst that accelerates a chemical reaction.
Epicardium. Outer layer of the heart.

Epidermis. Structurally the outer most layer of the skin containing no nerves, blood vessels or hair follicles.
Epididymis. Long, coiled tube that lies behind the testicle and connects it to the vas deferens.
Epigastrium. The central upper region of the abdomen.
Epiglottis. Leaf-like cartilaginous structure behind the back of the tongue which acts as a "lid" to cover the entrance to the voice box (larynx) preventing food/liquid entering it during swallowing.
Epiphysis. Growing part at the end of a long bone.
Ethmoid bone. Delicate T-shaped sponge-like bone forming the roof and upper sides of the nose and the inner walls of the eye sockets.
Euryon. One of the two most widely separated points in the transverse diameter of the skull.
Eustachian tube. A short passage leading backwards from the back of the nose, on either side, to the cavity of the middle ear allowing a balance of pressure on either side of the ear drum.
Exsanguination. Loss of a large amount of blood.
External carotid artery. Major artery that springs from the common carotid artery in the neck and supplies blood to the front of the face, neck, scalp, ear and sides of the head.
Extracellular. Space surrounding a cell/collection of cells.
Extradural haemorrhage. Bleeding between the skull and the outer layer of the brain lining (dura mater).
Facet. Small flat surface on a bone or tooth.
Facial index. Ratio of the length of the face to its width multiplied by 100.
Fallopian tube. Open-ended tube along which eggs travel from the ovaries to the womb.
Fascia. Tendon-like connective tissue arranged in sheets or layers under the skin between the muscles and around organs, blood vessels and nerves.
Femur. Thigh bone.
Fetal distress. Observable changes in the fetus during pregnancy/labour caused by an insufficient oxygen supply via the placenta.
Fever. Temperature of the body elevated above 37°C.
Fibula. Slender bone on the outer side of the main bone of the lower leg (tibia).
Flexion. Act of bending a joint.
Flexor. Muscle causing flexion of a joint.
Flexure. A bend/curve/angle or fold.
Fontanelles. Gaps between the bones of the vault of the growing skull of the body/young infant which can be felt.
Fourth ventricle. The centrally places, rear most of the four fluid-filled spaces in the brain.
Forea. Any shallow cup-like depression.
Fracture. Break, usually of a bone.
Frontal lobe. Large foremost part of the brain.

Frozen shoulder. Painful, persistent, stiffness of the shoulder joint restricting normal movement.
Gait. The particular way in which a person walks.
Gall bladder. Small fig-shaped bag, lying under the liver which stores and concentrates bile.
Gastronemius. Main muscle forming the bulge of the calf.
Glomerulus. Microscopic spherical tuft of blood capillaries in the kidney through which urine is filtered.
Gonads. The sex glands.
Gracilis. Long, slender muscle lying on the inner side of the thigh.
Granulation tissue. Tissue which forms on a raw surface or open wound in the process of healing.
Glanuloma. A localized mass of granulation tissue forming a nodule.
Haematoma. Accumulation of free blood anywhere in the body.
Haemptysis. Coughing of blood.
Haemoptysis. Abnormal escape of blood from a blood vessel.
Hallux. Big toe.
Hamstrings. The tendons of three long spindle-shaped muscles at the back of the thigh.
Hemiplegia. Paralysis of one half of the body.
Hernia. Abnormal protrusion of an organ/tissue through a natural or abnormal opening.
Humerus. Long upper arm bone that articulates at its upper end with a shallow cup in the side process of the shoulder blade (scapula) and, at its lower end, with the radius and ulnar bones of the lower arm.
Hypertension. Abnormally high blood pressure.
Hypotension. Low blood pressure.
Hypotonia. A condition in which the muscles offer reduced resistance to passive movement.
Hypoxaemia. Deficiency of oxygen in the blood.
Hypoxia. Deficiency of oxygen in the tissues.
Ileum. The third part of the small intestine.
Iliopsoas. Large muscle group arising from the inside of the back wall of the pelvis and the lower abdomen and insert in front of the thigh bone.
Ilium. Uppermost of the three bones into which the in nominate bone of the pelvis is arbitrarily divided.
Interlobar. Situated between lobes.
Iris. Colored diaphragm of the eye forming the real wall of the front, water-filled chamber and lying immediately in front of the crystalline lens.
Ischium. Lowest of three hip bones in which the nominate bones are divided.
Jejunum. The length of small intestine between Duodenum and ileum where most of the enzymatic digestion of food occurs.
Kyphosis. Abnormal degree of backward curvature of the dorsal spine.

Labyrinth. Group of communicating anatomical cavities especially in the inner ear.
Lacrimal. Pertaining to the tears.
Lacrimal gland. Tear secreting gland.
Larynx. “Adams” Apple or voice box.
Lateral. At or towards the side of the body.
Lateral ventricles. Fluid filled cavities in each half of the brain that communicate with the third ventricle.
Latissimus dorsi. Broadest muscle of the back.
Ligaments. Bundles of tough, fibrous, elastic protein called collagen that act as binding and supporting materials in the body.
Lordosis. Abnormal degree of forward curvature of the lower part of the spine.
Lunate bone. One of the bones of the wrist (carpal bones).
Lymph. Tissue fluids drained by the lymph vessels and returned to the large veins.
Lymph nodes. Small, oval or bean-shaped bodies up to 2 cm in length, situated in groups along the course of the lymph drainage vessels.
Malleolus. Either of the two bony prominence on either side of the ankle.
Malleus. Outermost and larger of the three small bones of the middle ear.
Mandible. Lower jaw bone.
Manubrium. The shield-shaped upper part of the breastbone.
*Massetes***. Short, thick, paired muscle in each cheek running down from the cheekbone to the outer corner of the jaw bone.
Mastoid bone. Prominent bony process which can be felt behind the lower part of the ear.
Maxilla. One of a pair of joined facial bones that form the upper jaw, the hard palate, part of the wall of the cavity of the nose and part of the floor of each eye socket.
Maxillary sinus. Mucous membrane-lined air space within each half of the maxillary bone.
Medial. Situated towards midline of the body.
Medulla oblongata. Part of the brainstem beneath pons and above spinal cord in front of the cerebellum containing nerves to spinal cord and centers for respiration and heart beat control.
Meningitis. Inflammation of the meninges.
Meninges. The three layers of membrane that surround the brain and spinal cord.
Metacarpal bone. One of the five long bones situated in palmar part of the hard immediately beyond the carpal bones of the wrist and articulating with bones of the fingers.
Metatarsal. One of the five long bones of the foot lying behind the TACSAl bones and articulating with the bones of the toes.
Middle ear. The narrow cleft within the temporal bone lying between the inside of the ear drum and the outer wall of the inner ear.
Molar. One of the 12 back grinding teeth.

Mucous membrane. The lining of most of the body cavities and hollow internal organs, e.g., mouth/nose
Mucus. Slimy, jelly-like material provided by globlet cells of mucous membranes.
Muscle. Tissue containing large numbers of parallel elongated cells with the power of shortening and thickening so as to approximate their ends and effect movement.
Nail. A protective and functional plate of a hard tough (Keratin) lying on the back surface of the end part of fingers/toes.
Nasal. Pertaining to the nose.
Neuralgia. Pain experienced in an area supplied by a sensory nerve as a result of nerve disorder that results in the production of pain impulses in the nerve.
Neuron. Functional unit of the nervous system.
Occipital lobe. Rear lobe of the main brain (cerebral hemisphere) concerned with vision.
Oesophagus. The gullet of a muscular tube of 24 cm length from the throat to the stomach.
Olecranon. Hook-shaped upper end of one of the forearm bones (ulna) that projects behind the elbow joint.
Olfactory. Pertaining to the sense of smell.
Opthalm-, Opthalma-. Pertaining to the eye.
Optic chiasma. The junction of the two optic nerves lying under the brain.
Optic disc. Small circular area at the back of the eye at which all the nerve fibres from the retina meet to form the optic nerve.
Orbit. The bony cavern in the skull that contains the eyeball and optic nerve, eye muscles, tear glands and blood vessels.
Ossicle. Small bone in middle ear.
Ossification. Process of conversion of other tissues into bone.
Osteoporosis. A form of bone atrophy involving both collagen scaffolding and the mineralization.
Ovary. One of paired female gonads situated in the pelvis.
Pancreas. A gland situated behind the stomach which has a duct, that secretes digestive enzyme into duodenum and hormones for glucose control.
Paraplegia. Paralysis of both lower limbs.
Parathyroid glands. Four yellow bean-shaped bodies lying behind the thyroid gland that secretes a hormone into the blood for maintenance of calcium levels.
Porotid gland. The largest of the three pairs of salivary glands.
Patella. Knee-cap.
Pelvis. The basin-like bony girdle at the lower end of the spine with which the legs articulate. It consists of the sacrum, coccyx and in nominate bones.
Periosteum. The tissue that surrounds bone.
Peritoneum. Double-layered serum secreting membrane that lines the inner wall of the abdomen and covers/supports abdominal organs.
Phalanges (S. Phalanx). Small bones of the fingers/toes.

Pharynx. The common passage to the gullet and wind pipe from the back of the mouth and nose.
Pia mater. Delicate, innermost layer of the meninges.
Pineal gland. Tiny, cone-shaped structure within the brain which appears to secretes a hormone called melatonin.
Pinna. Visible external ear.
Pituitary gland. The central controlling gland in the endocrine system which is situated on the underside of the brain that produces and stores many hormones of different functions.
Plantar. Pertaining to the sole of the foot.
Pleura. Tin, double-layered membrane that separates the lungs from the inside of the chest wall.
Pons. Middle part of the brainstem.
Prostate gland. Solid, chestnut-like organ situated under the bladder surrounding the first part of the urine tube (urethra) in the male that secretes seminal fluid.
Pulmonary. Pertaining to the lungs.
Pylorus. Narrowed outlet of the stomach.
Quadriceps muscles. The bulky muscle group on the front of the thigh, consisting of four muscles arising from the femur.
Quadriplegia. Paralysis of the muscles of both arms/legs and trunk.
Radial. Pertaining to the radius or its associated nerves or artery.
Radius. One of the two forearm bones on the thumb side.
Rectum. A 12.5 cm long, distensible terminal segment of the large intestine situated above the anal canal.
Rectus. Any of the several straight muscles, e.g., Abdomen – recks abdominis.
Reflex. Automatic, involuntary and predictable response to a stimulus applied to the body or arising within it.
Renal. Pertaining to the kidneys.
Retina. Complex membranes network of nerve cells, fibers and photoreceptors that lines the inside of the back of the eye and converts optical images formed by the lens system of the eye into nerve impulses.
Rib. Any of the flat, curved bones that form a protective cage for the chest organs and provides the means of varying the volume of the chest aiding respiration.
Sacral. Pertaining to the sacrum.
Sagittal. Pertaining to the lens that joins the Z parietal bones of the skull.
Sagittal plane. The front-to-back longitudinal vertical plane that divides the upright body into right and left halves.
Scapula. Shoulder blade.
Sclera. The white of the eye.
Seizure. An episode in which uncoordinated electrical activity in the brain causes sudden muscle contraction, either local or widespread.

Sigmoid colon. The S-shaped lower end of the colon extending down from the brim of the pelvis to the rectum.
Spasm. Involuntary muscular contraction.
Spinal cord. Downward cartrivation of the brainstem that lies within a canal in the spine, 45 cm long containing bundles of nerve-fibres tracts running up and down, to and from the brain.
Spleen. Large collection of lymph tissue acting as an organ to filter blood.
Stapes. The innermost of the three tiny linking bones of the middle ear.
Sternum. Breastbone.
Subarachnoid hemorrhage. Bleeding over and into the substance of the brain from a ruptured artery lying under the arachnoid layer of the meninges.
Subdural haematoma. A dangerous complication of head injury in which bleeding occurs from tearing of one of the blood vessels under the dura mater.
Sublingual. Under the tongue.
Supine. Lying on the back with the face upwards.
Symphysis. A joint on which the component bones are immovably hold together by strong, fibrous cartilage.
Talus. The second largest bone of the foot that rests on top of the heel bone.
Tarsal. Pertaining to the tarsal bones of the foot.
Tendon. A strong bond of collagen fibres that joins muscles to bone or cartilage and transmits force of muscle contraction to cause movement.
Testis. One of male gonad.
Thalamus. One of the two masses of grey matter lying on either side of the midline in the lower part of the brain. It collects, coordinates and selects information received by the body.
Thorax. Part of the trunk between neck and abdomen.
Thymus. Small, flat organ of the lymphatic system situated immediately behind the breastbone.
Thyroid gland. Gland situated in back of the neck across the wind pipe that secretes hormones affecting rate of metabolism.
Tibia. The shin bone of the lower leg.
Tonsil. Oval mass of lymphoid tissue situated in the back of the throat on either side of the soft palate.
Trachea. Wind pipe.
Tragus. Small projection of skin-covered cartilage lying in front of the external ear opening.
Transverse colon. The middle third of the colon.
Trapezius muscle. A large triangular back muscle extending from the lower part of the back of skull almost to the lumbar region of the spine on each side.
Trauma. An injury caused by a mechanical, physical, psychological agent.
Triceps muscle. A 3-headed muscle attached to the back of the upper arm bone (humerus) and to the outeredge of the shoulder blade and running down the back of the arm to be inserted by a strong tendon into the curved process on the back of the ulna, it allows the elbow to strengthen out.

Trochanter. One of the two major bony processes, the greater and lesser trochanters on the upper part of the femur.
Ulna. One of the pair of forearm long bones on the little finger side.
Umbilicus. The scar formed by the healing at the exit site of the umbilical cord after this has been tied and cut and the tissues have died and dropped off.
Uncus. Hook-shaped part near the front of the temporal lobe of the brain that is concerned with the senses of small and taste.
Ungual. Pertaining to a finger or toe nail.
Unilateral. On or affected one side only.
Ureter. Tube that carries urine from each kidney to the urinary bladder for temporary storage.
Urethra. Tube that carries urine from the bladder to the exterior.
Urinary bladder. Muscular bag for the temporary storage of urine situated in the midline of the pelvis at the lowest point in the abdomen, immediately behind the pubic bone.
Uterus. The female organ in which the fetus grows and is nourished until birth and is a hollow, muscular organ 8 cm long in non pregnant state.
Urea. The coat of the eye lying immediately under the outer sclera containing many blood vessels and a variable quantity of pigment.
Vagina. Fibromuscular tube of ≈ 8–10cm length lying behind the bladder and urethra and in front of the rectum in females.
Valgus. Abnormal displacement of a part in a direction away from the midline of the body.
Valve. A structure allowing movement in a predetermined direction only.
Varum/varus. Displaced or angulated towards the midline of the body.
Vas deferens. Fine tube that runs up in the spermatic cord on each side from the epididymis of the testicle, over the pubic bone and alongside the bladder to end by joining the seminal vesicle near its entry to the prostate gland. It conveys spermatozoa from the testicle to the seminal vesicle.
Vasospasm. Tightening or spasm of blood vessels.
Vena cavae. Largest veins in the body joined to right atrium of the heart.
Ventral. Pertaining to the front of the body.
Ventricle. A cavity or chamber filled with fluid, especially the Z lower pumping chambers of the heart.
Vertebra. One of the 24 bones of the vertebral column.
Vertebral Column. The bony spine.
Vitreous body. The transparent gel that occupies the main cavity of the eye between the back of the crystalline lens and the retina.
Volar. Pertaining to the palm of the hand or sole of foot.
Vulva. Female external genitalia.
Wind pipe. Trachea.
X-ray. A form of electromagnetic radiation produced when a beam of high speed electrons, accelerated by a high voltage, strikes a metal, e.g., copper.
Zygoma. Cheek bone.

Zygomatic arch. A bony arch extending below and to the outer side of the eye socket and forming the prominence of the cheek.

1.3 Human Body Regions and Organs

1.3.1 Body Regions

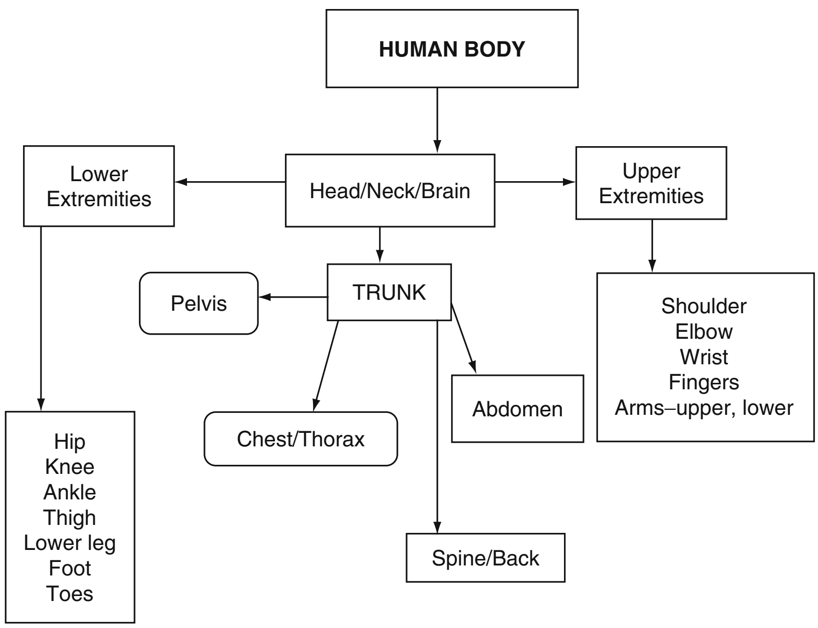
For trauma related engineering analysis, the ISS distinguishes different human body regions encompassing the limbs, organs, head, etc. Flowchart 1.2 shows identifying upper and lower extremities with respective organs as shown in Plates 1.1–1.5.

1.3.2 Body Organs Under Trauma

History of the Mechanism of Injury (MOI)

In the event of any level of trauma, there is a chance that any one or all relevant organs would be affected as shown in Plates 1.1–1.12. The mechanism of trauma and injury associated could be due to anyone of the following:

– Fall
– Road traffic accident (RTA)



Flowchart 1.2. Human body regions

– Assault
– Blunt and penetrating objects
– Motor/aircraft accidents
– Alcohol
– Occupational hazards/accidents

Post Medical History Related to Trauma

It is extremely important to take into consideration the past medical history. For example:

– Previous head injury trauma
– Existing medical conditions, e.g., epilepsy
– Medication, e.g., aspirin, warfarin
– Alcohol/illicit drug use
– Social history
– Allergies

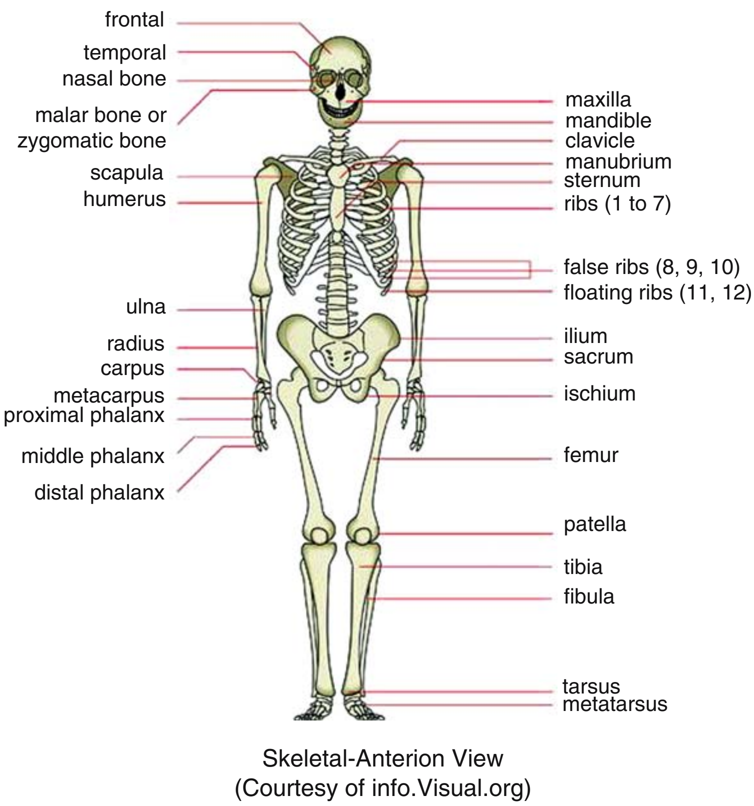
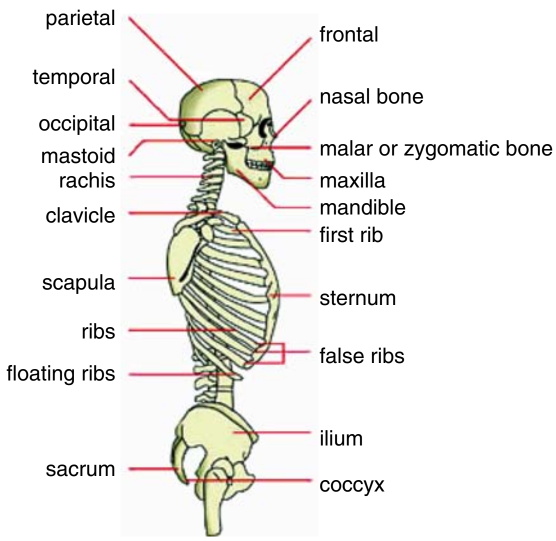


Plate 1.1. The skeletal system



Skeletal-Lateral View
(Courtesy of info.Visual.org)

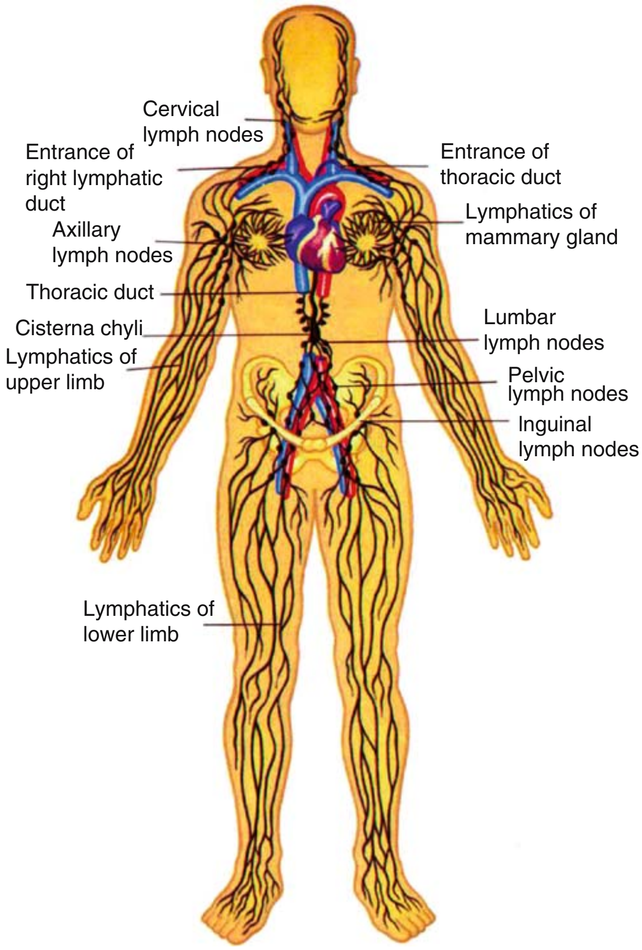
Plate 1.1. *Continued*

Treatment Priorities

This helps to assess patients based on their injuries and vital signs. Sensible and logical approach is needed to assess and treat trauma patients. Initially, this can be divided into:

1. Primary assessment
2. Secondary assessment
3. Begin definitive care

1. *Primary assessment*
   Airway maintenance with cervical spine protection
   Breathing and ventilation
   Circulation with hemorrhage control
   Disability (assessment of Neurological status)
   Exposure (undress patient with core to prevent hypothermia)
2. *Secondary assessment.* This involves obtaining a quick history of events and patients individual history from either patient, family or emergency service personnel.
   It also comprises a thorough assessment of the patient from head to toe for injuries, signs, causes and further care.
   Investigations can be carried out at this stage which initially includes: blood tests and standard trauma X-rays (chest, neck, pelvis). Subsequent



(Courtesy of lymphomation.org)

Plate 1.2. The lymphatic system

tests may be needed including specialized radiological scans like computer tomography (CT) or magnetic resonance imaging (MRI), to determine cause, need for transferring patient for specialized treatment/care or emergency operative intervention.

3. *Definitive care.* After assessment and stabilization of patient, the concept of definitive care arises. If latter is not possible at the local hospital then transfer to a center with appropriate facilities and trained staff is needed. This decision is judged as an individual basis by the trauma team.
   Prior to transfer, the patient must be stabilized and contact made with the receiving team and transferring personnel. Results from investigations and

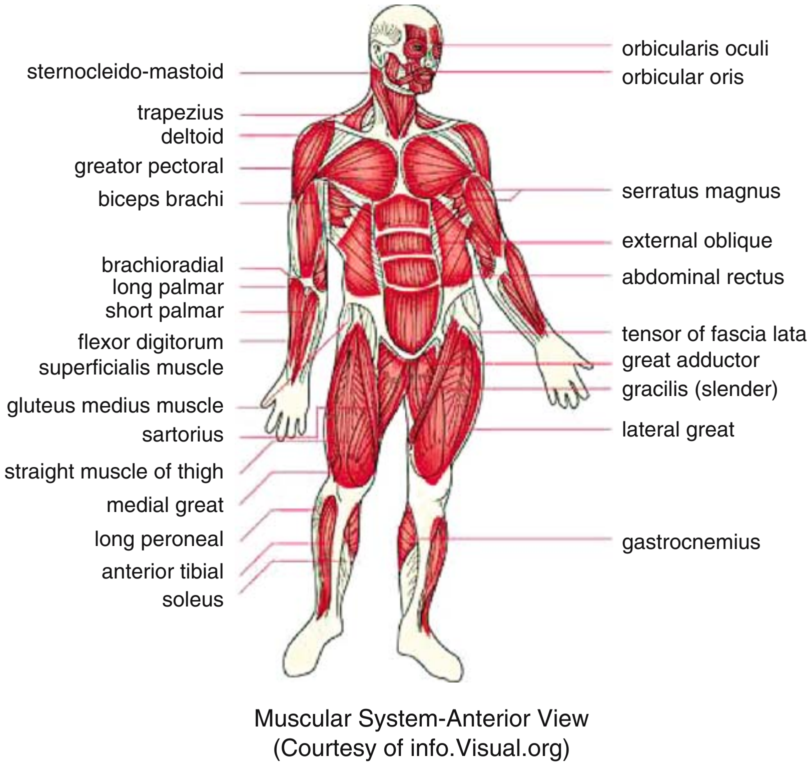


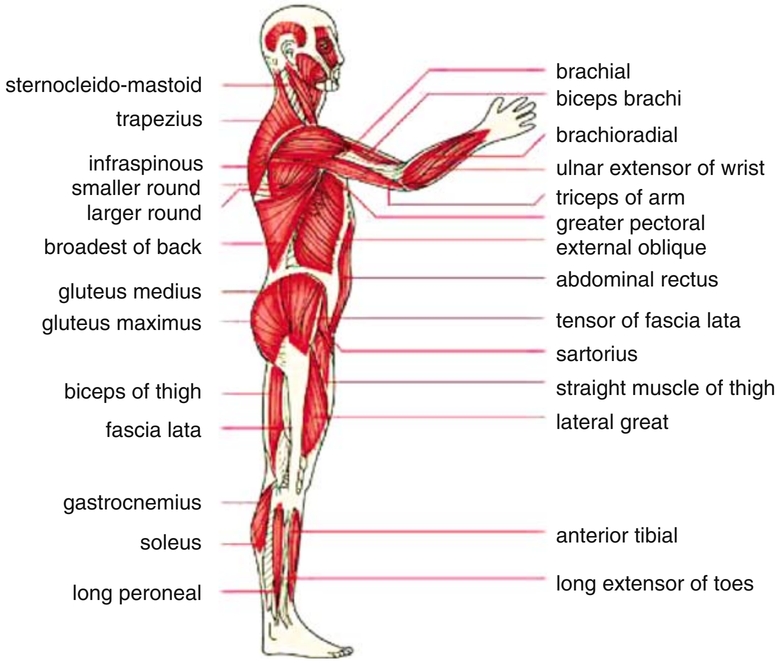
Plate 1.3. The muscular system

appropriate written documents should accompany the patient. The main purpose of caring for these individuals is to prevent further deterioration post trauma and optimizing their conditions for recovery.

1.4 Brain Structure and Trauma

The brain is one of the most essential yet complex organs of the body. It has influence on maintenance, supply, protection and transport to the remainder structures of the body. But this approximately three pound mass of pink grey tissue is what makes it distinctly human (Plate 1.6 and Flowchart 1.3).

It controls basic bodily functions as well giving anyone consciousness, self awareness, imagination and creativity. It contains more than 100 billion nerve cells and each of these electrically active units which can be connected with up to 10,000 others – creating a structure of mind-bogging complexity. If one counts the nerve connections of just the cortex, it would take 32 million years to finish the task. It seems to everyone that there are more nerve connections



Muscular System-Lateral View
(Courtesy of info.Visual.org)

Plate 1.3. *Continued*

in the brain than there are start in the sky, millions of electrical and chemical messages handled by the brain each second of anyone's life are carried at a speed of 200 miles per hour. In addition, although the brain represents about 2% of a person's body weight, it consumes about one-fourth oxygen requirements – a substantial amount of human daily energy intake. It is vital to know that about half of the 30,000 or so human genes are dedicated to brain functions such as the nonstop of the 50 or so known chemical neurotransmitters that are critical to every conscious thought and feeling.

One of the most enigmatic functions of the brain is to store memories of events that have taken place either in the recent or distant past. This ability of long-term preservation when one gets older is a subject of intensive research. The childhood memory appear to be stored in the hippo campus before eventually being itched into the cortex as long-term memories. The frontal cortex plays a critical role in retrieving memories of the past events. About 100,000 tests on dementia around 35% in cortex is shown to be heavily affected by mechanical impact, particularly in short-term cases. Paul Broca,

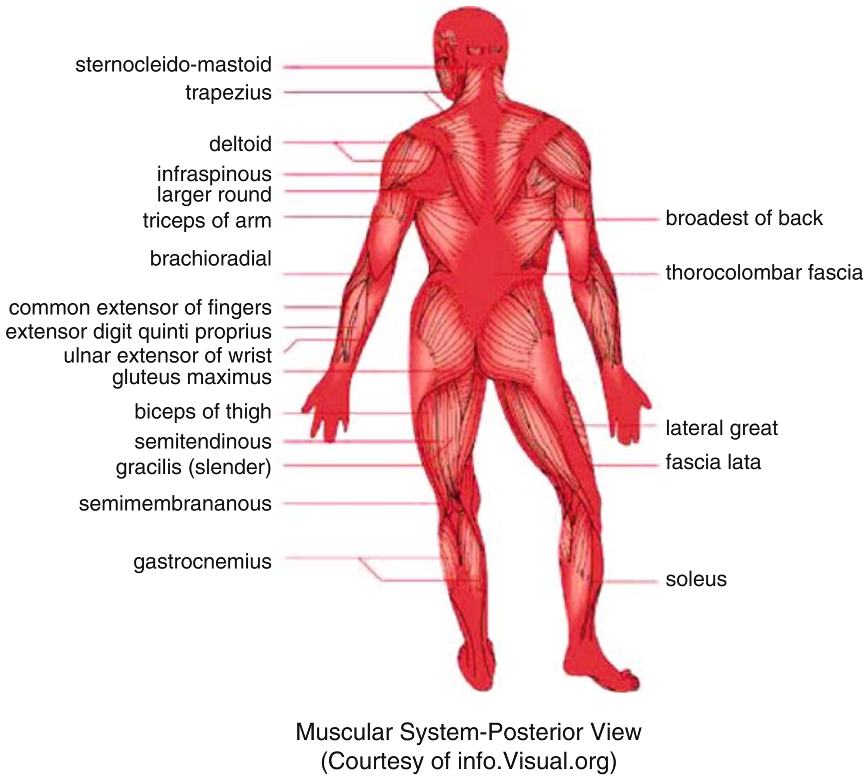
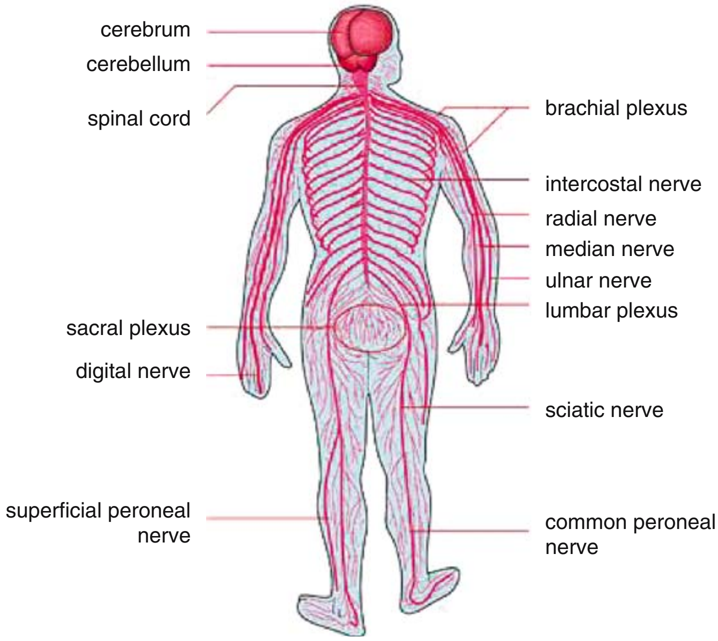


Plate 1.3. *Continued*

a French doctor described a patient in 1861 who could say one word and yet understand everything that was said. He has suffered a damage on the left-hand side of the cortex due to mechanical impact. Unfortunately, he has received pressure caused by impact on Wernicke, located in the temporal lobe. Both speech and language were affected. It is interesting to note that heavy impactive loads alter the sense of smell which has a direct connection to the brain via the olfactory nerves in the nasal cavity. Normally stimulating these nerves triggers activity in the brain smell center. On the question of psychological consequences, severe injuries to brain due to fall or impact can certainly alter basic emotions terminating into angry outbursts or loss of an overall control, by damaging frontal lobes and orbito-frontal cortex.

The brain controls essential biological functions of the body such as breathing, hormone (production/storage/release) and blood pressure. The control stems at the top of the healthy spinal cord. Another part of the brain called the hypothalamus controls other basic elements such as hunger or thirst due to trauma of any kind, there are huge changes occurring in secreting body



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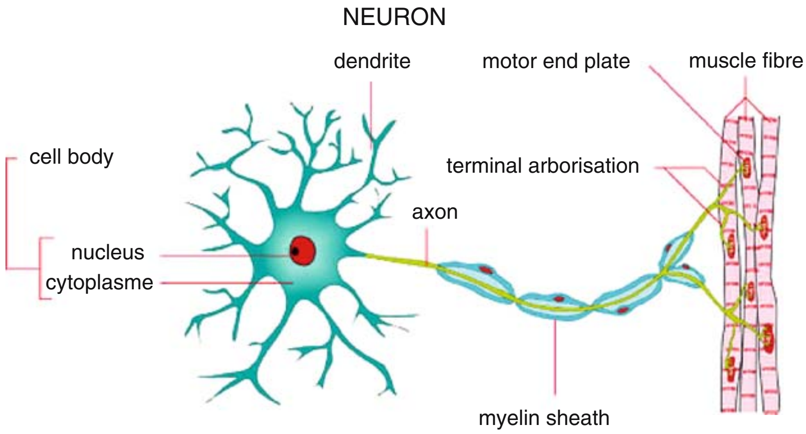
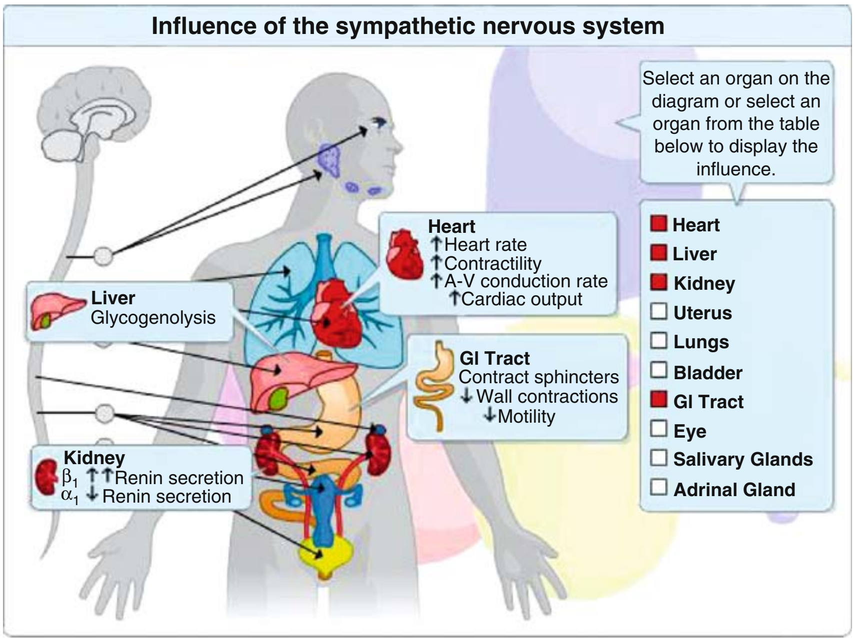


(Courtesy of info.Visual.org)

Plate 1.4. The nervous system



(Courtesy of vudat.msu.edu)

Plate 1.4. *Continued*

chemicals or hormones, thus not keeping constant temperature control for vital body mechanisms. Some case studies show the temporary loss of breathing and blood pressure and some times appetite.

The mechanical impact on head immediately causes vibrations in the air which are detected by sensory nerve cells in the ear and transmitted to the brain via two known auditory nerves. The temporal lobe containing the hearing center of the brain which determines tone and loudness will not focus on a particular source of sound after heavy impact. The sound among cacophony of background noises will, according to medical history be altered. The chances are that hearing can also be affected after severe trauma. The type of which determines whether or not is temporary.

There are hundreds of muscles in the body. The motor cortex at the back of the frontal lobes, allows the person to move his/her muscles consciously controlling the nerve impulses sent from the central nervous system to the face, limbs and torso. In case of trauma, the facial muscles affect the speech and other muscles will be slacked or loosened, some fractured, will affect fingers and hands. In such circumstances extreme dexterity would involve the motor cortex will ever be working efficiently.

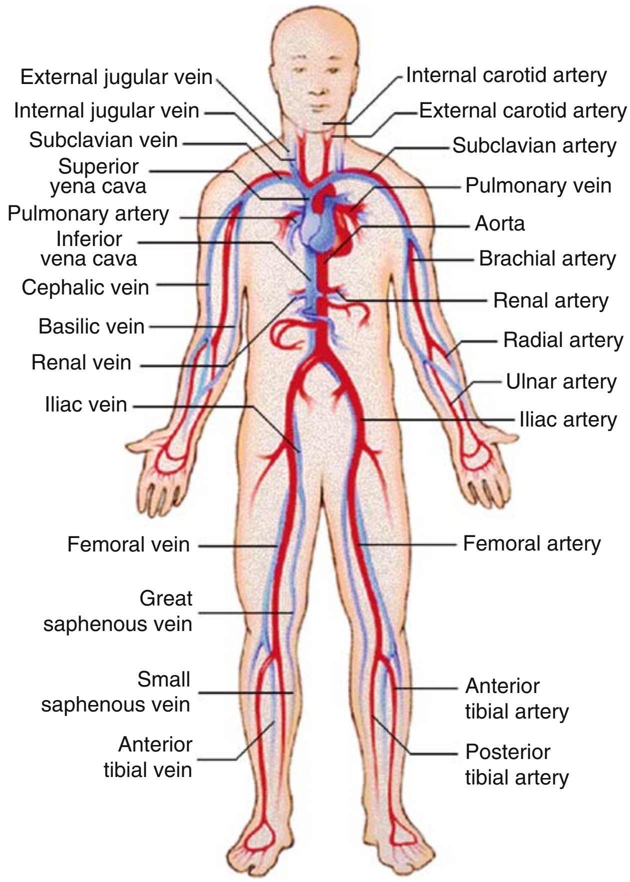
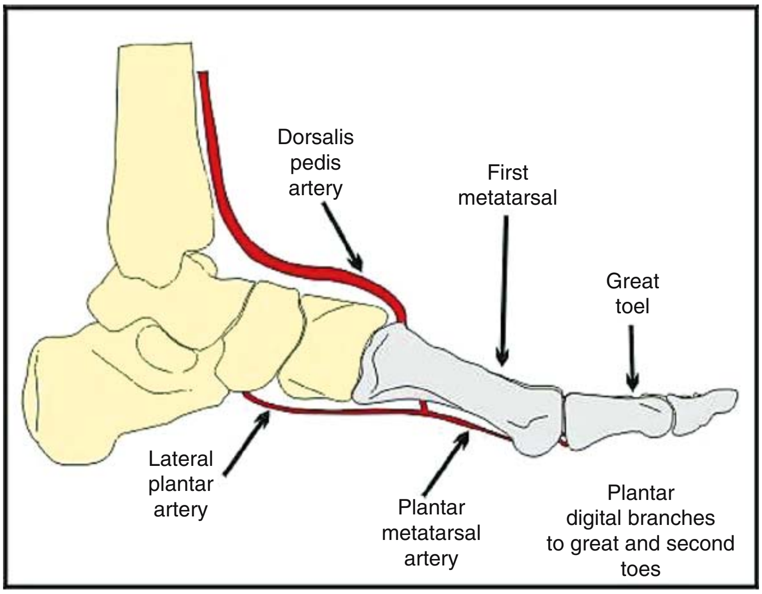


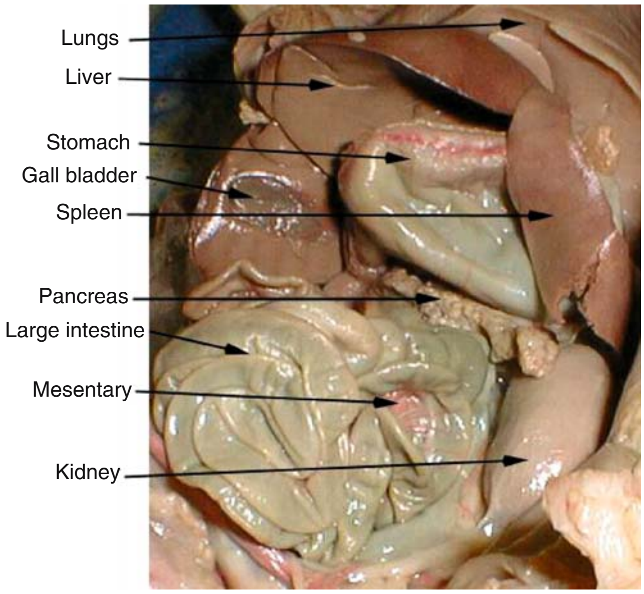
Plate 1.5. The vascular system and viscera

The skin is loaded with sensory receptors that send information about "touch," "pain," and other sensations to the brain. In case of trauma these messages are not easily handled and processed by sensory cortex, which just lies behind the motor cortex. The lips, finger tips and genitals will in some cases of trauma loose responsibility for generating much of this sensory information. The "no touch" sense will not keep human being in contact with immediate environment when a trauma occurs.

The cerebellum is a cauliflower-like appendage and the second largest structure of the brain after the cerebrum. It is known by the scientists as the brains "auto pilot," since it controls and coordinates complex muscle movements such as lifting, although one can walk easily. Owing to trauma of one



Vascular System with Grea
(Courtesy of microsurgeon.org)



Viscera Close
(Courtesy of dravin.bruch.cuny.edu.)

Plate 1.5. *Continued*

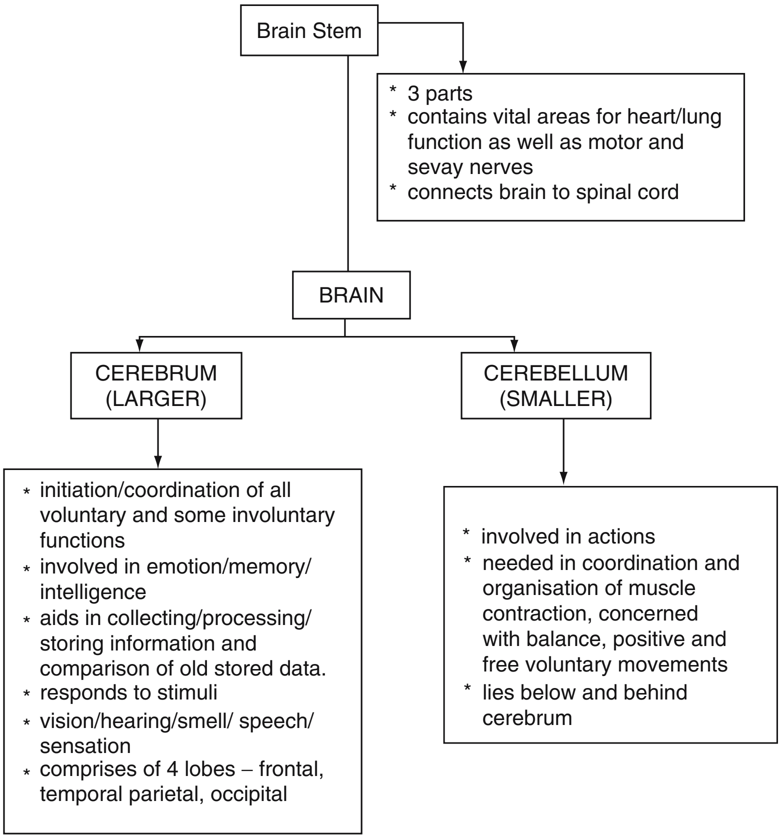


Plate 1.6. Composition of the brain

kind or the other, cerebellum shows clumsiness and can be tempered with it. The occipital lobes at the back of the brain are entirely devoted to the information process from the eyes. Color, light and movement can consume large resources of the brain. Due to impact, the damage to the vision centers of the brain causes a variety of disorders, from color blindness to the inability to recognise close relatives. The trauma would then seriously affect vision, memory and consciousness.

It is interesting to note from the case studies examined that anger, sadness, fear, disgust and other unhappy feelings can largely be out of control during or after specified period of trauma.

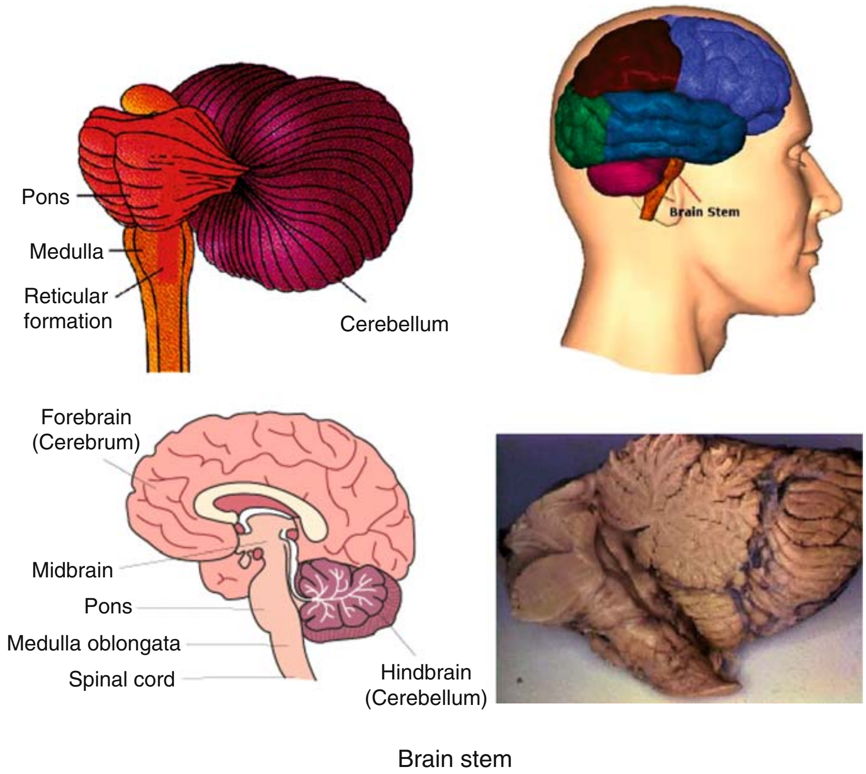
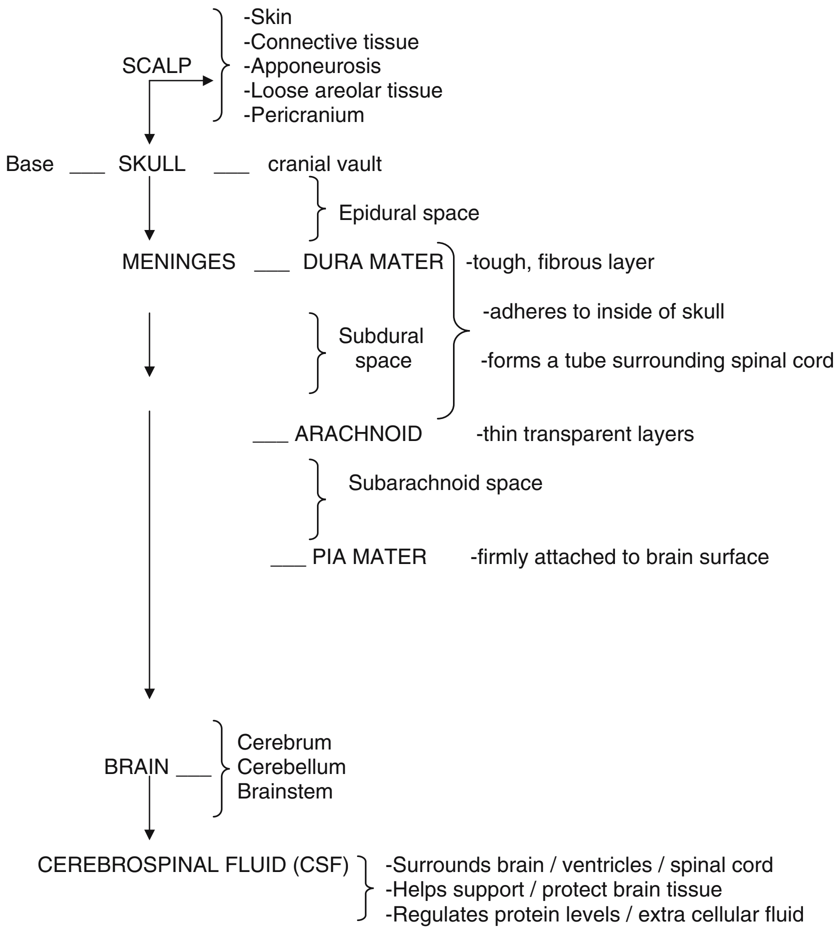


Plate 1.6. *Continued*

1.4.1 Head/Neck

(a) Head injury sustained in car accidents continues to be a leading cause of death and disability. Around 30% of all vehicular injuries, according to Kramer (1998) and Allsop and Kennett (2002), are head and face injuries. The human head (cranium) meaning skull is regarded as a multilayered structure with the scalp being (5 mm–7 m) the outer most layer followed by the skull, the meninges and eventually the central nervous system that represents the innermost tissue. The skull is a complex structure consisting of several bones fused together with associated suture lines as indicated in Plate 1.7. The only facial bone connected to the skull by free movable joints is the mandible. The thickness and the curvature of such bones may vary substantially. The inner surface of the cranial vault is concave with irregular plate type bone forming the base which contains several holes for arteries, veins and nerves. It has also a large hole which is known as "foramen magnum" through which the brain stem passes through the spinal cord. This spinal cord is supported by three membranes, known as "meninges" which protect this and the brain and separate them from the surrounding bones from outside to inside there is an "arachnoid" mater and the "dura mater" and the "pia mater." Out of these two the dura mater is a tough fibrous membrane while the arachnoid mater resembles a spider web.

Both membranes are separated by a narrow space – the "subdural space." The arachnoid mater is separated from the pia mater by this subarachnoid space. The surface of the brain, in turn, is covered by pia mater. Cerebrospinal fluid (CSF) between subarachnoid space and the ventricles of the brain act as a lubricant also for the spinal cord as and when shock and impact exist and they are subjected to them. The fluid now known as CSF constantly circulates and surrounds the brain as a buffer. It helps to support the brain. The meninges have several blood vessels which supply blood to the brain and the scalp. When trauma due to impact occurs, the subdural space can



Flowchart 1.3. Anatomy Of The cranium (head)

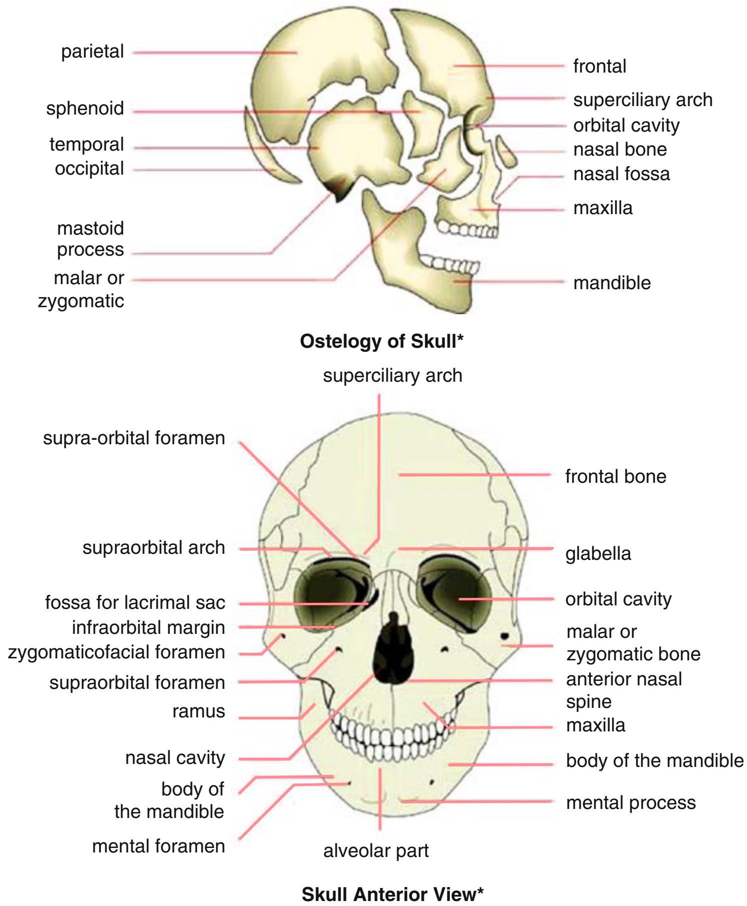
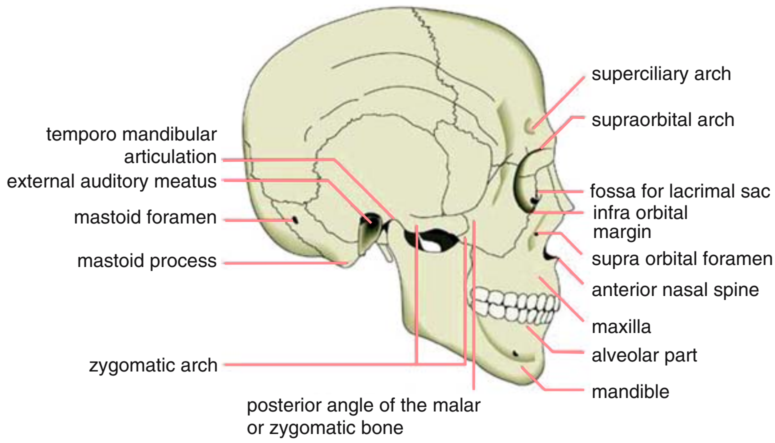


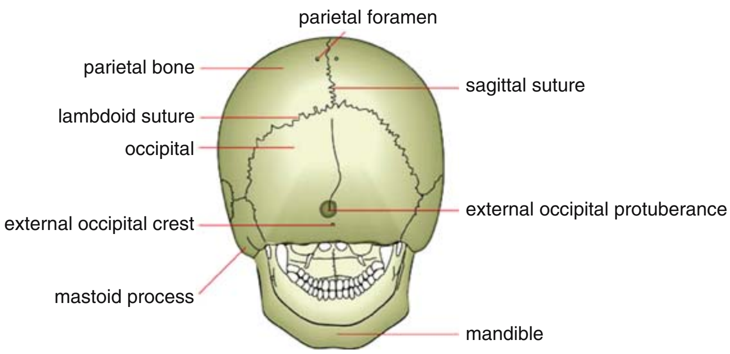
Plate 1.7. Skull structure

be subjected to injury through tearing. Due to severe head injury, brain which having five parts, namely cerebrum, cerebellum, mid brain, pons and medulla oblongata could easily be affected which in turns, include contusion (bruises) and laceration (cut) likewise facial injuries to the eyes and ears and fracture of nasal bone may cause a severe trauma to central nervous system. Such injuries are given AIS codes which are given in Table 1.2 Le Fort classification (adapted from Vetter (2000)) with facial fractures and head injuries is shown in Plate 1.8 More severe head injuries where fracture occurs, resulting "hematoma," can cause unending trauma. Three sources are identified for subdural hematoma which are:

(a) Laceration of cortical veins and arteries by penetrating wounds
(b) Confusion bleeding into subdural space
(c) Tearing of veins between the brain's surface and dural sinuses



Skull Lateral View*

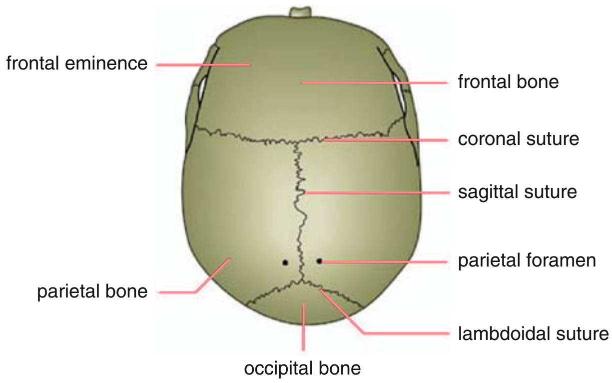


Skull Posterior View*

Plate 1.7. *Continued*

During impact and under impulsive loading, Melvin and Lighthall (2002) investigated the mortality rate of 30%. In such a trauma situation, when the brain accumulates blood, in contrast to contusion intracerebral haematoma occurs and a standard computer tomography can distinguish this type of hematoma. The injury mechanism will be dealt with in detail in a separate chapter.

(b) Neck Injury Criterion (NIC): In addition to the tolerance values for neck loading, a number of neck injury criteria are established. Simple load limits to more complex criteria are proposed, particularly the pseudo name such as whiplash or neck sprain injury. The type of impact can easily lead to type of injuries sustained. Different criteria have also been established which relate to different phases of crash and related occupant kinematics. The neck injury has to be assessed on the basis of impact direction. Researchers Bostrom et al.



Skull Upper View*

*(Courtesy of info.Visual.org)

Plate 1.7. *Continued*

(1996), Klinch et al. (1996), Schmitt (2001), Schmitt et al. (2002a), Kullgren et al. (2003) and Muser et al. (2003) have put forward their assessments on neck injuries based on rear end injuries of the neck with and without soft tissues. The AIS code for neck injuries are sustained in rear end collisions Table 1.3. Sometimes it is difficult to take neck trauma in isolation from cervical spine. It has been well-established that a sudden change of flow inside the fluid compartments of the cervical spine are related to neck injury. The neck injury criterion by US Natural Highway Traffic Society Administration (NHTSA) (Klinch et al. 1996 and Kleinberger et al. 1998) has been well-established including the neck protection criterion. Panjabi et al. (1999) proposed intervertebral neck injury criterion. The neck displacement criterion proposed (Viano and Davidsson 2001b) to assess the risk of soft tissue neck injury. Recently Heitplatz et al. (2003) neck injury criterion to assess the risk of soft tissue neck injury Table 1.4. Threshold values for neck load included in (FMVSS 208) will be discussed in the text under a separate section. However, one cannot ignore the data based on GDV Institute of Vehicle Safety, Munich which serves as a basis to determine the neck injury in real world accidents.

Spinal Anatomy

The vertebral or spinal column, known to most as the spine, is the principal load bearing structure of the head and torso. It is divided as follows:

A/7 cervical (C1–C7)	natural lordosis on lateral view flexible movement C1 (atlas) is a large bony ring with large articulated surfaces that forms the atlanto-occiptal joint with the skull (to allow nodding movements) and the atlanto-axial joint with C2 (axis) via its adontoid peg (allowing rotational head movement)
B/12 Thoracic (T1–T12)	natural kyphosis on lateral view restricted movement provides extra support to ribcage
C/5 Lumbar (L1–L5)	kyphosis on lateral view
D/ Sacrum	5 fused vertebrae
Coccyx	lower tip of sacrum

Table 1.2. AID classified head injury (AAAM 2004)

AIS	code description
AIS 1	skin/scalp – abrasion – super facial laceration face – nose fracture
AIS 2	skin – major avulsion – vault fracture (simple, undisplated) – mandible fracture (open and displaced) – maxilla fracture (LEFORT I and II)
AIS 3	basilar fracture – maxilla fracture LEFORT III – total scalp loss – single contrusion cerebellum
AIS 4	vault fracture – complex, open and torn – exposed and loss of tissues – small epidural or subdural hematoma
AIS 5	major penetrating injury – brain step compression – large subdural or epidural hematoma – diffuse axonal injury (DAI)
AIS 6	massive destruction – cranium – brain

Note: DAI describes the disruption to axons in the cerebral hemisphere and subcortical white matter

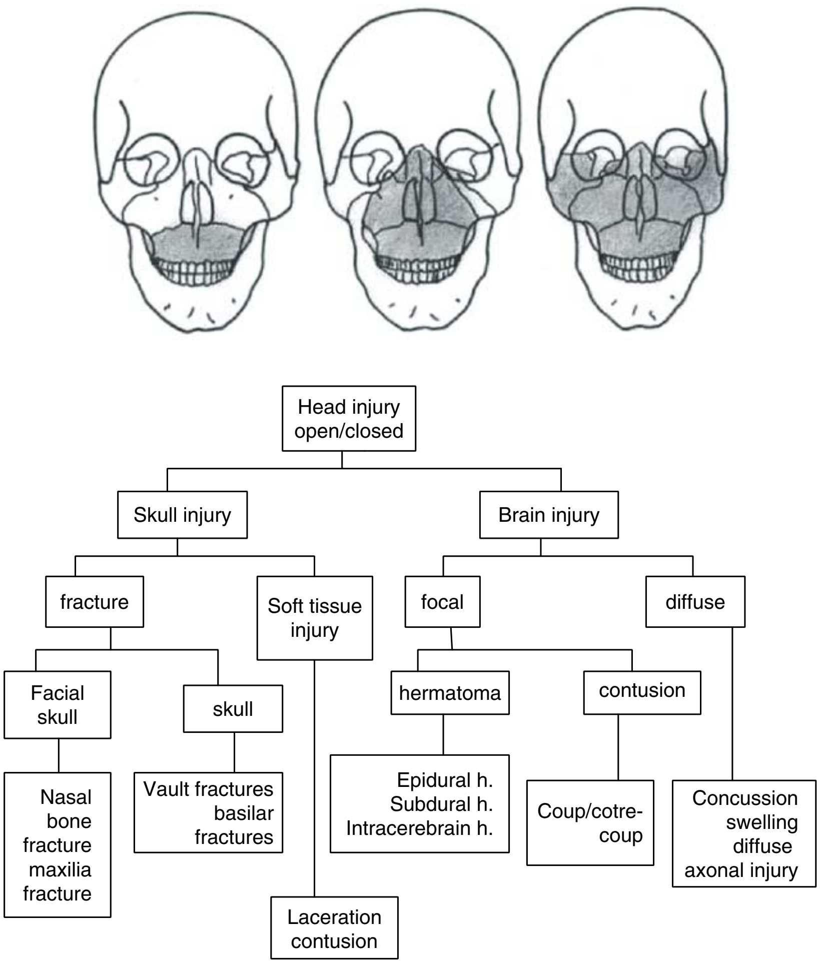


Plate 1.8. Head injuries

(c) Spinal Anatomy and Trauma

They consist of roughly the same shape but vertebral size appears to increase caudally. The vertebrae mainly have a vertebral body (anterior) which are separated from each other by intervertebral discs and are further stabilized by anterior and posterior longitudinal ligaments.

Behind the body lies an arch which encloses a space that carries the spinal cord. The arch also bears bony projections that aid in the further stabilization of column and ligament/muscle attachments, e.g., transverse or dorsal spines processes or facet joints. Note that in the cervical spine C1 (atlas) and C2 (axis) are designed differently from other vertebrae and also there is no intervertebral discs between C1 and C2.

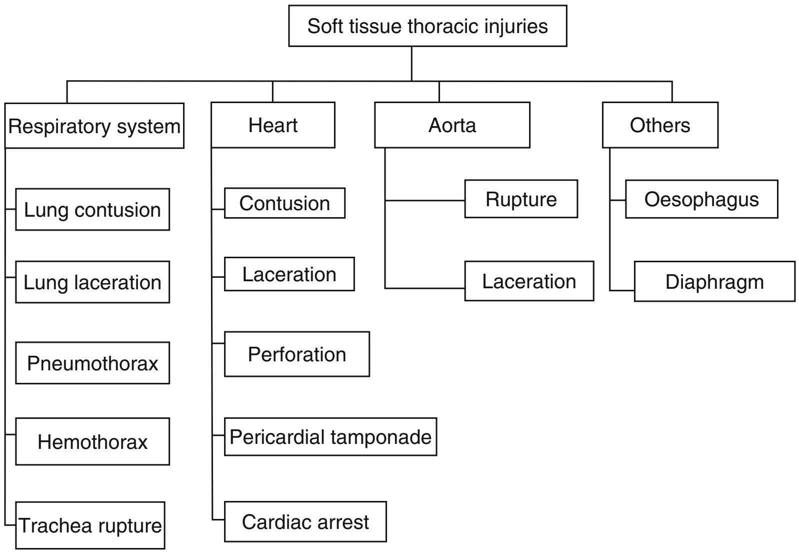


Plate 1.8. *Continued*

Table 1.3. Examples of spinal injuries according to AIS scale (AAAM 2004)

AIS code	description
1	skin, muscle: abrasion, contusion (hematoma), minor laceration
2	vertebral artery: minor laceration
	cervical/thoracic spine: dislocation without fracture
	thoracic/lumbar spine: disc herniation
3	vertebral artery: major laceration
	cervical/thoracic spine: multiple nerve root laceration
4	cervical/thoracic spine: spinal cord contusion incomplete
5	cervical/thoracic spine: spinal cord laceration without fracture
6	decapitation
	cervical spine: spinal cord laceration at C3 or higher with fracture

Reproduced from AAAM (2004) with compliments

The spinal cord begins at the medulla oblongata of the brainstem and exits the skull via the opening called the foramen magnum. It terminates around the L1 bony level where it becomes known as the conus medullaris and beneath this level as cauda equina.

As mentioned before the spinal cord lies within the spinal canal surrounded by cerebrospinal fluid. The cervical part of the canal is widest between the foramen magnum and C2. Injuries below level of C3 are associated with higher rate of neurological deficits. The dimensions of thoracic canal are narrow and hence any fracture dislocation will almost always lead to complete neurological deficit. A significant proportion of all spinal injuries occurs at the level of

Table 1.4. Neck injury criterion

AIS skeletal injury	AIS soft tissue injury
1. one rib fracture	1. contusion of bronchus
2. 2–3 rib fractures, sternum fracture	2. partial thickness bronchus tear
3. 4 or more rib fractures on one side, 2–3 rib fractures with hemothorax or pneumothorax	3. lung contusion, minor heart contusion
4. flail chest, four or more rib fractures on each of two sides, four or more rib fractures with hemo- or pneumothorax	4. bilateral lung laceration, minor aortic laceration, major heart contusion
5. bilateral flail chest	5. major aortic laceration, lung laceration with tension pneumothorax
	6. aortic laceration with hemorrhage not confined to mediastinum

thoracolumbar junction. The latter acts as a pivot between the rigid thoracic spine and strong lumbar area.

The spinal cord carries many nerve tracts in pairs as follows:

(1) Corticospinal tract	lies in posterolateral segment of cord responsible for ipsilateral motor power
(2) Spinothalamic tract	lies in anterolateral segment of cord conveys contralateral pain and temperature sensation
(3) Posterior columns	transmits ipsilateral position sense (proprioception) vibration sense and some light touch sensation

It is possible to test these nerve tracts clinically to assess any damage post injury.

Trauma Mechanism

Most spinal injuries can be classified into four main types:

- Burst Fractures — axial loading to the spine. Bone fragment may protrude into the spinal canal causing neurological deficit.
- Compression Fractures — hyperflexion of spine around a mid-disc space axis compromising bone integrity. This usually affects the anterior part of the vertebral body.
- Seat belt-related injuries — sudden deceleration injuries usually associated with lap-type seat belts, produces tensile forces on a flexed spine.

– Fracture Dislocations associated with different tensile forces that lead to loss of spinal stability via dislocation and subluxation of bone and joints.

This gives us a good idea as to the mechanism of injury.

Of all spinal segments, the cervical spine is most frequently injured. In the trauma analysis, the vast majority of cervical spine injuries are minor tissue, neck injuries usually graded as AISI, generally not exhibiting a morphological manifestation. These injuries are not associated with over structural types not causing damage to cervical spine or the central nervous system, are potentially treated as debilitating injury since they frequently occur in road accidents. Head, neck and spine injuries according to Morris and Thomas (1996). In a car accident as pointed by Byland and Bjornstig (1998), soft tissue injuries developed prolonged medical disability, resulting in long sick leave leading to granting disability pension. Hence for the accurate analysis, using finite element or other methods a greater understanding of the vehicle, occupants, and collision parameters are needed to assess soft tissue injuries. Murer et al. (2002) cannot regard the soft tissue injury mechanism whether in the head, neck or spine as conclusive. A greater data can be obtained from various sources. Soft tissue injuries require data base on epidemiology, injury assessments, medical diagnosis/treatment, and development of "whiplash" counter measures have been dealt with extensively by Ferrari (1999), Yoganandan and Pintar (2000), and McElhaney et al. (2002). Although in the last century "whiplash" was introduced (whiplash associated disorder – WAD) as a type of injury, the term "whiplash" is misleading and incorrect since it invokes a forward backward movement of the injury mechanism during the development of the "crack of the whip." The clinical presentation of the WAD is classified by the Quebec Task Force which is adapted from Spitzer et al. (1995) is given in Table 1.5. Regarding the injury mechanism whatever hypotheses do exist.

They have to rely on experimental, symptomatic clinical observations, and numerical-cum-computer aided analysis. This is due to the fact that the anatomy of the cervical variable structures are assembled in quite a small area

Table 1.5. Classification of WAD as proposed by the Quebec Task Force

grade	clinical presentation
0	no complaint about the neck no physical sign(s)
1	neck complaint of pain, stiffness or tenderness only no physical sign(s)
2	neck complaint and musculoskeletal sign(s)
3	neck complaint and neurologic sign(s)
4	neck complaint and fracture or dislocation

Courtesy Spitzer et al. (1995)

with complex anatomy. The neck injury is highly dependent on the injured tissues.

(d) Tissues and Trauma

Different tissues are proposed to the cause for neck injuries. Current studies suggest that ligaments and muscles are injured. The zygapophysial joint can also be injured or for that matter nerve tissues in the vicinity of "spinal ganglia" can be abnormally injured. Other hypothetical consideration presented by Ferrari (1999) identifying other tissues such as vertebral arteries and inter vertebral discs cannot be discounted by offering tissue injuries. The statistics shows that the movement of the neck (rear end and frontal collision) can result soft tissue neck injuries since kinematic sequences inclusive of mechanical loading conditions. During accident the contact and force transmission occurs in the "shoulder area." Since inertia force is developed, the head is not in contact with any part of the occupants car, the head will be accelerated forward and the head behind lags behind the torso. It moves back without rotation about the internal axis. The upper cervical spine is forced into flexion (bending) mode and as a result the lower cervical spine goes into extension. The deformation of the neck can also be in "S" shaped formation which is crucial for injury mechanism. This "S" shaped mechanism is fully supported by the research work carried out by Ono and Kaneoka (1997), Ono et al. (1998), Eichberger et al. (1998), Grauer et al. (1997), Svensson et al. (1993), Wheeler et al. (1998), and Yoganandan and Pintar (2000).

The entire cervical spine is extended maximum as soon as the head starts rotating backward. This phenomenon causes severe tissue injuries, however depending upon impact severity. During the forward movement the head, neck and torso causes tissue injuries depending upon how this phase strongly influenced by the elasticity of the seat and corresponding rebound effect. This phenomenon is fully examined by Muser et al. (2000). The occupants dynamics is further discussed in detail by Walz and Muser (1995). More innovative work is done for shear movement of vertebrae related to lesions of the facets of the intervertebral joints (Yang et al. 1997), the hyper extension of the neck and head movement and excursion angles (Mertz and Patrick 1971) and pressure gradient developing various and cerebrospinal fluid of the spinal and canal causing cellular injuries (Aldman 1986, Svensson et al. 1993, Schmitt 2001) and tissue neck injuries. However the literature indicates that tissue injuries have never been biomechanically understood. Since the S-shape deformation plays a crucial role when elucidating and explaining injury mechanism, especially relative motion between the head and torso, the finite element analysis and solution procedures can be the only answer to the problem. Here the engineering analysis can offer a greater assistance to the medical profession (Plate 1.9).

Injuries to the thoracolumbar spine injuries sustained are negligible to cervical spine injuries, back pain, and severe injuries to the spinal cord have been identified during and after vehicle crashes (King 2002) by anterior wedge fractures of the vertebral bodies burst fracture of vertebral bodies,

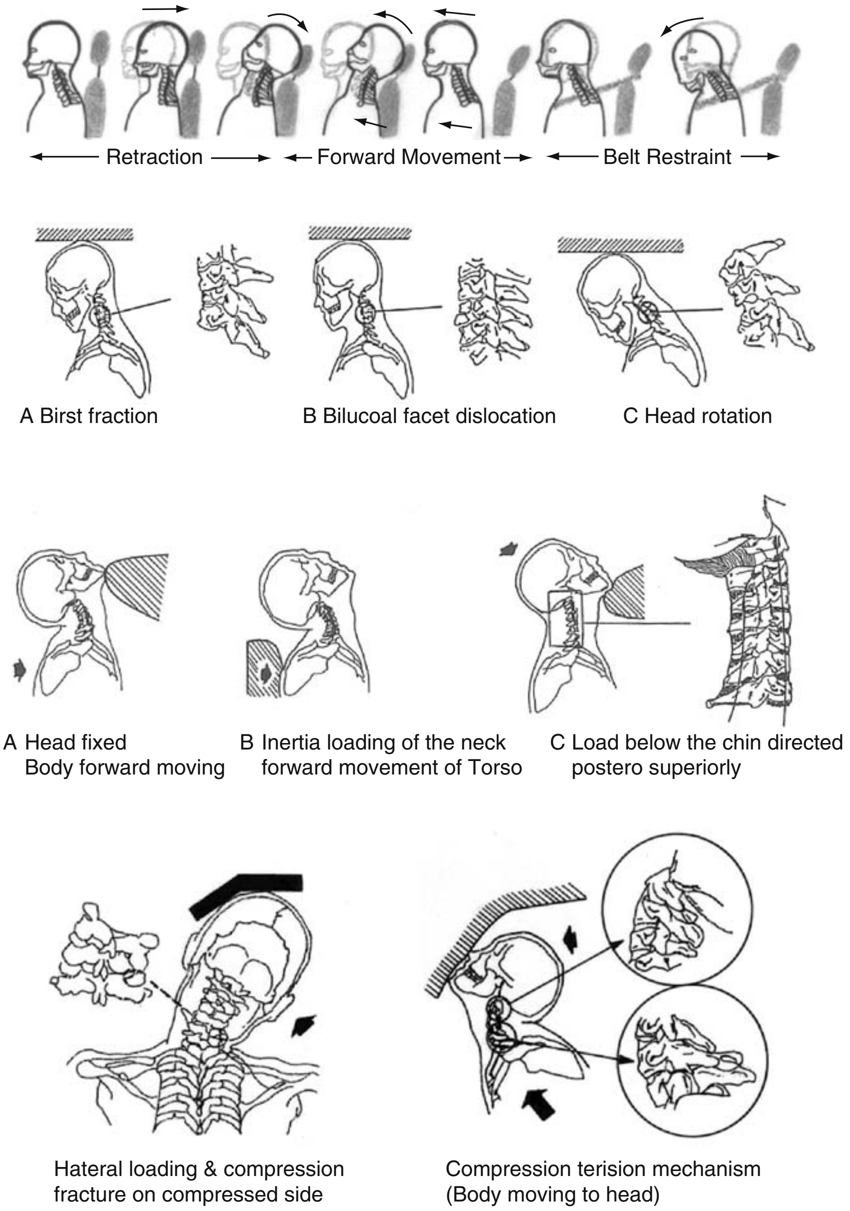


Plate 1.9. Neck and head movement mechanism. Reference: Library St. George Hospital and Medical School, London, UK (2004)

fracture/dislocation, rotational injuries, chance fracture, hyperextension injuries, and soft tissue injuries. Wedge fractures have been further examined by Begeman et al. (1973). Chance fractures are due to improper wearing of the lap belt in case of frontal collision. If the lap belt angle is too flat to the horizontal plane, the belt can ride over the iliac crest leading to compression produced in the abdominal organs. The lumbar spine flexion occurs which can separate posterior elements of spine stretch. The spine cord leading to subsequent injury. The soft tissue, as a result of the thoracolumbar spine, can certainly be injured. The rupture of the supra and interspinous ligaments can also occur. If suitable tools are devised, the engineering analysis can provide a comparative study with known experimental results.

1.5 Thorax, Chest, and Shoulder

1.5.1 Thorax and Chest

The thorax consists of the rib cage and the underlying soft tissue organs. It extends from the base of the neck to the diaphragm which inferiorly bounds the thorax and separates the thoracic cavity from the abdominal cavity. Twelve pairs of ribs from the rib cage: They are posterior connected to the thoracic vertebrae of the vertebral column. At the anterior side of the thorax the sternum fixes the upper seven ribs. However, the lower ribs are either connected indirectly to the sternum or attached to the muscles and the abdominal wall. They are called *floating ribs.* The ribs are inter-connected by means of intercostal muscles. These connections between ribs, vertebrae, and sternum are flexible as are intercostal muscles, however, the rib cage is quite rigid with movable cover of internal organs. This cover facilitates respiration. The trauma of the thorax is the direct result of injuries commonly occurring due to frontal and side impact and, in some cases, occur in between. Normally, the impact to the thorax occurs at the contact between the occupant and the vehicle interior such as the steering assembly, the door, the dash board and other restraint systems. In the engineering analysis, it becomes essential to represent restraints as contact or the gap elements in the global analysis using finite element or any other numerical techniques. The procedure is explained in the separate chapter. Based on AAAM (2004), the AIS codes for skeletal and soft tissue thoracic injuries are given in Table 1.4. According to the AIS code, a single rib fracture can be graded as AISI. If fractures occur in 2–3 ribs or multiple, life threatening complications may arise. When the skin and the soft tissue overlying in the fracture are intact, the fracture is known as *closed fracture*. The skin and soft tissue can be treated in the analysis as membrane spanning over a rib crack. This analysis is essential for the assessment of fracture by the medical professionals. If on the other hand, ribs perforate the chest wall, the impact analysis must take into consideration sharp edges of the broken ribs. These open fractures are of great concern they can eventually lead to pneumothorax, lung collapse and infections. The correct size of a fracture to evaluate is the main responsibility of the engineer, since the size factor can generate time-dependent spread of the above-mentioned scenario and that of visceral or parietal pleura causing especially respiratory problems.

The question arises what triggers a single rib collapse and for that matter the creation of multirib fracture. The answer is that sagittal loading of the thorax may cause single rib fracture and lateral impact or impulsive force is generally responsible for multiple fracture. In both cases maximum curvature at the level of the impactive force will occur prior to the rib cracking or fracturing. In order to assess all those cases the medical profession relies on the engineering analysis of developing or checking the requisite fractures in three dimensions. The description of the thoracic injuries then focuses on the impact in accidents where objects strike the chest with and without penetration. If the thorax is suddenly decelerated due to impact from blunt objects, three different injury mechanisms can be identified, namely, compression, viscous loading, and inertia loading of the internal organs.

In case of multirib fracture, the thorax wall may lose its overall stability or the disrupted thorax wall is sucked in, thus reduces the volume of the lung. On expiration the thorax wall moves outwards making it difficult to expel the air out of the lungs. The research of Stalnaker and Mohan (1974) and Melvin et al. (1975) shows that the greater the area of thorax wall damaged, the lesser the amount of air which can be exchanged. In some cases thorax wall moves outwards, making it difficult to expel air. The area of this condition is known as a *flail chest* which eventually results in *hypoxaemia*. The research concludes that the time-dependent force is directly related to the number of rib fractures which in turn depends on the magnitude rather than the rate of rib deflection. It is also noted that a lung contusion can occur due to thorax compression. The lung contusion is, unlike rib fractures, very much rate dependent as concluded by Fung and Yen (1984). At high velocity of impactive object, a pressure wave is transmitted through thorax wall to the lung tissue which can damage the capillary bed of the *alveoli*. In case of a serious complication, lung contusion may increase thus risking an inflammation of the lung tissue. Due to impactive force, laceration, and perforation of the lung tissue can occur. Various numerical methods and high level computer programs exist for the lung perforation, especially in areas where rib fracture exists. In such circumstances, laceration-cum-perforation may cause *pneumothorax* (Pleural cavity filled with air) and *hemothorax* (filled with blood). Where a combined situation exists, i.e., pleural cavity filled with air and blood, the case is termed as *hemo-pneumothorax*. When the impactive force is applied, a perforation of the pleura, i.e., a hole is created in the pleural sac between lung and the rib cage in case of broken rib, pneumothorax is resulted. When the lung leaks, the inter pleural pressure is reduced. However during expiration, the laceration in the lung tissue is compressed and the air in the pleural cavity is not able to be expelled. The more air comes from breathing, the size of the pleural cavity increases leading eventually to *a compressed lung*.

A time dependent finite element analysis under successfully reducing inter pleural pressure could be a great eye opener to the medical professionals, especially where a case study is examined. The same engineering analysis can be applied in case of a hemothorax which reduces the lung volume with the blood in pleural cavity. The laceration of the blood vessels can cause blood to accumulate in the pleural cavity.

Under large impactive or other impulsive forces, the *heart* can be subjected to several traumatic injuries including contusion and laceration. At a high rate of loading the heart may undergo *arrhythmias*, (e.g., Fibrillation) or arrest. High speed blunt impact such as occurring in the car accident, may interrupt electromechanical transduction of the heart wall. In such circumstances, there is a possibility thoracic blood vessels like the aorta, may be injured (Cavanaugh 2002; Smith and Chang 1986; Oschsner et al. 1989). Aortic rupture may occur from traction and shear forces as a result of loading rates (Viano 1983). The most vulnerable case is the thoracic aortic structures. These areas are dealt with later on in the modes and responses in the text under specific chapters.

1.5.2 Shoulder

The views are given in Plates 1.10 and 1.11 which vividly describe various areas of the shoulder.

Some important elements are:

– Bones – humerus, scapular, clavicle		
– Shoulder joint (glenohumeral)	ball and socket type wide range of movement involves head and humerus articulating with smaller glenoid fossa of the scapula	
– Articular capsule	fibrous forms loose sleeve around joint	
– Muscles	subscapularis infraspinatus supraspinatus teres minor	tendonsfusewith capsuletoformthe rotatoroff
– Ligaments	glenohumeral coraco clavicular acromioclavicular	
– Blood vessels/nerves/lymphatic vessels		

They are reproduced in Plate 1.11 as areas related to shoulders when judging impact involving skeletal, muscular and nervous systems leading to severe trauma. It is important to note that head and neck trauma can lead to possible shoulder trauma. For example, if subjected to tension–extension loading, tension–tension and tension–compression loading conditions. Shoulder injury can also result from impacts in vehicles. When a person is restrained by seat belts. Subsequent stresses and strains may lead to torsional effects. Direct

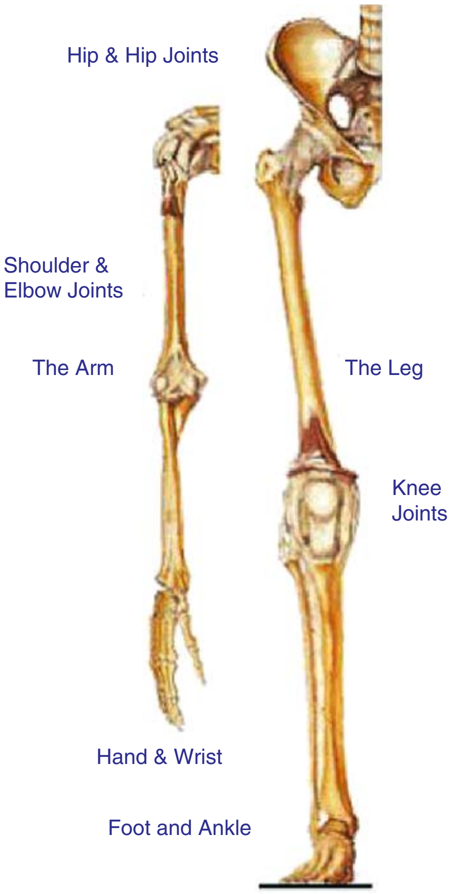


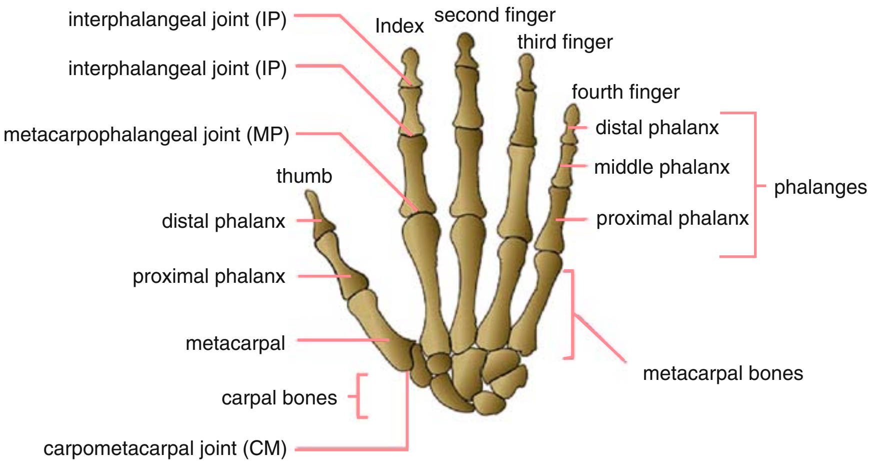
Plate 1.10. Bones and joints – skeletal

injury, e.g., falling into shoulder can lead to a damaged shoulder. Trauma to arms can have an effect on shoulders. A shoulder or shoulder girdle is also treated as part of four different areas of the upper limbs. They can be dealt with in a separate section.

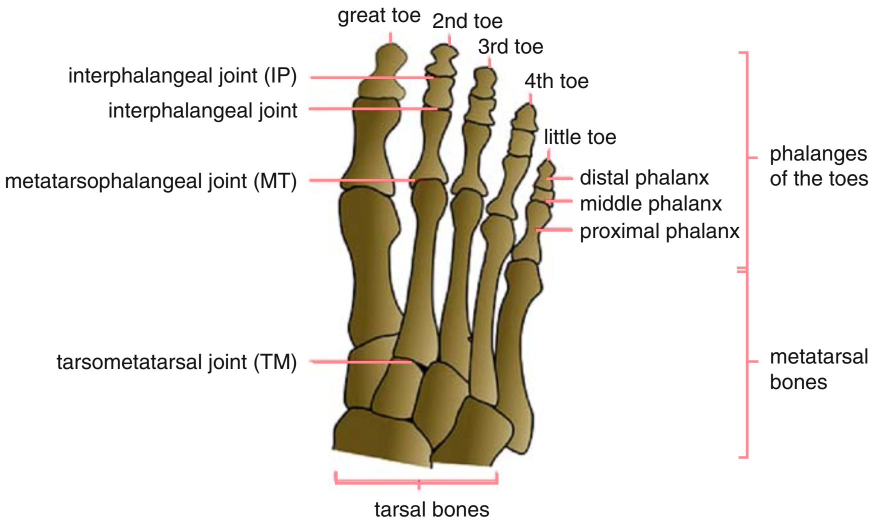
1.6 Traumatic Injuries of the Upper Extremities

The upper extremities can be divided into four different parts and they are:

– shoulder or shoulder girdle	
– the arm	humerus bone
– the fore arm	ulnar and radius bones
– the hand	phalanges metacarpal and carpal bones



Bones of the Hand-Dorsal View*



Bones of the Foot-Dorsal View*

(Courtesy of info.Visual.org)*

Plate 1.10. *Continued*

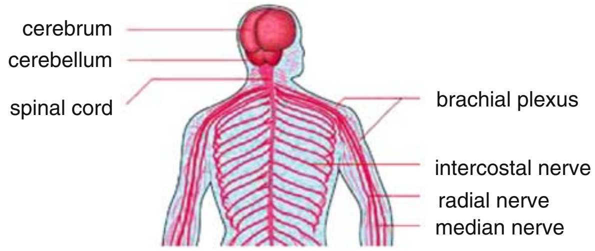
Ribcage-Anterior View*

Ribcage–cross section*

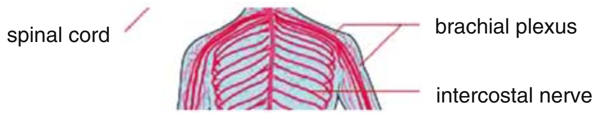
Muscles-Anterior View*

Muscles-cross section*

Plate 1.11. Skeletal, muscular- and nervous-cross section



Nervous System*



Nervous System-cross section*

(Courtery of info.Visual.org)

Plate 1.11. *Continued*

Plate 1.10 shows bones and joints of the upper extremities and the skeleton of the hand. Hand injuries are recorded during boxing and in some frontal collisions. In general, the following are some of the major upper extremity injuries investigated by Huelke et al. (1997), Segui-Gomez and Baker (2002), Atkinson et al. (2002), and Schneider et al. (1998):

(a) Direct contact to air bag.
(b) Contact of the arm with the interior part of the vehicle when arms are being flange by the airbag.
(c) Contact to the interior involving intrusions and side impacts.
(d) Inboard limb injuries owing mutual contacts among the occupants.
(e) clavicular fractures caused by seat belt diagonal section lying across the out board shoulder thereby transmitting the belt loads transversely across clavicula.

The early work by Weber (1859) and Messerer (1880) which determined load and moment to produces failure or fracture. The bones of the human upper extremities have to form the basis for the engineering analysis of Trauma. Since the advent of the computers and advanced numerical analyses and techniques, forearm fractures in which ulna night stick fractures and multiple fractures can be assessed. The engineering results will suggest that the humerus position, the forearm pronation angle and air bag module affecting the risk injuries.

Table 1.6. Failure tolerances for the humerus

humerus bending male (N m)	moment female (N m)	shear force male (k N)	female (k N)	reference
115	73			Weber (1859)
151	85			Messerer (1880)
157	84	1.96 (overall)		Kirkish et al. (1996)
230	130	2.5	1.7	Kirkish et al. (1996), scaled to 50% male and 5% female
138				Kallieris et al. (1997)
	154			Duma et al. (1998a)
217	128			Duma et al. (1998b), scaled to 50% male and 5% female

Like Pintar et al. (1998), these analyses can predict the dynamic bending mode. As a reference the failure tolerances given in Table 1.6 can be highly correlated to bone mineral density.

1.7 Trauma and Abdominal Injuries

1.7.1 General Introduction

The abdominal cavity is a sensitive and vulnerable region of the human body. Owing to any kind of impact, whether sharp or blunt, trauma to the abdomen is caused. It becomes worsened if any penetration occurs. Blunt impact in car accidents is frequently observed although not visible initially. Where penetration due to impact occurs, the injury can be life threatening. If it happens to be a side impact, according to Rouhana and Foster (1985), more than one-fifth of severe injuries (AIS ≥ 4) is abdominal. It is the one area where experimental studies are difficult to be performed and the results obtained are not quite meaningful. There is a lack of sufficient knowledge of injury mechanisms and injury predictors.

1.7.2 Anatomy of the Abdomen

The abdominal cavity is bounded by the diaphragm and caudally by the pelvic bones with attached muscles. The posterior boundary of the abdomen, in fact is formed by the lumbar vertebral column, sacrum and pelvis. Anteriorly and laterally the upper abdomen is defined as the lower rib cage. Sometimes the upper abdominal region is known as *hard thorax*.

The lower abdomen is surrounded anteriorly and laterally by musculature (Eppinger et al. 1982) gives an exhaustive analysis of Impactive load on the behavior of upper abdomen and found its impact response and tolerance are different from the lower abdomen. According to them the side impact is critical to lower ribs and organs directly in front of the vertebral column are at great risk of, when subject to frontal impact, receiving heavy compression.

The abdominal cavity hosts several organs that are generally divided into "solid" and "hollow" organs. The main characteristic to divide the organs into these two groups is the gross density of an organ (not the tissue density). Solid organs like the liver, spleen, pancreas, kidneys, ovaries, and adrenal glands have a higher density than hollow organs such as the stomach, large and small intestines, bladder, and uterus. The lesser density of the hollow organs is due to the presence of a relatively large cavity within the organ itself. Those cavities are, for example, filled with "air" or digestive matter. The solid organs, in contrast, contain fluid-filled vessels and therefore exhibit a higher density.

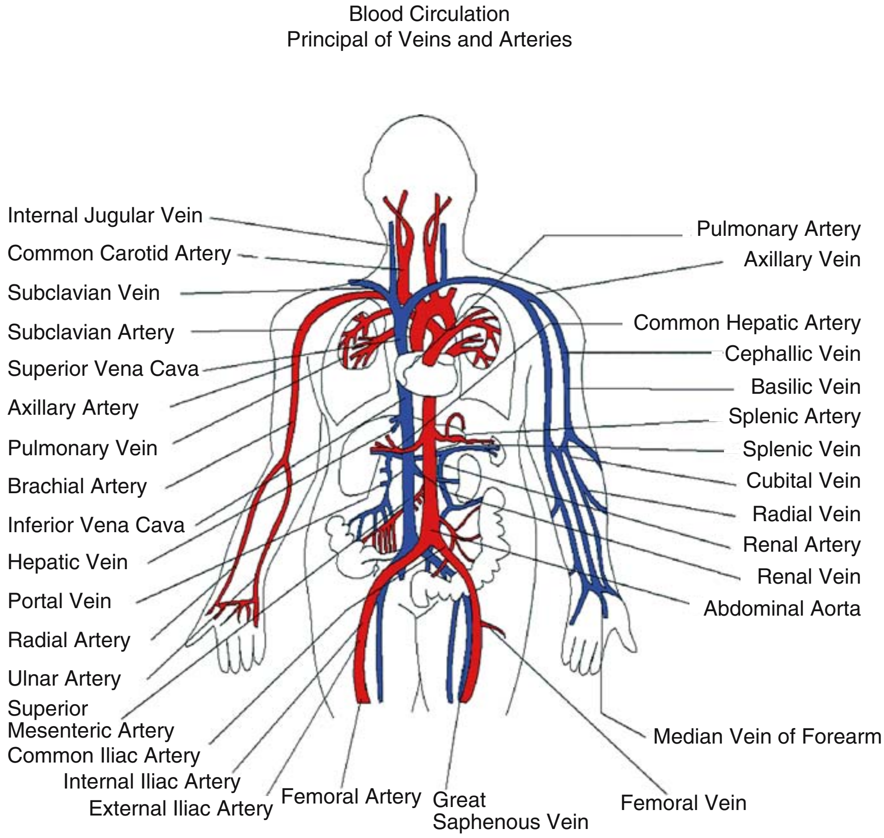
Major blood vessels are the abdominal, aorta, the inferior vena cava the iliac chip artery and hip or iliac vein. The geometry indicates that abdominal aorta and vena cava enter the abdomen from cranial through separate openings in diaphragm. Plate 1.12 shows various element of abdomen. Since organs inside in abdomen cavity has a relatively high.

Degree of mobility, the biomechanical response of nonrigidly fixed organs to the abdominal wall on traumatic impact needs a careful analysis. Partly these organs embedded in fat, particularly kidney, and partly the complicated nature of the performance of these organs, inside abdomen. The abdominal injury is extremely important. Under impact load, particularly blunt to the abdomen, Rouhana et al. (1986) , Rouhana (1987), Rouhana (2002), Miller (1989), and Stalnaker and Ulman (1985) have carried out comprehensive studies. One must keep in mind that solid organs of the abdomen are "fluid filled," the engineering analysis must consider a rate dependent behavior.

In case of low loading (under seat belt loading) maximum compression is a better predictor of the abdominal injury for high loading, the maximum velocity is a better injury predictor. The abdominal compression can correlate well with the probability of AIS ≥ 4 injury.

As far as the injury criteria is considered (ECER 95) – The European regulations for side impact loading, the abdominal peak force (ADF) can easily be evaluated using Euro SID Dummy, properly collaborated with engineering analysis. It is important not to ignore in the analysis of the "seat belt syndrome" owing to submarining as well as belt misplacement. In any case force displacement relationship of lower abdomen due to frontal impact (Nusholtz et al. 1988) must always be analyzed. The laceration hemorrhage to liver, laceration disrupture to spleen and contusion laceration to kidney must also be clinically assessed.

It is worth mentioning that correct placement of the belt is crucial for pregnant women to ensure that the fetus is not exposed to high loading. If the belt is placed above pelvis, it loads the abdomen instead of more stable pelvis. The structure of the seat also influences the probability of submarining.



(Courtesy of world indisible)

Plate 1.12. Blood circulation: Principle of veins and arteries

Lane (1994), and Rouhana (2002) carried out research and many studies indicate that unbetted occupants are twice as likely to sustain fatal injuries than betted occupants. At the same time, it must be clearly established that belt effectively reduces head, neck, and thorax injury.

1.8 Trauma, Lower Limb, and Pelvis

Crandall et al. (1996), Haland et al. (1998), and Parenteau et al. (1998) reported that air bag restraint system have reduced incidents of fatalities, thoracic and head trauma in automotive frontal collisions. Injuries to pelvis and lower extremities have emerged as the most frequent injuries resulting frontal crashes. In this section a short review of the anatomy is given which is followed by a brief description of failure mechanisms and resulting in injuries. The trauma response shall be analyzed on the basis of the criteria developed in this section to predict injuries of the lower limbs.

1.8.1 Anatomy of the Lower Limb

The lower limbs are divided into pelvis, thigh, knee, lower leg ankle, and foot. The pelvis which links the lower extremities to the spine is a ring of bones, four in number: two hip bones forming the side and front of the wall while the other two, namely sacrum and coccyx, form the rear wall. The pelvis mechanically identifying the only load path to transmit the torso weight to the ground. The hip bones consist of three fused bones (ilium, ischium, pubis) and host also a cup-shaped articular cavity forming one part of the hip joint, known as a cetabulum. The frontal part of the pelvis known as symphsis – a joint connecting the right and left pubic bone. The thinner parts of frame-like of pubic bones are called "superior" and "inferior" "pubic rami" which are vulnerable to traumic injury. The sacrum is a fusion of several vertebral sacral nerves called "siatic nerves" which arise from the spinal cord passing the sacrum. Both sacrum and coccyx are near to major blood vessels.

The femur is the long bone of the thigh and is proximally connected by the hip joint to the pelvis and also distally linked to the knee. Two bones, tibia and fibula, form the lower leg between the knee and the ankle. It is interesting to see the knee as a joint connecting the femur and the lower leg. Here the reader must know that it is anatomically dense area consisting of several muscles, tendons, and ligaments. The patella in the knee is often as a vulnerable structure is the recipient of the direct impact. A strong musculature which can create huge forces and hence may influence the injury mechanisms surrounding the legs. The foot is adjoined to the lower leg. As can be seen in Plate 1.10, the foot has a number of bones and they are:

$$\left.\begin{array}{l}\text{– calcaneus}\\ \text{– talus}\end{array}\right\}\ \text{proximal end}$$

$$\left.\begin{array}{l}\text{– metastarsal}\\ \text{– phalanx}\\ \text{– tarsal}\end{array}\right\}\ \text{distal end}$$

This engineering analysis of forearm for static and dynamic loads can easily be correlated, provided the right data are available with experimental tests carried out by Begeman et al. (1999) who had used a drop weight with a velocity of $3\,\mathrm{m\,s^{-1}}$ fracture of the ulna can be assessed. Despite the possibilities offered by the different arm test devices, the inconsistencies between test objects can be easily corrected by these advanced analyses such as a finite element technique or any other hybrid analyses. The differences in the results of interaction ofthe shoulder arm region recognized by Kallieris et al. (1997) can certainly be solved using the hybrid analyses, thus solving the most intricate problem in the medical profession.

Fractures to these delicate zones of the hard skeleton have been fully dealt with by Sobotta (1997). There are differences between females and males are the mass and bone mineral density. Fingers and wrist, in general, are subject to unusual fractures under minimal loads. In order to assist the medical profession, a comprehensive analysis can be carried out in order to develop a relationship between static/dynamic loads developed from various sources and the wrist fractures inclusive of ligament fractures in fingers.

1.8.2 Traumatic Injury Mechanism

Fractures in pelvis and the lower extremities occur more from sports accidents or falls rather than from automotive accidents (around 1%). Hip fractures are common from falls as per data base from various researchers such as Hubacher and Wettstein (2000), Kannus et al. (1999), King (2002), Kramer (1998), and Nass data base. The leg and foot injury are very common. The analysis of the lower extremities showed that the feet and the ankles are at high risk for AIS ≥ 2. The researchers mentioned that the traumatic injuries as twice high of the lower limb than the head injuries, even when occupants are belted and the vehicle is equipped with air bags. The best assessment is always based on AIS – the abbreviated injury scale. It must be noted that the pelvis and the proximal femur are simultaneously injured and such injuries are commonly referred to as a hip injury. A hip is, if the reader is reminded, the bony structure (femur head, pelvis, acetabulum). Table 1.7 gives the AIS rated injuries for pelvis and lower extremities.

Table 1.7. AIS rated injuries AAAM (2004) for pelvis and lower extremities

AIS code	description
1.	ankle, hip: sprain, contusion
2.	patella, tibia, fibula, calcaneus, metatarsal: fracture pelvis: fracture (closed, undisplaced) toe: amputation, crush hip, knee dislocation muscles, tendons: laceration (rupture, tear, avulsion)
3.	femur: fracture pelvis: fracture (open, displaced) traumatic amputation below knee
4.	pelvis: “open book” fracture traumatic amputation above knee
5.	pelvis: substantial deformation with associated vascular disruption and blood loss $> 20\%$ by volume

Reproduced with courtesy of AAAM (2004)

Classification of Fractures

In medical and engineering professions, various methodologies can be invoked to classify fractures. In medical profession fractures are assessed and examined while in engineering profession. They are developed and produced using analytical and numerical logistic approaches.

In this section classification based on medical aspects can be listed as below based on Levine (2002):

(a) Fractures open and closed.
(b) Closed fractures when intact soft tissues and skin are overlying the fracture.
(c) The position of the fractured segments displaced or undisplaced.
(d) Fracture location along the bone (Intra articular, Metaphyseal, disphyseal).
(e) Long bones of legs with fracture based on loose conditions such as,
  - Fracture due to direct loading – common in motor accidents.
  - Fracture due to indirect loading – common in motor accidents.
  - Fracture due to repetitive loading.
  - Fracture due to penetration.

For Injuries of pelvis and lower extremities, the AIS tables are considered for classification and categorization.

Traumatic Injuries to Pelvis and the Proximat Femur

In case of pelvis injury, it is categorized as an isolated single fracture of the pelvioting. In case of multiple fractures, the pelvic ring becomes unstable causing large displacement of the fractured segments. They can be with urogenital injuries. Sacrum fracture occurs in extensive pelvic injuries fracturing usually across the foramina or in the vicinity of the holes through which sacral nerves pass which are in danger in case of such injuries, especially hemorrhage. Excessive bleeding occurs from large blood vessels in the pelvic wall as well as from the fractured surfaces themselves. The pelvic fracture has been dealt by Otte (2002) in much greater detail. Femoral fractures can cause excessive bleeding due to its rich blood supply as well as obvious deformity sometimes post injury fractures involves neck of femur (hip) are commonly seen in elderly as a result of direct impact.

Leg, Knee, and Foot

Crandall (2000) has carried out investigation on the injury mechanism for femur fracture and has given the following details:

- Axial compression 62%
- Bending 24%
- Torsion and shear 5% each

He stated that fracture pattern femur, being bowed anteriorly, with convex side forward, plays a role especially in indirect loading.

Levine (2002) discovers that impact on knee, can under direct loading, cause patella to fracture. Patella fracture can also occur from strong muscles contraction (quadriceps) on partially fixed knee. In reality the bone anatomy of the knee gives very little support to the joints stability which in turn, makes the knee ligaments prone to injury. Assuming on some occasion, the knee becomes bent and an object hits the tibia backwards the posterior cruciate ligament can tear and the injury is termed *dash board injury*. When the pedestrian impact (lateral impact) occurs, the lateral ligament then ruptures. The knee joint is completely dislocated when all four knee joint ligaments rupture.

Tibia fractures can be caused by direct and indirect loading and are common in the lowest limb. Crandall (2001) states that tibia lies subcutaneously and the bone is covered by the skin and if breached deeply it will result such fractures are called *open fractures*. Most fractures occur between the mid shaft region and the distal third of the tibia Crandall (2001) reports that for tibia as well as for fibula injuries, the fracture is dependent on numerous things. Both tibia and fibula fractures when occurred will depend on stability that is the fracture is more unstable if both bones are broken on the same shaft level. A severe fracture of tibia involves the tibia plateau. The injury mechanisms of ankle and foot injuries are according to Crandall (2001), closely related to the possible motion range of the ankle and the hind foot. From the axial load in frontal collisions, injuries are 58%, inversion with 15% and eversion with 11%. Metatarsal injuries are solely caused by direct impact and 100% of all calcaneus injuries are due to axial loading Crandall (2001) indicates that pure axial loading can result talus fracture known as Pylon fracture. Inversion and eversion account for the vast majority of malleolar injuries especially ankle fractures, making the ankle most frequently injured major joint of the human body.

A number of tests have been carried out to determine factual data and some of them are known for basic work. Among them are Kitagawa et al. (1998a), Kitagawa et al. (1998a), Petit et al. (1996), in order to match with the list. Please check. Crandall et al. (1995) and Cappon et al. (1999) are known per experiments on injury mechanism of the lower limb injuries and studies addressing the role of muscles force.

1.9 Anthropomorphic Test Devices (ATD)

1.9.1 Introduction

The ATD is a mechanical model of the human body which is normally used as a human surrogate in crash testing. It offers also a possibility to measured static, dynamic and impact loading. Different types are used as crash – test dummies. The dummy is generally made of steel, aluminum (for skeleton), polymers (for joints and skin) and foam (for flesh). The dummies are equipped with accelerometers for measuring accelerations and load cells for recording force and deformation or displacement. The ATDs are used in the automotive engineering for new vehicles and occupant protection potential. Dummies can also be used in aircraft industry for testing and protection of individuals against aviation hazards, parachutes structure failure and ejection of seats. From the experimental purposes, crash test dummies should be sensitive to various parameters and injury mechanism. The ATDs should on one hand represent human in terms of size, mass and mass distribution and sitting posture and finally must have a human-like response that is biomechanical response impact and impulsive load. Hence the ATDs must have the following requirements:

(a) Anthropometry: Data on standing height 1.751 m, weight = 78.2 kg.
(b) Biofidelity: Data based on cadaver (dead body).
(c) Test repeatability: Data on test capability and calibration regularly.
(d) Model durability: To withstand a high number of tests and over loading up to 1.3 times, i.e., 102 kg.

1.9.2 Fields of Application

The following family of dummies are given as test models

Hybrid III Frontal Impact Loading

This dummy types consists of three, six and ten year old small adult female (fifth percentile), midsize adult male (50th percentile) and large size adult male (95th percentile). This family is designed for frontal impact test. The 50th percentile male dummy is a regulated test device in the European ECE regulations and in the US safety standards. The skull and skull cap of Hybrid III 50th percentile male dummy and it consists of the following:

- One piece cast in aluminium parts.
- Removable Vinyl skins.
- The neck is segmental rubber with aluminium attached a center cable.
- The rib cage has 6NO H.S. ribs with polymer based damping material to stimulate human chest force-displacement relations. Each rib consists of right and left anatomical contains again ribs in one continuous part while open with upper part (Sternum) and anchored to the back of thoracic spine. The sternum assembly includes a slider for the chest deflection/displacement rotary potentiometer.
- The angle between the neck and the upper torso has a neck bracket in corporated with a six axis neck transducer. A two piece clavicle (Collar Bone) and clevical link assemblies have integral *scapulae* to interface with shoulder belts.

– A curved cylindrical rubber lumbar spin (lower part) mount has been provided human like touch of a seated person and stuck to the pelvis through a three axis lumbar load cell. The pelvis constructed is of a vinyl skin/urethane foam molded on an aluminium casting in a seated position. The ball-jointed femur attachments offer hip moment-rotation characteristics.
– An allowance can be made to predict bone fracture by instrumenting femur, tibia and ankle. A typical ligament injury, heel compression and ankle rotations can be determined.

Thor Frontal Impact Loading

Thor (Test Device for Human Occupant Restraint) is a further impact dummy and is based on the anthropometry of the 50th percentile male. While comparing the design for Hybrid III family, here all dummy components have been improved except the arms which are identical to those of Hybrid III. In order to assess the facial fracture the facial region is instrumented with uni-directional load cells. It is interesting to know that the biofidelity and the geometry, the ribcage is made up of elliptical ribs and by improving instrumentation a SD dynamic compression can now be evaluated at four distinct points. A new abdominal assembly had been devised to measure directly belt intrusion and upper abdomen displacement due to air bag compression. Here changes are brought about in pelvis, lower limbs and ankle joint.

Dummies for Lateral Impact (SID)

Various types of dummies are available for lateral and sick impact and they are:

(a) EUROSID: This a European side impact dummy with different versions.
(b) EUROSID2: This is the European side impact dummy. This is an updated version of EUROSID. It is 50th percentile adult male. It consists of metal and plastic skeleton covered by flesh simulating material. Generally the sitting height is 0.904 m with mass 72 kg. It has no lower arms while the rest is the same as Hybrid III.
(c) SID: Is based on Hybrid III with an adapted Thorax but without arms and shoulder structures. It is the official US impact testing of new cars (FMVSS2140) and the size corresponds to the 50th percentile male. It measures injury to the head, chest and pelvis.
(d) SID HIII: To account for better head–neck biofidelity, this SID is equipped with a Hybrid III head and neck.
(e) SID IIS: This is a side impact dummy representing a 5th percentile female.
(f) BIOSID: This is a dummy of biofidelity side impact type.

(g) WORLD SID: The International Standardization Organization (ISO) has developed a harmonized side impact dummy of a mid size. This dummy is used through out the world. This is used for improved assessment of injury risk to car occupants in lateral collision. Besides an improved biofidelity, it leads to a harmonization in safety regulations.

Biofidelic Rear-End Dummy (BIO RID) or RID2

Injuries and trauma developed in low speed rear end collision, the need is emerged to modify anthropomorphic test device that allowed the investigation of such impact condition. Two different dummy types exist, namely Bio RID and RID2. Both are middle sized male dummies developed in Europe for assessing for so-called "Whiplash" injuries under low speed rear and impacts.

(a) Biofidelic Rear-End Dummy (BIO RID). The main feature is full segmented spine consisting of 24 segments. Each human spinal pivot point is reproduced. Due to such a detailed representation, a high biofidelic spinal is generally observed.
(b) The Rear Impact Dummy (RID2). This is based on the Hybrid III 50th percentile male. However, several modifications have been made of which new design of the neck. The most acceptable one is made up of seven aluminium discs with flexible thorax and lumbar spine.
Some difficulties in handling arise with specially designed rear-end dummies. Because of increased flexibility the positioning of dummies compared with Hybrid III becomes more difficult.

Polar Dummy

The polar dummy has been designed to simulate kinematics of the human body during car-pedestrian collisions. The dummy stands 175 cm tall and weighs 75 kg. It is intended to gather more accurate date on the pedestrians injuries. The instrumentations suggests, it is entirely meant for the car-pedestrian interacting and producing necessary answers.

Dummies Representing Children Trauma and Injuries

The following symbols adopted for dummies with instrumentations pertaining children injuries:

(a) PO – Newborn child.
(b) P3/4 – Nine month old child.
(c) P3 – Three year old child.
(d) P6 –
(e) P10 –
(f) Q-Dummies – Infant dummy types.

(g) CRABI – Child Restraint Air Bag Dummy. It is used to evaluate air bag exposure to infant restrainer in child safety seats. They come in three sizes

6 month old	Hybrid III family
12 month old	
18 month old	

TNO – 10

It is a loading device for testing safety belts in a simulated crash condition. It represents 50th percentile male dummy with size and weight distribution. The dummy has no lower arm and only one lower leg.

Impactors

The most common Impactors are

- Head Impactors
- Headship Impactors
- Pedestrian Impactors

Plate 1.13 gives test conditions and threshold values for vehicles tested under FMVSS208 and FMVSS214 and ECER94 and R.95. Plate 1.14 gives data on wind generated missiles and objects might cause impact to human body. Plate 1.15 indicates data for other vehicles as impactors or involved in trauma injury factors and data which effect the impact parameters and influence the evaluation of traumatic injuries.

Plate 1.13. Test conditions for lateral impact threshold values frontal impact threshold values

	FMVSS 208	ECE R94
dummies	2 hybrid III	2 hybrid III
head	HIC $< 1,000$	HPC $< 1,000$ a3ms < 80 g
neck	N_{ij}, 1.0	next, 57 Nm not exceeding defined force corridor
thorax	deflection < 76.2 mm a3ms < 60 g	deflection < 50 mm VC < 1.0
femur	axial force < 10 kN	not exceeding defined force corridor
knee		deflection < 15 mm
tibia		axial force < 8 kN TI < 1.3

Plate 1.13. *Continued*

	side impact threshold values	
	FMVSS 214	ECE R95
dummies	2 SID	1 EuroSID
head		HPC $< 1,000$
thorax	TTI < 85 g	VC < 1.0
abdomen		internal force < 2.5 kN
pelvis	A (peak) < 130 g	pubic force < 6 kN

test conditions applied by the Euro-NCAP (http>//www.euroncap.com)

impact	test conditions
frontal impact	64 km/h, deformable barrier, 40% overlap
side impact	50 km/h, trolley fitted with a deformable front is towed into the driver's side of the car

Plate 1.14. Wind generated elements in accidents with human beings

missile type	geometry				
	diameter (mm)	length (m)	impact area (m^2)	velocity (m/s)	weight (kg)
wooden plank	–	3.67	0.03	41.5	56.7
wooden pole	200	3.67	0.03	5.73	94.8
circular hollow sections in steel (average)	168.3	4.00	0.000026	70.2	60
sign boards (average)	–	–	6.0	57.0	56
steel I-beam light sections (average)	–	4.0	0.000032	40.5	100
steel members channel sections (average)	–	3.0	0.000013	50.5	30

Plate 1.14. *Continued*

missile type	geometry			velocity	weight
	diameter (mm)	length (m)	impact area (m^2)	(m/s)	(kg)
steel members L-sections (average)	–	3.0	0.000015	45.5	36
steel rafters T-sections (average)	–	3.0	0.000018	45.5	42
steel rod	25	0.92	0.00049	75.6	3.63
concrete lintels	–	3.0	0.025	60.5	1.80
concrete sleepers	–	2.70	0.0031	75.0	0.20
precast concrete beams or piles at delivery stage	–	9.0	0.09	60.5	19.44
precast concrete wall panels	–	5.0	11.5	2.5	1,380
prestressed concrete pipes	400	–	–	–	1.100
	500	–	–	–	1.375
	600	–	–	–	1.650
	700	–	–	–	1.920
	800	–	–	–	2.200
	900	–	–	–	2.474
	1,676	6.0	0.032	–	4.608
prestressed concrete poles	–	17.0	0.0019	30.5	65.7
		12.0	0.00080	50.1	14.46
		9.0	0.000025	65.2	9.65

Reproduced from
Bangash M.Y.H. Impact and Expulsion – Analysis and Design
Blackwell, Oxford (1993)

Plate 1.15. Data on Cars as Missiles for Traumatic Injuries

manufacturer vehicle	length (m)	width (m)	height (m)	wheel base (m)	laden weight (kg)	max. speed (miles h^{-1})
Alfa Romeo						
33 1.7 Sport Wagon Veloce	4.142	1.612	1.345	2.465	925	115
75 2.0i Veloce	4.330	1.630	1.350	2.510	1,147	124
164 3.0 V6	4.555	1.760	1.4	2.660	1,300	142
American Motors (USA)						
Jeep Wagoner limited	4.198	1.790	1.615	2.576	2,074	90
Aston Martin						
Lagonda	5.820	1.790	1.3	2.91	2,023	143
V8 Vantage Volante	4.39	1.86	0.1295	2.610	1,650	160
Vantage Zagato	4.39	1.86	0.1295	2.610	1,650	186
Audi (D)						
80 1.85	4.393	1.695	1.397	2.544	1,020	113
90 Quattro	4.393	1.695	1.397	2.546	1,270	125
100	4.792	1.814	1.422	2.687	1,250	118
100 Turbo Diesel	4.793	1.814	1.422	2.687	1,250	108
200 Avant Quattro	4.793	1.814	1.422	2.687	1,410	139
Austin						
Maestro 1.60 Mayfair	4.049	1.687	1.429	2.507	946	102
Metro 1.0 Mayfair 3-door	3.405	1.549	1.361	2.251	771	86
Montego Vanden Plas EFi Estate	4.468	1.710	1.445	2.570	1,111	110
Bentley (GB)						
Mulsanne	5.268	1.887	1.485	3.061	2,245	119
Mulsanne Turbo R	5.268	1.887	1.486	3.061	2,221	143
Bitler (D)						
Type III	4.450	1.765	1.395	–	1,300	140
BMW (D)						
320i Convertible	4.325	1.645	1.380	2.57	1,125	123
325i Touring	4.325	1.645	1.380	2.57	1,270	132
M 3	4.325	1.645	1.380	2.57	1,150	139
520i	4.72	1.751	1.412	2.761	1,400	126
735i	4.91	1.845	1.411	2.832	1,590	145
750i L	5.024	1.845	1.401	2.832	–	155
Z 1	3.921	–	–	2.45	110	140
Bristol (GB)						
Brigand Turbo	4.902	0.1765	1.4535	2.895	1,746	150
Buick (USA)						
Lesabre T-type Coupe	4.991	1.838	1.389	2.814	1,458	115

Plate 1.15. *Continued*

Cadillac (USA)						
Allante Convertible	4.537	1.864	1.325	2.525	1,585	110
Cadillac (USA)						
Allante Convertible	4.537	1.864	1.325	2.525	1,585	110
Chevrolet (USA)						
Camaro IROC-2	4.775	1.850	1.270	2.565	1,525	130
Corvette Convertible	4.483	1.805	1.185	2.438	1,414	142
Chrysler (USA)						
le Baron Convertible	4.697	1.738	1.326	2.546	1,474	110
GS Turbo 2	4.555	1.76	1.302	2.465	1,194	125
Portofino	–	–	–	–	–	150
Citroen (F)						
Ax 14 TRS	3.495	1.56	1.35	2.285	695	99
Bx 19 GTi 16v	4.229	1.657	1.365	2.655	1,093	130
Bx 25 GTi Turbo	4.660	1.77	1.36	2.845	1,385	126
Coleman Milne (GB)						
Grosvenor limousine	5.563	1.964	1.575	3.661	2,100	115
Dacia (R)						
Duster 4 × 4 GLX	3.777	1.6	1.74	2.4	1,180	70
Daihatsu (J)						
Charade LX Diesel Turbo	3.61	1.615	1.385	2.34	810	87
Charade GT ti	3.61	1.615	1.385	2.34	816	114
Fourtrak Estate EL TD	4.065	1.580	1.915	2.53	1,660	83
Daimler						
3.6	4.988	2.005	1.358	2.87	1,770	137
Dodge (USA)						
Daytonna Shelby 2	4.545	1.76	1.279	2.464	1,220	120
Ferrari						
F40	4.43	1.981	1.13	2.451	1,100	201
Mondial 3.2 Quattro valvole	4.58	1.79	1.26	2.65	1,430	143
Fiat						
Croma Turbo ie	4.495	1.76	1.433	2.66	1,180	131
Panda 4 × 4	3.378	1.485	1.46	2.159	761	83
Ford						
AC (GB)	3.962	1.816	1.168	2.477	907	140
Ford (D)						
Escort RS Turbo	4.046	1.588	1.348	2.4	1,017	124
Granada 2.4i GL	4.669	1.76	1.41	2.761	1,265	120
Scorpio 4 × 4 2.9i	4.669	1.766	1.453	2.765	1,385	126
XR3i Cabriolet	4.049	1.64	1.336	2.398	925	115

Plate 1.15. *Continued*

manufacturer vehicle	length (m)	width (m)	height (m)	wheel base	laden weight (kg)	max. speed (miles h^{-1})
Ford (GB, B)						
Sierra Sapphire GLS 2.0EFi	4.468	1.699	1.359	2.609	1,060	115
Ford (B)						
Sierra Ghia 4 × 4 Estate	4.511	1.694	1.359	2.612	1,315	119
Ford (USA)						
Taurus	4.785	1.796	1.795	2.692	1,299	105
Ginetta (GB)						
G32	3.758	1.651	1.168	2.21	753	135
Honda (J)						
Accord Aerodeck 2.0 EXL	4.335	1.651	1.335	2.6	1,147	110
Legend Coupe	4.755	1.745	1.37	2.705	1,395	132
Prelude 2.0L-16	4.460	1.695	1.295	2.565	1,145	128
Hyundai (J)						
Pony 1.5 GLS	3.985	1.595	1.38	2.38	890	96
Stellar 1.6 GSL	4.427	1.72	1.372	2.579	1,034	98
Isuzu (J)						
Trooper Turbo Diesel	4.38	1.65	1.8	2.3	1,655	78
Jaguar (GB)						
Sovereign 3.6	4.988	2.005	1.358	2.87	1,770	137
XJ6 2.9	4.988	2.005	1.38	3.87	1,720	117
Lada (Su)						
Riva Cossack	3.708	1.676	1.638	2.197	1,150	77
Samara 1300 SL	4.006	1.62	1.335	2.46	900	92
Lamborghini (I)						
Countach 5000s Quattro valvole	4.14	2.0	1.07	2.45	1,446	178
Lancia (I)						
Delta 1.6 GTie	3.895	1.62	1.38	2.475	995	115
Delta HF vitegrade	3.9	1.7	1.38	1.38	1,200	134
Thema 2.0ie Turbo Estate	4.59	1.755	1.433	2.66	1,150	139
Thema 8.32	4.59	1.755	1.433	2.66	1,400	139
Y10 Turbo	3.392	1.507	1.425	2.159	790	111
Land Rover (GB)						
One Ten Diesel Turbo	4.445	1.79	2.035	2.795	1,931	73
Range Rover Vogue Turbo D	4.47	1.718	1.778	2.591	2,061	90
Lincoln (USA)						
Continental	5.21	1.847	1.412	2.769	1,645	112

Plate 1.15. *Continued*

Lotus (GB)						
Esprit Turbo	4.331	1.859	1.138	2.459	1,268	152
Maserati (I)						
Bi Turbo 228	4.46	1.865	1.33	2.6	1,240	151
Mazda (J)						
121 1.3LX Sun Top	3.475	1.605	1.565	2.295	775	99
626 2.0 GLX Hatchback	4.515	1.69	1.375	2.575	1,196	111
626 2.0i GT Coupe	4.45	1.69	1.36	2.515	1,230	130
RX7	4.29	1.69	1.265	2.43	1,221	134
Mercedes Benz (D)						
190E 2.6	4.427	1.678	1.39	2.665	1,209	130
300CE	4.655	1.682	1.41	2.715	1,390	126
560 SEL	5.16	2.006	1.446	1.555	1,780	147
Mercury (USA)						
Topa 3 XR5	4.468	1.747	1.339	2.537	1,135	92
MG (GB)						
Maestro 2.0 EFi	4.05	1.69	1.42	2.51	975	114
Metro Turbo	3.403	1.563	1.359	2.251	840	110
Montego Turbo	4.468	1.71	1.42	2.565	1,079	125
Mitsubishi (J)						
Galant Sapporo	4.66	1.695	1.375	2.6	1,230	114
Starion 2000 Turbo	4.43	1.745	1.315	2.435	1,308	133
Mitsubishi Colt (J)						
Lancer 1500 GLX Estate	4.135	1.635	1.42	2.38	950	95
Morgan (GB)						
Plus 8	3.96	1.575	1.32	2.49	830	122
Nissan (J)						
Bluebird 1.6 LS	4.405	4.365	1.69	1.395	1,120	103
Praire Anniversary II	4.09	1.655	1.6	2.51	1,070	95
Silvia Turbo ZX	4.351	1.661	1.33	2.425	1,136	124
Oldsmobile (USA)						
Trofeo	4.763	1.798	1.346	2.741	1,526	115
Panther (GB)						
Kallista 2.9i	3.905	1.712	1.245	2.549	1,020	112
Solo 2	4.344	1.78	2.18	2.53	1,100	150
Peugeot (F)						
205 GTi Cabriolet	3.706	1.572	1.354	2.421	884	116
205 GRD	3.706	1.572	1.369	2.421	895	96
Peugeot (GB)						
309 SRD	4.051	1.628	1.379	2.469	950	99
Plymouth (USA)						
Sundance	2.463	1.71	1.339	2.463	1,131	105
Pontiac (USA)						
Bonneville SSE	5.046	2.838	1.409	2.814	1,504	112

Plate 1.15. *Continued*

manufacturer vehicle	length (m)	width (m)	height (m)	wheel base	laden weight (kg)	max. speed (miles h^{-1})
Porsche (D)						
911 Speedster	4.291	1.65	1.283	2.273	1,140	152
944 S	4.2	1.735	1.275	2.4	1,280	140
Reliant (GB)						
Scimitar 1800 Ti	3.886	1.582	1.24	2.133	889	124
Renault (F)						
Espace 2000 – 1	4.25	1.277	1.66	2.58	1,177	105
5 GTD	3.65	1.585	1.397	2.466	830	94
21 GTS	4.46	1.714	1.415	2.659	976	113
21 Turbo	4.498	1.714	1.375	2.597	1,095	141
Rolls-Royce (GB)						
Silver Spirit	5.27	1.887	1.495	3.06	2,245	119
Rover (GB)						
216 Vanden Plas	4.16	1.62	1.39	2.45	945	107
820i	4.694	1.946	1.398	2.759	1,270	126
Saab (S)						
900 Turbo 16S Convertible	4.739	1.69	1.42	2.525	1,185	124
9000i	4.62	1.765	1.43	2.672	1,311	118
Seat (E)						
Ibiza 1.5 GLX 5-door	3.638	1.609	1.394	2.448	928	107
Malaga 1.5 GLX	4.273	1.65	1.4	2.448	975	103
Skoda (CS)						
130 Cabriolet LUX	4.2	1.61	1.4	2.4	890	95
Subaru (J)						
Justy 4 × 4	3.535	1.535	1.42	2.85	770	90
XT Turbo Coupe	4.49	1.69	1.335 1.370	2.465	1,139	119
Suzuki (J)						
Santana	3.43	1.46	1.69	2.03	830	68
Swoft 1.3 GTi	3.67	1.545	1.35	2.245	750	109
Toyota (J)						
Celica 2.0 GTi Convertible	4.365	1.71	1.29	2.525	1,195	125
Corolla GTi	4.215	1.655	1.365	2.43	945	122
Space Cruiser	4.285	1.67	1.815	2.235	1,320	87
Supra 3.0i	4.62	1.745	1.31	2.595	1,550	135
TVR						
S Convertible	4	1.45	1.117	2.286	900	128
TVR (GB)						
9205 EAC Convertible	4.051	1.628	1.379	2.469	950	99
Vauxhall						
Astra Cabriolet	2.463	1.71	1.339	2.463	1,131	105
Astra GTE 2.0ie 16v	5.046	2.838	1.409	2.814	1,504	112
Carlton CD 2.0i	4.291	1.65	1.283	2.273	1,140	152
Carlton GSi 3000	4.2	1.735	1.275	2.4	1,280	140
Senator 3.0i CD	3.886	1.582	1.24	2.133	889	124

Plate 1.15. *Continued*

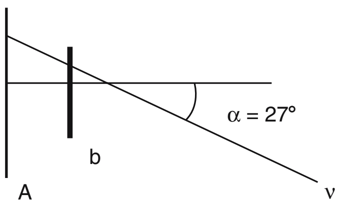
Volkswagon (D)						
Golf GTi 16v	4.25	1.277	1.66	2.58	1,177	105
Jetta GTi 16v	3.65	1.585	1.397	2.466	830	94
Scirocco GTX	4.46	1.714	1.415	2.659	976	113
Volvo (NL)						
360 GLY	4.498	1.714	1.375	2.597	1,095	141
480 ES	5.27	1.887	1.495	3.06	2,245	119
Volvo (S)						
760 GLE	4.16	1.62	1.39	2.45	945	107
Yugo (YU)						
65A GLX	4.694	1.946	1.398	2.759	1,270	126

type of missile	weight (kg)	impact area (cm^2)	impact velocity ($m\,s^{-1}$)
control rod mechanism or fuel rod	53	15.5	91.5
disc 90° sector	1,288	4,975	125
disc 120° sector	1,600	6,573	156
hexagon head bolts			
1.4 cm diameter	0.20	1.54	250
2.0 cm diameter	0.30	2.30	230
2.4 cm diameter	0.37	2.84	189
3.3 cm diameter	0.42	3.22	150
6.8 cm diameter	0.97	7.44	100
turbine rotor fragments			
high trajectory			
heavy	3,649	5,805	198
moderate	1,825	3,638	235
light	89	420	300
low trajectory			
heavy	3,649	5,805	128
moderate	1,825	3,638	235
light	89	420	244
valve bonnets			
heavy	445	851	79
moderate	178	181	43
light	33	129	37
valve stems			
heavy	23	25.0	27.5
moderate	14	9.7	20.0
other			
30 cm pipe	337.0	260.00	68
12 cm hard steel disc	1.6	113.0	140
steel washers	0.0005	3.0	250
Winfrith Test missile	15.6	176.0	240

Plate 1.16. Data on Impacting Two Vehicles and Missile Shapes

KEY Two vehicles Impacting

1. FMVSS – USA



Data FMVSS 214

Width $b = 1,676\,\mathrm{mm}$

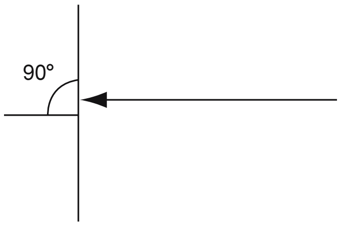
Mass $m = 1,368\,\mathrm{kg}$

Speed $v = 33.5\,\mathrm{m\,h^{-1}} = 54\,\mathrm{km\,h^{-1}}$

A one vehicle 90°
B other vehicle Impact angle $a = 27°$

2. ECE-R95 Europe

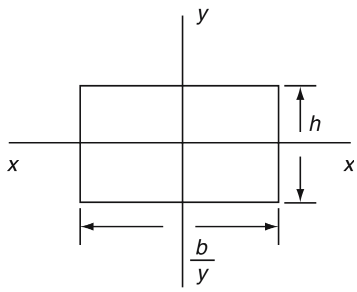
$b = 1,500\,\mathrm{mm}$
$m = 950\,\mathrm{kg}$
$v = 50\,\mathrm{km\,h^{-1}}$



A one vehicle 90°
B other vehicle $a = 0$
i.e., at right angle to each other
For unit weight all expressions are multiplied by p

(1) Rectangular cross section of a missile

$$I_{xx} = bh^3/12,$$
$$I_{yy} = hb^3/12.$$



(2) Solid circular cross section of diameter D

$$I_{xx} = I_{yy} = \pi d^4/64.$$

(3) Hollow circular cross section of outer diameter D and inner diameter d

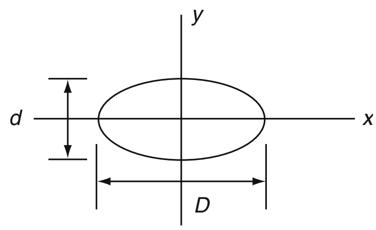
$$I_{xx} = I_{yy} = \pi(D^4 - d^4).$$

(4) Thin-walled tubular cross section of outer diameter D and thickness t.

$$I_{xx} = 1_{yy} = \pi t D^3/8.$$

(5) Elliptical type

$$I_{xx} = \pi D d^3/64,$$
$$I_{yy} = \pi D^3 d/64.$$

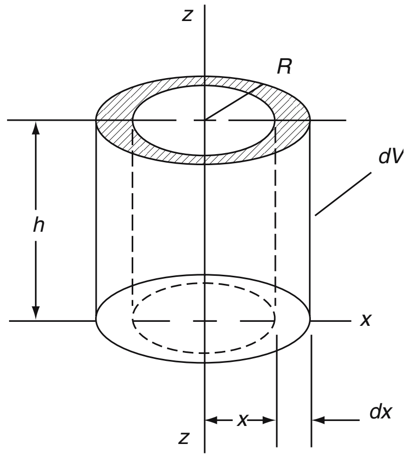


(6) Triangular cross section with base b and height h

$$I_{xx}\,(\text{parallel to } b) = bh^3/36$$

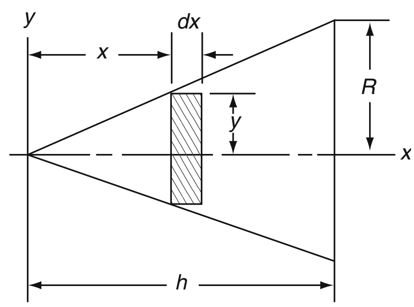
(7) Right circular cylindrical type missile

$$I_{zz} = \pi h R^4/2,$$
$$M = p\pi R^2\text{h}.$$



(8) Cone-shaped missile

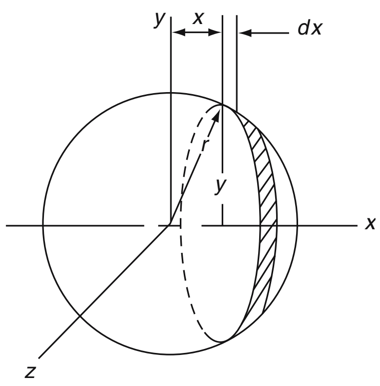
$$I_{xx} = R^4 h/10,$$
$$P = m/(\pi R^2 h/3).$$



(9) Solid spherical missile

$$I_{xx} = 8/15\pi r^5,$$
$$x = \sqrt{(r^2 - y^2)},$$
$$y = \sqrt{(r^2 - x^2)},$$

where $p = m/4/3\pi r^3$

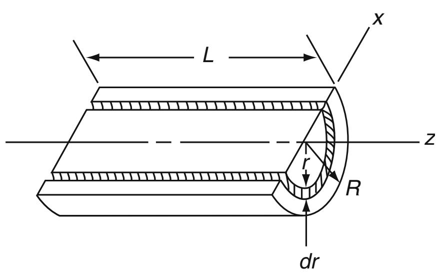


(10) Hollow spherical missile

$$I_{xx} = I_{yy} = I_{zz} = 2/3\,Wr^2,$$
$$W = 4p\pi r^2.$$

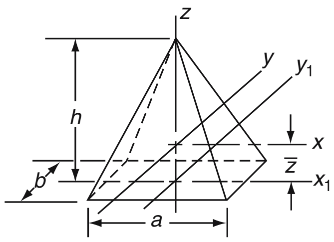
(11) Wedge-shaped semicylindrical missile

$$I_{zz} = ph\pi R4/4,$$
$$\text{Where } p = m/\pi^2 h.$$



(12) Pyramid-shaped missile
(a) Right rectangular pyramid

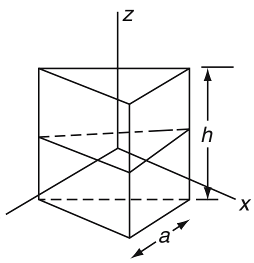
$$I_{xx} = W/20(b^2 + 3h^2/4),$$
$$I_{x1x1} = W/20(b^2 + 2h^2),$$
$$I_{yy} = W/20(a^2 + 3/4h^2),$$
$$I_{y1y1} = W/20(a^2 + 2h^2),$$
$$I_{zz} = W/20(a^2 + b^2),$$
$$W = pabh/2.$$



(i) Right rectangular pyramid–type missile.

(b) Regular triangular prism

$$I_{xx} = I_{yy} = W/24(a^2 + 2h^2),$$
$$I_{zz} = Wa^2/12,$$
$$W = \sqrt{3/4a^2h}.$$

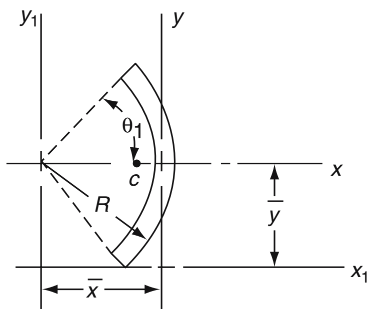


(ii) Regular triangular prism–type missile.

(13) Rod-shaped missile

(1) Segment of a circular rod

$$I_{xx} = WR^2[1/2 - (\sin\theta_1 \cos\theta_1)/2\theta_1)$$
$$I_{x1x1} = WR^2[1/2 - (\sin\theta_1 \cos\theta_1)/2\theta_1) + \sin^2\theta],$$
$$I_{yy} = WR^2[1/2 + (\sin\theta_1 \cos\theta_1/2\theta_1) - \sin^2\theta/\pi^2),$$
$$I_{y1y1} = WR^2(1/2 + \sin\theta_1 \cos\theta_1/2\theta_1)X$$
$$X = R\sin\theta_1/\theta_1$$
$$I_c = WR^2(1 - \sin^2\theta_1/\theta_1^2),$$
$$Y = R\sin\theta_1,$$
$$W = (\text{density})(\text{volume}).$$



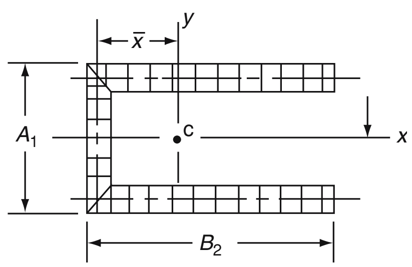
Rod (segment–shaped) missile.

(2) Elliptical rod

$$
\begin{aligned}
I_{xx} &= Wb^2(55a^4 + 10a^2b^2 - b^4)/2(45a^4 + 22a^2b^2 - 3b^4),\\
I_{yy} &= Wa^2(35a^4 + 34a^2b^2 - 5b^4)/2(45a^4 + 22a^2b^2 - 3b^4),\\
I_c &= I_{xx} + I_{yy}.
\end{aligned}
$$

(3) U-rod shaped missile

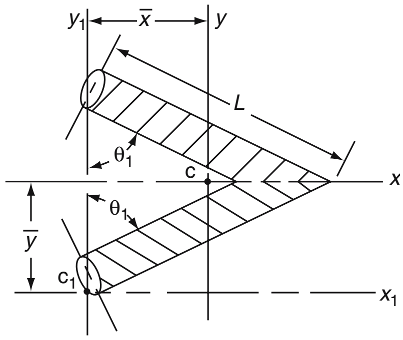
$$
\begin{aligned}
X &= L_2^2/(L_1 + 2L_2);\ y = A_1/2,\\
I_{xx} &= WA_1^2(A_1 + 6B_2)12(A_1 = 2B_2),\\
I_{yy} &= WB^3/_2(2A_1 + B_2/3(A_1 + 2B_2)^2,\\
I_c &= I_{xx} + I_{yy}.
\end{aligned}
$$



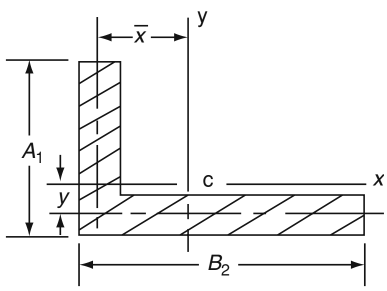
(4) V-rod shaped missile

$$
\begin{aligned}
X &= {}^1\!/_2 L\sin\theta_1;\ y = L\cos\theta_1\\
I_{xx} &= {}^1\!/_3 WL^2 \cos^2\theta_1
\end{aligned}
$$

$$I_{x1x1} = 4/3WL^2 \cos^2\theta_1,$$
$$Iyy = \frac{WL^2}{12} \sin^2\theta_1,$$
$$Iy_1y_1 = {}^1\!/\!_3WL^2 \sin^2\theta_1,$$
$$I_c = I_{xx} + I_{yy},$$
$$I_c = I_{x1x1} + I_{y1y1}.$$



V–rod–shaped missile.



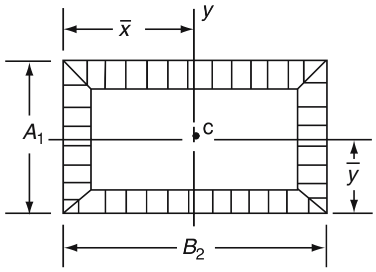
L–rod–shaped missile.

(5) L-rod shaped missile

$$x = {}^1\!/\!_2B_2;\ y = {}^1\!/\!_2A_1$$
$$I_{xx} = WA_1^2(A_1 + 3B_2)/12(A_1 + B_2),$$
$$I_{yy} = WB_2^2(3A_1 + B_2)/12(A_1 + B_2),$$
$$I_c = I_{xx} + I_{yy}.$$

(6) Hollow rectangular missile

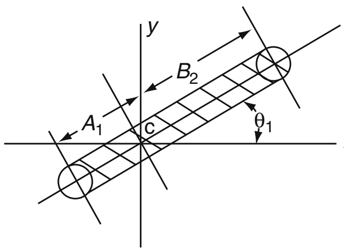
$$
\begin{aligned}
{\scriptstyle Ixx-} &= \frac{WA^2}{12} /_1(A_1 + 3B_2)/A_1 + B_2)^2, \\
I_{yy} &= WB_2^2(3A_1 + B_2)/(A_1 + B_2)^2, \\
I_c &= I_{xx} + I_{yy}.
\end{aligned}
$$



Hollow rectangular missile.

(7) Inclined rod-shaped missile flight (not through centroidal axis)

$$
\begin{aligned}
I_{xx} &= 1/3 W \sin^2\theta_1(Ax^2 - A_1B_2 + B_2^2), \\
I_{yy} &= 1/3 \mathrm{W}\cos^2\theta_1(Ax^2 - A_1B_2 + B_2^2), \\
I_c &= I_{xx} + I_{yy}.
\end{aligned}
$$



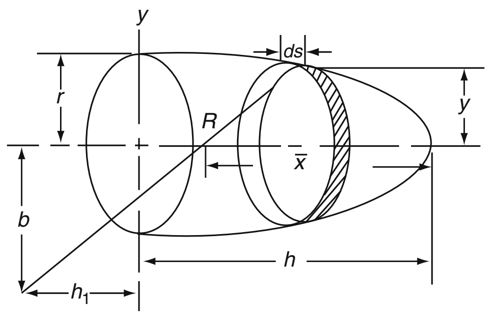
Rod-shaped missile at an inclination.

(8) Ogive-shaped missile

$$
\begin{aligned}
A_s x &= \text{surface area developed}; x = \text{centroid}, \\
A_s x &= 2\pi f_0^h \; xyds, \\
&= 2\pi R\{h^2 - br + bh_1[\sin^{-1}(h + h_1)/R - \sin^{-1} h_1/R]\}, \\
y &= [(R^2 - h_1^2) - 2h_1 x - x^2]^{1/2} - b,
\end{aligned}
$$

$$A_s = \text{surface area developed; } x = \text{centroid,}$$
$$A_s = 2\pi R(h - b[\sin^{-1}(h + h_1)/R - \sin^{-1} h_1/R]\}.$$

I_{xx} and I_{yy} can thus be easily calculated for a typical curve of radius R.

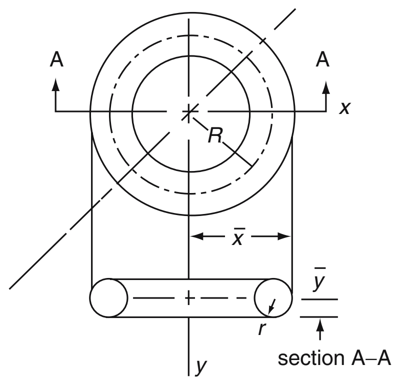


Ogive–shaped missile.

(9) Torus and spherical sector missiles

(a) Torus

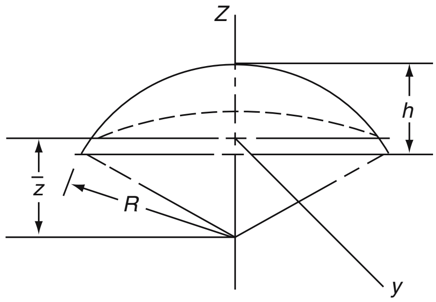
$$I_{xx} = I_{zz} = \frac{W}{8}(4R^2 + 5r^2),$$
$$Iyy = \frac{W}{4}(4R^2 + 3r^2),$$
$$W = 2\pi^2 r^2 p,$$
$$X = z = R + r,$$



Torus–shaped missile.

(b) Spherical sector

$$I_{zz} = \frac{\mathrm{Wh}}{5}(3R - h),$$
$$W = {}^{2}\!/\!_{3}\pi p R^{2} h$$



Spherical sector type missile.

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