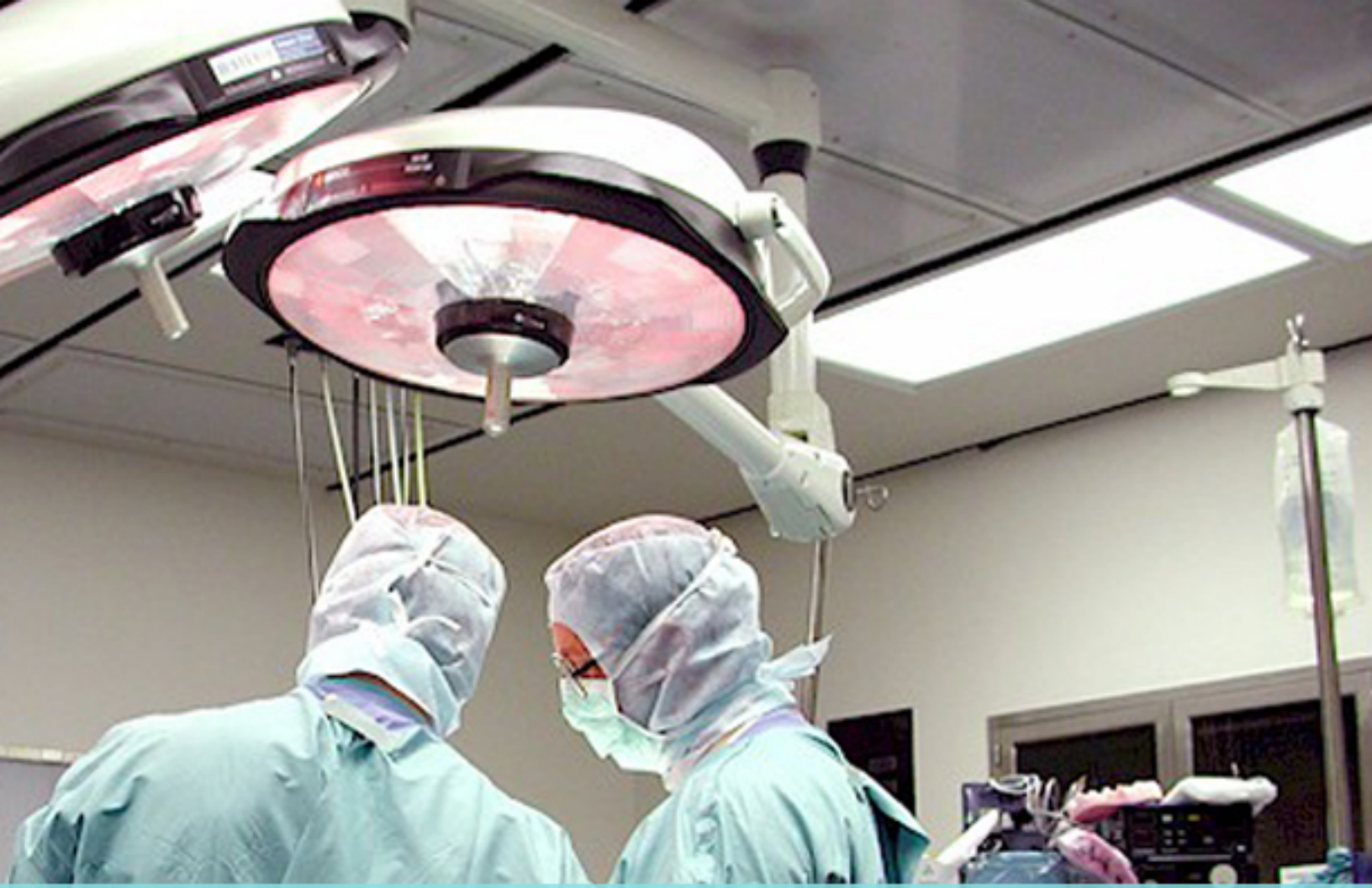

Traumatology and Intensive-Care Medicine

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First Edition, 2012

ISBN 978-81-323-1436-3

Published by:
College Publishing House
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

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Chapter 1

Trauma

Trauma refers to "a body wound or shock produced by sudden physical injury, as from violence or accident." It can also be described as "a physical wound or injury, such as a fracture or blow." Major trauma (defined by an Injury Severity Score of greater than 15) can result in secondary complications such as circulatory shock, respiratory failure and death. Resuscitation of a trauma patient often involves multiple management procedures. Trauma is the sixth leading cause of death worldwide, accounting for 10% of all mortality, and is a serious public health problem with significant social and economic costs.

Classification

Trauma can be classified by the affected area of the body (percentages of total incidence):

- Polytrauma (40%)
- Head injury (30%)
- Chest trauma (20%)
- Abdominal trauma (10%)
- Extremity trauma (2%)
- Facial trauma
- Spinal cord injury
- Genitourinary system trauma
- Pelvic trauma
- Soft tissue injury

Trauma may also be classified by the affected demographic group (for example, trauma in the pregnant, pediatric, or geriatric patient). They may also be classified by the type of force applied to the body, such as blunt trauma versus penetrating trauma.

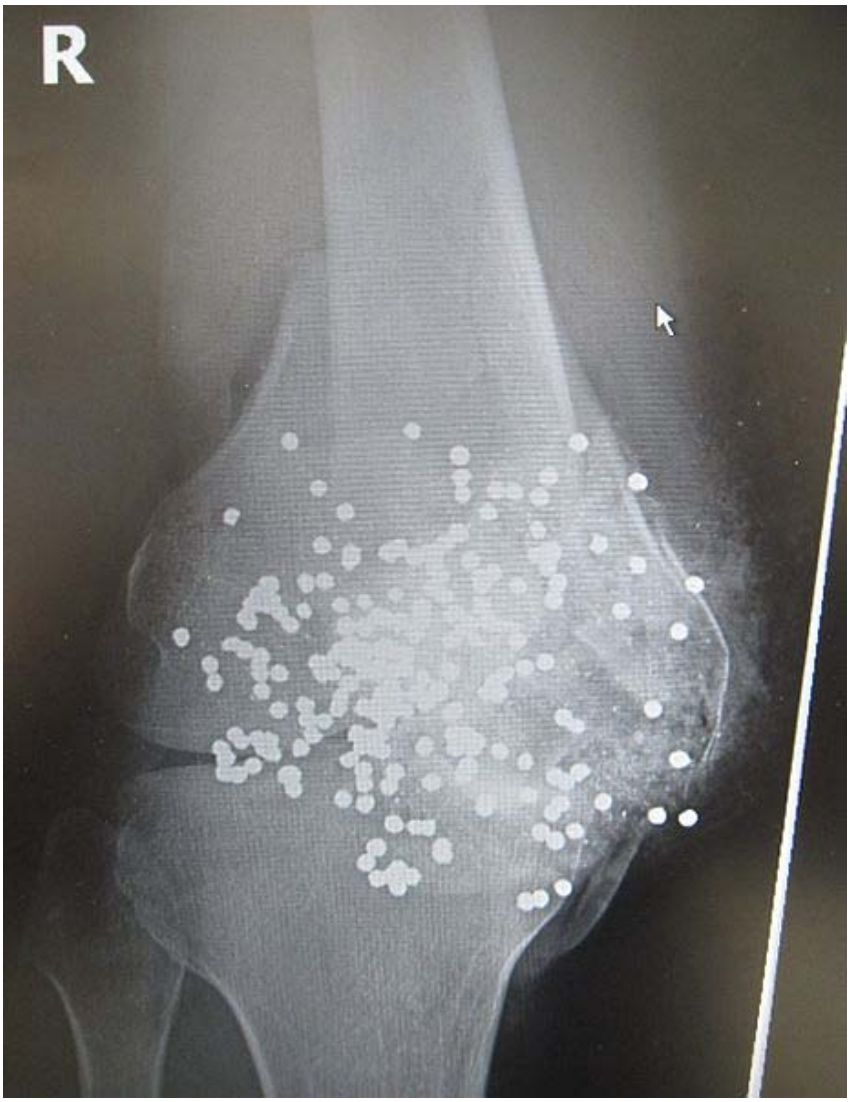
Causes and risk factors

Blunt trauma is the leading cause of traumatic death in the United States. Most cases of blunt trauma are caused by motor vehicle accidents. Falls, a subset of blunt trauma, are the second most common cause of traumatic death. In most cases a fall of greater than three times the victim's height is defined as a severe fall. Penetrating trauma is caused when a foreign object such as a bullet or a knife enters a tissue of the body, creating an open wound. In the United

States most deaths caused by penetrating trauma occur in urban areas and 80% of these deaths are caused by firearms. Blast injury is a complex cause of polytrauma. It commonly includes both blunt and penetrating trauma and may also be accompanied by a burn injury.

By identifying risk factors present within a community and creating solutions to decrease the incidence of injury, trauma referral systems can help to enhance the overall health of its population. Ingestion of alcohol and illicit drugs are risk factors for trauma, particularly traffic collisions, violence and abuse. Long-acting benzodiazepines increase the risk of trauma in elderly people.

Diagnosis



Radiograph of a close-range shotgun blast injury to the knee. Birdshot pellets are visible within and around the shattered patella, distal femur and proximal tibia.

Physical examination

The purpose of the primary survey is to identify life-threatening problems. Upon completion of the primary survey, the secondary survey is begun. This may occur during transport or upon arrival at the hospital. The secondary survey consists of a systematic assessment of the abdominal, pelvic and thoracic area, complete inspection of the body surface to find all injuries, and a neurological examination. The purpose of the secondary survey is to identify all injuries so that they may be treated. A missed injury is one which is not found during the initial assessment (for example, as a patient is brought into a hospital's emergency department), but rather manifests itself at a later point in time.

Imaging

X-rays of the chest and pelvis are commonly performed in major trauma. Focused assessment with sonography for trauma (FAST), can also be used. Computed tomography (CT) scans are the gold standard in imaging in major trauma. They however may only be performed in people with a relatively stable blood pressure, heart rate, and sufficient oxygenation. Full-body CT scans known as pan-scans improve survival in those who have suffered major trauma. The scans are done using intravenous radiocontrast but not oral contrast. There are concerns of radiation exposure and concerns regarding negative effects of contrast on the kidneys. However some centers routinely do CTs with contrast before verifying renal function even in the elderly and have not found negative side effects with respect to the kidneys. With modern imaging technology a complete scan can be performed in less than 10 minutes. In the emergency department in the United States CT or MRI imaging is done in 15% of people who present with injuries as of 2007 (up from 6% in 1998). In those who are significantly hemodynatically unstable from presumed abdominal bleeding delaying surgery for abdominal CT imaging may worsen outcomes.

Surgical techniques

Surgical techniques, such as diagnostic peritoneal lavage, placement of a thoracostomy tube, or pericardiocentesis are often used in cases of severe blunt trauma to the chest or abdomen, especially in the setting of deteriorating hemodynamic stability. In those who are hypotensive due to presumed internal abdominal bleeding transfer to the operating room for a laporotomy is the preferred method of determining a definitive diagnosis.

Management

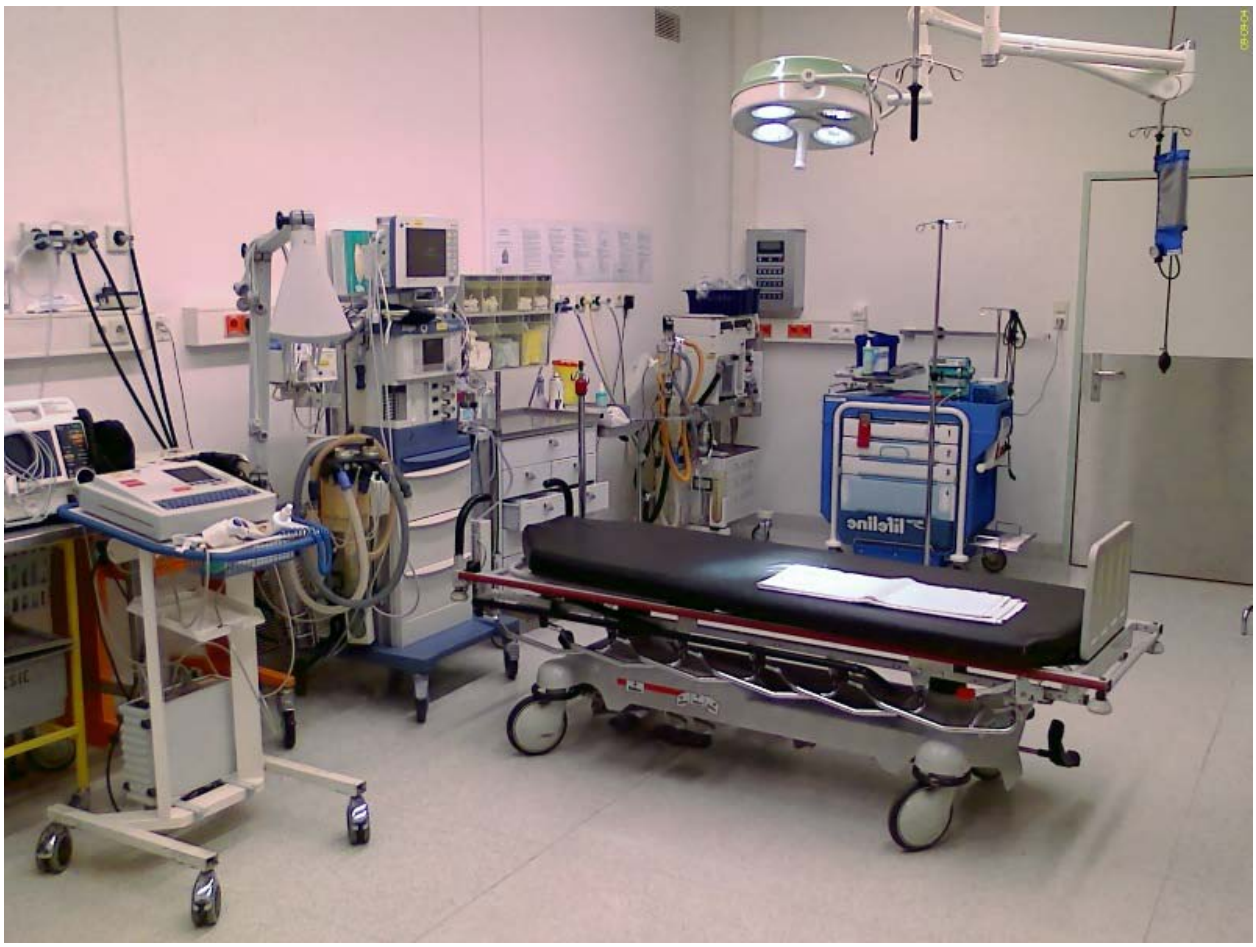
A Navy corpsmen listens for the correct tube placement on an intubated trauma victim during a search and rescue (SAR) exercise

People who have suffered trauma may require specialized care, including surgery and blood transfusion. Outcomes are better if this occurs as quickly as possible thus the so called golden hour of trauma. This is not a strict deadline, but recognizes that many deaths which could have been prevented by appropriate care occur in a relatively short time after injury as shown by the fact most deaths by trauma occur in the first several hours after the event.

Community-based trauma referral systems seek to decrease overall injury-related morbidity and mortality and years of life lost within a population by ensuring the provision of optimal care during both the acute and late phases of injury. Such systems have been established in many places to provide rapid care for injured people. Research has shown that deaths from physical trauma decline where there are organized trauma systems. The care of acutely injured people is a public health issue that involves bystanders and community members, health care professionals, and health care systems. It encompasses prehospital assessment and care by emergency medical

services personnel, emergency department assessment, treatment, and stabilization, and in-hospital care among all age groups. An established trauma system network is also an important component of community disaster preparedness, facilitating the care of victims of natural disasters or terrorist attacks. In those with cardiac arrest due to trauma cardiopulmonary resuscitation (CPR) is considered futile but still recommended.

Stabilization and transportation



The trauma room in the emergency department of the University Hospital in Mannheim, Germany

In the prehospital setting the use of stabilization techniques improve the chances of a person surviving the transport to the nearest trauma-equipped hospital. After ensuring their own safety and taking isolation precautions, a primary survey is performed, consisting of checking and treating airway, breathing, and circulation (called the ABC's) then an assessment of the level of consciousness. To prevent further injury, unnecessary movement of the spine is minimized by securing the neck with a cervical collar, and the back with a long spine board with head supports, or other medical transport device such as a Kendrick extrication device, before moving the person. Unless the person is in imminent danger of death, first responders will typically "load and go," transporting immediately to the nearest appropriate facility.

Rapid transportation of those who are severely injured is associated with improved outcomes. In the prehospital environment, the availability of advanced life support does not improve outcomes for major trauma, when compared with basic life support. The evidence is also inconclusive with respect to support for prehospital intravenous fluid resuscitation and some evidence has found it may be harmful.

People who have severe trauma frequently require specialized physicians and equipment. Designated trauma centers have improved outcomes compared to non designated centers. The transfer directly to a trauma center is associated with improved outcomes compared to transfer to a non trauma center.

Intravenous fluids

Traditionally high volume intravenous fluids were given in people with hemodynamic instability due to trauma. This is still appropriate for those with isolated extremity, thermal or head injuries. The current evidence however supports limiting the use of fluids for penetrating thorax and abdominal injuries allowing mild hypotension to persist. If blood products are needed a greater relative use of fresh frozen plasma and platelets to packed red blood cells has been found to result in improved survival and less overall blood product usage.

Blood substitutes such as hemoglobin-based oxygen carriers and perfluorocarbon emulsions are in development. As of June 2008 however there are none available for commercial use in North America or Europe. The only countries where these products are available for general use is South Africa and Russia.

Medications

In people who are bleeding due to trauma tranexamic acid decreases mortality. Factor VII may also be appropriate in certain cases associated with severe bleeding such as those who have bleeding disorders. While it decreases blood use it does not appear to decrease mortality.

Surgery

Damage control surgery is employed in the management of trauma. This involves performing the least number of procedures to save life and limb. Less critical procedures are left until the person is more stable.

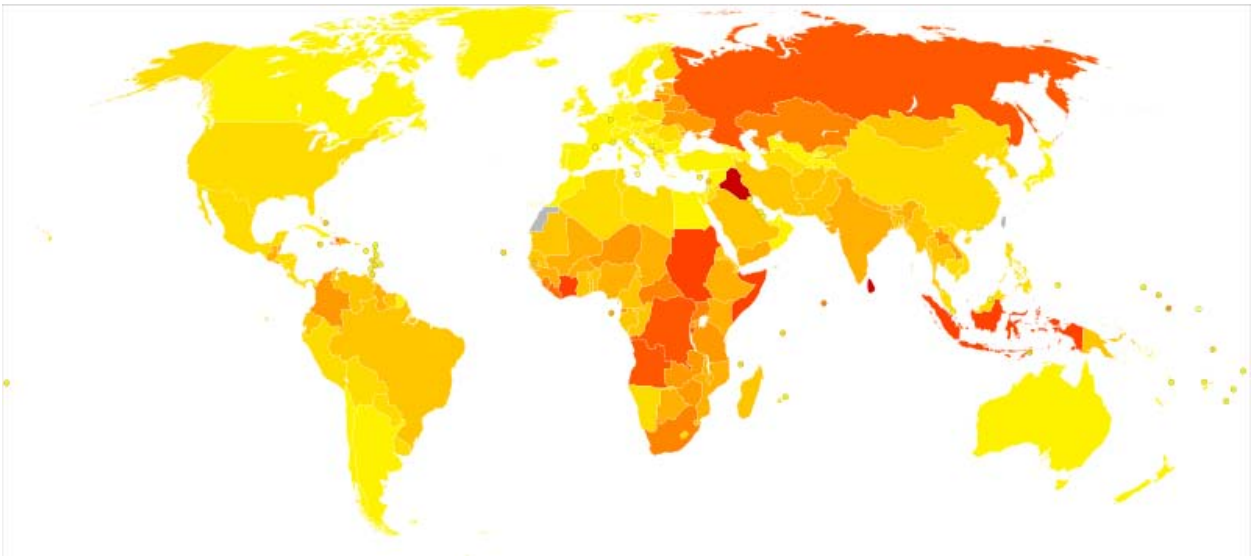
Prognosis

Death from trauma have been classically described as occurring during three peaks: immediately, early, and late. The immediate deaths are usually due to apnea, severe brain or high spinal cord injury, and rupture of the heart or large blood vessels. The early deaths occur within minutes to hours and are often due to a subdural hematoma, epidural hematoma, hemothorax, pneumothorax, ruptured spleen, liver laceration, or pelvic fractures. This is known as the golden

hour. The late deaths occur days or weeks after the injury. This classical distribution however may no longer be occurring in the United States due to improvements in care.

Long term prognosis is also frequently complicated by pain with over half of people having moderately severe pain one year later. Many also experience a reduced quality of life years later. 20% of people who sustain a traumatic injury will sustain some form of disability. Physical trauma can lead to development of post-traumatic stress disorder (PTSD). However, a study found no correlation between the severity of trauma and the development of PTSD.

Epidemiology



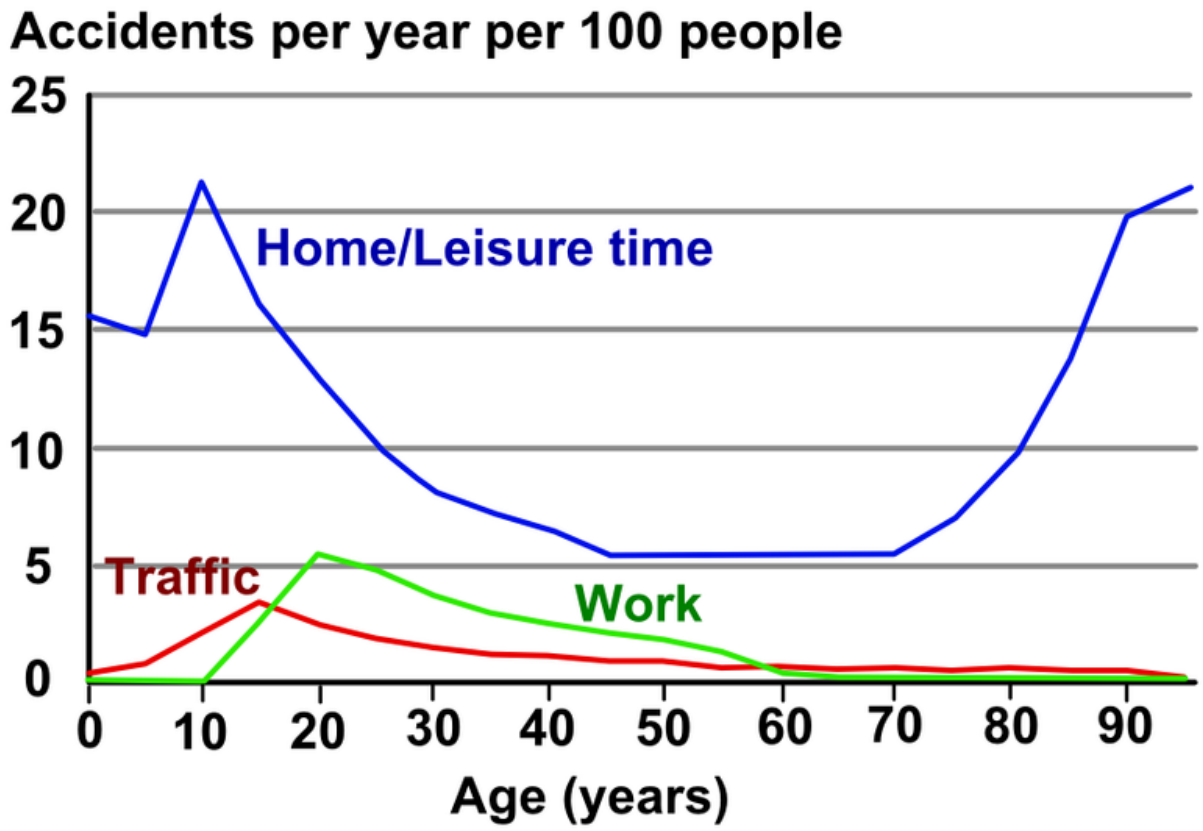
Deaths from injuries per 100,000 inhabitants in 2004

- no data
- < 25
- 25-50
- 50-75
- 75-100
- 100-125
- 125-150
- 150-175
- 175-200
- 200-225

225-250

250-275

> 275



Incidence of accidents by activity

Trauma is the sixth leading cause of death (accounting for 10% of all mortality) worldwide, and the fifth leading cause of significant disability. In people between the ages of 1–45 years, trauma is the leading cause of death. The primary causes of death are central nervous system injury, followed by exsanguination.

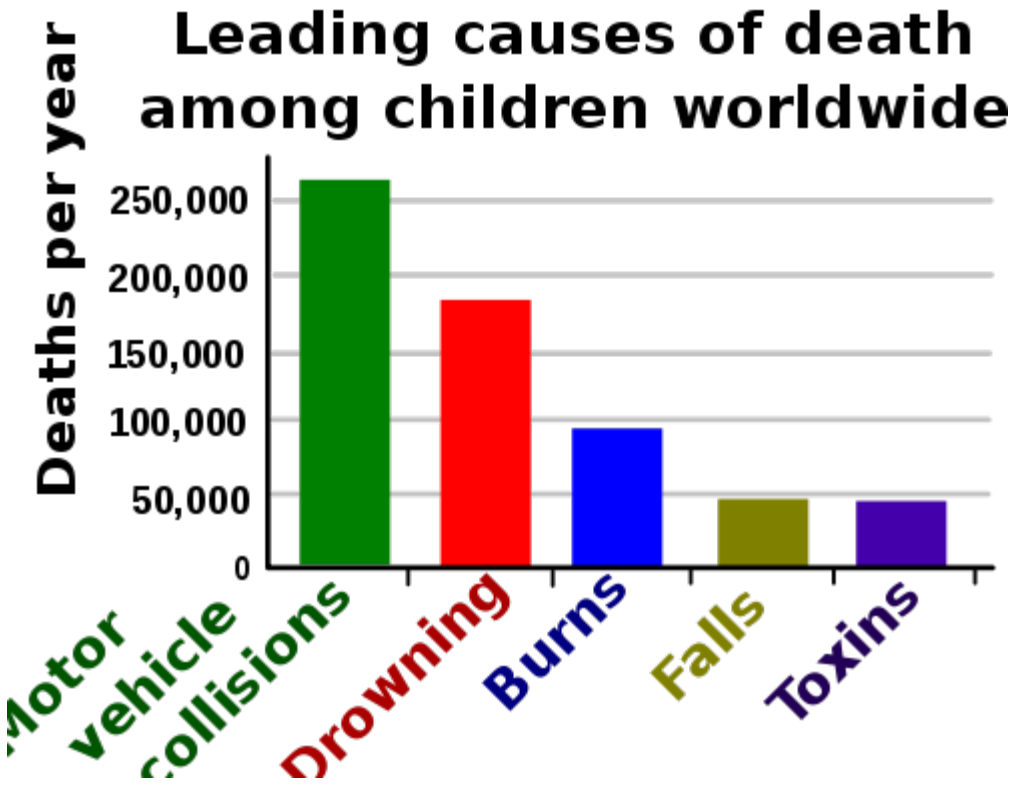
Research

Patients who were admitted into an ICU and received a trauma diagnosis causes a negative change in their health related quality of life with a potential to create anxiety and symptoms of depression.

In children

Accidents are the leading cause of death in children 1–14 years of age. In the US approximatively 16,000,000 children go to an emergency department due to some form of injury every year. Male children are more frequently injured then female children by a ratio of two to one. The top five worldwide unintentional injuries in children are as follows:

Cause	Number of deaths resulting
Traffic collision	260,000 per year
Drowning	175,000 per year
Burns	96,000 per year
Falls	47,000 per year
Toxins	45,000 per year



An important part of managing trauma in children is weight estimation. A number of methods to estimate weight exist including the: Broselow tape, Leffler formula, and Theron formula.

In pregnancy

Trauma occurs in 6-7% of all pregnancies and is the leading cause of maternal death. Trauma during pregnancy is a serious issue as the mothers will have a increased heart rate and increased blood pressure to accommodate the child, these hemodynamic changes will alter the presentation of shock.

There are also diagnostic issues with trauma during pregnancy as ionizing radiation as it can cause birth defects.

Chapter 2

Wound

Wound

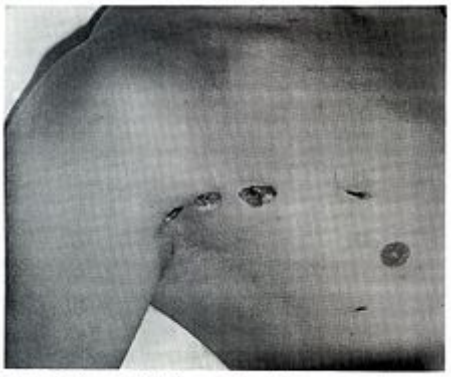


FIGURE 1.—Superficial bullet wounds of chest wall not involving bony structures.

Wounded man

ICD-10	T14.0-T14.1
ICD-9	872-893
MeSH	D014947

In medicine, a **wound** is a type of injury in which skin is torn, cut or punctured (an *open* wound), or where blunt force trauma causes a contusion (a *closed* wound). In pathology, it specifically refers to a sharp injury which damages the dermis of the skin.

Classification

Open

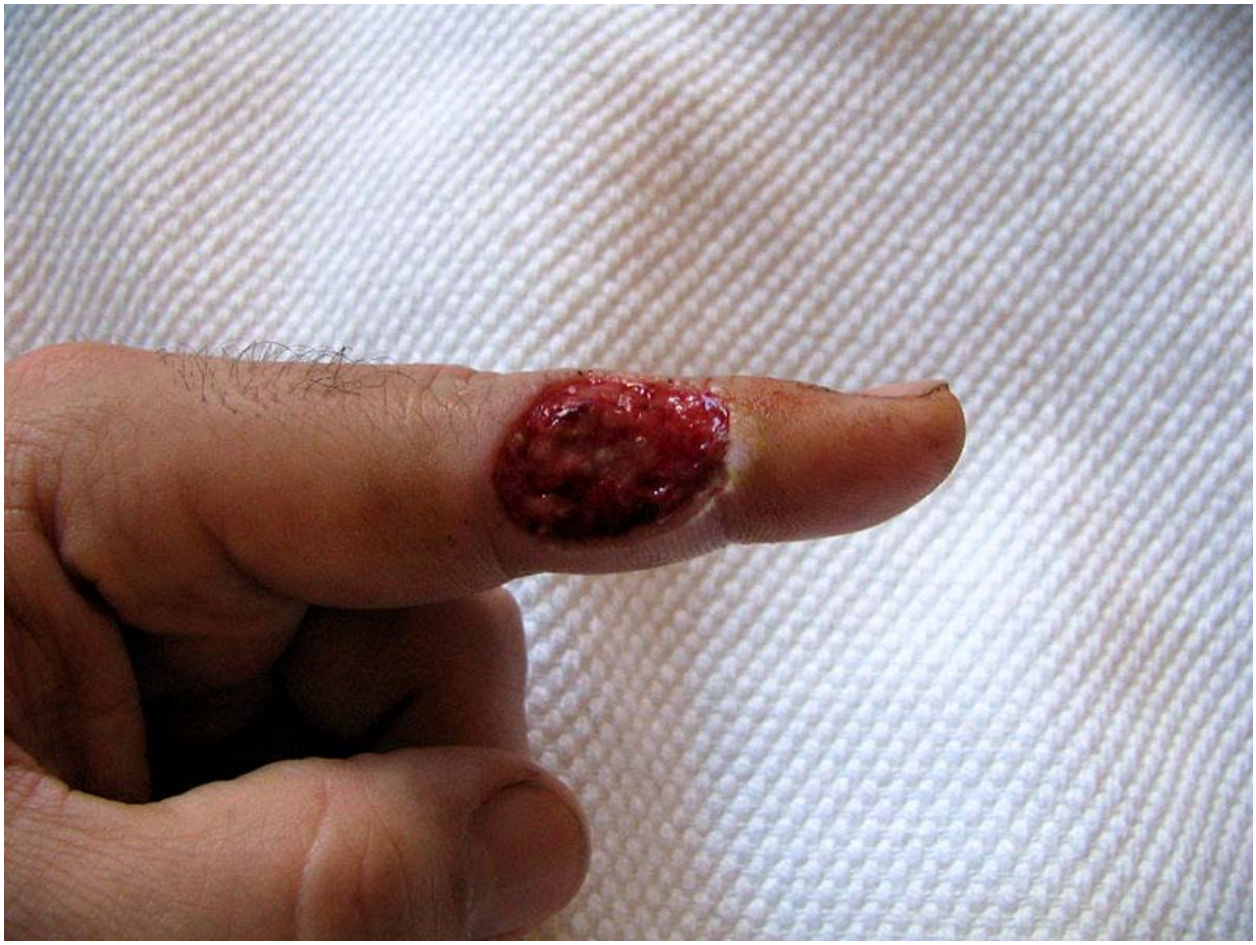
Open wounds can be classified according to the object that caused the wound. The types of open wound are:

- **Incisions** or **incised wounds**, caused by a clean, sharp-edged object such as a knife, a razor or a glass splinter.
- **Lacerations**, irregular tear-like wounds caused by some blunt trauma. Lacerations and incisions may appear linear (regular) or stellate (irregular). The term *laceration* is commonly misused in reference to incisions.
- **Abrasions** (grazes), superficial wounds in which the topmost layer of the skin (the epidermis) is scraped off. Abrasions are often caused by a sliding fall onto a rough surface.
- **Puncture wounds**, caused by an object puncturing the skin, such as a nail or needle.
- **Penetration wounds**, caused by an object such as a knife entering and coming out from the skin.
- **Gunshot wounds**, caused by a bullet or similar projectile driving into or through the body. There may be two wounds, one at the site of entry and one at the site of exit, generally referred to as a "through-and-through."

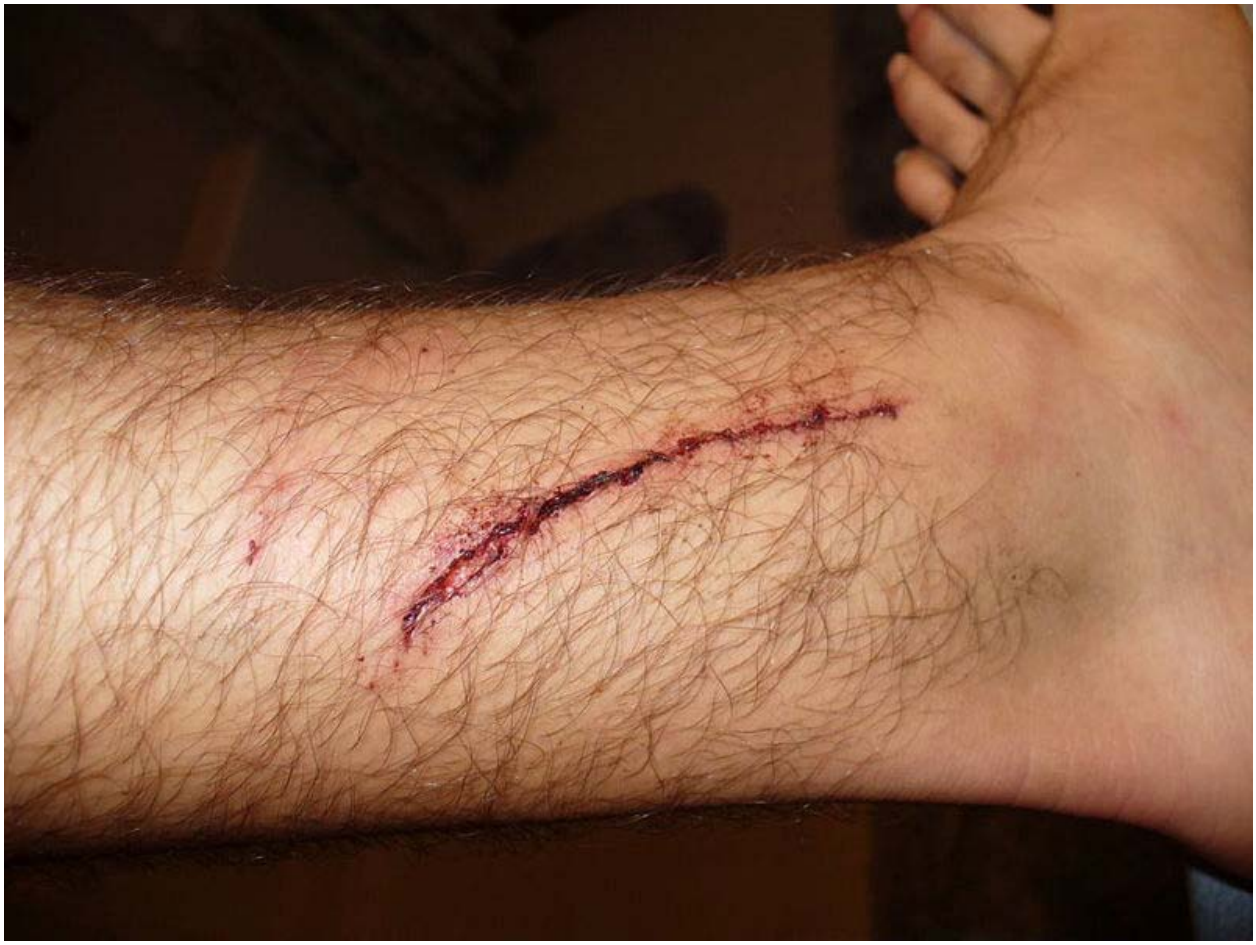
Closed

Closed wounds have fewer categories, but are just as dangerous as open wounds. The types of closed wounds are:

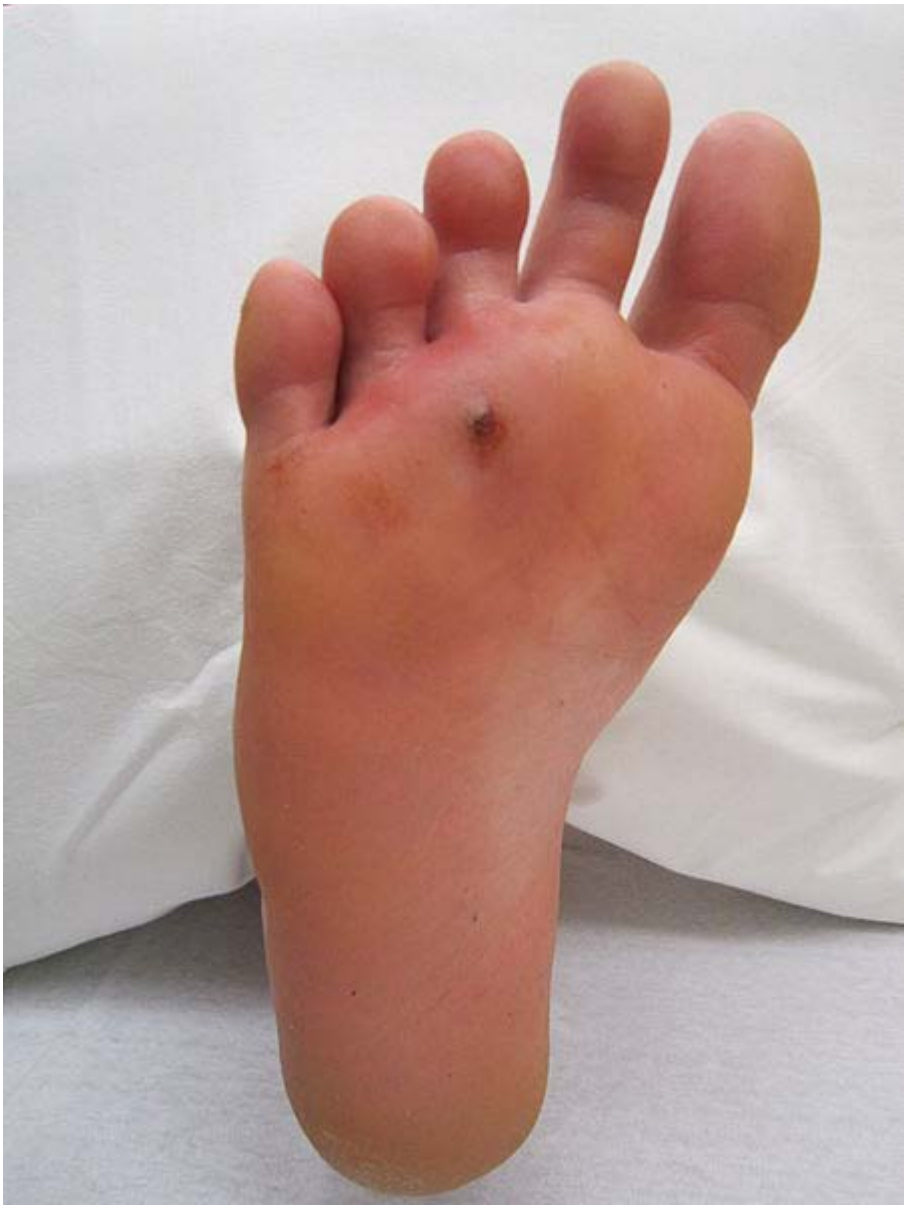
- **Contusions**, more commonly known as bruises, caused by a blunt force trauma that damages tissue under the skin.
- **Hematomas**, also called a blood tumor, caused by damage to a blood vessel that in turn causes blood to collect under the skin.
- **Crush injury**, caused by a great or extreme amount of force applied over a long period of time.
- **Chronic and Acute** Acute or traumatic wounds are the result of injuries that disrupt the tissue. Chronic wounds are those that are caused by a relatively slow process that leads to tissue damage. Chronic wounds include pressure, venous, and diabetic ulcers. Typically, an insufficiency in the circulation or other systemic support of the tissue causes it to fail and disintegrate. Infection then takes hold of the site and becomes a chronic abscess. Once the infection hits a critical point, it can spread locally or become systemic (sepsis).



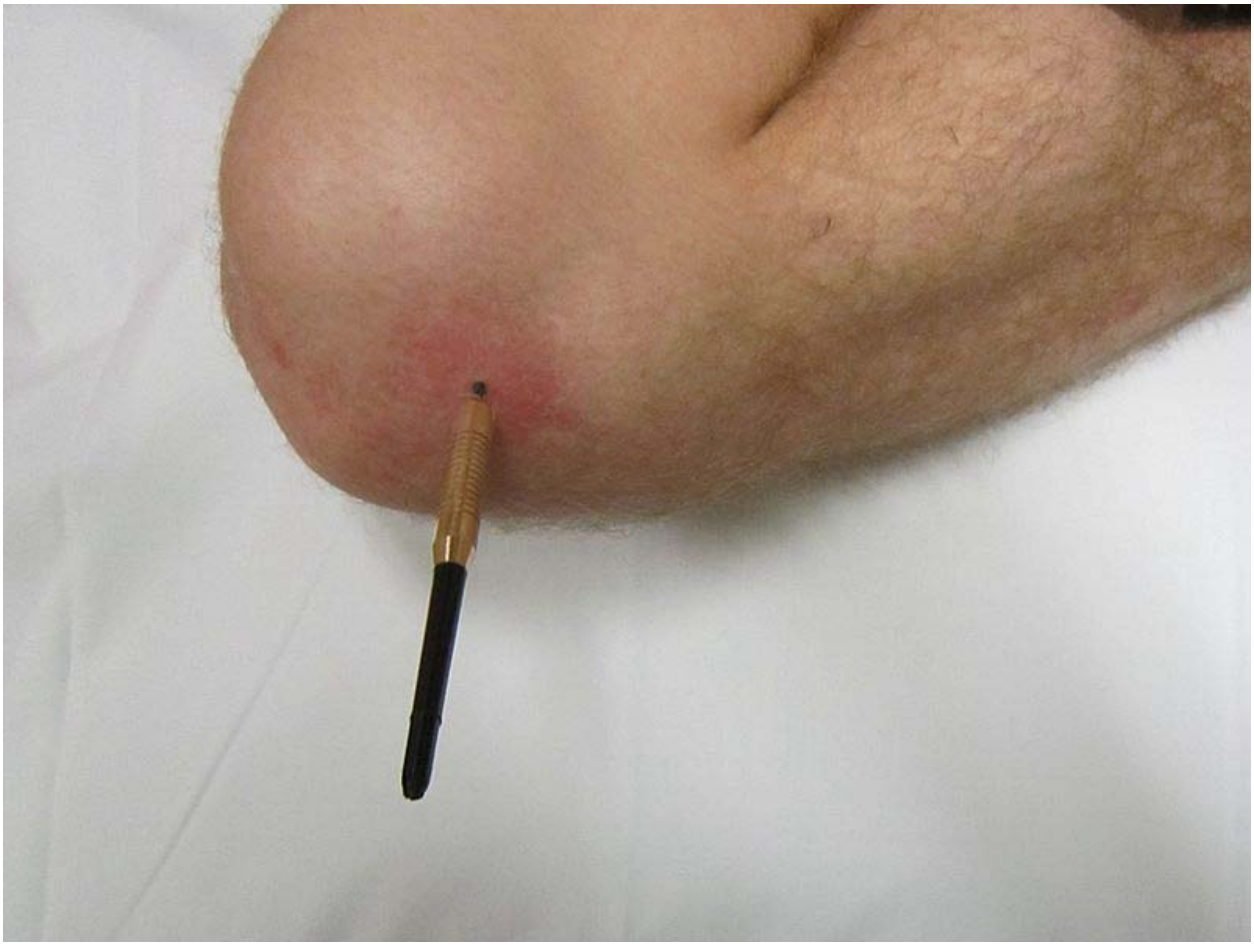
An open wound



A laceration to the leg



An infected puncture wound to the bottom of the forefoot



A puncture wound from playing darts

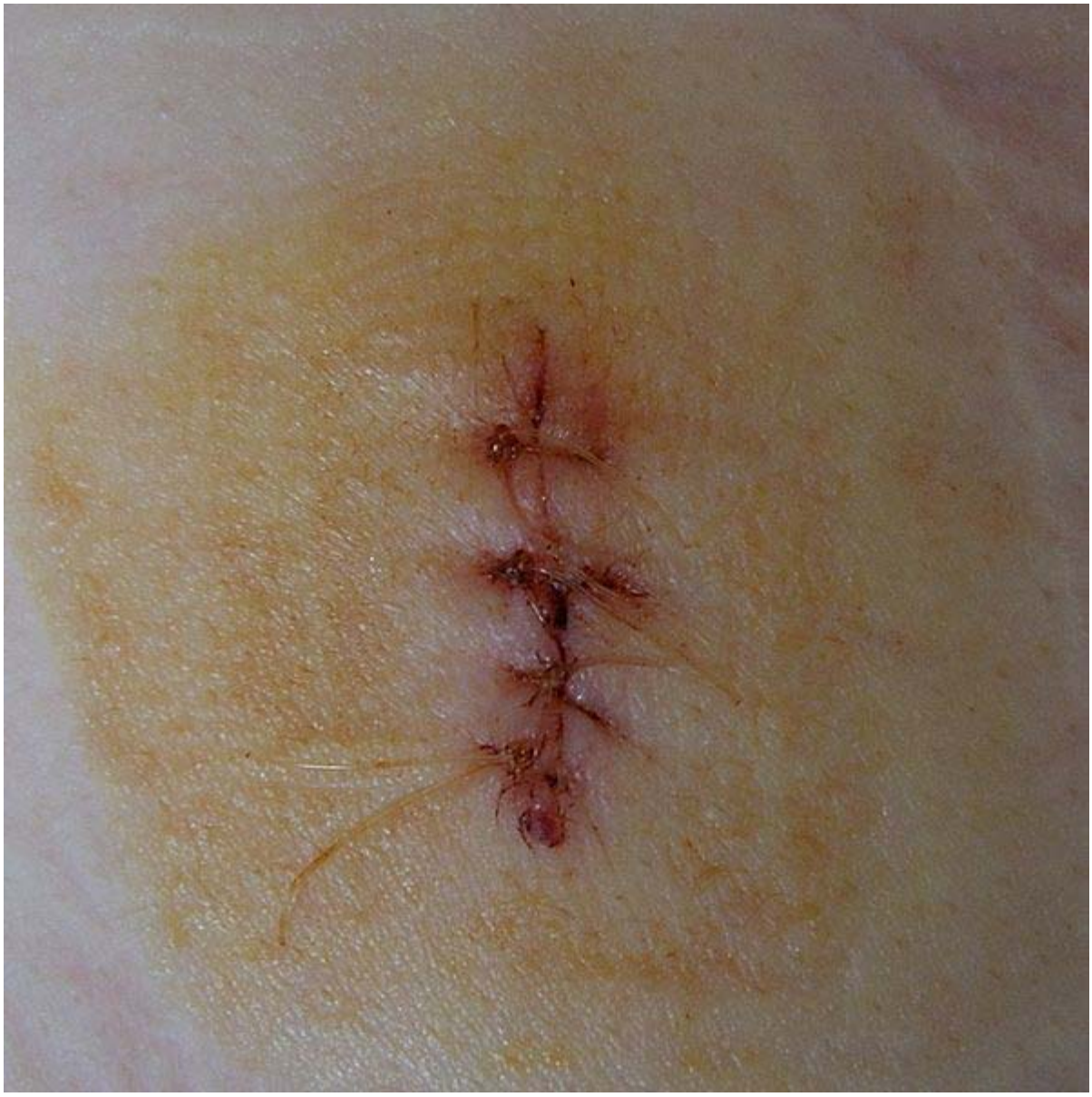
Risk factors

Anyone can develop a wound or infection. There are however some people who may have poor healing abilities like the elderly because of declining immune system. Individuals who are malnourished or who do not eat right foods and lack vitamins, nutrients or have protein deficiency are at risk too. Those who are chronically ill, bedridden or non ambulatory also have high risk factors as well as people who have undergone prolonged corticosteroid use or have been administered a potent immunosuppressive drug. Radiation therapy patients as well as diabetics, the obese and those that have had a stroke or some sort of peripheral vascular disease are also more likely to develop some sort of wound infection.

Pathophysiology

To heal a wound, the body undertakes a series of actions collectively known as the wound healing process.

Management



Wound, sewn with four stitches

The treatment depends on the type, cause, and depth of the wound as well as whether other structure beyond the skin are involved. Treatment of recent lacerations involves examination, cleaning, and closing the wound. If the laceration occurred some time ago it may be allowed to heal by secondary intention due to the high rate of infection with immediate closure. Minor wounds like bruises will heal on their own with skin discoloration usually disappears in 1–2 weeks. Abrasions which are wounds with intact skin usually require no active treatment except keeping the area clean with soap and water. Puncture wounds may be prone to infection

depending on the depth of penetration. The entry of puncture wound is left open to allow for bacteria or debris to be removed from inside.

Cleaning

For simple lacerations cleaning can be accomplished using a number of different solutions including tap water, sterile saline solution, or antiseptic solution. Infection rates may be lower with the use of tap water in regions where water quality is high. Evidence for the effectiveness of any cleaning of simple wound however is limited.

Closure

Incisions caused by a knife or a sharp object need to be thoroughly cleaned and the edges trimmed. If the wounds are fresh and less than 12 hours old, they can be closed with sutures or staples. Any wound which is more than 24 hours old should be suspected to be contaminated and not closed completely. Only the deeper tissues can be approximated and the skin should be left open. If closure of a wound is decided upon a number of techniques can be used. These include bandages, a cyanoacrylate glue, staples, and sutures. Absorbable sutures have the benefit over non absorbable sutures of not requiring removal. They are often preferred in children. Buffering the pH of lidocaine makes the freezing less painful.

Dressings

The effectiveness of dressings and creams containing silver to prevent infection or improve healing is not currently supported by evidence.

Antibiotics

Most clean open wounds do not require any antibiotics unless the wound is contaminated or the bacterial cultures are positive. Excess use of antibiotics only leads to resistance and side effects. All open wounds should be cleaned at least twice a day with warm water and soap. Once the wound is cleaned, it should be covered with moist gauze. This should be followed by application of dry gauze and then the wound covered with a bandage. The purpose of a wet to dry dressing allows the bandage to adhere to dead tissue performing a mechanical debridement when removed.This allows new healthy skin to grow and prevents debris from collecting. When the wound is clean, it may be closed with a skin graft. No wound is ever closed if it is suspected to be infected.

Complications

Bacterial infection of wound can impede the healing process and lead to life threatening complications. Scientists at Sheffield University have identified a way of using light to rapidly detect the presence of bacteria. They are developing a portable kit in which specially designed molecules emit a light signal when bound to bacteria. Current laboratory-based detection of bacteria can take hours or even days.

Work up

Individuals who have wounds that are not healing need to be worked up to find the causes. Many microbiological agents can be responsible for this. The basic work up includes evaluating the wound, its extent and severity. Cultures are usually obtained both from the wound site and blood. X rays are obtained and a tetanus shot may be administered if there is any doubt about prior vaccination

Chronic non-healing

Non-healing wounds of the diabetic foot are considered one of the most significant complications of diabetes, representing a major worldwide medical, social, and economic burden that greatly affects patient quality of life. Almost 24 million Americans—one in every 12—are diabetic and the disease is causing widespread disability and death at an epidemic pace, according to the Centers for Disease Control and Prevention. Of those with diabetes, 6.5 million are estimated to suffer with chronic or non-healing wounds. Associated with inadequate circulation, poorly functioning veins, and immobility, non-healing wounds occur most frequently in the elderly and in people with diabetes—populations that are sharply rising as the nation ages and chronic diseases increase.

Although diabetes can ravage the body in many ways, non-healing ulcers on the feet and lower legs are common outward manifestations of the disease. Also, diabetics often suffer from nerve damage in their feet and legs, allowing small wounds or irritations to develop without awareness. Given the abnormalities of the microvasculature and other side effects of diabetes, these wounds take a long time to heal and require a specialized treatment approach for proper healing.

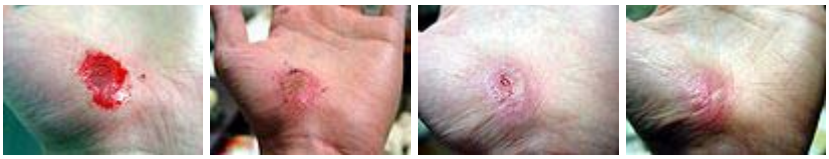
As many as 25% of diabetic patients will eventually develop foot ulcers, and recurrence within five years is 70%. If not aggressively treated, these wounds can lead to amputations. It is estimated that every 30 seconds a lower limb is amputated somewhere in the world because of a diabetic wound. Amputation often triggers a downward spiral of declining quality of life, frequently leading to disability and death. In fact, only about one third of diabetic amputees will live more than five years, a survival rate equivalent to that of many cancers.

Many of these lower extremity amputations can be prevented through an interdisciplinary approach to treatment involving a variety of advanced therapies and techniques, such as debridement, hyperbaric oxygen treatment therapy, dressing selection, special shoes, and patient education. When wounds persist, a specialized approach is required for healing.

Chapter 3

Wound Healing

Hand abrasion



Approximate days since injury

0 2 17 30

Wound healing, or **wound repair**, is an intricate process in which the skin (or another organ-tissue) repairs itself after injury. In normal skin, the epidermis (outermost layer) and dermis (inner or deeper layer) exists in a steady-state equilibrium, forming a protective barrier against the external environment. Once the protective barrier is broken, the normal (physiologic) process of wound healing is immediately set in motion. The classic model of wound healing is divided into three or four sequential, yet overlapping, phases: (1) hemostasis (not considered a phase by some authors), (2) inflammatory, (3) proliferative and (4) remodeling. Upon injury to the skin, a set of complex biochemical events takes place in a closely orchestrated cascade to repair the damage. Within minutes post-injury, platelets (thrombocytes) aggregate at the injury site to form a fibrin clot. This clot acts to control active bleeding (hemostasis).

In the inflammatory phase, bacteria and debris are phagocytosed and removed, and factors are released that cause the migration and division of cells involved in the proliferative phase.

The proliferative phase is characterized by angiogenesis, collagen deposition, granulation tissue formation, epithelialization, and wound contraction. In angiogenesis, new blood vessels are formed by vascular endothelial cells. In fibroplasia and granulation tissue formation, fibroblasts grow and form a new, provisional extracellular matrix (ECM) by excreting collagen and fibronectin. Concurrently, re-epithelialization of the epidermis occurs, in which epithelial cells proliferate and 'crawl' atop the wound bed, providing cover for the new tissue.

In contraction, the wound is made smaller by the action of myofibroblasts, which establish a grip on the wound edges and contract themselves using a mechanism similar to that in smooth muscle cells. When the cells' roles are close to complete, unneeded cells undergo apoptosis.

In the maturation and remodeling phase, collagen is remodeled and realigned along tension lines and cells that are no longer needed are removed by apoptosis.

However, this process is not only complex but fragile, and susceptible to interruption or failure leading to the formation of chronic non-healing wounds. Factors which may contribute to this include diabetes, venous or arterial disease, old age, and infection.

Early vs cellular phase

As mentioned above, wound healing is classically divided into hemostasis, inflammation, proliferation, and remodeling. Although a useful construct, this model employs considerable overlapping among individual phases. Recently, a complementary model has been described, such that the many elements of wound healing are more-clearly delineated. The importance of this new model becomes more apparent through its utility in the fields of regenerative medicine and tissue engineering. In this construct, the process of wound healing is divided into major two phases: *early phase* and *cellular phase*:

The early phase, which begins immediately following skin injury, involves cascading molecular and cellular events leading to hemostasis and formation of an early, makeshift extracellular matrix—providing structural support for cellular attachment and subsequent cellular proliferation.

The cellular phase follows the early phase, and involves several types of cells working together to mount an inflammatory response, synthesize granulation tissue, and restore the epithelial layer. Subdivisions of the cellular phase are: Macrophages and inflammatory components (within 1–2 days), Epithelial-mesenchymal interaction: re-epithelialization (phenotype change within hours, migration begins on day 1 or 2, Fibroblasts and myofibroblasts: progressive alignment, collagen production, and matrix contraction (between day 4 day 14), Endothelial cells and angiogenesis (begins on day 4), Dermal matrix: elements of fabrication (begins on day 4, lasting 2 weeks) and alteration/remodeling (begins after week 2, lasting weeks to months—depending on wound size.).

Inflammatory phase

Just before the inflammatory phase is initiated, the clotting cascade takes place in order to obtain hemostasis, or stop blood loss by way of a fibrin clot. Thereafter, various soluble factors (including chemokines and cytokines) are released to attract cells that phagocytise debris, bacteria, and damaged tissue, in addition to releasing signaling molecules that initiate the proliferative phase of wound healing.

Clotting cascade

When tissue is first wounded, blood comes in contact with collagen, triggering blood platelets to begin secreting inflammatory factors. Platelets also express glycoproteins on their cell membranes that allow them to stick to one another and to aggregate, forming a mass.

Fibrin and fibronectin cross-link together and form a plug that traps proteins and particles and prevents further blood loss. This fibrin-fibronectin plug is also the main structural support for the wound until collagen is deposited. Migratory cells use this plug as a matrix to crawl across, and platelets adhere to it and secrete factors. The clot is eventually lysed and replaced with granulation tissue and then later with collagen.

Platelets, the cells present in the highest numbers shortly after a wound occurs, release a number of things into the blood, including ECM proteins and cytokines, including growth factors. Growth factors stimulate cells to speed their rate of division. Platelets also release other proinflammatory factors like serotonin, bradykinin, prostaglandins, prostacyclins, thromboxane, and histamine, which serve a number of purposes, including to increase cell proliferation and migration to the area and to cause blood vessels to become dilated and porous.

Vasoconstriction and vasodilation

Immediately after a blood vessel is breached, ruptured cell membranes release inflammatory factors like thromboxanes and prostaglandins that cause the vessel to spasm to prevent blood loss and to collect inflammatory cells and factors in the area. This vasoconstriction lasts five to ten minutes and is followed by vasodilation, a widening of blood vessels, which peaks at about 20 minutes post-wounding. Vasodilation is the result of factors released by platelets and other cells. The main factor involved in causing vasodilation is histamine. Histamine also causes blood vessels to become porous, allowing the tissue to become edematous because proteins from the bloodstream leak into the extravascular space, which increases its osmolar load and draws water into the area. Increased porosity of blood vessels also facilitates the entry of inflammatory cells like leukocytes into the wound site from the bloodstream.

Polymorphonuclear neutrophils

Within an hour of wounding, polymorphonuclear neutrophils (PMNs) arrive at the wound site and become the predominant cells in the wound for the first two days after the injury occurs, with especially high numbers on the second day. They are attracted to the site by fibronectin, growth factors, and substances such as kinins. Neutrophils phagocytise debris and bacteria and also kill bacteria by releasing free radicals in what is called a 'respiratory burst'. They also cleanse the wound by secreting proteases that break down damaged tissue. Neutrophils usually undergo apoptosis once they have completed their tasks and are engulfed and degraded by macrophages.

Other leukocytes to enter the area include helper T cells, which secrete cytokines to cause more T cells to divide and to increase inflammation and enhance vasodilation and vessel permeability. T cells also increase the activity of macrophages.

Macrophages

Macrophages are essential to wound healing. They replace PMNs as the predominant cells in the wound by two days after injury. Attracted to the wound site by growth factors released by platelets and other cells, monocytes from the bloodstream enter the area through blood vessel walls. Numbers of monocytes in the wound peak one to one and a half days after the injury occurs. Once they are in the wound site, monocytes mature into macrophages. The spleen contains half the body's monocytes in reserve ready to be deployed to injured tissue.

The macrophage's main role is to phagocytize bacteria and damaged tissue, and they also debride damaged tissue by releasing proteases. Macrophages also secrete a number of factors such as growth factors and other cytokines, especially during the third and fourth post-wounding days. These factors attract cells involved in the proliferation stage of healing to the area., although they may restrain the contraction phase. Macrophages are stimulated by the low oxygen content of their surroundings to produce factors that induce and speed angiogenesis. and they also stimulate cells that reepithelialize the wound, create granulation tissue, and lay down a new extracellular matrix. By secreting these factors, macrophages contribute to pushing the wound healing process into the next phase.

Decline of inflammatory phase

As inflammation dies down, fewer inflammatory factors are secreted, existing ones are broken down, and numbers of neutrophils and macrophages are reduced at the wound site. These changes indicate that the inflammatory phase is ending and the proliferative phase is underway. In vitro evidence, obtained using the dermal equivalent model, suggests that the presence of macrophages actually delays wound contraction and thus the disappearance of macrophages from the wound may be essential for subsequent phases to occur.

Because inflammation plays roles in fighting infection, clearing debris and inducing the proliferation phase, it is a necessary part of healing. However, inflammation can lead to tissue damage if it lasts too long. Thus the reduction of inflammation is frequently a goal in therapeutic settings. Inflammation lasts as long as there is debris in the wound. Thus the presence of dirt or other objects can extend the inflammatory phase for too long, leading to a chronic wound.

Proliferative phase

About two or three days after the wound occurs, fibroblasts begin to enter the wound site, marking the onset of the proliferative phase even before the inflammatory phase has ended. As in the other phases of wound healing, steps in the proliferative phase do not occur in a series but rather partially overlap in time.

Angiogenesis

Also called neovascularization, the process of angiogenesis occurs concurrently with fibroblast proliferation when endothelial cells migrate to the area of the wound. Because the activity of

fibroblasts and epithelial cells requires oxygen and nutrients, angiogenesis is imperative for other stages in wound healing, like epidermal and fibroblast migration. The tissue in which angiogenesis has occurred typically looks red (is erythematous) due to the presence of capillaries.

Stem cells of endothelial cells, originating from parts of uninjured blood vessels, develop pseudopodia and push through the ECM into the wound site to establish new blood vessels.

Endothelial cells are attracted to the wound area by fibronectin found on the fibrin scab and chemotactically by angiogenic factors released by other cells, e.g. from macrophages and platelets when in a low-oxygen environment. Endothelial growth and proliferation is also directly stimulated by hypoxia, and presence of lactic acid in the wound.

To migrate, endothelial cells need collagenases and plasminogen activator to degrade the clot and part of the ECM. Zinc-dependent metalloproteinases digest basement membrane and ECM to allow cell migration, proliferation and angiogenesis.

When macrophages and other growth factor-producing cells are no longer in a hypoxic, lactic acid-filled environment, they stop producing angiogenic factors. Thus, when tissue is adequately perfused, migration and proliferation of endothelial cells is reduced. Eventually blood vessels that are no longer needed die by apoptosis.

Fibroplasia and granulation tissue formation

Simultaneously with angiogenesis, fibroblasts begin accumulating in the wound site. Fibroblasts begin entering the wound site two to five days after wounding as the inflammatory phase is ending, and their numbers peak at one to two weeks post-wounding. By the end of the first week, fibroblasts are the main cells in the wound Fibroplasia ends two to four weeks after wounding.

In the first two or three days after injury, fibroblasts mainly migrate and proliferate, while later, they are the main cells that lay down the collagen matrix in the wound site. Origins of these fibroblasts are thought to be from the adjacent uninjured cutaneous tissue (although new evidence suggests that some are derived from blood-borne, circulating adult stem cells/precursors). Initially fibroblasts utilize the fibrin cross-linking fibers (well-formed by the end of the inflammatory phase) to migrate across the wound, subsequently adhering to fibronectin. Fibroblasts then deposit ground substance into the wound bed, and later collagen, which they can adhere to for migration.

Granulation tissue functions as rudimentary tissue, and begins to appear in the wound already during the inflammatory phase, two to five days post wounding, and continues growing until the wound bed is covered. Granulation tissue consists of new blood vessels, fibroblasts, inflammatory cells, endothelial cells, myofibroblasts, and the components of a new, provisional extracellular matrix (ECM). The provisional ECM is different in composition from the ECM in normal tissue and its components originate from fibroblasts. Such components include fibronectin, collagen, glycosaminoglycans, elastin, glycoproteins and proteoglycans. Its main components are fibronectin and hyaluronan, which create a very hydrated matrix and facilitate

cell migration. Later this provisional matrix is replaced with an ECM that more closely resembles that found in non-injured tissue.

Growth factors (PDGF, TGF-β) and fibronectin encourage proliferation, migration to the wound bed, and production of ECM molecules by fibroblasts. Fibroblasts also secrete growth factors that attract epithelial cells to the wound site. Hypoxia also contributes to fibroblast proliferation and excretion of growth factors, though too little oxygen will inhibit their growth and deposition of ECM components, and can lead to excessive, fibrotic scarring.

Collagen deposition

One of fibroblasts' most important duties is the production of collagen.

Collagen deposition is important because it increases the strength of the wound; before it is laid down, the only thing holding the wound closed is the fibrin-fibronectin clot, which does not provide much resistance to traumatic injury. Also, cells involved in inflammation, angiogenesis, and connective tissue construction attach to, grow and differentiate on the collagen matrix laid down by fibroblasts.

Type III collagen and fibronectin are generally beginning to be produced in appreciable amounts at somewhere between approximately 10 hours and 3 days, depending mainly on wound size. Their deposition peaks at one to three weeks. They are the predominating tensile substances until the later phase of maturation, in which they are replaced by the stronger type I collagen.

Even as fibroblasts are producing new collagen, collagenases and other factors degrade it. Shortly after wounding, synthesis exceeds degradation so collagen levels in the wound rise, but later production and degradation become equal so there is no net collagen gain. This homeostasis signals the onset of the later maturation phase. Granulation gradually ceases and fibroblasts decrease in number in the wound once their work is done. At the end of the granulation phase, fibroblasts begin to commit apoptosis, converting granulation tissue from an environment rich in cells to one that consists mainly of collagen.

Epithelialization

The formation of granulation tissue in an open wound allows the reepithelialization phase to take place, as epithelial cells migrate across the new tissue to form a barrier between the wound and the environment. Basal keratinocytes from the wound edges and dermal appendages such as hair follicles, sweat glands and sebacious (oil) glands are the main cells responsible for the epithelialization phase of wound healing. They advance in a sheet across the wound site and proliferate at its edges, ceasing movement when they meet in the middle.

Keratinocytes migrate without first proliferating. Migration can begin as early as a few hours after wounding. However, epithelial cells require viable tissue to migrate across, so if the wound is deep it must first be filled with granulation tissue. Thus the time of onset of migration is variable and may occur about one day after wounding. Cells on the wound margins proliferate on the second and third day post-wounding in order to provide more cells for migration.

If the basement membrane is not breached, epithelial cells are replaced within three days by division and upward migration of cells in the stratum basale in the same fashion that occurs in uninjured skin. However, if the basement membrane is ruined at the wound site, reepithelization must occur from the wound margins and from skin appendages such as hair follicles and sweat and oil glands that enter the dermis that are lined with viable keratinocytes. If the wound is very deep, skin appendages may also be ruined and migration can only occur from wound edges.

Migration of keratinocytes over the wound site is stimulated by lack of contact inhibition and by chemicals such as nitric oxide. Before they begin to migrate, cells must dissolve their desmosomes and hemidesmosomes, which normally anchor the cells by intermediate filaments in their cytoskeleton to other cells and to the ECM. Transmembrane receptor proteins called integrins, which are made of glycoproteins and normally anchor the cell to the basement membrane by its cytoskeleton, are released from the cell's intermediate filaments and relocate to actin filaments to serve as attachments to the ECM for pseudopodia during migration. Thus keratinocytes detach from the basement membrane and are able to enter the wound bed.

Before they begin migrating, keratinocytes change shape, becoming longer and flatter and extending cellular processes like lamellipodia and wide processes that look like ruffles. Actin filaments and pseudopodia form. During migration, integrins on the pseudopod attach to the ECM, and the actin filaments in the projection pull the cell along. The interaction with molecules in the ECM through integrins further promotes the formation of actin filaments, lamellipodia, and filopodia.

Epithelial cells climb over one another in order to migrate. This growing sheet of epithelial cells is often called the epithelial tongue. The first cells to attach to the basement membrane form the stratum basale. These basal cells continue to migrate across the wound bed, and epithelial cells above them slide along as well. The more quickly this migration occurs, the less of a scar there will be.

Fibrin, collagen, and fibronectin in the ECM may further signal cells to divide and migrate. Like fibroblasts, migrating keratinocytes use the fibronectin cross-linked with fibrin that was deposited in inflammation as an attachment site to crawl across.

As keratinocytes migrate, they move over granulation tissue but underneath the scab (if one was formed), separating it from the underlying tissue. Epithelial cells have the ability to phagocytize debris such as dead tissue and bacterial matter that would otherwise obstruct their path. Because they must dissolve any scab that forms, keratinocyte migration is best enhanced by a moist environment, since a dry one leads to formation of a bigger, tougher scab. To make their way along the tissue, keratinocytes must dissolve the clot, debris, and parts of the ECM in order to get through. They secrete plasminogen activator, which activates plasminogen, turning it into plasmin to dissolve the scab. Cells can only migrate over living tissue, so they must excrete collagenases and proteases like matrix metalloproteinases (MMPs) to dissolve damaged parts of the ECM in their way, particularly at the front of the migrating sheet. Keratinocytes also dissolve the basement membrane, using instead the new ECM laid down by fibroblasts to crawl across.

As keratinocytes continue migrating, new epithelial cells must be formed at the wound edges to replace them and to provide more cells for the advancing sheet. Proliferation behind migrating keratinocytes normally begins a few days after wounding and occurs at a rate that is 17 times higher in this stage of epithelialization than in normal tissues. Until the entire wound area is resurfaced, the only epithelial cells to proliferate are at the wound edges.

Growth factors, stimulated by integrins and MMPs, cause cells to proliferate at the wound edges. Keratinocytes themselves also produce and secrete factors, including growth factors and basement membrane proteins, which aid both in epithelialization and in other phases of healing. Growth factors are also important for the innate immune defense of skin wounds by stimulation of the production of antimicrobial peptides and neutrophil chemotactic cytokines in keratinocytes.

Keratinocytes continue migrating across the wound bed until cells from either side meet in the middle, at which point contact inhibition causes them to stop migrating. When they have finished migrating, the keratinocytes secrete the proteins that form the new basement membrane. Cells reverse the morphological changes they underwent in order to begin migrating; they reestablish desmosomes and hemidesmosomes and become anchored once again to the basement membrane. Basal cells begin to divide and differentiate in the same manner as they do in normal skin to reestablish the strata found in reepithelialized skin.

Contraction

Contraction is a key phase of wound healing. If contraction continues for too long, it can lead to disfigurement and loss of function. Thus there is a great interest in understanding the biology of wound contraction, which can be modelled in vitro using the collagen gel contraction assay or the dermal equivalent model.

Contraction commences approximately a week after wounding, when fibroblasts have differentiated into myofibroblasts. In full thickness wounds, contraction peaks at 5 to 15 days post wounding. Contraction can last for several weeks and continues even after the wound is completely reepithelialized. A large wound can become 40 to 80% smaller after contraction. Wounds can contract at a speed of up to 0.75 mm per day, depending on how loose the tissue in the wounded area is. Contraction usually does not occur symmetrically; rather most wounds have an 'axis of contraction' which allows for greater organization and alignment of cells with collagen.

At first, contraction occurs without myofibroblast involvement. Later, fibroblasts, stimulated by growth factors, differentiate into myofibroblasts. Myofibroblasts, which are similar to smooth muscle cells, are responsible for contraction. Myofibroblasts contain the same kind of actin as that found in smooth muscle cells.

Myofibroblasts are attracted by fibronectin and growth factors and they move along fibronectin linked to fibrin in the provisional ECM in order to reach the wound edges. They form connections to the ECM at the wound edges, and they attach to each other and to the wound edges by desmosomes. Also, at an adhesion called the fibronexus, actin in the myofibroblast is

linked across the cell membrane to molecules in the extracellular matrix like fibronectin and collagen. Myofibroblasts have many such adhesions, which allow them to pull the ECM when they contract, reducing the wound size. In this part of contraction, closure occurs more quickly than in the first, myofibroblast-independent part.

As the actin in myofibroblasts contracts, the wound edges are pulled together. Fibroblasts lay down collagen to reinforce the wound as myofibroblasts contract The contraction stage in proliferation ends as myofibroblasts stop contracting and commit apoptosis. The breakdown of the provisional matrix leads to a decrease in hyaluronic acid and an increase in chondroitin sulfate, which gradually triggers fibroblasts to stop migrating and proliferating. These events signal the onset of the maturation stage of wound healing.

Maturation and remodeling

When the levels of collagen production and degradation equalize, the maturation phase of tissue repair is said to have begun. During maturation, type III collagen, which is prevalent during proliferation, is gradually degraded and the stronger type I collagen is laid down in its place. Originally disorganized collagen fibers are rearranged, cross-linked, and aligned along tension lines. The onset of the maturation phase may vary extensively, depending on the size of the wound and whether it was initially closed or left open, ranging from approximately 3 days to 3 weeks The maturation phase can last for a year or longer, similarly depending on wound type.

As the phase progresses, the tensile strength of the wound increases, with the strength approaching 50% that of normal tissue by three months after injury and ultimately becoming as much as 80% as strong as normal tissue. Since activity at the wound site is reduced, the scar loses its red appearance as blood vessels that are no longer needed are removed by apoptosis.

The phases of wound healing normally progress in a predictable, timely manner; if they do not, healing may progress inappropriately to either a chronic wound such as a venous ulcer or pathological scarring such as a keloid scar.

Research and development

Up until a decade ago, the classic paradigm of wound healing, involving stem cells restricted to organ-specific lineages, has never been seriously challenged. Since then, the notion of adult stem cells having cellular *plasticity* or the ability to differentiate into non-lineage cells has emerged as an alternative explanation. To be more specific, hematopoietic progenitor cells (that give rise mature cells in the blood) may have the ability *de-differentiate* back into hematopoietic stem cells and/or *transdifferentiate* into non-lineage cells, such as fibroblasts.

Stem cells and cellular plasticity

Multipotent adult stem cells have the capacity to be self-renewal and give rise to different cell types. Stem cells give rise to progenitor cells, which are cells that are not self-renewal, but can

generate several types of cells. The extent of stem cell involvement in cutaneous (skin) wound healing is complex and not fully understood.

It is thought that the epidermis and dermis are reconstituted by mitotically active stem cells that reside at the apex of rete ridges (basal stem cells or BSC), the bulge of hair follicles (hair follicular stem cell or HFSC), and the papillary dermis (dermal stem cells). Moreover, bone marrow may also contain stem cells that play a major role in cutaneous wound healing.

In rare circumstances, such as extensive cutaneous injury, self-renewal subpopulations in the bone marrow are induced to participate in the healing process, whereby they give rise to collagen-secreting cells that seem to play a role during wound repair. These two self-renewal subpopulations are (1) bone marrow-derived mesenchymal stem cells (MSC) and (2) hematopoietic stem cells (HSC). Bone marrow also harbors a progenitor subpopulation (endothelial progenitor cells or EPC) that, in the same type of setting, are mobilized to aid in the reconstruction of blood vessels. Moreover, it thought that, extensive injury to skin also promotes the early trafficking of a unique subclass of leukocytes (circulating fibrocytes) to the injured region, where they perform various functions related to wound healing.

Wound repair versus regeneration

There is a subtle distinction between ‘repair’ and ‘regeneration'. An injury is an interruption of morphology and/or functionality of a given tissue. Repair refers to the physiologic adaptation of an organ after injury in an effort to re-establish continuity without regards to exact replacement of lost/damaged tissue. True tissue regeneration refers to the replacement of lost/damaged tissue with an ‘exact’ copy, such that both morphology and functionality are completely restored. Mammals do not regenerate spontaneously. In some instances, such as skin, ‘partial regeneration’ may be induced by the use of biodegradable (collagen-glycoaminoglycan) scaffolds. These scaffolds are structurally analogous to extracellular matrix (ECM) found in normal/un-injured dermis. Interestingly, fundamental conditions required for tissue regeneration often oppose conditions that favor efficient wound repair, including inhibition of (1) platelet activation, (2) inflammatory response, and (3) wound contraction. In addition to providing support for fibroblast and endothelial cell attachment, biodegradable scaffolds inhibit wound contraction, thereby allowing the healing process to proceed towards a more-regenerative/less-scarring pathway.

Types

Primary intention

involves epidermis and dermis without total penetration of dermis healing by process of epithelialization

- When wound edges are brought together so that they are adjacent to each other (re-approximated)
- Minimizes scarring
- Most surgical wounds heal by primary intention healing

- Wound closure is performed with sutures (stitches), staples, or adhesive tape
- Examples: well-repaired lacerations,well reduced bone fractures,healing after flap surgery

Secondary intention

- The wound is allowed to granulate
- Surgeon may pack the wound with a gauze or use a drainage system
- Granulation results in a broader scar
- Healing process can be slow due to presence of drainage from infection
- Wound care must be performed daily to encourage wound debris removal to allow for granulation tissue formation
- examples:gingivectomy,gingivoplasty,tooth extraction sockets, poorly reduced fractures.

Tertiary intention

(Delayed primary closure or secondary suture):

- The wound is initially cleaned, debrided and observed, typically 4 or 5 days before closure.
- The wound is purposely left open
- examples:healing of wounds by use of tissue grafts.

Chapter 4

Psychological Trauma

Psychological trauma is a type of damage to the psyche that occurs as a result of a traumatic event. When that trauma leads to posttraumatic stress disorder, damage may involve physical changes inside the brain and to brain chemistry, which changes the person's response to future stress.

A traumatic event involves a single experience, or an enduring or repeating event or events, that completely overwhelm the individual's ability to cope or integrate the ideas and emotions involved with that experience. The sense of being overwhelmed can be delayed by weeks, years or even decades, as the person struggles to cope with the immediate circumstances. Psychological trauma can lead to serious long-term negative consequences that are often overlooked even by mental health professionals: "If clinicians fail to look through a trauma lens and to conceptualize client problems as related possibly to current or past trauma, they may fail to see that trauma victims, young and old, organize much of their lives around repetitive patterns of reliving and warding off traumatic memories, reminders, and affects."

Trauma can be caused by a wide variety of events, but there are a few common aspects. There is frequently a violation of the person's familiar ideas about the world and of their human rights, putting the person in a state of extreme confusion and insecurity. This is also seen when people or institutions, depended on for survival, violate or betray or disillusion the person in some unforeseen way.

Psychological trauma may accompany physical trauma or exist independently of it. Typical causes and dangers of psychological trauma are sexual abuse, bullying, domestic violence, indoctrination, the victim of alcoholism, the threat of either, or the witnessing of either, particularly in childhood. Catastrophic events such as earthquakes and volcanic eruptions, war or other mass violence can also cause psychological trauma. Long-term exposure to situations such as extreme poverty or milder forms of abuse, such as verbal abuse, can be traumatic (though verbal abuse can also potentially be traumatic as a single event).

However, different people will react differently to similar events. One person may experience an event as traumatic while another person would not suffer trauma as a result of the same event. In other words, not all people who experience a potentially traumatic event will actually become psychologically traumatized.

Some theories suggest childhood trauma can lead to violent behavior. Some ideas believe such violent behavior can be as extreme as serial murder. For example, Hickey's Trauma-Control Model which suggests "childhood trauma for serial murderers may serve as a triggering mechanism resulting in an individual's inability to cope with the stress of certain events."

Symptoms of trauma

People who go through these types of extremely traumatic experiences often have certain symptoms and problems afterward. How severe these symptoms are depends on the person, the type of trauma involved, and the emotional support they receive from others. Reactions to and symptoms of trauma can be wide and varied, and differ in severity from person to person. A traumatized individual may experience one or several of them.

After a traumatic experience, a person may **re-experience** the trauma mentally and physically, hence avoiding trauma reminders, also called triggers, as this can be uncomfortable and even painful. They may turn to psychoactive substances including alcohol to try to escape the feelings. Re-experiencing symptoms are a sign that the body and mind are actively struggling to cope with the traumatic experience.

Triggers and cues act as reminders of the trauma, and can cause anxiety and other associated emotions. Often the person can be completely unaware of what these triggers are. In many cases this may lead a person suffering from traumatic disorders to engage in disruptive or self-destructive coping mechanisms, often without being fully aware of the nature or causes of their own actions. Panic attacks are an example of a psychosomatic response to such emotional triggers.

Consequently, intense feelings of anger may surface frequently, sometimes in very inappropriate or unexpected situations, as danger may always seem to be present. Upsetting memories such as images, thoughts, or flashbacks may haunt the person, and nightmares may be frequent. Insomnia may occur as lurking fears and insecurity keep the person vigilant and on the lookout for danger, both day and night.

The person may not remember what actually happened while emotions experienced during the trauma may be reexperienced without the person understanding why. This can lead to the traumatic events being constantly experienced as if they were happening in the present, preventing the subject from gaining perspective on the experience. This can produce a pattern of prolonged periods of acute arousal punctuated by periods of physical and mental exhaustion.

In time, emotional exhaustion may set in, leading to distraction, and clear thinking may be difficult or impossible. Emotional detachment, as well as dissociation or "numbing out", can frequently occur. Dissociating from the painful emotion includes numbing all emotion, and the person may seem emotionally flat, preoccupied, distant, or cold. The person can become confused in ordinary situations and have memory problems.

Some traumatized people may feel permanently damaged when trauma symptoms do not go away and they do not believe their situation will improve. This can lead to feelings of despair,

loss of self-esteem, and frequently depression. If important aspects of the person's self and world understanding have been violated, the person may call their own identity into question. Often despite their best efforts, traumatized parents may have difficulty assisting their child with emotion regulation, attribution of meaning, and containment of post-traumatic fear in the wake of the child's traumatization, leading to adverse consequences for the child. In such instances, it is in the interest of the parent(s) and child for the parent(s) to seek consultation as well as to have their child receive appropriate mental health services.

Self medication

Self-medication is the use of drugs, alcohol, or other self-soothing forms of behavior to treat mental distress, stress, anxiety, mental illnesses and/or other effects of psychological trauma.

Situational trauma

Trauma can be caused by man-made and natural disasters, including war, abuse, violence, earthquakes, mechanized accidents (car, train, or plane crashes, etc.) or medical emergencies.

Responses to psychological trauma There are several behavioral responses common towards stressors including the proactive, reactive, and passive responses. Proactive responses include attempts to address and correct a stressor before it has a noticeable effect on lifestyle. Reactive responses occur after the stress and possible trauma has occurred, and are aimed more at correcting or minimizing the damage of a stressful event. A passive response is often characterized by an emotional numbness or ignorance of a stressor.

Those who are able to be proactive can often overcome stressors and are more likely to be able to cope well with unexpected situations. On the other hand, those who are more reactive will often experience more noticeable effects from an unexpected stressor. In the case of those who are passive, victims of a stressful event are more likely to suffer from long term traumatic effects and often enact no intentional coping actions. These observations may suggest that the level of trauma associated with a victim is related to such independent coping abilities.

"Betrayal trauma theory suggests that psychogenic amnesia is an adaptive response to childhood abuse. When a parent or other powerful figure violates a fundamental ethic of human relationships, victims may need to remain unaware of the trauma not to reduce suffering but rather to promote survival. Amnesia enables the child to maintain an attachment with a figure vital to survival, development, and thriving. Analysis of evolutionary pressures, mental modules, social cognitions, and developmental needs suggests that the degree to which the most fundamental human ethics are violated can influence the nature, form, and processes of trauma and responses to trauma."

There is also a distinction between trauma induced by recent situations and long-term trauma which may have been buried in the unconscious from past situations such as childhood abuse. Trauma is often overcome through healing; in some cases this can be achieved by recreating or revisiting the origin of the trauma under more psychologically safe circumstances, such as with a therapist.

Treatment

A number of psychotherapy approaches have been designed with the treatment of trauma in mind—EMDR, Somatic Experiencing, Internal Family Systems Therapy, and Sensorimotor psychotherapy.

Trauma in psychoanalysis

French neurologist Jean-Martin Charcot argued that psychological trauma was the origin of all instances of the mental illness known as hysteria. Charcot's "traumatic hysteria" often manifested as a paralysis that followed a physical trauma, typically years later after what Charcot described as a period of "incubation". Sigmund Freud, Charcot's student and the father of psychoanalysis, examined the concept of psychological trauma throughout his career. Jean Laplanche has given a general description of Freud's understanding of trauma, which varied significantly over the course of Freud's career: "An event in the subject's life, defined by its intensity, by the subject's incapacity to respond adequately to it and by the upheaval and long-lasting effects that it brings about in the psychical organization".

The French psychoanalyst Jacques Lacan claimed that what he called "The Real" had a traumatic quality external to symbolization. As an object of anxiety, Lacan maintained that The Real is "the essential object which isn't an object any longer, but this something faced with which all words cease and all categories fail, the object of anxiety *par excellence*".

Trauma and stress disorders

In times of war, psychological trauma has been known as shell shock or combat stress reaction. Psychological trauma may cause an acute stress reaction which may lead on to posttraumatic stress disorder (PTSD). PTSD emerged as the label for this condition after the Vietnam War in which many veterans returned to their respective countries demoralized, and sometimes, addicted to psychoactive substances. Psychological trauma is treated with therapy and, if indicated, psychotropic medications.

Following traumatic events, persons involved are often asked to talk about the events soon after, sometimes even immediately after the event occurred in order to start a healing process. This practice may not garner the positive results needed to recover psychologically from a traumatic event.

Victims of traumatic occurrences who were debriefed immediately after the event in general do far better than others who received therapy at a later time, though there is also evidence to suggest forcing immediate debriefing may distort the natural psychological healing process.

Chapter 5

Classification of Trauma

Trauma can be classified by the affected area of the body (percentages of total incidence):

- Polytrauma (40%)
- Head injury (30%)
- Chest trauma (20%)
- Abdominal trauma (10%)
- Extremity trauma (2%)
- Facial trauma
- Spinal cord injury
- Genitourinary system trauma
- Pelvic trauma
- Soft tissue injury

Polytrauma

Polytrauma or **multiple trauma** is a medical term describing the condition of a person who has been subjected to multiple traumatic injuries, such as a serious head injury in addition to a serious burn. It is defined via an Injury Severity Score ISS >=17. The term has become common among US military doctors in describing the seriously injured soldiers returning from *Operation Iraqi Freedom* (Iraq) and *Operation Enduring Freedom* (Afghanistan). The term however is generic, and has been in use for a long time for any case involving multiple traumata.

Civilian medicine

In civilian life, polytraumas are often associated with motor vehicle accidents. This is because car accidents often occur at a high velocities causing multiple injuries. On admission to hospital any trauma patient should immediately undergo x-ray diagnosis of their cervical spine, chest and their pelvis, commonly known as a 'trauma series', to ascertain possible life threatening injuries. Examples would be a fractured cervical vertebra, a severely fractured pelvis, or a haemothorax. Once the initial survey is complete, x-rays can be taken of the limbs to assess for other possible fractures. It is also quite common in severe trauma for patients to go straight to CT or a surgery theatre if they require emergency treatment.

ECMO can be effective in treating some polytrauma patients with pulmonary or cardiopulmonary failure.

A retrospective study of 93 children (average age of 8.0 +/- 4.1 years) with polytrauma and at least one major musculoskeletal injury showed that 80% of the incidents had been caused in this way (motor vehicle accident).

Military medicine

Blast injuries account for most battlefield polytrauma

Overview

Polytrauma often results from blast injuries sustained by improvised explosive devices, or by a hit with a rocket-propelled grenade, with *"Improvised explosive devices, blasts, landmines, and fragments account[ing] for 65 percent of combat injuries..."*. The combination of high-pressure waves, explosive fragments, and falling debris may produce multiple injuries including brain injury, loss of limbs, burns, fractures, blindness and hearing loss, with 60 percent of those injured in this way having some degree of traumatic brain injury.

In some ways, the high incidence of polytrauma is in fact a sign of medical advancement, for in previous wars, soldiers with such multiple damage types simply did not survive in most cases,

even if quickly transferred into hospital care. The downside is however that many of the victims, though surviving, will never fully regain their physical or mental form. They are also prone to psychological complications such as post traumatic stress disorder.

U.S. treatment

One of the four US clinics specialising in polytrauma, this one in Palo Alto

There are currently four rehabilitation centers in the US specialising in polytrauma (as of 2010). They are managed by the United States Department of Veterans Affairs and are located in Minneapolis, MN; Palo Alto, CA; Richmond, VA; and Tampa, FL. In addition to the actual intensive care insofar as still required, these hospitals mainly specialize in rehabilitative treatment. In addition the Department of Veterans Affairs has 18 polytrauma network sites, located throughout the country. As of April 2007, the Department of Veterans Affairs has treated over 350 service members in their inpatient centers.

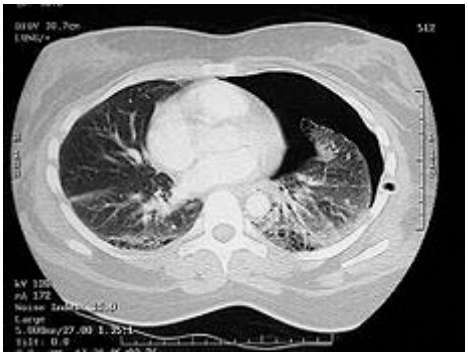
The treatment and rehabilitative care for polytrauma patients is a very extensive and time-consuming activity. The recommended staffing numbers (FTE = Full Time Equivalent) for six rehabilitation treatment beds are:

- 0.5 FTE - Physician Discipline FTE Rehabilitation
- 5.5 FTE - Registered Nurse (1.0 must be CRRN)
- 4.0 FTE - Licensed Practical Nurse and/or Certified Nursing Assistant
- 0.5 FTE - Nurse Manager
- 0.5 FTE - Clinical Case Manager, Admission and Follow-up
- 1.0 FTE - Social Worker Case Manager
- 0.5 FTE - Social Worker
- 1.0 FTE - Speech-Language Pathologist
- 1.0 FTE - Physical Therapist
- 1.0 FTE - Occupational Therapist
- 0.5 FTE - Recreation Therapist
- 0.5 FTE - Counseling Psychologist
- 0.5 FTE - Neuropsychologist

In other words - 2.8 people are required full time (24h), for every patient, often for months, while some care may be required for life.

Chest trauma

Chest trauma

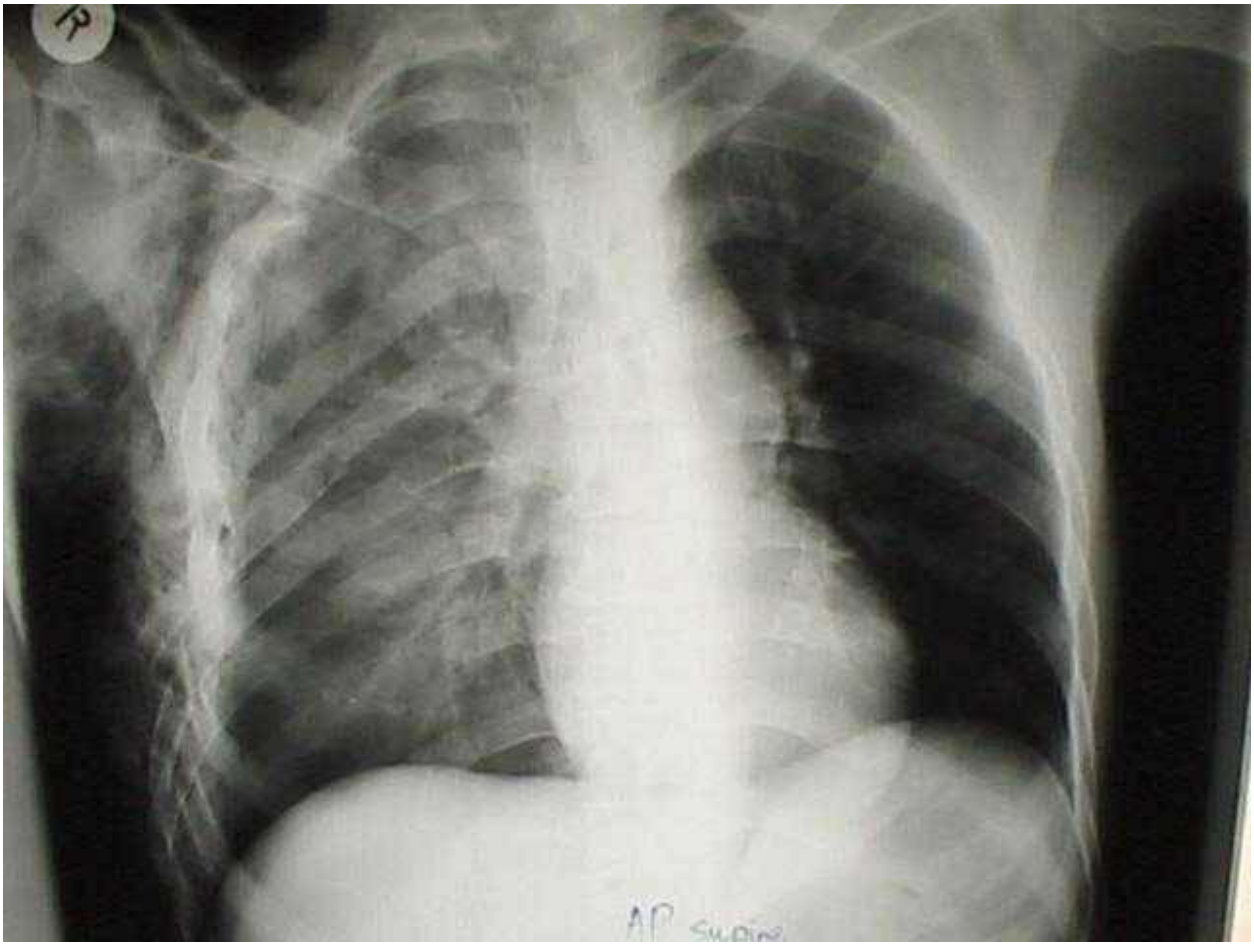


A CT scan of a pneumothorax

eMedicine	med/2916 med/3658
MeSH	D013898

Chest trauma (or **thoracic trauma**) is a serious injury of the chest. Thoracic trauma is a common cause of significant disability and mortality, the leading cause of death from physical trauma after head and spinal cord injury. Blunt thoracic injuries are the primary or a contributing cause of about a quarter of all trauma-related deaths. The mortality rate is about 10%. Chest injuries were first described in detail in around 1600 BC in the ancient Egyptian Edwin Smith Papyrus.

Classification



A chest X-ray of a right sided pulmonary contusion associated with flail chest and subcutaneous emphysema

Chest trauma can be classified as blunt or penetrating. Blunt and penetrating injuries have different pathophysiologies and clinical courses.

Specific types of chest trauma include:

- Injuries to the chest wall
  - Chest wall contusions or hematomas.
  - Rib fractures
  - Flail chest
  - Sternal fractures
  - Fractures of the shoulder girdle
- Pulmonary injury (injury to the lung) and injuries involving the pleural space
  - Pulmonary contusion
  - Pulmonary laceration
  - Pneumothorax

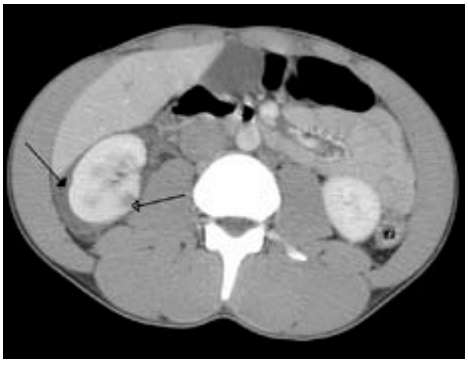
    - Hemothorax
    - Hemopneumothorax
- Injury to the airways
    - Tracheobronchial tear
- Cardiac injury
    - Pericardial tamponade
    - Myocardial contusion
- Blood vessel injuries
    - Traumatic aortic rupture, thoracic aorta injury, aortic dissection
- And injuries to other structures within the torso
    - Esophageal injury (Boerhaave syndrome)
    - Diaphragm injury

Diagnosis

Most blunt injuries are managed with relatively simple interventions like tracheal intubation and mechanical ventilation and chest tube insertion. Diagnosis of blunt injuries may be more difficult and require additional investigations such as CT scanning. Penetrating injuries often require surgery, and complex investigations are usually not needed to come to a diagnosis. Patients with penetrating trauma may deteriorate rapidly, but may also recover much faster than patients with blunt injury.

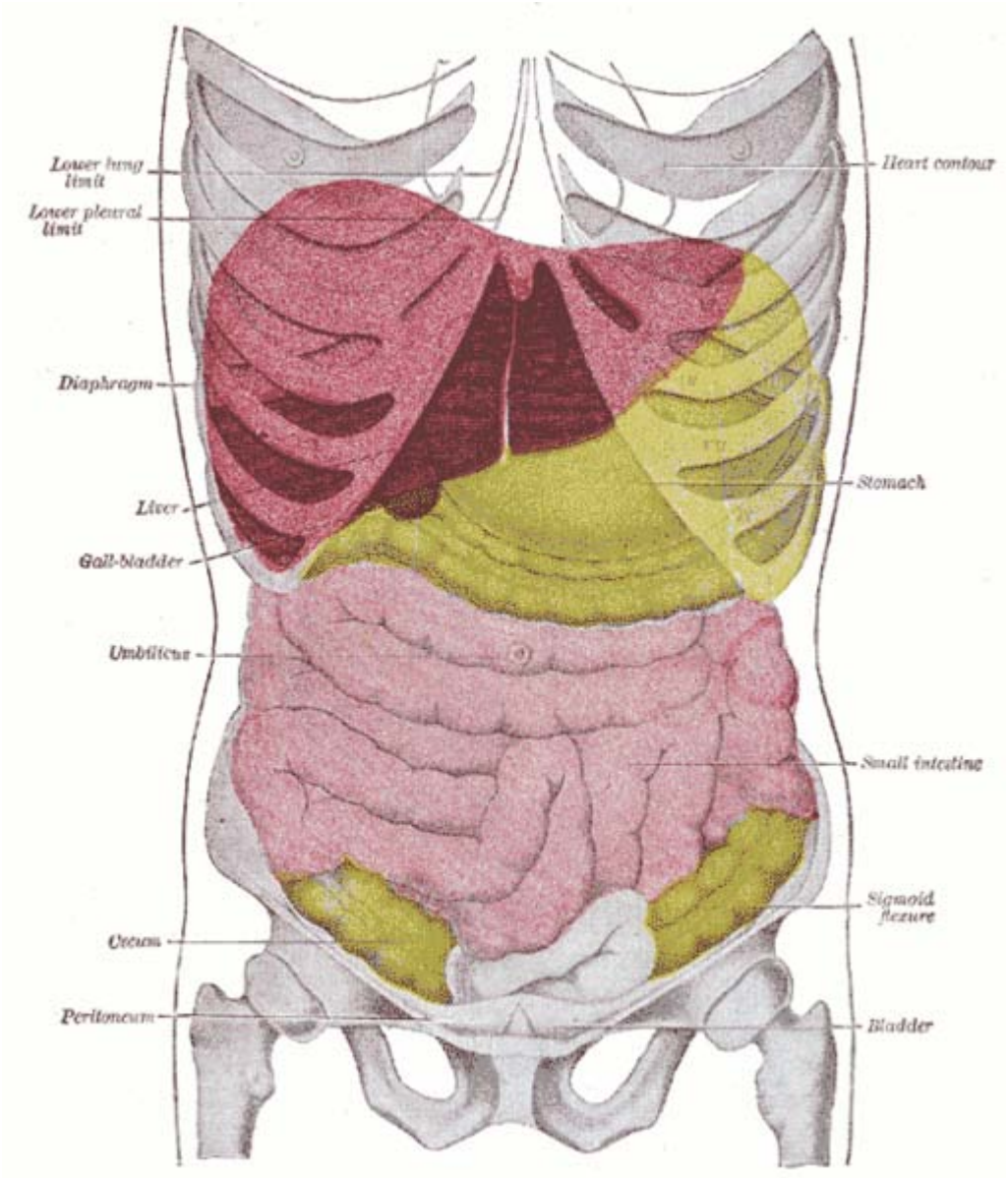
Abdominal trauma

Abdominal trauma



Abdominal trauma resulting in a right kidney contusion (open area) and blood surround the kidney (closed arrow) as seen on CT.

ICD-10	S30.-S39.
ICD-9	868
eMedicine	med/2805 emerg/1
MeSH	D000007



The abdominal organs

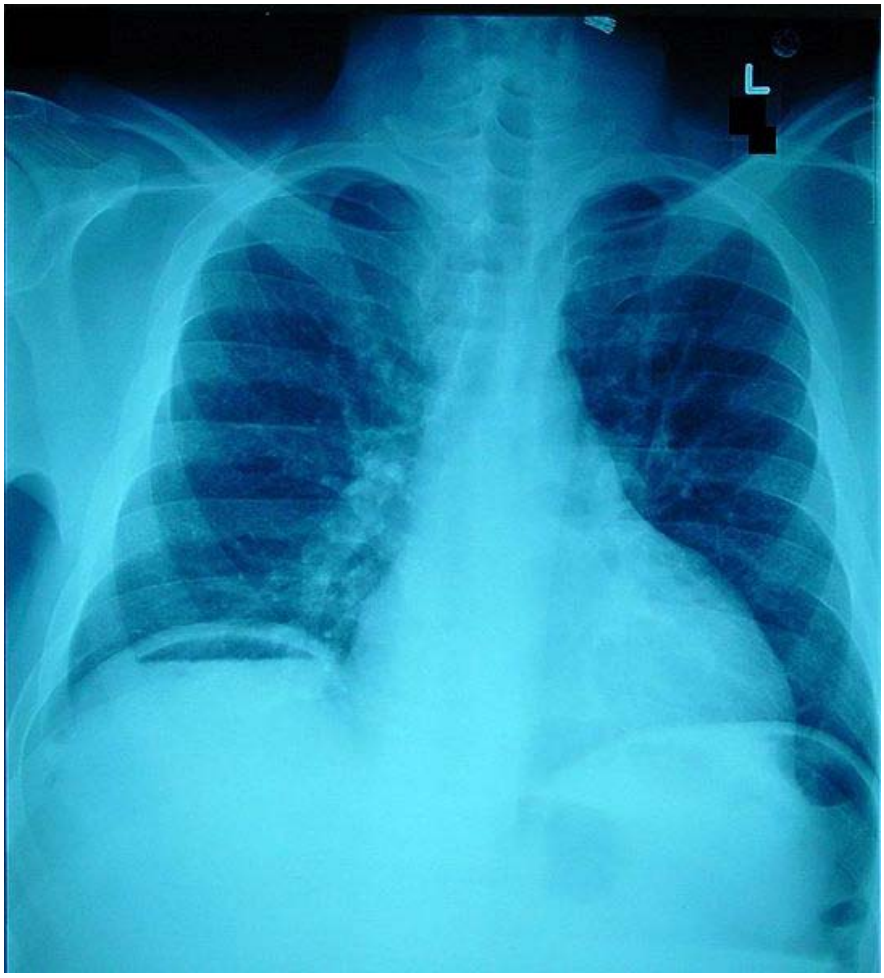
Abdominal trauma is an injury to the abdomen. It may be blunt or penetrating and may involve damage to the abdominal organs. Signs and symptoms include abdominal pain, tenderness,

rigidity, and bruising of the external abdomen. Abdominal trauma presents a risk of severe blood loss and infection. Diagnosis may involve ultrasonography, computed tomography, and peritoneal lavage, and treatment may involve surgery. Injury to the lower chest may cause splenic or liver injuries.

Classification

Abdominal trauma is divided into blunt and penetrating types. While penetrating abdominal trauma (PAT) is usually diagnosed based on clinical signs, diagnosis of blunt abdominal trauma is more likely to be delayed or altogether missed because clinical signs are less obvious. Blunt injuries predominate in rural areas, while penetrating ones are more frequent in urban settings. Penetrating trauma is further subdivided into stab wounds and gunshot wounds, which require different methods of treatment.

Signs and symptoms



Pneumoperitoneum, seen as an air bubble on the lower left side of the X-ray film

People injured in motor vehicle collisions may present with a "seat belt sign," bruising on the abdomen along the site of the lap portion of the safety belt; this sign is associated with a high rate of injury to the abdominal organs. Seatbelts may also cause abrasions and hematomas; up to 30 percent of people with such signs have associated internal injuries. Early indications of abdominal trauma include nausea, vomiting, and fever. Blood in the urine is another sign. The injury may present with abdominal pain, tenderness, distension, or rigidity to the touch, and bowel sounds may be diminished or absent. Abdominal guarding is a tensing of the abdominal wall muscles to guard inflamed organs within the abdomen. Pneumoperitoneum, air or gas in the abdominal cavity, may be an indication of rupture of a hollow organ. In penetrating injuries, an evisceration (protrusion of internal organs out of a wound) may be present.

Injuries associated with intra-abdominal trauma include rib fractures, vertebral fractures, pelvic fractures, and injuries to the abdominal wall.

Guidelines

Presentation Cause Haemorrage. Liver / spleen rupture Hematuria. Kidney, bladder, ureter injury Back pain. Injury to retroperitoneum Peritonitis. Injury hollow viscus Respiratory. Pneumothorax

Causes

Motor vehicle collisions are a common source of blunt abdominal trauma. Seat belts reduce the incidence of injuries such as head injury and chest injury, but present a threat to such abdominal organs as the pancreas and the intestines, which may be displaced or compressed against the spinal column. Children are especially vulnerable to abdominal injury from seat belts, because they have softer abdominal regions and seat belts were not designed to fit them. In children, bicycle mishaps are also a common cause of abdominal injury, especially when the abdomen is struck by the handlebars. Sports injuries can affect abdominal organs such as the spleen and kidneys. Falls and sports are also frequent mechanisms of abdominal injury in children. Abdominal injury may result from child abuse and is the second leading cause of child abuse-related death, after traumatic brain injury.

Gunshot wounds, which are higher energy than stab wounds, are usually more damaging than the latter. Gunshot wounds that penetrate the peritoneum result in significant damage to major intra-abdominal structures in some 90 percent of cases.

Pathophysiology

Abdominal trauma can be life threatening because abdominal organs, especially those in the retroperitoneal space, can bleed profusely, and the space can hold a great deal of blood. Solid abdominal organs, such as the liver and kidneys, bleed profusely when cut or torn, as do major blood vessels such as the aorta and vena cava. Hollow organs such as the stomach, while not as likely to result in shock from profuse bleeding, present a serious risk of infection, especially if such an injury is not treated promptly. Gastrointestinal organs such as the bowel can spill their

contents into the abdominal cavity. Hemorrhage and systemic infection are the main causes of deaths that result from abdominal trauma.

One or more of the intra-abdominal organs may be injured in abdominal trauma. The characteristics of the injury are determined in part by which organ or organs are injured.

Liver

The liver, the most vulnerable abdominal organ to blunt injury because of its size and location (in the upper right quadrant of the abdomen), is injured in about five percent of all people admitted to a hospital for trauma. The liver is also vulnerable to penetrating trauma. Liver injuries present a serious risk for shock because the liver tissue is delicate and has a large blood supply and capacity. In children, the liver is the most commonly injured abdominal organ. The liver may be lacerated or contused, and a hematoma may develop. It may leak bile, usually without serious consequences. If severely injured, the liver may cause exsanguination (bleeding to death), requiring emergency surgery to stop the bleeding.

Spleen

Spleen is the most common damaged organ in blunt abdominal trauma. The spleen is the second most commonly injured intra-abdominal organ in children. A laceration of the spleen may be associated with hematoma. Because of the spleen's ability to bleed profusely, a ruptured spleen can be life threatening, resulting in shock. However, unlike the liver, penetrating trauma to the spleen, pancreas and kidneys do not present as much of an immediate threat of shock unless they lacerate a major blood vessel supplying the organs, such as the renal artery. Fractures of the left lower ribs are associated with spleen lacerations in 20 percent of cases.

Pancreas

The pancreas may be injured in abdominal trauma, for example by laceration or contusion. Pancreatic injuries, most commonly caused by bicycle accidents (especially by impact with the handlebars) in children and vehicular accidents in adults, usually occur in isolation in children and accompanied by other injuries in adults. Indications that the pancreas is injured include enlargement and the presence of fluid around the pancreas.

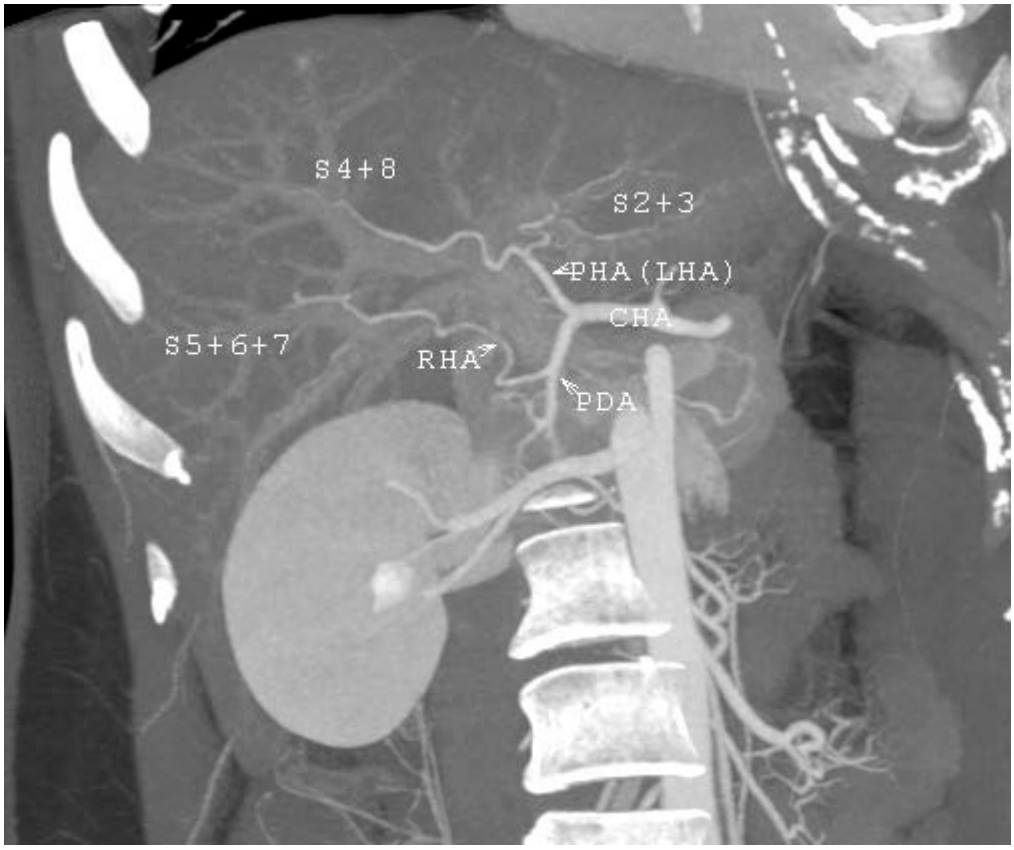
Kidneys

The kidneys may also be injured; they are somewhat but not completely protected by the ribs. Kidney lacerations and contusions may also occur. Kidney injury, a common finding in children with blunt abdominal trauma, may be associated with bloody urine. Kidney lacerations may be associated with urinoma, leakage of urine into the abdomen. A *shattered kidney* is one with multiple lacerations and an associated fragmentation of the kidney tissue.

Bowel

The small intestine takes up a large part of the abdomen ironically and is likely to be damaged in penetrating injury. The bowel may be perforated. Gas within the abdominal cavity seen on CT is understood to be a diagnostic sign of bowel perforation; however intra-abdominal air can also be caused by pneumothorax (air in the pleural cavity outside the lungs that has escaped from the respiratory system) or pneumomediastinum (air in the mediastinum, the center of the chest cavity). The injury may not be detected on CT. Bowel injury may be associated with complications such as infection, abscess, bowel obstruction, and the formation of a fistula. Bowel perforation requires surgery.

Diagnosis



CT scan showing the liver and a kidney

One study found that ten percent of polytrauma patients who had no clinical signs of abdominal injury did have evidence of the such injuries using radiological imaging. Diagnostic techniques used include CT scanning, ultrasound, and X-ray. X-ray can help determine the path of a penetrating object and locate any foreign matter left in the wound, but may not be helpful in blunt trauma. Diagnostic peritoneal lavage is a controversial technique but can be used to detect injury to abdominal organs: a catheter is placed in the peritoneal cavity, and if fluid is present, it is aspirated and examined for blood or evidence of organ rupture. If this does not reveal evidence

of injury, sterile saline is infused into the cavity and evacuated and examined for blood or other material. While peritoneal lavage is an accurate way to test for bleeding, it carries a risk of injuring the abdominal organs, may be difficult to perform, and may lead to unnecessary surgery; thus it has largely been replaced by ultrasound in Europe and North America. Ultrasound can detect fluid such as blood or gastrointestinal contents in the abdominal cavity, and it is a noninvasive procedure and relatively safe for the patient. CT scanning is the preferred technique for people who are not at immediate risk of shock, but since ultrasound can be performed right in an emergency room, the latter is recommended for people who are not stable enough to move to CT scanning. However, people with abdominal trauma frequently need CT scans for other trauma (for example, head or chest CT); in these cases abdominal CT can be performed at the same time without wasting time in patient care. Diagnostic laparoscopy or exploratory laparotomy may also be performed if other diagnostic methods do not yield conclusive results.

CT

CT is only able to detect 76% of hollow viscous injuries and patients who have negative scans must often be observed and rechecked if they deteriorate. However, CT has been demonstrated to be useful in screening patients with certain forms of abdominal trauma in order to avoid unnecessary laparotomies, which can significantly increase the cost and length of hospitalizations. A meta-analysis of CT use in penetrating abdominal traumas demonstrated sensitivity, specificity and accuracy >= 95%, with a PPV of 85% and an NPV of 98%. This suggests that CT is excellent for avoiding unnecessary laparotomies but must be augmented by other clinical criteria to determine the need for surgical exploration (23.37 positive likelihood ratio, 0.05 negative likelihood ratio).

Treatment

Initial treatment involves stabilizing the patient enough to ensure adequate airway, breathing, and circulation, and identifying other injuries. Surgery may be needed to repair injured organs. Surgical exploration is necessary for people with penetrating injuries and signs of peritonitis or shock. Laparotomy is often performed in blunt abdominal trauma, and is urgently required if an abdominal injury causes a large, potentially deadly bleed. However, intra-abdominal injuries are also frequently successfully treated nonoperatively. The use of CT scanning allows care providers to use less surgery because they can identify injuries that can be managed conservatively and rule out other injuries that would need surgery. Depending on the injuries, a patient may or may not need intensive care.

Prognosis

If abdominal injury is not diagnosed promptly, a worse outcome is associated. Delayed treatment is associated with an especially high morbidity and mortality if perforation of the gastrointestinal tract is involved.

Head injury

Head injury	
ICD-10	S00.0S09.
ICD-9	800-879
eMedicine	neuro/153
MeSH	D006259

Head injury refers to trauma of the head. This may or may not include injury to the brain. However, the terms *traumatic brain injury* and *head injury* are often used interchangeably in medical literature.

The incidence (number of new cases) of head injury is 300 of every 100,000 per year (0.3% of the population), with a mortality rate of 25 per 100,000 in North America and 9 per 100,000 in Britain. Head trauma is a common cause of childhood hospitalization.

Classification

Head injuries include both injuries to the brain and those to other parts of the head, such as the scalp and skull.

Head injuries may be closed or open. A closed (non-missile) head injury is where the dura mater remains intact. The skull can be fractured, but not necessarily. A penetrating head injury occurs when an object pierces the skull and breaches the dura mater. Brain injuries may be diffuse, occurring over a wide area, or focal, located in a small, specific area.

A head injury may cause a minor headache skull fracture, which may or may not be associated with injury to the brain. Some patients may have linear or depressed skull fractures.

If intracranial hemorrhage occurs, a hematoma within the skull can put pressure on the brain. Types of intracranial hemorrage include subdural, subarachnoid, extradural, and intraparenchymal hematoma. Craniotomy surgeries are used in these cases to lessen the pressure by draining off blood.

Brain injury can be at the site of impact, but can also be at the opposite side of the skull due to a *contrecoup* effect (the impact to the head can cause the brain to move within the skull, causing the brain to impact the interior of the skull opposite the head-impact).

If the impact causes the head to move, the injury may be worsened, because the brain may ricochet inside the skull causing additional impacts, or the brain may stay relatively still (due to inertia) but be hit by the moving skull (both are contrecoup injuries).

Specific problems after head injury can include:

- Skull fracture
- Lacerations to the scalp and resulting hemorrhage of the skin
- Traumatic subdural hematoma, a bleeding below the dura mater which may develop slowly
- Traumatic extradural, or epidural hematoma, bleeding between the dura mater and the skull
- Traumatic subarachnoid hemorrhage
- Cerebral contusion, a bruise of the brain
- Concussion, a temporary loss of function due to trauma
- Dementia pugilistica, or "punch-drunk syndrome", caused by repetitive head injuries, for example in boxing or other contact sports
- A severe injury may lead to a coma or death
- Shaken Baby Syndrome - a form of child abuse

Concussion

Over 4 million concussions are estimated to occur each year

Mild concussions are associated with sequelae. Severity is measured using various concussion grading systems.

A slightly greater injury is associated with both anterograde and retrograde amnesia (inability to remember events before or after the injury). The amount of time that the amnesia is present correlates with the severity of the injury. In all cases the patients develop postconcussion syndrome, which includes memory problems, dizziness, tiredness, sickness and depression.

Cerebral concussion is the most common head injury seen in children.

Intracranial hemorrhage

Types of intracranial hemorrhage are roughly grouped into intra-axial and extra-axial. The hemorrhage is considered a focal brain injury; that is, it occurs in a localized spot rather than causing diffuse damage over a wider area.

Intra-axial hemorrhage

Intra-axial hemorrhage is bleeding within the brain itself, or cerebral hemorrhage. This category includes intraparenchymal hemorrhage, or bleeding within the brain tissue, and intraventricular hemorrhage, bleeding within the brain's ventricles (particularly of premature infants). Intra-axial hemorrhages are more dangerous and harder to treat than extra-axial bleeds.

Extra-axial hemorrhage

type	Epidural	Subdural
Location	Between the skull and the dura	Between the *dura* and the arachnoid
Involved vessel	Temperoparietal locus (most likely) - Middle meningeal artery Frontal locus - anterior ethmoidal artery Occipital locus - transverse or sigmoid sinuses Vertex locus - superior sagittal sinus	Bridging veins
Symptoms	Lucid interval followed by unconsciousness	Gradually increasing headache and confusion
Appearance on CT	Biconvex lens	Crescent-shaped

Extra-axial hemorrhage, bleeding that occurs within the skull but outside of the brain tissue, falls into three subtypes:

- Epidural hemorrhage (extradural hemorrhage) which occur between the dura mater (the outermost meninx) and the skull, is caused by trauma. It may result from laceration of an artery, most commonly the middle meningeal artery. This is a very dangerous type of injury because the bleed is from a high-pressure system and deadly increases in intracranial pressure can result rapidly. However, it is the least common type of meningeal bleeding and is seen in 1% to 3% cases of head injury.
    - Patients have a loss of consciousness (LOC), then a lucid interval, then sudden deterioration (vomiting, restlessness, LOC)
    - Head CT shows lenticular (convex) deformity.
- Subdural hemorrhage results from tearing of the bridging veins in the subdural space between the dura and arachnoid mater.
    - Head CT shows crescent-shaped deformity
- Subarachnoid hemorrhage, which occur between the arachnoid and pia meningeal layers, like intraparenchymal hemorrhage, can result either from trauma or from ruptures of aneurysms or arteriovenous malformations. Blood is seen layering into the brain along sulci and fissures, or filling cisterns (most often the suprasellar cistern because of the presence of the vessels of the circle of Willis and their branchpoints within that space). The classic presentation of subarachnoid hemorrhage is the sudden onset of a severe headache (a thunderclap headache). This can be a very dangerous entity, and requires emergent neurosurgical evaluation, and sometimes urgent intervention.

Cerebral contusion

Cerebral contusion is bruising of the brain tissue. The majority of contusions occur in the frontal and temporal lobes. Complications may include cerebral edema and transtentorial herniation. The goal of treatment should be to treat the increased intracranial pressure. The prognosis is guarded.

Diffuse axonal injury

Diffuse axonal injury, or DAI, usually occurs as the result of an acceleration or deceleration motion, not necessarily an impact. Axons are stretched and damaged when parts of the brain of differing density slide over one another. Prognoses vary widely depending on the extent of damage.

Signs and symptoms

Presentation varies according to the injury. Some patients with head trauma stabilize and other patients deteriorate. A patient may present with or without neurologic deficit.

Patients with concussion may have a history of seconds to minutes unconsciousness, then normal arousal. Disturbance of vision and equilibrium may also occur.

Common symptoms of head injury include coma, confusion, drowsiness, personality change, seizures, nausea and vomiting, headache and a lucid interval, during which a patient appears conscious only to deteriorate later.

Symptoms of skull fracture can include:

- leaking cerebrospinal fluid (a clear fluid drainage from nose, mouth or ear) may be and is strongly indicative of basilar skull fracture and the tearing of sheaths surrounding the brain, which can lead to secondary brain infection.
- visible deformity or depression in the head or face; for example a sunken eye can indicate a maxillar fracture
- an eye that cannot move or is deviated to one side can indicate that a broken facial bone is pinching a nerve that innervates eye muscles
- wounds or bruises on the scalp or face.
- Basilar skull fractures, those that occur at the base of the skull, are associated with Battle's sign, a subcutaneous bleed over the mastoid, hemotympanum, and cerebrospinal fluid rhinorrhea and otorrhea.

Because brain injuries can be life threatening, even people with apparently slight injuries, with no noticeable signs or complaints, require close observation. The caretakers of those patients with mild trauma who are released from the hospital are frequently advised to rouse the patient several times during the next 12 to 24 hours to assess for worsening symptoms.

The Glasgow Coma Scale is a tool for measuring degree of unconsciousness and is thus a useful tool for determining severity of injury. The Pediatric Glasgow Coma Scale is used in young children.

Causes

Common causes of head injury are motor vehicle traffic collisions, home and occupational accidents, falls, and assaults. Bicycle accidents are also a cause of head injury-related death and disability, especially among children. Wilsons disease has also been indicative of head injury.

Diagnosis

The need for imaging in patients who have suffered a minor head injury is debated. A non-contrast CT of the head should be performed immediately in all those who have suffered a moderate or severe head injury,an MRI is also an option.

Management

Most head injuries are of a benign nature and require no treatment beyond analgesics and close monitoring for potential complications such as intracranial bleeding. If the brain has been severely damaged by trauma, neurosurgical evaluation may be useful. Treatments may involve controlling elevated intracranial pressure. This can include sedation, paralytics, cerebrospinal fluid diversion. Second line alternatives include decompressive craniectomy (Jagannathan et al. found a net 65% favorable outcomes rate in pediatric patients), barbiturate coma, hypertonic saline and hypothermia. Although all of these methods have potential benefits, there has been no randomized study that has shown unequivocal benefit.

Facial trauma

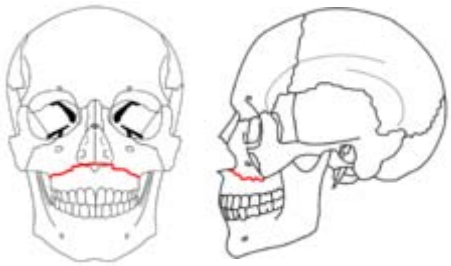
Facial trauma, also called **maxillofacial trauma**, is any physical trauma to the face. Facial trauma can involve soft tissue injuries such as burns, lacerations and bruises, or fractures of the facial bones such as nasal fractures and fractures of the jaw, as well as trauma such as eye injuries. Symptoms are specific to the type of injury; for example, fractures may involve pain, swelling, loss of function, or changes in the shape of facial structures.

Facial injuries have the potential to cause disfigurement and loss of function; for example, blindness or difficulty moving the jaw can result. Although it is seldom life-threatening, facial trauma can also be deadly, because it can cause severe bleeding or interference with the airway; thus a primary concern in treatment is ensuring that the airway is open and not threatened so that the patient can breathe. Depending on the type of facial injury, treatment may include bandaging and suturing of open wounds, administration of ice, antibiotics and pain killers, moving bones

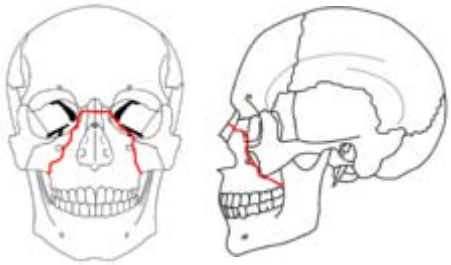
back into place, and surgery. When fractures are suspected, radiography is used for diagnosis. Treatment may also be necessary for other injuries such as traumatic brain injury, which commonly accompany facial trauma.

In developed countries, the leading cause of facial trauma used to be motor vehicle accidents, but this mechanism has been replaced by interpersonal violence; however auto accidents still predominate as the cause in developing countries and are still a major cause elsewhere. Thus prevention efforts include awareness campaigns to educate the public about safety measures such as seat belts and motorcycle helmets, and laws to prevent drunk and unsafe driving. Other causes of facial trauma include falls, industrial accidents, and sports injuries.

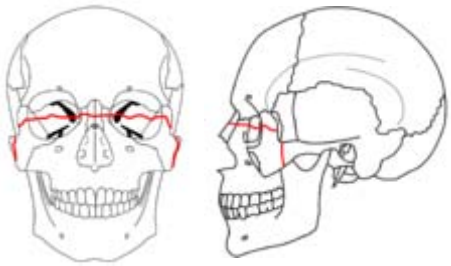
Classification



Le Fort I fractures

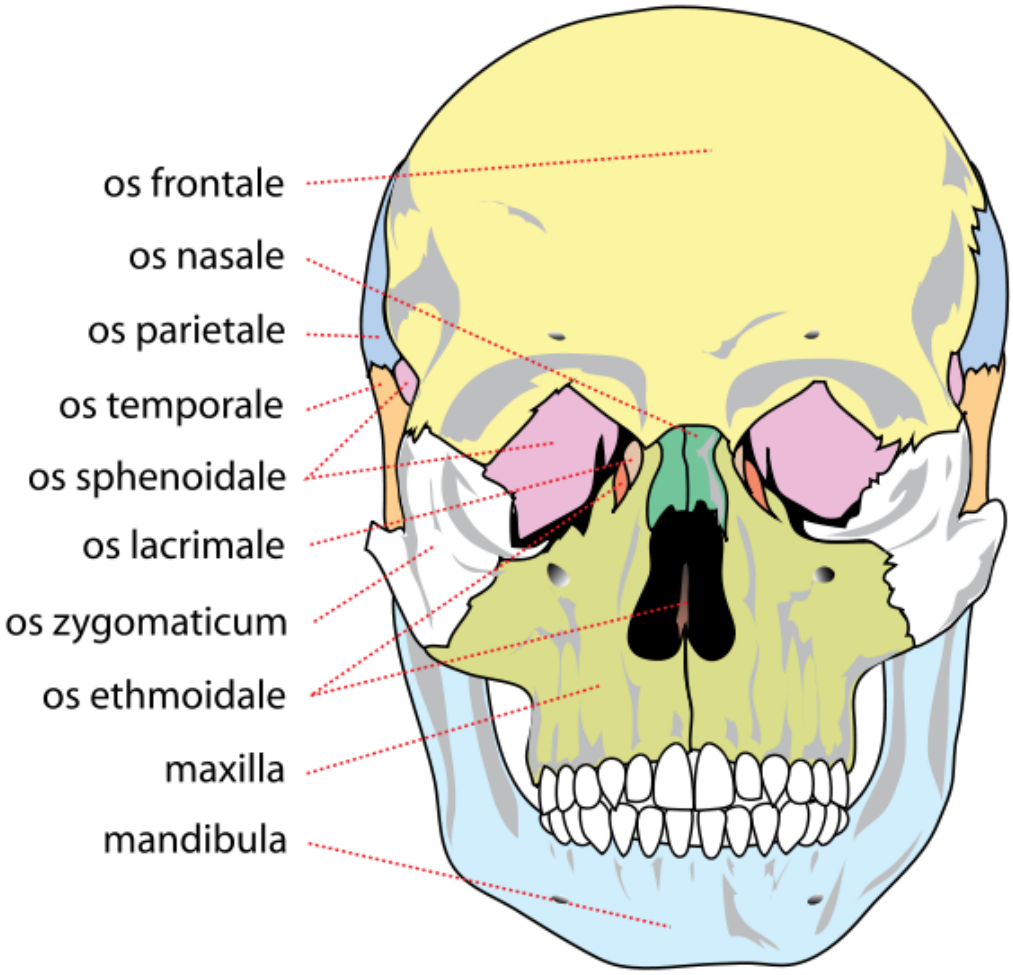


Le Fort II fractures



Le Fort III fractures

Soft tissue injuries include abrasions, lacerations, avulsions, bruises, burns and cold injuries



The facial bones

Commonly injured facial bones include the nasal bone (the nose), the maxilla (the bone that forms the upper jaw), and the mandible (the lower jaw). The mandible may be fractured at its symphysis, body, angle, ramus, and condoyle. The zygoma (cheekbone) and the frontal bone (forehead) are other sites for fractures. Fractures may also occur in the bones of the palate and those that come together to form the orbit of the eye.

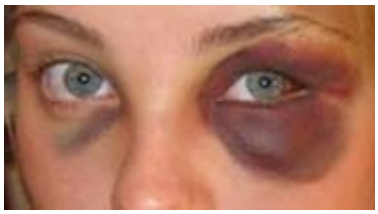
At the beginning of the 20th century, René Le Fort mapped typical locations for facial fractures; these are now known as Le Fort I, II, and III fractures (right). Le Fort I fractures, also called Guérin or horizontal maxillary fractures, involve the maxilla, separating it from the palate. Le Fort II fractures, also called pyramidal fractures of the maxilla, cross the nasal bones and the orbital rim. Le Fort III fractures, also called craniofacial disjunction and transverse facial fractures, cross the front of the maxilla and involve the lacrimal bone, the lamina papyracea, and the orbital floor, and often involve the ethmoid bone. are the most serious. Le Fort fractures, which account for 10–20% of facial fractures, are often associated with other serious injuries. Le Fort made his classifications based on work with cadaver skulls, and the classification system has been criticized as imprecise and simplistic since most midface fractures involve a

combination of Le Fort fractures. Although most facial fractures do not follow the patterns described by Le Fort precisely, the system is still used to categorize injuries.

Causes

Injury mechanisms such as falls, assaults, sports injuries, and vehicle crashes are common causes of facial trauma in children as well as adults. Blunt assaults, blows from fists or objects, are a common cause of facial injury. Facial trauma can also result from wartime injuries such as gunshots and blasts. Animal attacks and work-related injuries such as industrial accidents are other causes. Vehicular trauma is one of the leading causes of facial injuries. Trauma commonly occurs when the face strikes a part of the vehicle's interior, such as the steering wheel. In addition, airbags can cause corneal abrasions and lacerations (cuts) to the face when they deploy.

Signs and symptoms



Bruising, a common symptom in facial trauma

Fractures of facial bones, like other fractures, may be associated with pain, bruising, and swelling of the surrounding tissues (such symptoms can occur in the absence of fractures as well). Fractures of the nose, base of the skull, or maxilla may be associated with profuse nosebleeds. Nasal fractures may be associated with deformity of the nose, as well as swelling and bruising. Deformity in the face, for example a sunken cheekbone or teeth which do not align properly, suggests the presence of fractures. Asymmetry can suggest facial fractures or damage to nerves. People with mandibular fractures often have pain and difficulty opening their mouths and may have numbness in the lip and chin. With Le Fort fractures, the midface may move relative to the rest of the face or skull.

Diagnosis

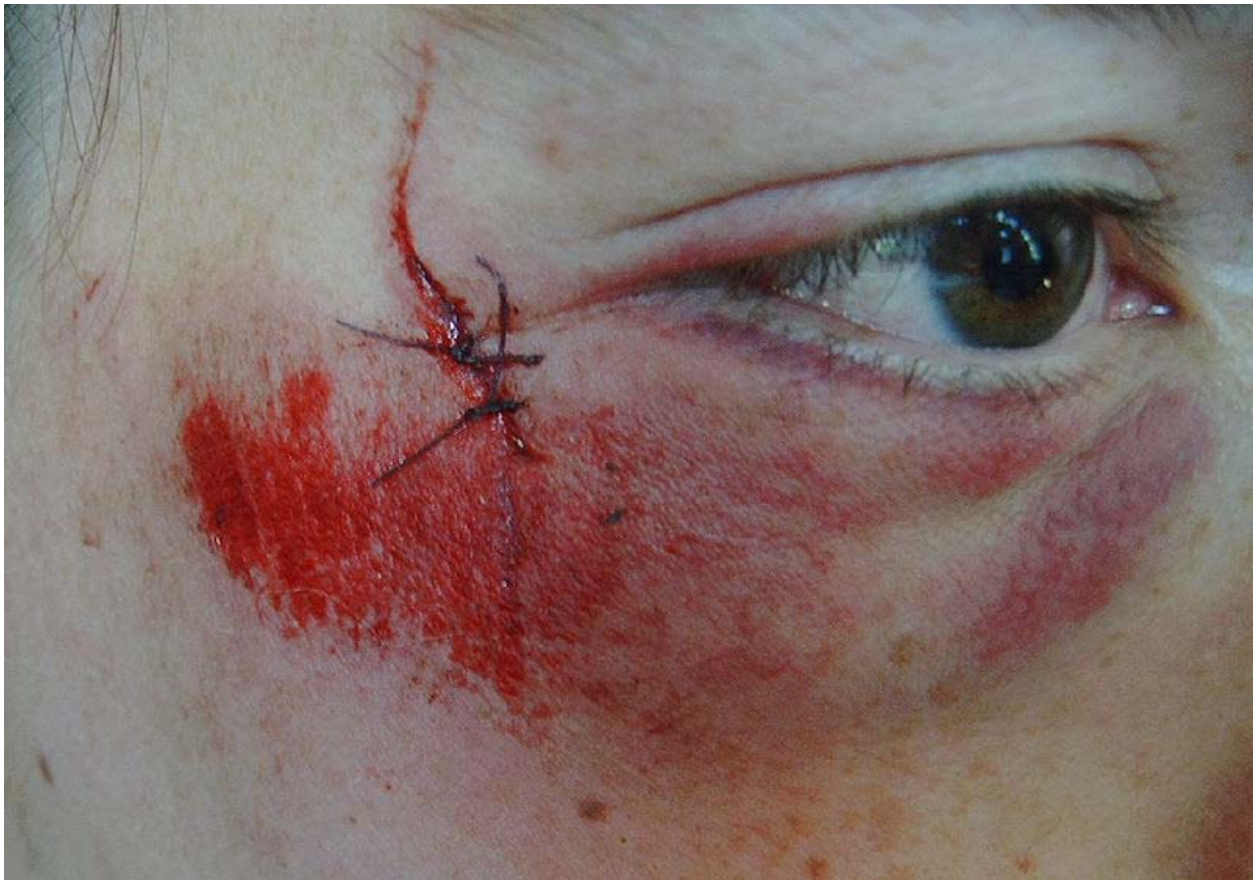
Radiography, imaging of tissues using X-rays, is used to rule out facial fractures. Angiography (X-rays taken of the inside of blood vessels) can be used to locate the source of bleeding. However the complex bones and tissues of the face can make it difficult to interpret plain radiographs; CT scanning is better for detecting fractures and examining soft tissues, and is often needed to determine whether surgery is necessary, but it is more expensive and difficult to obtain. CT scanning is usually considered to be more definitive and better at detecting facial injuries than X-ray. CT scanning is especially likely to be used in people with multiple injuries who need CT scans to assess for other injuries anyway.

Prevention

Measures to reduce facial trauma include laws enforcing seat belt use and public education to increase awareness about the importance of seat belts and motorcycle helmets. Efforts to reduce drunk driving are other preventative measures; changes to laws and their enforcement have been proposed, as well as changes to societal attitudes toward the activity. Information obtained from biomechanics studies can be used to design automobiles with a view toward preventing facial injuries. While seat belts reduce the number and severity of facial injuries that occur in crashes, airbags alone are not very effective at preventing the injuries. In sports, safety devices including helmets have been found to reduce the risk of severe facial injury. Additional attachments such as face guards may be added to sports helmets to prevent orofacial injury (injury to the mouth or face).

Treatment

An immediate need in treatment is to ensure that the airway is open and not threatened (for example by tissues or foreign objects), because airway compromise can occur rapidly and insidiously, and is potentially deadly. Material in the mouth that threatens the airway can be removed manually or using a suction tool for that purpose, and supplemental oxygen can be provided. Facial fractures that threaten to interfere with the airway can be reduced by moving the bones back into place; this both reduces bleeding and moves the bone out of the way of the airway. Tracheal intubation (inserting a tube into the airway to assist breathing) may be difficult or impossible due to swelling. Nasal intubation, inserting an endotracheal tube through the nose, may be contraindicated in the presence of facial trauma because if there is an undiscovered fracture at the base of the skull, the tube could be forced through it and into the brain. If facial injuries prevent oraotracheal or nasotracheal intubation, a surgical airway can be placed to provide an adequate airway. Although cricothyrotomy and tracheostomy can secure an airway when other methods fail, they are used only as a last resort because of potential complications and the difficulty of the procedures.



Sutures may be used to close wounds.

A dressing can be placed over wounds to keep them clean and to facilitate healing, and antibiotics may be used in cases where infection is likely. People with contaminated wounds who have not been immunized against tetanus within five years may be given a tetanus vaccination. Lacerations may require stitches to stop bleeding and facilitate wound healing with as little scarring as possible. Although it is not common for bleeding from the maxillofacial region to be profuse enough to be life threatening, it is still necessary to control such bleeding. Severe bleeding occurs as the result of facial trauma in 1–11% of patients, and the origin of this bleeding can be difficult to locate. Nasal packing can be used to control nose bleeds and hematomas that may form on the septum between the nostrils. Such hematomas need to be drained. Mild nasal fractures need nothing more than ice and pain killers, while breaks with severe deformities or associated lacerations may need further treatment, such as moving the bones back into alignment and antibiotic treatment.

Treatment aims to repair the face's natural bony architecture and to leave as little apparent trace of the injury as possible. Fractures may be repaired with metal plates and screws. They may also be wired into place. Bone grafting is another option to repair the bone's architecture, to fill out missing sections, and to provide structural support. Medical literature suggests that early repair of facial injuries, within hours or days, results in better outcomes for function and appearance.

Surgical specialists who commonly treat specific aspects of facial trauma include otorhinolaryngologists, plastic surgeons, and oral and maxillofacial surgeons. These surgical specialists are trained in the comprehensive management of trauma to the lower, middle and upper face and have to take written and oral board examinations covering the management of facial injuries.

Prognosis and complications

By itself, facial trauma rarely presents a threat to life; however it is often associated with dangerous injuries, and life-threatening complications such as blockage of the airway may occur. The airway can be blocked due to bleeding, swelling of surrounding tissues, or damage to structures. Burns to the face can cause swelling of tissues and thereby lead to airway blockage. Broken bones such as combinations of nasal, maxillary, and mandibular fractures can interfere with the airway. Blood from the face or mouth, if swallowed, can cause vomiting, which can itself present a threat to the airway because it has the potential to be aspirated. Since airway problems can occur late after the initial injury, it is necessary for healthcare providers to monitor the airway regularly.

Even when facial injuries are not life threatening, they have the potential to cause disfigurement and disability, with long-term physical and emotional results. Facial injuries can cause problems with eye, nose, or jaw function and can threaten eyesight. As early as 400 BC, Hippocrates is thought to have recorded a relationship between blunt facial trauma and blindness. Injuries involving the eye or eyelid, such as retrobulbar hemorrhage, can threaten eyesight; however, blindness following facial trauma is not common.

Nerves and muscles may be trapped by broken bones; in these cases the bones need to be put back into their proper places quickly. For example, fractures of the orbital floor or medial orbital wall of the eye can entrap the medial rectus or inferior rectus muscles. In facial wounds, tear ducts and nerves of the face may be damaged. Fractures of the frontal bone can interfere with the drainage of the frontal sinus and can cause sinusitis.

Infection is another potential complication, for example when debris is ground into an abrasion and remains there. Injuries resulting from bites carry a high infection risk.

Epidemiology

As many as 50–70% of people who survive traffic accidents have facial trauma. In most developed countries, violence from other people has replaced vehicle collisions as the main cause of maxillofacial trauma; however in many developing countries traffic accidents remain the major cause. Increased use of seat belts and airbags has been credited with a reduction in the incidence of maxillofacial trauma, but fractures of the mandible (the jawbone) are not decreased by these protective measures. The risk of maxillofacial trauma is decreased by a factor of two with use of motorcycle helmets. A decline in facial bone fractures due to vehicle accidents is thought to be due to seat belt and drunk driving laws, strictly enforced speed limits and use of

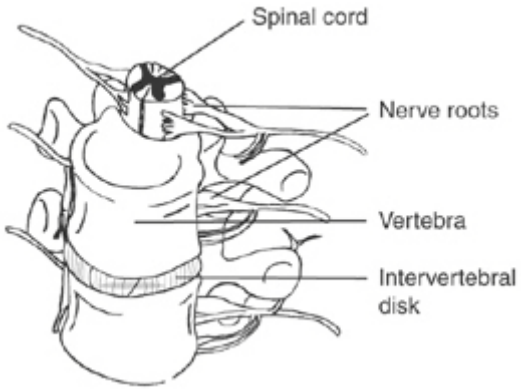
airbags. In vehicle accidents, drivers and front seat passengers are at highest risk for facial trauma.

Facial fractures are distributed in a fairly normal curve by age, with a peak incidence occurring between ages 20 and 40, and children under 12 suffering only 5–10% of all facial fractures. Most facial trauma in children involves lacerations and soft tissue injuries. There are several reasons for the lower incidence of facial fractures in children: the face is smaller in relation to the rest of the head, children are less often in some situations associated with facial fractures such as occupational and motor vehicle hazards, there is a lower proportion of cortical bone to cancellous bone in children's faces, poorly developed sinuses make the bones stronger, and fat pads provide protection for the facial bones.

Head and brain injuries are commonly associated with facial trauma, particularly that of the upper face; brain injury occurs in 15–48% of people with maxillofacial trauma. Coexisting injuries can affect treatment of facial trauma; for example they may be emergent and need to be treated before facial injuries. People with trauma above the level of the collar bones are considered to be at high risk for cervical spine injuries (spinal injuries in the neck) and special precautions must be taken to avoid movement of the spine, which could worsen a spinal injury.

Spinal cord injury

Spinal cord injuries



View of the vertebral column and spinal cord

ICD-10 G95.9, T09.3

DiseasesDB 12327 29466

eMedicine	emerg/553 neuro/711 pmr/182 pmr/183 orthoped/425
MeSH	D013119

A **Spinal cord injury** (**SCI**) refers to any injury to the spinal cord that is caused by trauma instead of a disease. Depending on where the spinal cord and nerve roots are damaged, the symptoms can vary widely, from pain to paralysis to incontinence. Spinal cord injuries are described at various levels of "incomplete" which can vary from having no effect on the patient to a "complete" injury which means a total loss of function.

Treatment of spinal cord injuries starts with restraining the spine and controlling inflammation to prevent further damage. The actual treatment can vary widely depending on the location and extent of the injury. In many cases, spinal cord injuries require substantial physical therapy and rehabilitation, especially if the patient's injury interferes with activities of daily life.

Spinal cord injuries have many causes, but are typically associated with major trauma from motor vehicle accidents, falls, sports injuries, and violence. Research into treatments for spinal cord injuries includes controlled hypothermia and stem cells, though many treatments have not been studied thoroughly and very little new research has been implemented in standard care.

Classification

The American Spinal Injury Association (ASIA) first published an international classification of spinal cord injury in 1982, called the *International Standards for Neurological and Functional Classification of Spinal Cord Injury*. Now in its sixth edition, the *International Standards for Neurological Classification of Spinal Cord Injury* (ISNCSCI) is still widely used to document sensory and motor impairments following SCI. It is based on neurological responses, touch and pinprick sensations tested in each dermatome, and strength of ten key muscles on each side of the body, including hip flexion (L2), shoulder shrug (C4), elbow flexion (C5), wrist extension (C6), and elbow extension (C7). Traumatic spinal cord injury is classified into five categories on the ASIA Impairment Scale:

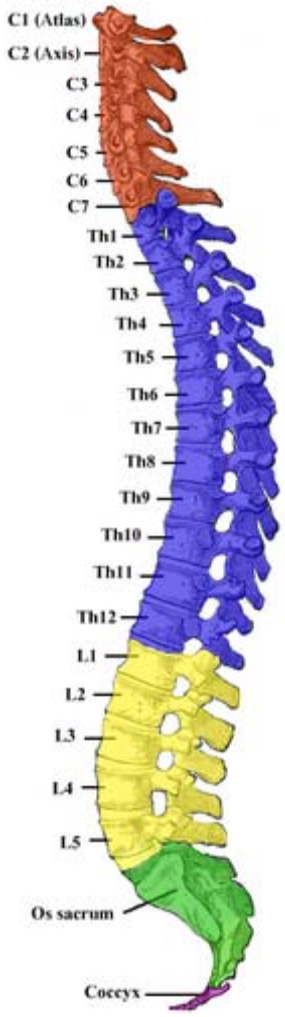
- A indicates a "complete" spinal cord injury where no motor or sensory function is preserved in the sacral segments S4-S5.
- B indicates an "incomplete" spinal cord injury where sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5. This is typically a transient phase and if the person recovers any motor function below the neurological level, that person essentially becomes a motor incomplete, i.e. ASIA C or D.
- C indicates an "incomplete" spinal cord injury where motor function is preserved below the neurological level and more than half of key muscles below the neurological level have a muscle grade of less than 3, which indicates active movement with full range of motion against gravity.
- D indicates an "incomplete" spinal cord injury where motor function is preserved below the neurological level and at least half of the key muscles below the neurological level have a muscle grade of 3 or more.

- E indicates "normal" where motor and sensory scores are normal. Note that it is possible to have spinal cord injury and neurological deficits with completely normal motor and sensory scores.

Dimitrijevic proposed a further class, the so-called discomplete lesion, which is clinically complete but is accompanied by neurophysiological evidence of residual brain influence on spinal cord function below the lesion.

Signs and symptoms

Divisions of Spinal Segments



Segmental Spinal Cord Level and Function

Level	Function
C1-C6	Neck flexors
C1-T1	Neck extensors
C3, C4, C5	Supply diaphragm (mostly C4)
C5, C6	Shoulder movement, raise arm (deltoid); flexion of elbow (biceps); **C6** externally rotates the arm (supinates)
C6, C7	Extends elbow and wrist (triceps and wrist extensors); pronates wrist
C7, T1	Flexes wrist
C7, T1	Supply small muscles of the hand
T1 -T6	Intercostals and trunk above the waist
T7-L1	Abdominal muscles
L1, L2, L3, L4	Thigh flexion
L2, L3, L4	Thigh adduction
L4, L5, S1	Thigh abduction
L5, S1, S2	Extension of leg at the hip (gluteus maximus)
L2, L3, L4	Extension of leg at the knee (quadriceps femoris)
L4, L5, S1, S2	Flexion of leg at the knee (hamstrings)
L4, L5, S1	Dorsiflexion of foot (tibialis anterior)

L4, L5, S1	Extension of toes
L5, S1, S2	Plantar flexion of foot
L5, S1, S2	Flexion of toes

Signs observed by a physician and symptoms experienced by a patient will vary depending on where the spine is injured and the extent of the injury. These are all determined by the area of the body that the injured area of the spine innervates. A section of skin innervated through a specific part of the spine is called a dermatome, and spinal injury can cause pain, numbness, or a loss of sensation in the relevant areas. A group of muscles innervated through a specific part of the spine is called a myotome, and injury to the spine can cause problems with voluntary motor control. The muscles may contract uncontrollably, become weak, or be completely unresponsive. The loss of muscle function can have additional effects if the muscle is not used, including atrophy of the muscle and bone degeneration.

A severe injury may also cause problems in parts of the spine below the injured area. In a "complete" spinal injury, all function below the injured area are lost. In an "incomplete" injury, some or all of the functions below the injured area may be unaffected. If the patient has the ability to contract the anal sphincter voluntarily or to feel a pinprick or touch around the anus, the injury is considered to be incomplete. The nerves in this area are connected to the very lowest region of the spine, the sacral region, and retaining sensation and function in these parts of the body indicates that the spinal cord is only partially damaged.

A complete injury frequently means that the patient has little hope of functional recovery. The relative incidence of incomplete injuries compared to complete spinal cord injury has improved over the past half century, due mainly to the emphasis on better initial care and stabilization of spinal cord injury patients. Most patients with incomplete injuries recover at least some function.

In addition to sensation and muscle control, the loss of connection between the brain and the rest of the body can have specific effects depending on the location of the injury.

Determining the exact "level" of injury is critical in making accurate predictions about the specific parts of the body that may be affected by paralysis and loss of function. The level is assigned according to the location of the injury by the vertebra of the spinal column. While the prognosis of complete injuries are generally predictable since recovery is rare, the symptoms of incomplete injuries can vary and it is difficult to make an accurate prediction of the outcome.

Cervical

Cervical (neck) injuries usually result in full or partial tetraplegia (Quadriplegia). However, depending on the specific location and severity of trauma, limited function may be retained.

- Injuries at the C-1/C-2 levels will often result in loss of breathing, necessitating mechanical ventilators or phrenic nerve pacing.
- **C3 vertebrae and above**: Typically results in loss of diaphragm function, necessitating the use of a ventilator for breathing.
- **C4:** Results in significant loss of function at the biceps and shoulders.
- **C5**: Results in potential loss of function at the shoulders and biceps, and complete loss of function at the wrists and hands.
- **C6**: Results in limited wrist control, and complete loss of hand function.
- **C7 and T1**: Results in lack of dexterity in the hands and fingers, but allows for limited use of arms.

Patients with complete injuries above C7 typically cannot handle activities of daily living and cannot function independently.

Additional signs and symptoms of cervical injuries include:

- Inability or reduced ability to regulate heart rate, blood pressure, sweating and hence body temperature.
- Autonomic dysreflexia or abnormal increases in blood pressure, sweating, and other autonomic responses to pain or sensory disturbances.

Thoracic

Complete injuries at or below the thoracic spinal levels result in paraplegia. Functions of the hands, arms, neck, and breathing are usually not affected.

- **T1 to T8**: Results in the inability to control the abdominal muscles. Accordingly, trunk stability is affected. The lower the level of injury, the less severe the effects.
- **T9 to T12**: Results in partial loss of trunk and abdominal muscle control.

Lumbosacral

The effects of injuries to the lumbar or sacral regions of the spinal cord are decreased control of the legs and hips, urinary system, and anus.

- Bowel and bladder function is regulated by the sacral region of the spine. In that regard, it is very common to experience dysfunction of the bowel and bladder, including infections of the bladder and anal incontinence, after traumatic injury.
- Sexual function is also associated with the sacral spinal segments, and is often affected after injury. During a psychogenic sexual experience, signals from the brain are sent to spinal levels T10-L2 and in case of men, are then relayed to the penis where they trigger an erection. A reflex erection, on the other hand, occurs as a result of direct physical contact to the penis or other erotic areas such as the ears, nipples or neck. A reflex erection is involuntary and can occur without sexually stimulating thoughts. The nerves that control a man's ability to have a reflex erection are located in the sacral nerves (S2-S4) of the spinal cord and could be affected after a spinal cord injury.

Other syndromes of incomplete injury

Central cord syndrome is a form of incomplete spinal cord injury characterized by impairment in the arms and hands and, to a lesser extent, in the legs. This is also referred to as inverse paraplegia, because the hands and arms are paralyzed while the legs and lower extremities work correctly.

Most often the damage is to the cervical or upper thoracic regions of the spinal cord, and characterized by weakness in the arms with relative sparing of the legs with variable sensory loss.

This condition is associated with ischemia, hemorrhage, or necrosis involving the central portions of the spinal cord (the large nerve fibers that carry information directly from the cerebral cortex). Corticospinal fibers destined for the legs are spared due to their more external location in the spinal cord.

This clinical pattern may emerge during recovery from spinal shock due to prolonged swelling around or near the vertebrae, causing pressures on the cord. The symptoms may be transient or permanent.

Anterior cord syndrome is often associated with flexion type injuries to the cervical spine, causing damage to the anterior portion of the spinal cord and/or the blood supply from the anterior spinal artery. Below the level of injury motor function, pain sensation, and temperature sensation are lost. While touch, proprioception (sense of position in space), and sense of vibration remain intact.

Posterior cord syndrome can also occur, but is very rare. Damage to the posterior portion of the spinal cord and/or interruption to the posterior spinal artery causes the loss of proprioception and epicritic sensation (eg: stereognosis, graphesthesia) below the level of injury. Motor function, sense of pain, and sensitivity to light touch remain intact.

Brown-Séquard syndrome usually occurs when the spinal cord is hemisectioned or injured on the lateral side. True hemisections of the spinal cord are rare, while partial lesions due to penetrating wounds (eg: gunshot wounds or knife penetrations) are more common. On the ipsilateral side of the injury (same side), there is a loss of motor function, proprioception, vibration, and light touch. Contralaterally (opposite side of injury), there is a loss of pain, temperature, and crude touch sensations.

Tabes Dorsalis results from injury to the posterior part of the spinal cord, usually from infection diseases such as syphilis, causing loss of touch and proprioceptive sensation.

Conus medullaris syndrome results from injury to the tip of the spinal cord, located at L1 vertebra.

Causes

Spinal cord injuries are most often traumatic, caused by lateral bending, dislocation, rotation, axial loading, and hyperflexion or hyperextension of the cord or cauda equina. Motor vehicle accidents are the most common cause of SCIs, while other causes include falls, work-related accidents, sports injuries, and penetrations such as stab or gunshot wounds. SCIs can also be of a non-traumatic origin, as in the case of cancer, infection, intervertebral disc disease, vertebral injury and spinal cord vascular disease.

Diagnosis

A radiographic evaluation using a x-ray, MRI or CT scan can determine if there is any damage to the spinal cord and where it is located. A neurologic evaluation incorporating sensory testing and reflex testing can help determine the motor function of a person with a SCI.

Management

Modern trauma care includes a step called clearing the cervical spine, where a patient with a suspected injury is treated as if they have a spinal injury until that injury is ruled out. The objective is to prevent any further spinal cord damage. Patients are immobilized at the scene of the inury until it is clear that there is no damage to the highest portions of the spine. This is traditionally done using a device called a long spine board.

Once the patient is brought to a hospital and immediate life-threatening injuries have been addressed, they are evaluated for spinal injury, typically by x-ray or CT scan. Complications of spinal cord injuries include neurogenic shock, respiratory failure, pulmonary edema, pneumonia, pulmonary emboli and deep venous thrombosis, many of which can be recognized early in treatment and avoided. SCI patients often require extended treatment in an intensive care unit.

Surgery may also be necessary to remove any bone fragments from the spinal canal and to stabilize the spine. Inflammation can cause further damage to the spinal cord, and patients are sometimes treated with a corticosteroid drug such as methylprednisolone to reduce swelling. The drug is used within 8 hours of the injury. This practice is based on the National Acute Spinal Cord Injury Studies (NASCIS) I and II, though other studies have shown little benefit and concerns about side effects from the drug have changed this practice. A food dye, brilliant blue G, has also been shown to have some effect at reducing inflammation after spinal injury.

One experimental treatment, therapeutic hypothermia, is used but there is no evidence that that it improve outcomes. Maintaining mean arterial blood pressures of at least 85 to 90 mmHg using intravenous fluids, transfusion, and vasopressors to ensure adequate blood supply to nerves and prevent damage is another treatment with little evidence of effectiveness.

Rehabilitation

The rehabilitation process following a spinal cord injury typically begins in the acute care setting. Physical therapists, occupational therapists, social workers, psychologists and other health care professionals typically work as a team to decide on goals with the patient and develop a plan of discharge that is appropriate for the patient's condition.

In the acute phase physical therapists focus on the patient's respiratory status, prevention of indirect complications (such as pressure sores), maintaining range of motion, and keeping available musculature active. Physical therapists can assist immobilized patients with effective cough techniques, secretion clearance, stretching of the thoracic wall, and suggest abdominal support belts when necessary. The amount of time a patient is immobilized may depend on the level of the spinal cord injury. Physical therapists work with the patient to prevent any complications that may arise due to this immobilization.

As a team, health-care professionals help to re-orient the patient, provide support for the patient and family, and begin to develop goals with the patient.

Occupational therapy plays an important role in the management of SCI.

Recent studies emphasize the importance of early occupational therapy, started immediately after the client is stable. This process includes teaching of coping skills, and physical therapy.

In the first step, acute recovery, the focus is on support and prevention. Inteventions aim to give the individual a sense of control over a situation in which the patient likely feels little independence.

As the patient becomes more stable, they may move to a rehabilitation facility or remain in the acute care setting. The patient begins to take more of an active role in their rehabilitation at this stage and works with the team to develop reasonable functional goals.

Though rehabilitation interventions are performed during the acute phase, recent literature suggests that 44% of the total hours spent on rehabilitation during the first year after spinal cord injury, occur after discharge from inpatient rehabilitation. Participants in this study received 56% of their total physical therapy hours and 52% of their total occupational therapy hours after discharge. This suggests that inpatient rehabilitation lengths of stay are reduced and that post-discharge therapy may replace some of the inpatient treatment.

Whether patients are placed in inpatient rehabilitation or discharged, physical therapists attempt to maximize functional independence at this stage. Depending on the level of the spinal cord injury, whatever sparing the patient has is optimized. Bed mobility, transfers, wheelchair mobility skills, and performing other activities of daily living (ADLs) are just a few of the interventions that physical therapists can help the patient with.

ADLs can be difficult for an individual with a spinal cord injury; however, through the rehabilitation process, individuals with SCI may be able to live independently in the community with or without full-time attendant care, depending on the level of their injury.

Further interventions focus on support and education for the individual and caregivers. This includes an evaluation of limb function to determine what the patient is capable of doing independently, and teaching the patient self-care skills. Independence in daily activities like eating, bowel and bladder management and mobility is the goal, as obtaining competency in self-care tasks contributes significantly to an individual's sense of self confidence and reduces the burden on caregivers. Quality of life issues such as sexual health and function are also addressed.

Assistive devices such as wheelchairs have a substantial effect on the quality of life of the patient, and careful selection is important. Teaching the patient how to transfer from different positions, such as from a wheelchair into bed, is an important part of therapy, and devices such as sliding transfer boards and grab bars can assist in these tasks. Individuals who are able to transfer independently from their wheelchair to the driver's seat using a sliding transfer board may be able to return to driving in an adapted vehicle. Complete independence with driving also requires the ability to load and unload one's wheelchair from the vehicle.

In addition to acquiring skills such as wheelchair transfers, individuals with a spinal cord injury can greatly benefit from exercise reconditioning. In the majority of cases, spinal cord injury leaves the lower limbs either entirely paralyzed, or with insufficient strength, endurance, or motor control to support safe and effective physical training. Therefore, most exercise training employs the use of arm crank ergometry, wheelchair ergometry, and swimming. In one study, subjects with traumatic spinal cord injury participated in a progressive exercise training program, which involved arm ergometry and resistance training. Subjects in the exercise group experienced significant increases in strength for almost all muscle groups when compared to the control group. Exercisers also reported less stress, fewer depressive symptoms, greater satisfaction with physical functioning, less pain, and better quality of life. Physical therapists are able to provide a variety of exercise interventions, including, passive range of motion exercises, upper body wheeling (arm crank ergometry), functional electrical stimulation, and electrically stimulated resistance exercises all of which can improve arterial function in those living with SCI. Physical therapists can improve the quality of life of individuals with spinal cord injury by developing exercise programs that are tailored to meet individual patient needs. Adapted physical activity equipment can also be used to allow for sport participation: for example, sit-skiis can be used by individuals with a spinal cord injury for cross-country or downhill skiing.

Body weight supported treadmill training is another intervention that physiotherapists may assist with. Body weight supported treadmill training has been researched in an attempt to prevent bone loss in the lower extremities in individuals with spinal cord injury. Research has shown that early weight-bearing after acute spinal cord injury by standing or treadmill walking (5 times weekly for 25 weeks) resulted in no loss or only moderate loss in trabecular bone compared with immobilized subjects who lost 7-9% of trabecular bone at the tibia. Gait training with body weight support, among patients with incomplete spinal cord injuries, has also recently been shown to be more effective than conventional physiotherapy for improving the spatial-temporal and kinematic gait parameters.

The patient's living environment can also be modified to improve independence. For example, ramps or lifts can be added to a patient's home, and part of rehabilitation involves investigating options for returning to previous interests as well as developing new pursuits. Community participation is an important aspect in maintaining quality of life.

Prognosis

In general, patients with complete injuries recover very little lost function and patients with incomplete injuries have more hope of recovery. Some patients that are initially assessed as having complete injuries are later changed to incomplete injuries.

Recovery is typically quickest during the first six months, with very few patients experiencing any substantial recovery more than nine months after the injury.

Tetraplegia

The ASIA motor score (AMS) is a 100 point score based on ten pairs of muscles each given a five point rating. A person with no injury should score 100. In complete tetraplegia, a recovery of nine points on this scale is average regardless of where the patient starts. Patients with higher levels of injury will typically have lower starting scores.

In incomplete tetraplegia, 46 percent of patients were able to walk one year after injury, though they may require assistance such as crutches and braces. These patients had similar recovery in muscles of the upper and lower body. Patients who had pinprick sensation in the sacral dermatomes such as the anus recovered better than patients that could only sense a light touch.

Paraplegia

In one study on 142 individuals after one year of complete paraplegia, none of the patients where the initial injury was above the ninth thoracic vertebra (T9) were able to recover completely. Less than half, 38 percent, of the studied subjects had any sort of recovery. Very few, five percent, recovered enough function to walk, and those required crutches and other assistive devices, and all of them had injuries below T11. A few of the patients, four percent, had what were originally classified as complete injuries and were reassessed as having incomplete injuries, but only half of that four percent regained bowel and bladder control.

Of the 54 patients in the same study with incomplete paraplegia 76 percent were able to walk with assistance after one year. On average, patients improved 12 points on the 50 point lower extremity motor score (LEMS) scale. The amount of improvement was not dependent on the location of the injury, but patients with higher injuries had lower initial motor scores and correspondingly lower final motor scores. A LEMS of 50 is normal, and scores of 30 or higher typically predict ability to walk.

Epidemiology

Spinal injury can occur without trauma. Many people suffer transient loss of function ("stingers") in sports accidents or pain in "whiplash" of the neck without neurological loss and relatively few of these suffer spinal cord injury sufficient to warrant hospitalization. The prevalence of spinal cord injury is not well known in many large countries. In some countries, such as Sweden and Iceland, registries are available. In the United States, the incidence of spinal cord injury has been estimated to be about 40 cases (per 1 million people) per year or around 12,000 cases per year. The most common causes of spinal cord injury are motor vehicle accidents, falls, violence and sports injuries. The average age at the time of injury has slowly increased from a reported 29 years of age in the mid-1970's to a current average of around 40. Over 80% of the spinal injuries reported to a major national database occurred in males. In the United States there are around 250,000 individuals living with spinal cord injuries. In China, the incidence of spinal cord injury is approximately 60,000 per year.

Soft tissue injury

A **Soft tissue injury** (STI) is the damage of muscles, ligaments and tendons throughout the body. Common soft tissue injuries usually occur from a sprain, strain, a one off blow resulting in a contusion or overuse of a particular part of the body. Soft tissue injuries can result in pain, swelling, bruising and loss of function (Lovering, 2008).

Management

Immediately after the injury occurs one should apply the PRICE principle to minimize the local tissue damage and reduce inflammation.

’P’rotection ’R’est ’I’ce ’C’ompression ‘E’levation

’PROTECTION’ Protect the individual from further injury by preventing them from moving and keep further hazards away from the individual (Flegel, 2004).

‘REST’ Rest the individual from any activity that causes pain. If simple movements such as bending, straightening or walking are causing pain ‘’rest’’ means immobilizing the injury by splinting or preventing weight bearing with crutches (Flegel, 2004). If walking does not cause any pain, continue to walk for short distances as comfort allows (Lindsay, Watson, Hickmott, Broadfoot & Bruynel, 1994).

’ICE’ During the first 72 hours following an injury ice can help minimize pain and control swelling caused by bleeding and fluid loss from the injured tissue (Flegel, 2004). Icing is recommended for 15minutes every 4 hours to help control the swelling and pain (Subotnick, 1991).

‘COMPRESSION’ Compression is the application of pressure over the injured area with the use of a bandage, elastic wrap or compression tape (Lindsay et al., 1994). This is to control the initial bleeding of joint or limb tissues, or to reduce residual swelling (Flegel, 2004). It is vital that compression is applied within the first few minutes following the injury to see the benefits (Lindsay et al., 1994).

‘ELEVATION’ Used in combination with ice and compression, elevation can also minimize initial tissue bleeding and swelling. Elevate the injured part above the level of the heart as much as possible for the first 72hours, or longer of the swelling persists. (Flegel, 2004).

Treatment

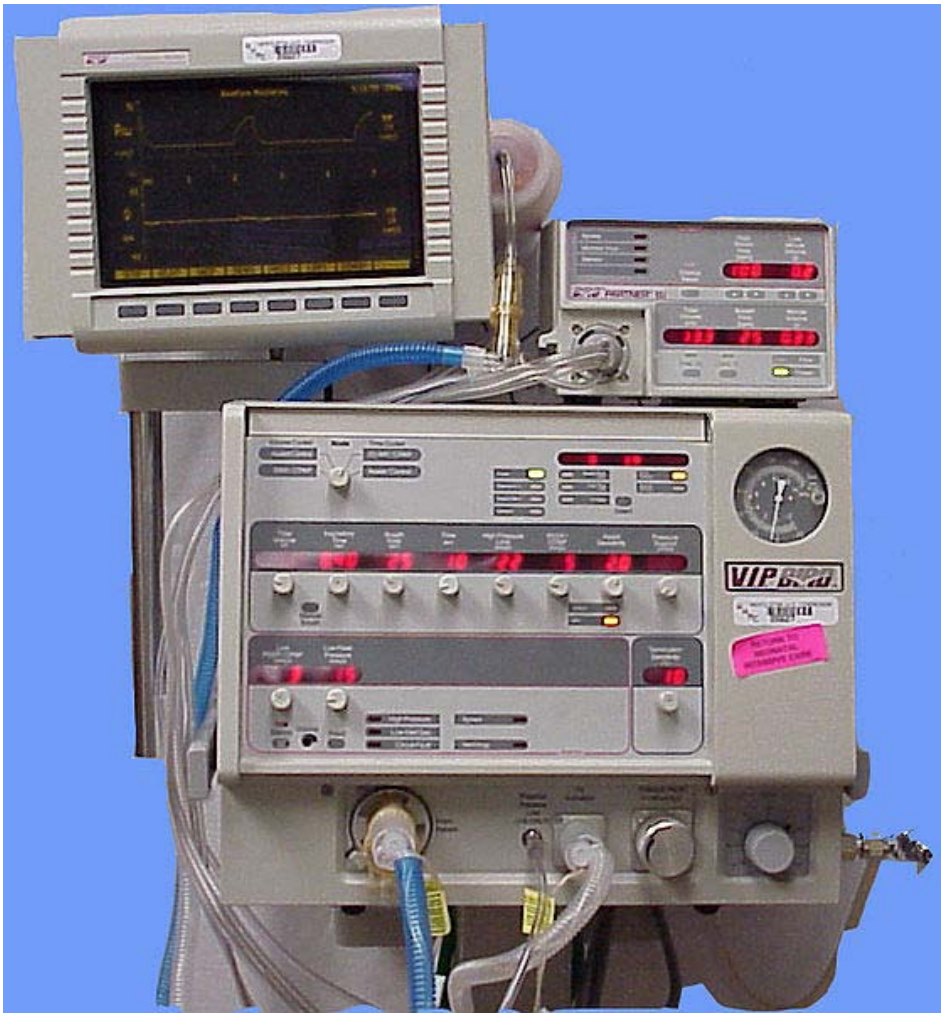
If severe pain persists after the first 24hours it is recommended that an individual consults with a professional who can make a diagnosis and implement a treatment plan so the patient can return to everyday activities (Flegel, 2004). These are some of the tools that a professional can use to help make a full diagnosis;

Nerve conduction studies may also be used to localize nerve dysfunction (*e.g.*, carpal tunnel syndrome), assess severity, and help with prognosis. Electrodiagnosis also helps differentiate between myopathy and neuropathy.

Ultimately, the best method of imaging soft tissue is magnetic resonance imaging (MRI), though it is cost-prohibitive and carries a high false positive rate.

Chapter 6

Intensive-Care Medicine



Mechanical ventilation may be required if a patient's unassisted breathing is insufficient to oxygenate the blood.

Intensive-care medicine or **critical-care medicine** is a branch of medicine concerned with the provision of life support or organ support systems in patients who are **critically ill** and who usually require intensive monitoring.

Overview

Patients requiring intensive care may require support for hemodynamic instability (hypertension/hypotension), airway or respiratory compromise (such as ventilator support), acute renal failure, potentially lethal cardiac arrhythmias, or the cumulative effects of multiple organ failure, more commonly referred to now as multiple organ dysfunction syndrome. They may also be admitted for intensive/invasive monitoring, such as the crucial hours after major surgery when deemed too unstable to transfer to a less intensively monitored unit.

Intensive care is usually only offered to those whose condition is potentially reversible and who have a good chance of surviving with intensive care support. Since the critically ill are so close to dying, the outcome of this intervention is difficult to predict. A prime requisite for admission to an Intensive Care Unit is that the underlying condition can be overcome.

Medical studies suggest a relation between intensive care unit (ICU) volume and quality of care for mechanically ventilated patients. After adjustment for severity of illness, demographic variables, and characteristics of the ICUs (including staffing by intensivists), higher ICU volume was significantly associated with lower ICU and hospital mortality rates. For example, adjusted ICU mortality (for a patient at average predicted risk for ICU death) was 21.2% in hospitals with 87 to 150 mechanically ventilated patients annually, and 14.5% in hospitals with 401 to 617 mechanically ventilated patients annually. Hospitals with intermediate numbers of patients had outcomes between these extremes.

In general, it is the most expensive, technologically advanced and resource-intensive area of medical care. In the United States, estimates of the 2000 expenditure for critical care medicine ranged from US$15–55 billion, accounting for about 0.5% of GDP and about 13% of national health care expenditure (Halpern, 2004).

Organ systems

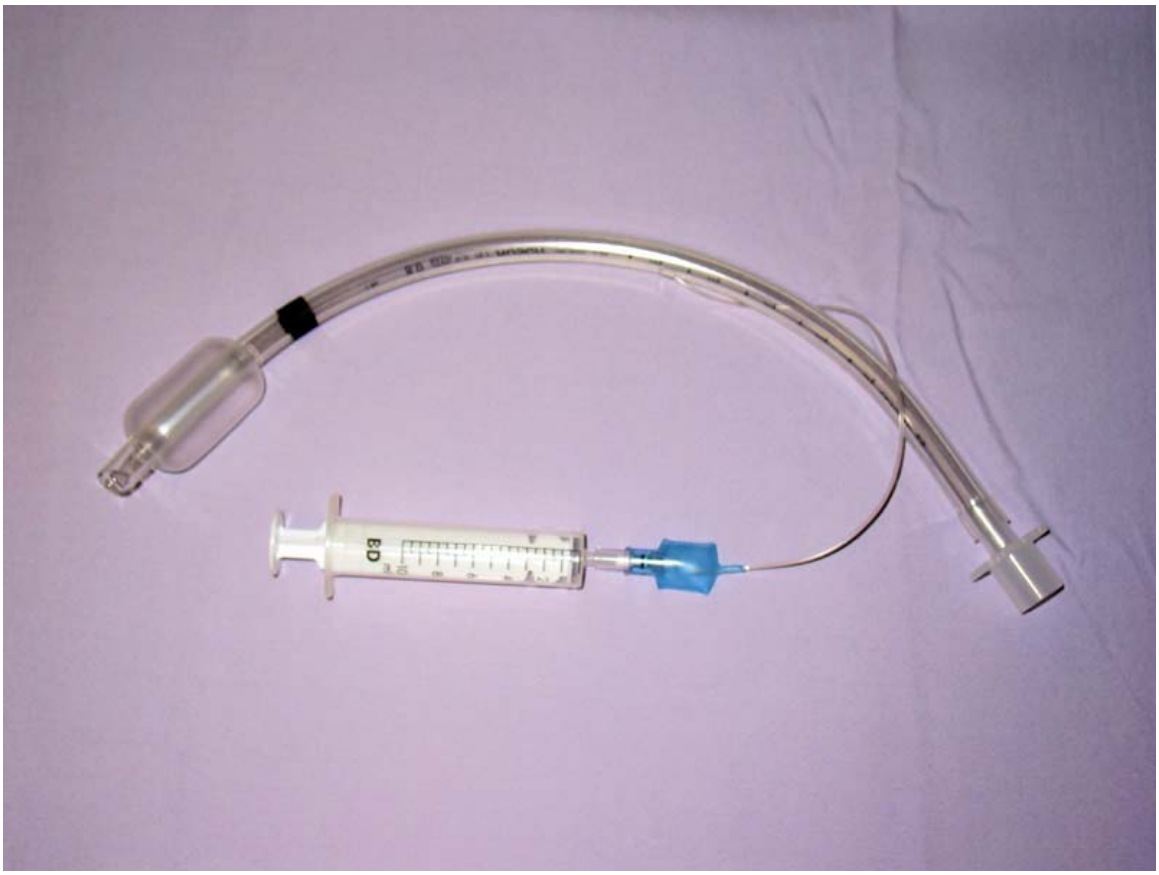
Intensive care usually takes a system by system approach to treatment, rather than the *SOAP* (subjective, objective, analysis, plan) approach of high dependency care. The nine key systems are each considered on an observation-intervention-impression basis to produce a daily plan. As well as the key systems, intensive-care treatment raises other issues including psychological health, pressure points, mobilisation and physiotherapy, and secondary infections.

The nine key IC systems are (alphabetically): cardiovascular system, central nervous system, endocrine system, gastro-intestinal tract (and nutritional condition), hematology, microbiology (including sepsis status), peripheries (and skin), renal (and metabolic), respiratory system.

The provision of intensive care is, in general, administered in a specialized unit of a hospital called the intensive-care unit (ICU) or critical-care unit (CCU). Many hospitals also have designated intensive-care areas for certain specialities of medicine, such as the coronary intensive-care unit (CCU or sometimes CICU, depending on hospital) for heart disease, medical intensive-care unit (MICU), surgical intensive-care unit (SICU), pediatric intensive-care unit

(PICU), neuroscience critical-care unit (NCCU), overnight intensive-recovery (OIR), shock/trauma intensive-care unit (STICU), neonatal intensive-care unit (NICU), and other units as dictated by the needs and available resources of each hospital. The naming is not rigidly standardized. For a time in the early 1960s, it was not clear that specialized intensive care units were needed, so intensive-care resources were brought to the room of the patient that needed the additional monitoring, care, and resources. It became rapidly evident, however, that a fixed location where intensive-care resources and personnel were available provided better care than ad hoc provision of intensive care services spread throughout a hospital.

Equipment and systems



An endotracheal tube

Common equipment in an intensive-care unit (ICU) includes mechanical ventilation to assist breathing through an endotracheal tube or a tracheotomy; hemofiltration equipment for acute renal failure; monitoring equipment; intravenous lines for drug infusions fluids or total parenteral nutrition, nasogastric tubes, suction pumps, drains and catheters; and a wide array of drugs including inotropes, sedatives, broad spectrum antibiotics and analgesics.

Medical specialties

Critical-care medicine is a relatively new but increasingly important medical specialty. Physicians with training in critical-care medicine are referred to as intensivists. The specialty requires additional fellowship training for physicians having completed their primary residency training in internal medicine, anesthesiology, or surgery. Board certification in critical care medicine is available through all three specialty boards. Nurse intensivists receive their training after basic education through ASTNA. Paramedics are certified to levels of CCEMTP or FP-C. Intensivists-physicians with a primary training in internal medicine sometimes pursue combined fellowship training in another subspecialty such as pulmonary medicine, cardiology, infectious disease, or nephrology. The Society of Critical Care Medicine is a well-established multiprofessional society for practitioners working in the ICU, including intensivists. Most medical research has demonstrated that ICU care provided by intensivists produces better outcomes and more cost-effective care. This has led the Leapfrog Group to make a primary recommendation that all ICU patients be managed or co-managed by a dedicated intensivist who is exclusively responsible for patients in one ICU. However, there is a critical shortage of intensivists in the United States, and most hospitals lack this critical physician team member.

Patient management in intensive-care differs significantly between countries. In Australia, where Intensive Care Medicine is a well-established speciality, ICUs are described as 'closed'. In a closed unit the intensive-care specialist takes on the senior role where the patient's primary doctor now acts as a consultant. The advantage of this system is a more coordinated management of the patient based on a team who work exclusively in ICU. Other countries have open Intensive Care Units, where the primary doctor chooses to admit and, in general, makes the management decisions. There is increasingly strong evidence that 'closed' Intensive-Care Units staffed by Intensivists provide better outcomes for patients.

History

Florence Nightingale era

Florence Nightingale

The ICU's roots can be traced back to the Monitoring Unit of critical patients through nurse Florence Nightingale. The Crimean War began in 1853 when Britain, France, and Turkey declared war on Russia. Because of the lack of critical care and the high rate of infection, there was a high mortality rate of hospitalised soldiers, reaching as high as 40% of the deaths recorded during the war. Nightingale and 38 other volunteers had to leave for the Fields of Scurati, and took their "critical care protocol" with them. Upon arriving, and practicing, the mortality rate fell

to 2%. Nightingale contracted typhoid, and returned in 1856 from the war. A school of nursing dedicated to her was formed in 1859 in England. The school was recognised for its professional value and technical calibre, receiving prizes throughout the British government. The school of nursing was established in Saint Thomas Hospital, as a one-year course, and was given to doctors. It used theoretical and practical lessons, as opposed to purely academic lessons. Nightingale's work, and the school, paved the way for intensive care medicine.

Dandy era

Walter Edward Dandy was born in Sedalia, Missouri. He received his BA in 1907 through the University of Missouri and his M.D. in 1910 through the Johns Hopkins University School of Medicine. Dandy worked one year with Dr. Harvey Cushing in the Hunterian Laboratory of Johns Hopkins before entering its boarding school and residence in the Johns Hopkins Hospital. He worked in the Johns Hopkins College in 1914 and remained there until his death in 1946. One of the most important contributions he made for neurosurgery was the air method in ventriculography, in which the cerebrospinal fluid is substituted with air to help an image form on an X-Ray of the ventricular space in the brain. This technique was extremely successful for identifying brain injuries. Dr. Dandy was also a pioneer in the advances in operations for illnesses of the brain affecting the glossopharyngeal as well as Ménière's syndrome, and he published studies that show that high activity can cause sciatic pain. Dandy created the first ICU in the world, 03 beds in Boston in 1926.

Ibsen era

Bjørn Aage Ibsen (1915–2007) graduated in 1940 from medical school at the University of Copenhagen and trained in anesthesiology from 1949 to 1950 at the Massachusetts General Hospital, Boston. He became involved in the 1952 poliomyelitis outbreak in Denmark, where 2722 patients developed the illness in a 6 month period, with 316 suffering respiratory or airway paralysis. Treatment had involved the use of the few negative pressure respirators available, but these devices, while helpful, were limited and did not protect against aspiration of secretions. Ibsen changed management directly, instituting protracted positive pressure ventilation by means of intubation into the trachea, and enlisting 200 medical students to manually pump oxygen and air into the patients lungs. At this time Carl-Gunnar Engström had developed one of the first positive pressure volume controlled ventilators, which eventually replaced the medical students. In this fashion, mortality declined from 90% to around 25%. Patients were managed in 3 special 35 bed areas, which aided charting and other management. In 1953, Ibsen set up what became the world's first Medical/Surgical ICU in a converted student nurse classroom in Kommunehospitalet (The Municipal Hospital) in Copenhagen, and provided one of the first accounts of the management of tetanus with muscle relaxants and controlled ventilation. In 1954 Ibsen was elected Head of the Department of Anaesthesiology at that institution. He jointly authored the first known account of ICU management principles in Nordisk Medicin, September 18, 1958: ‘Arbejdet på en Anæsthesiologisk Observationsafdeling’ (‘The Work in an Anaesthesiologic Observation Unit’) with Tone Dahl Kvittingen from Norway. He died in 2007.

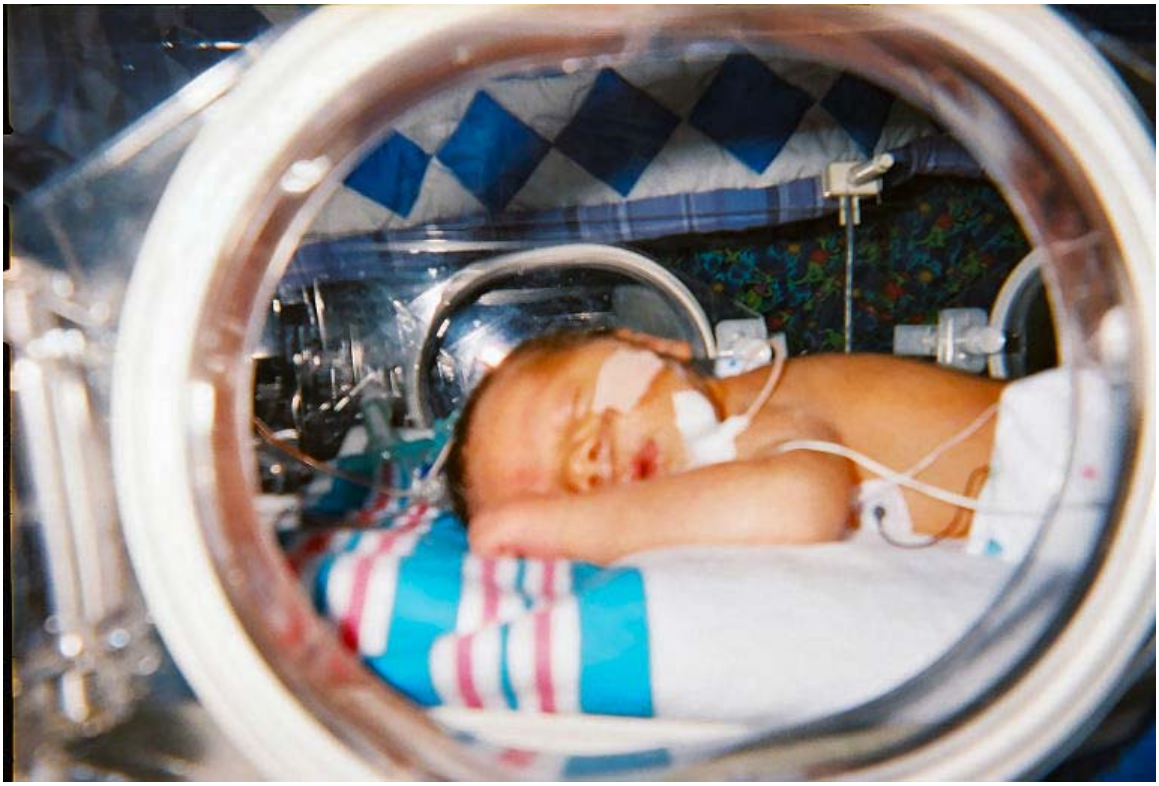
Safar era

Peter Safar, the first Intensivist doctor in the USA, was born in Austria as the son of two doctors. He first migrated to the United States in 1949. Safar first got certification as an anesthesiologist, and, in the 1950s, he started and praised the "Urgency & Emergency" room setup (now known as an ICU). It was at this time the ABC (Airway, Breathing, and Circulation) protocols were formed, and artificial ventilation as well as cardiopulmonary resuscitation became popular. These experiments counted on volunteers of its team, and used only minimal sedation. It was through these experiments that the techniques for maintaining life in the critical patient were established.

The first surgical ICU was established in Baltimore, and, in 1962, in the University of Pittsburgh, the first Critical Care Residency was established in the United States. It was around this time that the induction of hypothermia in critical patients was also tested.

Chapter 7

Neonatal Intensive-Care Unit



A newborn infant sleeping in an incubator

A **neonatal intensive care unit**, usually shortened **NICU** (sometimes pronounced "Nickyou") and also called a newborn intensive care unit, intensive care nursery (ICN), and special care baby unit, or a humidicrib, is a unit of a hospital specializing in the care of ill or premature newborn infants. The NICU is distinct from a special care nursery (SCN) in providing a high level of intensive care to premature infants while the SCN provides specialized care for medical problems.

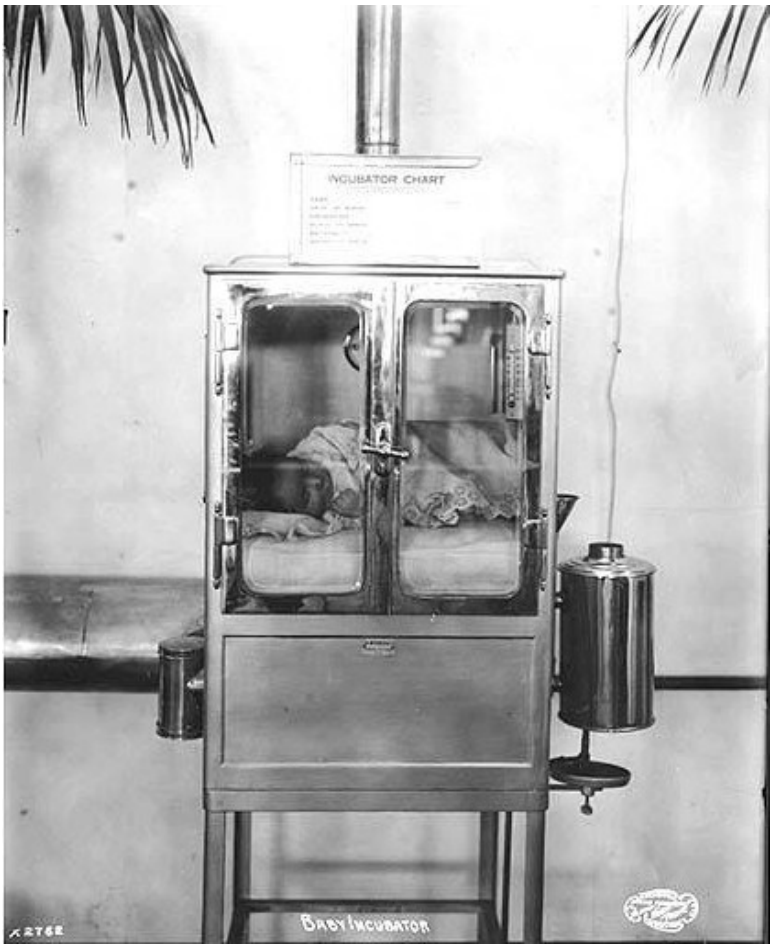
NICUs were developed in the 1950s and 1960s by pediatricians to provide better temperature support, isolation from infection risk, specialized feeding, and greater access to specialized equipment and resources. Infants are cared for in **incubators** or "open warmers." Some low birth weight infants need respiratory support ranging from extra oxygen (by head hood or nasal

cannula) to continuous positive airway pressure (CPAP) or mechanical ventilation. Public access is limited, and staff and visitors are required to take precautions to reduce transmission of infection. Nearly all children's hospitals have NICUs, but they can often be found in large general hospitals as well.

A NICU is typically directed by one or more neonatologists and staffed by nurses, nurse practitioners, Nursery Nurses, physician assistants, resident physicians, and respiratory therapists. Many other ancillary services are necessary for a top-level NICU. Other physicians, especially those with "organ-defined" specialties often assist in the care of these infants.

Equipment

Incubator



An early incubator, 1909

An *incubator* (or *open warmer* or *isolette*) is an apparatus used to maintain environmental conditions suitable for a neonate (newborn baby). It is used in preterm births or for some ill full-term babies.

Possible functions of a neonatal incubator are:

- **Oxygenation**, through oxygen supplementation by head hood or nasal cannula, or even continuous positive airway pressure (CPAP) or mechanical ventilation. Infant respiratory distress syndrome is the leading cause of death in preterm infants, and the main treatments are CPAP, in addition to administering surfactant and stabilizing the blood sugar, blood salts, and blood pressure.
- **Observation**: Modern neonatal intensive care involves sophisticated measurement of temperature, respiration, cardiac function, oxygenation, and brain activity.
- **Protection** from cold temperature, infection, noise, drafts and excess handling: Incubators may be described as bassinets enclosed in plastic, with climate control equipment designed to keep them warm and limit their exposure to germs.
- Provision of **nutrition**, through intravenous catheter or NG tube.
- Administration of **medications**.
- **Maintaining fluid balance** by providing fluid and keeping a high air humidity to prevent too great a loss from skin and respiratory evaporation.

A *transport incubator* is an incubator and the most necessary neonatal instruments in a transportable format, and is used when a sick or premature baby is moved, e.g., from one hospital to another, as from a community hospital to a larger medical facility with a proper neonatal intensive care unit. It usually has a miniature ventilator, cardio-respiratory monitor, IV pump, pulse oximeter, and oxygen supply built into its frame.

Early years

Doctors took an increasing role in childbirth from the eighteenth century onwards. However, the care of newborn babies, sick or well, remained largely in the hands of mothers and midwives. Some baby incubators, similar to those used for hatching chicks, were devised in the late nineteenth century. In the United States these were shown at commercial exhibitions, complete with babies inside, until 1931. Dr A. Robert Bauer MD at Henry Ford Hospital in Detroit, MI successfully combined oxygen, heat, humidity, ease of accessibility, and ease of nursing care in 1931 .It wasn't until after the Second World War that special care baby units (SCBUs) were established in many hospitals. In Britain, early SCBUs opened in Birmingham and Bristol. At Southmead Hospital, Bristol, initial opposition from obstetricians lessened after quadruplets born there in 1948 were successfully cared for in the new unit. More resources became available - the first unit had been set up with £100. Most early units had little equipment and relied on careful nursing and observation.

Incubators were expensive so the whole room often was kept warm instead. Cross-infection between babies was greatly feared. Strict nursing routines involved staff wearing gowns and masks, constant hand washing and minimal handling of babies. Parents were sometimes allowed to watch through the windows of the unit. Much was learned about feeding - frequent, tiny feeds seemed best - and breathing. Oxygen was given freely until the end of the 1950s, when it was shown that the high concentrations reached inside incubators caused some babies to go blind. Monitoring conditions in the incubator, and the baby itself, was to become a major area of research. Although incubators provided oxygen and warmth, science in the 1950s was limited

and it was not until later that technology played a larger role in the decline of infant mortality. Even though the elimination of infectious disease was mostly responsible for decline in infant mortality, low birth weight infant mortality remained high. Yet, because of medical advances in neonatology, low birth weight infants today are surviving on average 15 years more than low weight infants born in the 1950s.

Increasing technology

Neonatal intensive care unit from 1980

By the 1970s SCBUs were an established part of hospitals in the developed world. In Britain, some early units ran community programmes, sending experienced nurses to help care for premature babies at home. But increasingly technological monitoring and therapy meant special care for babies became hospital-based. By the 1980s, over 90% of births took place in hospital anyway. The emergency dash from home to SCBU with baby in a transport incubator had become a thing of the past, though transport incubators were still needed. Specialist equipment and expertise were not available at every hospital, and strong arguments were made for large, centralised SCBUs. On the downside was the long travelling time for frail babies and for parents. A 1979 study showed that 20% of babies in SCBUs for up to a week were never visited by either parent. Centralised or not, by the 1980s few questioned the role of SCBUs in saving babies. Around 80% of babies born weighing under 1.5 kg now survived, compared to around 40% in the 1960s. From 1982 in Britain pediatricians could train and qualify in the sub-specialty of neonatal medicine.

Neonatal intensive care unit in 2009

Not only careful nursing, but also new techniques and instruments now played a major role. As in adult intensive care units, the use of monitoring and life support systems became routine. These needed special modification for small babies, whose bodies were tiny and often immature. Adult ventilators, for example, could damage babies lungs and gentler techniques with smaller pressure changes were devised. The many tubes and sensors used for monitoring the baby's condition, blood sampling and artificial feeding made some babies scarcely visible beneath the technology. Furthermore, by 1975, over 18% of newborn babies in Britain were being admitted to SCBUs. Some hospitals admitted all babies delivered by Caesarian section, or under 2500g in weight. The fact that these babies missed early close contact with their mothers was a growing concern. As in other area of medicine, the 1980s saw questions being raised about the human, and the economic costs of too much technology. Admission policies gradually changed. In addition, treating low birth weight infants is expensive, especially when there are much cheaper ways of ensuring healthy babies. The key is prevention. Money can be spent on programs educating mothers on staying healthy during their pregnancy. One program (one that encourages women to stop smoking) is one third the price of neonatal intensive care and has been proven to work. During this program, a significant number of women often quit.

Changing priorities

SCBUs now concentrate on treating very small, premature, or otherwise sick babies. Some of these babies are from higher-order multiple births, but most are still single babies born too early. Premature labour, and how to prevent it, remains a perplexing problem for doctors. Even though medical advancements allow doctors to save low birth weight babies, it is almost invariably better to delay such births.

A new mother holds her premature baby at Kapiolani Medical Center NICU in Honolulu, Hawaii

Over the last 10 years or so, SCBUs have become much more 'parent friendly', encouraging maximum involvement with the babies. Routine gowns and masks have gone and parents are encouraged to help with care as much as possible. Cuddling, and skin-to-skin contact, also known as Kangaroo care, are seen as beneficial for all but the frailest (very tiny babies are exhausted by the stimulus of being handled, or larger critically ill infants). Less stressful ways of delivering high-technology medicine to tiny patients have been devised - stick-on sensors to measure blood oxygen levels through the skin, for example, and ways of reducing the amount of blood taken for tests.

Some major problems of the SCBU have almost disappeared. Exchange transfusions, in which all the blood is removed and replaced, little by little, are rare now. Rhesus incompatibility (a difference in blood groups) between mother and baby is largely preventable. Breathing difficulties and brain hemorrhage still claim many infant lives and are the focus of many current research projects.

The long term outlook for premature babies saved by SCBUs has always been a concern. From the early years, it was reported that a higher proportion than normal grew up with disabilities, including cerebral palsy and learning difficulties. Now that treatments are available for many of the problems faced by tiny or immature babies in the first weeks of life, long-term follow-up, and minimising long-term disability, are major research areas.

Besides prematurity and extreme low birth weight, common diseases cared for in a NICU include perinatal asphyxia, extreme cases of preeclampsia/eclampsia, major birth defects, sepsis, neonatal jaundice, and respiratory distress syndrome due to immaturity of the lungs. The leading cause of death in NICUs is generally necrotizing enterocolitis. Complications of extreme prematurity may include intracranial hemorrhage, chronic bronchopulmonary dysplasia, or retinopathy of prematurity. An infant may spend a day of observation in a NICU or may spend many months there. Overall survival rates, for all gestational ages lumped together, are roughly 70%.

Neonatology and NICUs have greatly increased the survival of very low birth weight and extremely premature infants. In the era before NICUs, infants of birth weight less than 1400 grams (3 lb, usually about 30 weeks gestation) rarely survived. Today, infants of 500 grams at 26 weeks have a fair chance of survival.

The NICU environment provides challenges as well as benefits. Stressors for the infants can include continual light, a high level of noise, separation from their mothers, reduced physical contact, painful procedures, and interference with the opportunity to breastfeed. A NICU can be stressful for the staff as well. A special aspect of NICU stress for both parents and staff is that infants may survive, but with damage to the brain or eyes.

NICU rotations are essential aspects of pediatric and obstetric residency programs, but NICU experience is encouraged by other specialty residencies, such as family practice, surgery, Pharmacy, and emergency medicine.

Chapter 8

Geriatric Intensive-Care Unit

Geriatric intensive care unit is a special type of intensive care unit dedicated to management of critically ill elderly.

Geriatric intensive care unit's goal is to restore physiologic stability, prevent complications, maintain comfort and safety, and preserve pre-illness functional ability and quality of life (QOL) in older adults admitted to critical-care units.

Origin

Geriatric intensive care units appeared in response to the world's population aging. Managing Geriatrics diseases is not like managing adults or pediatrics diseases, especially if they are critically ill. Geriatric medicine was not included in the curricula of undergraduate or advanced medical training until recently, so not all critical care physicians were oriented by the peculartes of geriatric patients. Despite the fact that geriatric patients constitute many of the critically ill patients, the training of critical care team still lacks the training on the geriatrics giants.

Critically ill older adult: a person, age 65 or older, who is currently experiencing or at risk for some form of physiologic instability or alteration warranting urgent or emergent, advanced nursing/medical interventions and monitoring.

- More than half (55.8%) of all ICU days are incurred by patients older than 65.
- Older adults are living longer, are more racially and ethnically diverse, often have multiple chronic conditions, and more than one-quarter report difficulty performing one or more activities of daily living (ADLs). These factors may affect both the course and outcome of critical illness.
- Once hospitalized for a life-threatening illness, older adults often:

1. Experience high ICU, hospital, and long-term crude mortality rates.
2. Are at risk for deterioration in functional ability and post-discharge institutional care.

- Older age is also a factor that may lead to:

1. Physician bias in refusing ICU admission.
2. The decision to withhold mechanical ventilation, surgery, or dialysis.
3. An increased likelihood of an established resuscitation directive.

- Most critically ill older adults:

1. Demonstrate resiliency.
2. Report being satisfied with their QOL post-discharge.
3. Would reaccept ICU care and mechanical ventilation if needed.

- Chronologic age alone is not an acceptable or accurate predictor of poor outcomes after critical illness.
- Factors that may influence an older adult's ability to survive a catastrophic illness include:

1. Severity of illness
2. Nature and extent of co-morbidities
3. Diagnosis, reason for/duration of mechanical ventilation
4. Complications length of ICU/hospital stay.

Goal

Goal is to restore physiologic stability, prevent complications, maintain comfort and safety, and preserve pre-illness functional ability and quality of life (QOL) in older adults admitted to critical-care units.

Distribution in the world

Geriatric intensive care units are starting to be disseminated and are currently present in Japan, USA, China, Egypt, India & Europe (France, Italy, Poland, Germany).

Practice issues

Critical care practice by necessity is focused on the physiological parameters of the patients being served. Thus, the most important effort revolves around maintaining physiological function and restoring homeostasis for the person who is critically ill. However, when the urgent episode subsides, inappropriate practice guidelines and clinical approaches are often used in the care of older adults. Older individuals have less physiological reserve than younger ones and, therefore, are more likely to have dire consequences following critical care events such as cardiac or respiratory arrest. Further, there are associated geriatric syndromes, medication issues and problems that can be prevented if they are anticipated. Sleep disorders are prevalent in the elderly. During a critical care episode, sleeping and waking cycles are disturbed. Because of the noise in an ICU, less sleep and more noise may trigger delirium. Improving critical care practice for the elderly requires attention to sleep deficits, which means appropriate rest and recovery time.

Altered Eating and Feeding Patterns are more common in geriatric intensive care units. Tubes and other devices, which can impede the ability to obtain adequate nutrition, are common in an intensive care unit. While total parenteral nutrition lines can be inserted to provide calories, the pleasure of eating is lost, as is the sensory stimulation (i.e., smell, taste, texture) of the food,

which might increase appetite. Careful attention must be paid to weight loss in the elderly during the critical care episode. Because albumin levels may already be potentially compromised, the older individual will be at risk for pressure ulcers if their nutrition falls to critically low levels. Other reasons for impaired nutrition include mouth sores; dry, cracked mouths; or a lack of dentures. These issues may be overlooked in busy units.

Foley catheters are regularly inserted in patients in the intensive care unit to monitor fluid balance, this should be changed. urinary catheters are known to cause urinary tract infections, which are potentially lethal to the elderly. Thus, when possible, catheters should be avoided in the ICU. In addition, the use of incontinence undergarments should be avoided, given the propensity for skin irritation and breakdown.

The ICU environment has been linked to delirium in the elderly. Disorientation to time or place because of overstimulation, pain and metabolic imbalances frequently results in cognitive changes. Optimally, critical care nurses must obtain a baseline mental status on the older patient upon admission and follow the changes through the use of a standardized assessment instrument such as a Mini-Mental State Examination. Early detection and intervention can reduce the use of either physical or chemical restraints.

Elderly admitted to intensive care units need special management as regard pharmacotherapy. They can suffer from special cardiovascular diseases, severe infections as MRSA of systemic fungal infections. And may need special posoperative analgesia. Also elderly need assessment by special instruments to predict the prognosis of ICU patients older than 75 years.

Ethical issues

Geriatrics critical care dictate many ethical issues which have been put into the focus of some researches & discussions. Also visiting hours in the geriatric ICU need special organisation different from other ICUs.

Not only do critical care units utilize up to a third of hospital expenditures and about 1% of GNP, the critically ill elderly consume a disproportionate amount of ICU resources. Outcome prediction models for very elderly critically ill patients have been proposed with age as one of numerous model variables; but such models have not been widely validated. Despite the burgeoning emphasis on evidence-based population approach to health care, there is insufficient research to guide the critical care clinician. There remains a modicum of subjectivity in crucial decisions that affect the elderly patient receiving intensive care.

Older age is also one of the factors that lead to a physician bias in refusing ICU admission. Many Critical care physicians generally consider their older patients' quality of life to be worse than do the patients, although other studies that have assessed the quality of live show no age-related differences among ICU survivors. Furthermore, physicians' estimations of patient quality of life significantly influence physicians' attitudes to futility of care issues, in contrast to patients' perceptions.

Threshold for life-sustaining treatment in the elderly will continue to be different among the ICUs. Clinical decisions will be subjected to many ethical, legal, and socioeconomic pressures. Personal and religious beliefs will inevitably influence societal expectations and clinician practices. Severity of illness has the biggest influence on outcome in a critical illness. Age alone is not a predictor of short-term or long-term outcome in the older patient who is critically ill. Critical illness in the elderly remains a fertile area for future research. Also some people tend to put a stigma on the geriatric intensive-care patient in community and in games.

Some studies suggest that patients who are perceived not to benefit from critical care are more often refused intensive care unit admission; refusal is associated with an increased risk of hospital death. During times of decreased critical bed availability, several factors, including age, illness severity, and medical diagnosis, are used to triage patients, although their relative importance is uncertain.

Some studies suggest the solution of subintensive care units. Which are now present in many places.

Training & education programs

Geriatric intensive care unit physicians are trained in geriatric medicine & critical care medicine. Some Universities & medical schools offer training sessions on Geritric critical care medicine. Some books focusing on older patients in the emergency department and critical care unit are available. And other online resources

Geriatric intensive care unit nurses receive special training in critical care of elderly in their basic training, advanced and clinical training. Some Nursing school faculties are establishing research in Geriatric critical care nursing. And a Geriatric Critical Care Nursing Research (GCCNR) Group was established, the purpose of this group is to serve as a forum to share, query, and exchange ideas and strategies related to the research involving and benefiting older ICU patients.

Chapter 9

Mechanical Ventilation

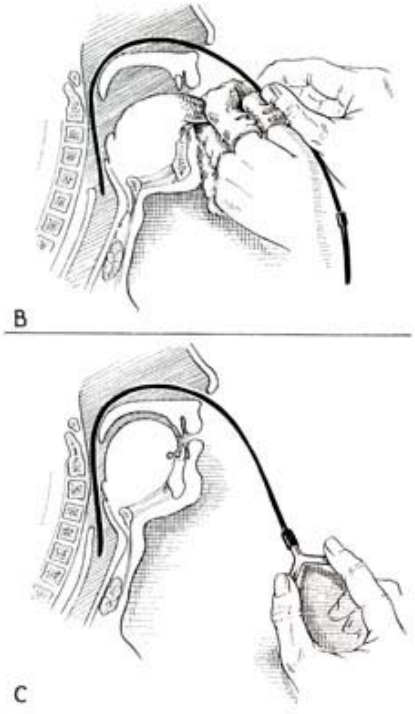


FIGURE 62.—Continued. B. Forward fixation of larynx with left hand, by holding tongue forward with gauze-covered fingers. With the right hand, the catheter is rapidly advanced through the nares and past the glottis as the patient inspires deeply. If he is comatose, a mouth gag is used, and the epiglottis is picked up with the left forefinger. The catheter is then guided through the larynx. C. Advancement of catheter into trachea by intermittent suction over Y-tube. Once it is in trachea, it is moved back and forth to stimulate coughing.

Nasotracheal intubation

In medicine, **mechanical ventilation** is a method to mechanically assist or replace spontaneous breathing.

This may involve a machine called a ventilator or the breathing may be assisted by a physician or other suitable person compressing a bag or set of bellows. Traditionally divided into negative-pressure ventilation, where air is essentially sucked into the lungs, or positive pressure ventilation, where air (or another gas mix) is pushed into the trachea.

It can be used as a short term measure, for example during an operation or critical illness (often in the setting of an intensive care unit). It may be used at home or in a nursing or rehabilitation institution if patients have chronic illnesses that require long-term ventilatory assistance.

Owing to the anatomy of the human pharynx, larynx, and esophagus and the circumstances for which ventilation is required then additional measures are often required to "secure" the airway during positive pressure ventilation to allow unimpeded passage of air into the trachea and avoid air passing into the esophagus and stomach. Commonly this is by insertion of a tube into the trachea which provides a clear route for the air. This can be either an endotracheal tube, inserted through the natural openings of mouth or nose or a tracheostomy inserted through an artificial opening in the neck. In other circumstances simple airway maneuvres, an oropharyngeal airway or laryngeal mask airway may be employed. If the patient is able to protect their own airway such as in non-invasive ventilation or negative-pressure ventilation then no airway adjunct may be needed.

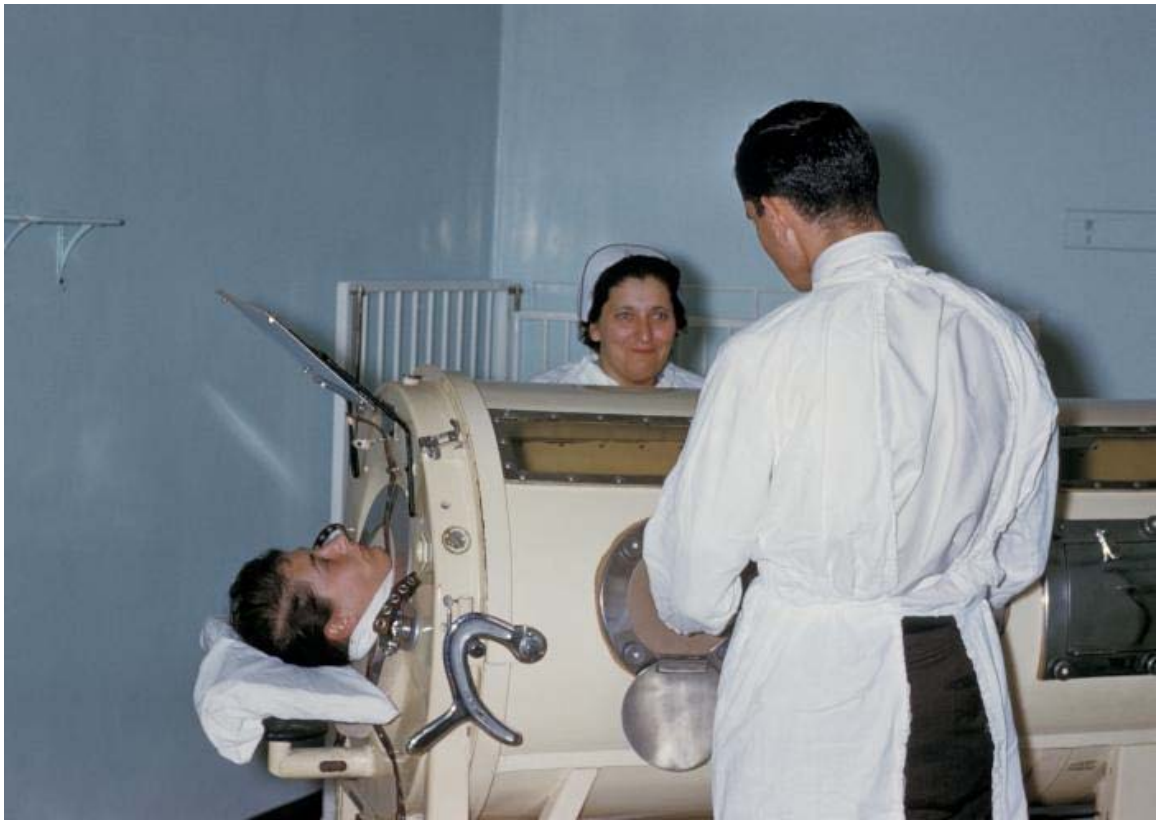
Mechanical ventilation is often a life-saving intervention, but carries many potential complications including pneumothorax, airway injury, alveolar damage, and ventilator-associated pneumonia..

In many healthcare systems prolonged ventilation as part of intensive care is a limited resource (in that there are only so many patients that can receive care at any given moment). It is used to support a single failing organ system (the lungs) and cannot reverse any underlying disease process (such as terminal cancer). For this reason there can be (occasionally difficult) decisions to be made about whether it is suitable to commence someone on mechanical ventilation. Equally many ethical issues surround the decision to discontinue mechanical ventilation.

History

The Roman physician Galen may have been the first to describe mechanical ventilation: "If you take a dead animal and blow air through its larynx [through a reed], you will fill its bronchi and watch its lungs attain the greatest distention." Vesalius too describes ventilation by inserting a reed or cane into the trachea of animals. In 1908 George Poe demonstrated his mechanical respirator by asphyxiating dogs and seemingly bringing them back to life.

Negative pressure machines



An Iron Lung

The iron lung, also known as the Drinker and Shaw tank, was developed in 1929 and was one of the first negative-pressure machines used for long-term ventilation. It was refined and used in the 20th century largely as a result of the polio epidemic that struck the world in the 1940s. The machine is effectively a large elongated tank, which encases the patient up to the neck. The neck is sealed with a rubber gasket so that the patient's face (and airway) are exposed to the room air.

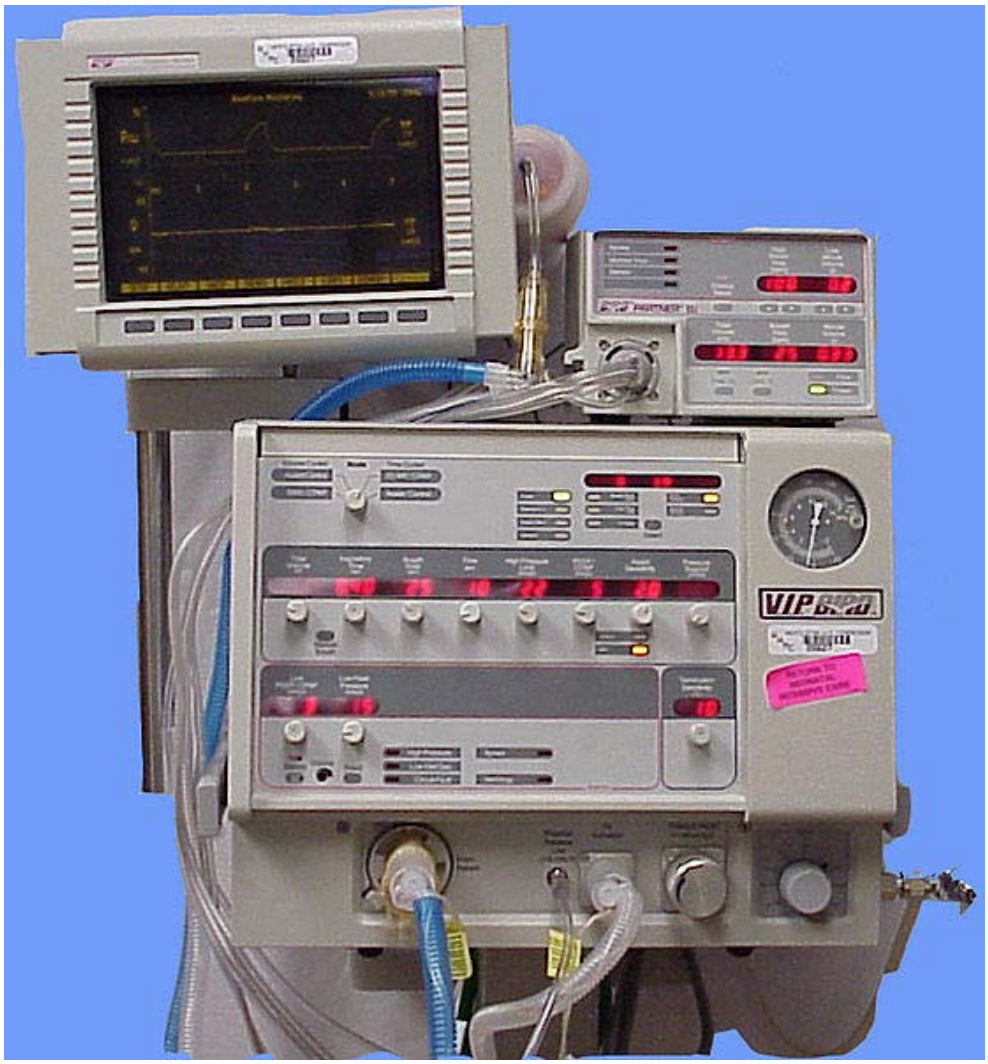
While the exchange of oxygen and carbon dioxide between the bloodstream and the pulmonary airspace works by diffusion and requires no external work, air must be moved into and out of the lungs to make it available to the gas exchange process. In spontaneous breathing, a negative pressure is created in the pleural cavity by the muscles of respiration, and the resulting gradient between the atmospheric pressure and the pressure inside the thorax generates a flow of air.

In the iron lung by means of a pump, the air is withdrawn mechanically to produce a vacuum inside the tank, thus creating negative pressure. This negative pressure leads to expansion of the chest, which causes a decrease in intrapulmonary pressure, and increases flow of ambient air into the lungs. As the vacuum is released, the pressure inside the tank equalizes to that of the ambient pressure, and the elastic coil of the chest and lungs leads to passive exhalation. However, when the vacuum is created, the abdomen also expands along with the lung, cutting off venous flow back to the heart, leading to pooling of venous blood in the lower extremities. There are large

portholes for nurse or home assistant access. The patients can talk and eat normally, and can see the world through a well-placed series of mirrors. Some could remain in these iron lungs for years at a time quite successfully.

Today, negative pressure mechanical ventilators are still in use, notably with the Polio Wing Hospitals in England such as St. Thomas' (by Westminster in London) and the John Radcliffe in Oxford. The prominent device used is a smaller device known as the cuirass. The cuirass is a shell-like unit, creating negative pressure only to the chest using a combination of a fitting shell and a soft bladder. Its main use is in patients with neuromuscular disorders who have some residual muscular function. However, it was prone to falling off and caused severe chafing and skin damage and was not used as a long term device. In recent years this device has re-surfaced as a modern polycarbonate shell with multiple seals and a high pressure oscillation pump in order to carry out biphasic cuirass ventilation.

Positive pressure machines



Neonatal mechanical ventilator

The design of the modern positive-pressure ventilators were mainly based on technical developments by the military during World War II to supply oxygen to fighter pilots in high altitude. Such ventilators replaced the iron lungs as safe endotracheal tubes with high volume/low pressure cuffs were developed. The popularity of positive-pressure ventilators rose during the polio epidemic in the 1950s in Scandinavia and the United States and was the beginning of modern ventilation therapy. Positive pressure through manual supply of 50% oxygen through a tracheostomy tube led to a reduced mortality rate among patients with polio and respiratory paralysis. However, because of the sheer amount of man-power required for such manual intervention, mechanical positive-pressure ventilators became increasingly popular.

Positive-pressure ventilators work by increasing the patient's airway pressure through an endotracheal or tracheostomy tube. The positive pressure allows air to flow into the airway until the ventilator breath is terminated. Subsequently, the airway pressure drops to zero, and the elastic recoil of the chest wall and lungs push the tidal volume -- the breath—out through passive exhalation.

Indications for use

Mechanical ventilation is indicated when the patient's spontaneous ventilation is inadequate to maintain life. It is also indicated as prophylaxis for imminent collapse of other physiologic functions, or ineffective gas exchange in the lungs. Because mechanical ventilation only serves to provide assistance for breathing and does not cure a disease, the patient's underlying condition should be correctable and should resolve over time. In addition, other factors must be taken into consideration because mechanical ventilation is not without its complications (*see below*)

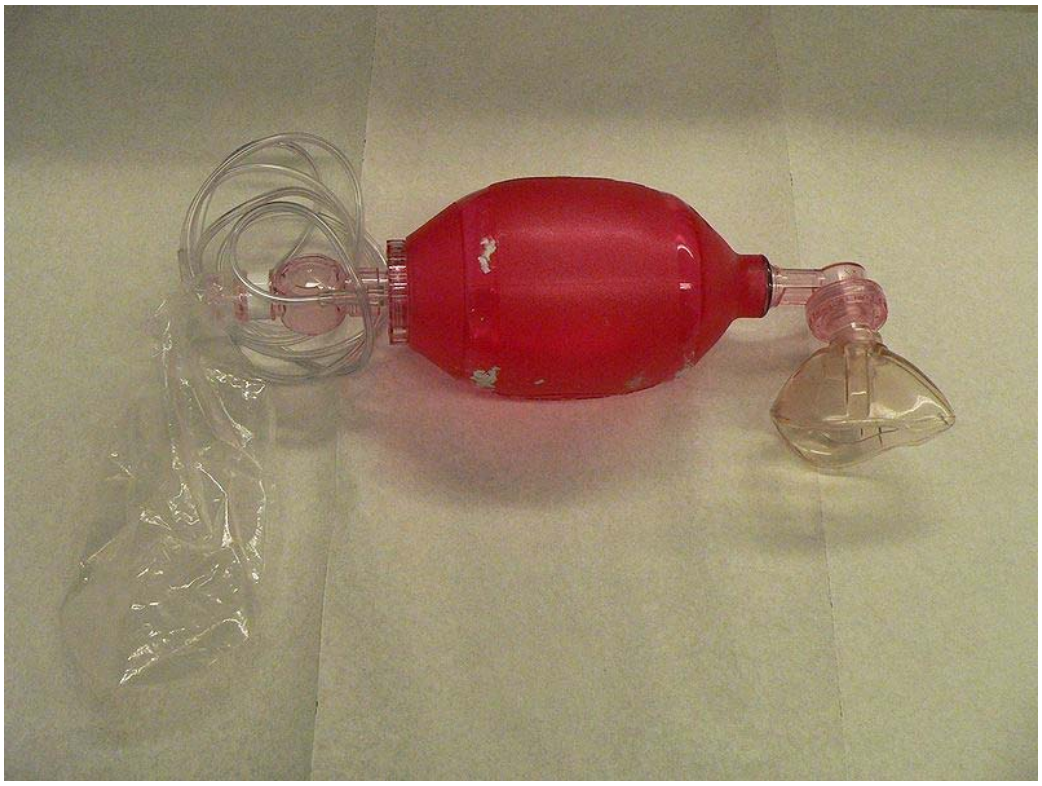
Common medical indications for use include:

- Acute lung injury (including ARDS, trauma)
- Apnea with respiratory arrest, including cases from intoxication
- Chronic obstructive pulmonary disease (COPD)
- Acute respiratory acidosis with partial pressure of carbon dioxide (pCO_2) > 50 mmHg and pH < 7.25, which may be due to paralysis of the diaphragm due to Guillain-Barré syndrome, Myasthenia Gravis, spinal cord injury, or the effect of anaesthetic and muscle relaxant drugs
- Increased work of breathing as evidenced by significant tachypnea, retractions, and other physical signs of respiratory distress
- Hypoxemia with arterial partial pressure of oxygen (PaO_2) with supplemental fraction of inspired oxygen (FiO_2) < 55 mm Hg
- Hypotension including sepsis, shock, congestive heart failure
- Neurological diseases such as Muscular Dystrophy and Amyotrophic Lateral Sclerosis

Types of ventilators

Ventilation can be delivered via:

- Hand-controlled ventilation such as:



SMART BAG MO Bag-Valve-Mask Resuscitator

    - Bag valve mask
    - Continuous-flow or Anaesthesia (or T-piece) bag
- A mechanical ventilator. Types of mechanical ventilators include:
    - Transport ventilators. These ventilators are small, more rugged, and can be powered pneumatically or via AC or DC power sources.
    - ICU ventilators. These ventilators are larger and usually run on AC power (though virtually all contain a battery to facilitate intra-facility transport and as a back-up in the event of a power failure). This style of ventilator often provides greater control of a wide variety of ventilation parameters (such as inspiratory rise time). Many ICU ventilators also incorporate graphics to provide visual feedback of each breath.
        - NICU ventilators. Designed with the preterm neonate in mind, these are a specialized subset of ICU ventilators which are designed to deliver the smaller, more precise volumes and pressures required to ventilate these patients.
    - PAP ventilators. these ventilators are specifically designed for non-invasive ventilation. this includes ventilators for use at home, in order to treat sleep apnea.

Modes of ventilation

Conventional ventilation

The modes of ventilation can be thought of as classifications based on how to control the ventilator breath. Traditionally ventilators were classified based on how they determined when to stop giving a breath. The three traditional categories of ventilators are listed below. As microprocessor technology is incorporated into ventilator design, the distinction among these types has become less clear as ventilators may use combinations of all of these modes as well as flow-sensing, which controls the ventilator breath based on the flow-rate of gas versus a specific volume, pressure, or time.

Breath termination

Modes of ventilation are classified by the means that they determine the inspired breath is complete. This is sensed by either pressure or volume.

- Volume ventilation - A predetermined tidal volume (V_t) is set for the patient and is delivered with each inspiration. The amount of pressure necessary to deliver this volume will fluctuate from breath to breath based on the resistance and compliance of the patient and ventilator circuit. If the tidal volume is set at 500ml, the ventilator will continue to inspire gas until it reaches its goal. Upon completion of the inspired volume, the ventilator will open a valve allowing the patient to passively exhale.

- Pressure ventilation - A predetermined peak inspiratory pressure (PIP) is determined based on the patient's condition and pathophysiology. The ventilator will flow gas into the patient until this set pressure is reached. Upon reaching the preset PIP, the ventilator allows for passive exhalation. Caution and close observation must be given in this mode due to potential for either hypoventilation or hyperventilation because the tidal volume is variable.

Several manufactures have incorporated features from both of theses modes in an attempt to accommodate patients needs.
These modes are flow-variable, volume-targeted, pressure-regulated, time-limited modes (for example, pressure regulated volume control - PRVC). This means that instead of providing an exact tidal volume each breath, a target volume is set and the ventilator will vary the inspiratory flow at each breath to achieve the target volume at the lowest possible peak pressure. The inspiratory time (T_i) limits the length of the inspiratory cycle and therefore the I:E ratio. Pressure regulated modes such as PRVC, Auto-flow (Draeger)or Average Volume Assured Pressure Support (AVAPS) from Philips can most easily be thought of as turning a volume mode into a pressure mode with the added benefit of maintaining more control over tidal volume than with strictly pressure-control.

Breath initiation

The other method of classifying mechanical ventilation is based on how to determine when to start giving a breath. Similar to the termination classification noted above, microprocessor

control has resulted in a myriad of hybrid modes that combine features of the traditional classifications. Note that most of the timing initiation classifications below can be combined with any of the termination classifications listed below.

- Assist Control (AC). In this mode the ventilator provides a mechanical breath with either a pre-set tidal volume or peak pressure every time the patient initiates a breath. Traditional assist-control used only a pre-set tidal volume—when a preset peak pressure is used this is also sometimes termed Intermittent Positive Pressure Ventilation or IPPV. However, the initiation timing is the same—both provide a ventilator breath with every patient effort. In most ventilators a back-up minimum breath rate can be set in the event that the patient becomes apnoeic. Although a maximum rate is not usually set, an alarm can be set if the ventilator cycles too frequently. This can alert that the patient is tachypneic or that the ventilator may be auto-cycling (a problem that results when the ventilator interprets fluctuations in the circuit due to the last breath termination as a new breath initiation attempt).
- Synchronized Intermittent Mandatory Ventilation (SIMV). In this mode the ventilator provides a pre-set mechanical breath (pressure or volume limited) every specified number of seconds (determined by dividing the respiratory rate into 60 seconds - thus a respiratory rate of 12 results in a 5 second cycle time). Within that cycle time the ventilator waits for the patient to initiate a breath using either a pressure or flow sensor. When the ventilator senses the first patient breathing attempt within the cycle, it delivers the preset ventilator breath. If the patient fails to initiate a breath, the ventilator delivers a mechanical breath at the end of the breath cycle. Additional spontaneous breaths after the first one within the breath cycle do not trigger another SIMV breath. However, SIMV may be combined with pressure support (see below). SIMV is frequently employed as a method of decreasing ventilatory support (weaning) by turning down the rate, which requires the patient to take additional breaths beyond the SIMV triggered breath.
- Controlled Mechanical Ventilation (CMV). In this mode the ventilator provides a mechanical breath on a preset timing. Patient respiratory efforts are ignored. This is generally uncomfortable for children and adults who are conscious and is usually only used in an unconscious patient. It may also be used in infants who often quickly adapt their breathing pattern to the ventilator timing.
- Pressure Support Ventilation (PSV). When a patient attempts to breathe spontaneously through an endotracheal tube, the narrowed diameter of the airway results in higher resistance to airflow, and thus a higher work of breathing. PSV was developed as a method to decrease the work of breathing in-between ventilator mandated breaths by providing an elevated pressure triggered by spontaneous breathing that "supports" ventilation during inspiration. Thus, for example, SIMV might be combined with PSV so that additional breaths beyond the SIMV programmed breaths are supported. However, while the SIMV mandated breaths have a preset volume or peak pressure, the PSV breaths are designed to cut short when the inspiratory flow reaches a percentage of the peak inspiratory flow (e.g. 10-25%). New generation of ventilators provides user-adjustable inspiration cycling off threshold, and some even are equipped with automatic inspiration cycling off threshold function. This helps the patient ventilator synchrony. The peak pressure set for the PSV breaths is usually a lower pressure than that set for the full ventilator mandated breath. PSV can be also be used as an independent mode.
- Continuous Positive Airway Pressure (CPAP). A continuous level of elevated pressure is provided through the patient circuit to maintain adequate oxygenation, decrease the work of breathing, and decrease the work of the heart (such as in left-sided heart failure — CHF). Note that no cycling of ventilator pressures occurs and the patient must initiate all breaths. In addition, no

additional pressure above the CPAP pressure is provided during those breaths. CPAP may be used invasively through an endotracheal tube or tracheostomy or non-invasively with a face mask or nasal prongs.

- Positive end-expiratory pressure (PEEP) is functionally the same as CPAP, but refers to the use of an elevated pressure during the expiratory phase of the ventilatory cycle. After delivery of the set amount of breath by the ventilator, the patient then exhales passively. The volume of gas remaining in the lung after a normal expiration is termed the *functional residual capacity* (FRC). The FRC is primarily determined by the elastic qualities of the lung and the chest wall. In many lung diseases, the FRC is reduced due to collapse of the unstable alveoli, leading to a decreased surface area for gas exchange and intrapulmonary shunting (*see above*), with wasted oxygen inspired. Adding PEEP can reduce the work of breathing (at low levels) and help preserve FRC.

APRV (Airway Pressure Release Ventilation)

APRV begins from an elevated baseline (called P_{high} or measured high pressure) and achieves tidal ventilation with a brief release of the P_{high}. This brief release allows CO_2 removal through passive exhalation secondary to elastic recoil. The exhalation time (T_{low}) is shortened to usually less than one second to prevent alveolar derecruitment and collapse - it is essentially CPAP with a brief release.

Ever increasing empirical evidence and clinical experience is showing that APRV is the primary mode to use when ventilating a patient with ARDS or ALI (Acute Lung Injury).

Advantages to APRV ventilation include: decreased airway pressures, decreased minute ventilation, decreased dead-space ventilation, promotion of spontaneous breathing, almost 24 hour a day alveolar recruitment, decreased use of sedation, near elimination of neuromuscular blockade, optimized arterial blood gas results, mechanical restoration of FRC (functional residual capacity), a positive effect on cardiac output (due to the negative inflection from the elevated baseline with each spontaneous breath), increased organ and tissue perfusion, potential for increased urine output due to increased renal perfusion.

A patient with ARDS on average spends 8 to 11 days on a mechanical ventilator; APRV may reduce this time significantly and therefore reduce the incidence of VAP (ventilator acquired pneumonia), a risk that increases with each hour an intubated patient spends on the ventilator (VAP rate is 100% at 100 days on the vent) and carries with it a near 50% mortality rate. So, hospitals that are reporting a 0% incidence of VAP, may be improperly coding or improperly reporting.

** A controlled clinical trial testing APRV against the current ARDSNet protocol must be initiated.*

High Frequency Ventilation (HFV)

Sensormedics 3100 High Frequency ventilator

High-Frequency Ventilation refers to ventilation that occurs at rates significantly above that found in natural breathing (as high as 240-900 "breaths" per minute). Within the category of high-frequency ventilation, the three principal types are high-frequency jet ventilation (HFJV), high-frequency flow interruption (HFFI), and high-frequency oscillatory ventilation (HFOV).

High Frequency Jet Ventilation employs a endotracheal tube adaptor in place for the normal 15 mm ET tube adaptor. A high pressure ‘’jet’’ of gas flows out of the adaptor and into the airway. This jet of gas occurs for a very brief duration, about 0.02 seconds, and at high frequency: 4-11 hertz. Tidal volumes ≤ 1 ml/Kg are used during HFJV. This combination of

small tidal volumes delivered for very short periods of time create the lowest possible distal airway and alveolar pressures produced by a mechanical ventilator. Exhalation is passive. Jet ventilators utilize various I:E ratios--between 1:1.1 and 1:12-- to help achieve optimal exhalation. Conventional mechanical breaths are sometimes used to aid in reinflating the lung. Optimal PEEP is used to maintain alveolar inflation and promote ventilation-to-perfusion matching. Jet ventilation has been shown to reduce ventilator induced lung injury by as much as 20%.

"HFFI" operates similarly to a conventional ventilator, providing increased circuit pressure during the inspiratory phase and dropping back to PEEP during the expiratory phase.

In "HFOV" the pressure wave is driven by an electromagnetically controlled diaphragm similar to a loudspeaker. Because this can rapidly change the volume in the circuit, HFOV can produce a pressure that is lower than ambient pressure during the expiratory phase. This is sometimes called "active" expiration. In both types of high-frequency ventilation the pressure wave that is generated at the ventilator is markedly attenuated by passage down the endotracheal tube and the major conducting airways. This helps protect the alveoli from volutrauma that occurs with traditional positive pressure ventilation. Although the alveoli are kept at a relatively constant volume, similar to CPAP, other mechanisms of gas exchange allow ventilation (the removal of CO_2) to occur without tidal volume exchange. Ventilation in HFOV is a function of frequency, amplitude, and I:E ratio and is best described graphically as the area under the curve of an oscillatory cycle. Amplitude is analogous to tidal volume in conventional ventilation; larger amplitudes remove more CO_2. Seemingly paradoxical, lower frequencies remove more CO_2 in HFOV whereas in conventional ventilation the opposite is true. As frequency decreases, there is less attenuation of the pressure wave transmitted to the alveoli. This results in increased mixing of gas and thus ventilation. I-time is set as a percentage of total time (usually 33%). Innovations in HFOV technology (Vision α, Novalung) fascilitate a better CO2 removal, allowing for CO2 removal at higher oscillatory frequencies, without the need to modify I-time. Amplitude is a function of power and is subject to variability due to changes in compliance or resistance. Therefore, power requirements may vary significantly during treatment and from patient to patient. Patient characteristics and ventilator settings determine whether $PaCO_2$ changes may be more sensitive to amplitude or frequency manipulation. In HFOV, mean airway pressure (MAP) is delivered via a continuous flow through the patient circuit which passes through a variable restriction valve (mushroom valve) on the expiratory limb. Increasing the flow through the circuit and/or increasing the pressure in the mushroom valve increases MAP. The MAP in HFOV functions similarly to PEEP in conventional ventilation in that it provides the pressure for alveolar recruitment.

Non-invasive ventilation (Non-invasive Positive Pressure Ventilation or NIPPV)

This refers to all modalities that assist ventilation without the use of an endotracheal tube. Non-invasive ventilation is primarily aimed at minimizing patient discomfort and the complications associated with invasive ventilation. It is often used in cardiac disease, exacerbations of chronic pulmonary disease, sleep apnea, and neuromuscular diseases. Non-invasive ventilation refers only to the patient interface and not the mode of ventilation used; modes may include spontaneous or control modes and may be either pressure or volume modes.

Some commonly used modes of NIPPV include:

- Continuous positive airway pressure (CPAP).
- Bi-level Positive Airway Pressure (BIPAP). Pressures alternate between Inspiratory Positive Airway Pressure (IPAP) and a lower Expiratory Positive Airway Pressure (EPAP), triggered by patient effort. On many such devices, backup rates may be set, which deliver IPAP pressures even if patients fail to initiate a breath.(Wheatley 2000 et all)
- Intermittent positive pressure ventilation (IPPV) via mouthpiece or mask
- Biphasic Cuirass Ventilation A form of non-invasive ventilation that uses a cuirass instead of a facemask. Allows active control of both inspiration and exhalation.

Proportional Assist Ventilation (PAV)

Proportional Assist Ventilation (PAV) is a form of synchronised ventilator support based upon the Equation of Motion in which the ventilator generates pressure in proportion to the instantaneous patient effort. Unlike other modes of partial support, there is no target flow, tidal volume or pressure. PAV's objective is to allow the patient to attain ventilation and breathing pattern his ventilatory control system desires. The main operational advantages of PAV are automatic synchrony with inspiratory efforts, exhalation and adaptability to change in ventilatory demand.

Proportional Assist Ventilation Plus — PAV+ (Puritan Bennett – 840 ventilator range, **Proportional Pressure Support — PPS** (Drager Evita series)and Respironics BiPAP Vision PAV , are commercially available implementations of PAV which automatically amplify the patient's own spontaneous effort to breathe by increasing airway pressure during inspiration proportionally to a set amplification factor.
In PAV+, the level of amplification, thus the level of work of breathing, is set through a single setting (%support) and the pressure applied is continuously and automatically adjusted based on measures (including automatic assessment of Elastance and Resistance) taken throughout the inspiratory cycle to maintain an appropriate level of support.

Adaptive Support Ventilation (ASV)

Adaptive Support Ventilation (ASV) is a positive pressure mode of mechanical ventilation that is closed-loop controlled. In this mode, the frequency and tidal volume of breaths of a patient on the ventilator are automatically adjusted based on the patient's requirements. The lung mechanics data are used to adjust the depth and rate of breaths to minimize the work rate of breathing. In the ASV mode, every breath is synchronized with patient effort if such an effort exists, and otherwise, full mechanical ventilation is provided to the patient.

ASV technology was originally described as one of the embodiments of US Patent No. 4986268. In this invention, a modified version of an equation derived in physiology in 1950 to minimize the work rate of breathing in man, was used for the first time to find the optimum frequency of mechanical ventilation. The rationale was to make the patient's breathing pattern comfortable and natural within safe limits, and thereby stimulate spontaneous breathing and reduce the weaning time. A prototype of the system was built by the inventor in late 1980s. The inventor is Dr. Fleur

T. Tehrani who is a university professor in the US. Shortly after the Patent was issued in 1991, Hamilton Medical, a ventilator manufacturing company, contacted the inventor and discussed marketing the technology with her. Some years later, Hamilton Medical marketed this closed-loop technique under license of this Patent as ASV.

Since the issuance of the Patent, a number of articles have been published by the inventor and her colleagues that are related to the invention, and some of them describe further advancements of the closed-loop techniques presented in the Patent.

Neurally Adjusted Ventilatory Assist (NAVA)

Neurally Adjusted Ventilatory Assist (NAVA) is a unique positive pressure mode to mechanical ventilation based on neural respiratory output, in connections with invasive and non-invasive NAVA.

The act of taking a breath is controlled by the respiratory center of the brain, which decides the characteristics of each breath, timing and size. The respiratory center sends a signal along the phrenic nerve, excites the diaphragm muscle cells, leading to muscle contraction and descent of the diaphragm dome. As a result, the pressure in the airway drops, causing an inflow of air into the lungs.

With NAVA, the electrical activity of the diaphragm (Edi) is captured, fed to the ventilator and used to assist the patient's breathing in synchrony with and in proportion to the patients own efforts, regardless of patient category or size. As the work of the ventilator and the diaphragm is controlled by the same signal, coupling between the diaphragm and the SERVO-i ventilator is synchronized simultaneously. Reference: New method permits neural control of mechanical ventilation

Choosing amongst ventilator modes

Assist-control mode minimizes patient effort by providing full mechanical support with every breath. This is often the initial mode chosen for adults because it provides the greatest degree of support. In patients with less severe respiratory failure, other modes such as SIMV may be appropriate. Assist-control mode should not be used in those patients with a potential for respiratory alkalosis, in which the patient has an increased respiratory drive. Such hyperventilation and hypocapnia (decreased systemic carbon dioxide due to hyperventilation) usually occurs in patients with end-stage liver disease, hyperventilatory sepsis, and head trauma. Respiratory alkalosis will be evident from the initial arterial blood gas obtained, and the mode of ventilation can then be changed if so desired.

Positive End Expiratory Pressure may or may not be employed to prevent atelectasis in adult patients. It is almost always used for pediatric and neonatal patients due to their increased tendency for atelectasis.

High frequency oscillation is used most frequently in neonates, but is also used as an always alternative mode in adults with severe ARDS.

Pressure Regulated Volume Control is another option.

Initial ventilator settings

The following are general guidelines that may need to be modified for the individual patient.

As a general rule, whenever possible, spontaneous breathing must be maintained or supported, to avoid muscular atrophy of the diaphragm (Ventilator Induced Dysfunction of Diaphragm, VIDD) . To limit VALI and VILI, protective ventilation pattern should be applied to the patient. If this results in severe hypercapnia, exceeding accepted levels for permissive hypercapnia (pH below 7.2), measures for extracorporeal CO2 removal (iLA Membranventilator, Novalung) should be installed at an early stage of mechanical ventilation, to terminate cascades of inflammatory response from the lung tissue, resulting in multiorgan failure respective.

Tidal volume, rate, and pressures

- For adult patients and older children
  - tidal volume(Vt) is calculated in milliliters per kilogram. Traditionally 10 ml/kg was used but has been shown to cause barotrauma, or injury to the lung by overextension, so 6 to 8 ml/kg is now common practice in ICU. Hence a patient weighing 70 kg would get a Vt of 420–480 ml. In adults a rate of 12 strokes per minute is generally used.
  - with acute respiratory distress syndrome (ARDS) a tidal volume of 6–8 ml/kg is used with a rate of 10–12 per minute. This reduced tidal volume allows for minimal volutrauma but may result in an elevated pCO_2 (due to the relative decreased oxygen delivered) but this elevation does not need to be corrected (termed *permissive hypercapnia*)
- For infants and younger children
  - without existing lung disease—a tidal volume of 4–8 ml/kg to be delivered at a rate of 30–35 breaths per minute
  - with ARDS—decrease tidal volume and increase respiratory rate sufficient to maintain pCO_2 between 45 and 55. Allowing higher pCO_2 (sometimes called permissive hypercapnia) may help prevent ventilator induced lung injury

As the amount of tidal volume increases, the pressure required to administer that volume is increased. This pressure is known as the *peak airway pressure*. If the peak airway pressure is persistently above 45 cmH_2O (4.4 kPa) for adults, the risk of barotrauma is increased (*see below*) and efforts should be made to try to reduce the peak airway pressure. In infants and children it is unclear what level of peak pressure may cause damage. In general, keeping peak pressures below 30 cmH_2O (2.9 kPa) is desirable.

Monitoring for barotrauma can also involve measuring the *plateau pressure*, which is the pressure *after* the delivery of the tidal volume but *before* the patient is allowed to exhale. Normal breathing pattern involves inspiration, then expiration. The ventilator is programmed so that after delivery of the tidal volume (inspiration), the patient is not allowed to exhale for a half a second. Therefore, pressure must be maintained in order to prevent exhalation, and this pressure is the

plateau pressure. Barotrauma is minimized when the plateau pressure is maintained < 30–35 cmH_2O.

Sighs

An adult patient breathing spontaneously will usually sigh about 6–8 times per hour to prevent microatelectasis, and this has led some to propose that ventilators should deliver 1½–2 times the amount of the preset tidal volume 6–8 times per hour to account for the sighs. However, such high quantity of volume delivery requires very high peak pressure that predisposes to barotrauma. Currently, accounting for sighs is not recommended if the patient is receiving 10-12 mL/kg or is on PEEP. If the tidal volume used is lower, the sigh adjustment can be used, as long as the peak and plateau pressures are acceptable.

Sighs are not generally used with ventilation of infants and young children.

Initial FiO_2

Because the mechanical ventilator is responsible for assisting in a patient's breathing, it must then also be able to deliver an adequate amount of oxygen in each breath. The FiO_2 stands for *fraction of inspired oxygen*, which means the percent of oxygen in each breath that is inspired. (Note that normal room air has ~21% oxygen content). In adult patients who can tolerate higher levels of oxygen for a period of time, the initial FiO_2 may be set at 100% until arterial blood gases can document adequate oxygenation. An FiO_2 of 100% for an extended period of time can be dangerous, but it can protect against hypoxemia from unexpected intubation problems. For infants, and especially in premature infants, avoiding high levels of FiO_2 (>60%) is important.

Positive end-expiratory pressure (PEEP)

PEEP is an adjuvant to the mode of ventilation used to help maintain functional residual capacity (FRC). At the end of expiration, the PEEP exerts pressure to oppose passive emptying of the lung and to keep the airway pressure above the atmospheric pressure. The presence of PEEP opens up collapsed or unstable alveoli and increases the FRC and surface area for gas exchange, thus reducing the size of the shunt. For example, if a large shunt is found to exist based on the estimation from 100% FiO_2 (*see above*), then PEEP can be considered and the FiO_2 can be lowered (< 60%) in order to maintain an adequate PaO_2, thus reducing the risk of oxygen toxicity.

In addition to treating a shunt, PEEP may also be useful to decrease the work of breathing. In pulmonary physiology, compliance is a measure of the "stiffness" of the lung and chest wall. The mathematical formula for compliance (*C*) equals change in volume divided by change in pressure. The higher the compliance, the more easily the lungs will inflate in response to positive pressure. An underinflated lung will have low compliance and PEEP will improve this initially by increasing the FRC, since the partially inflated lung takes less energy to inflate further. Excessive PEEP can however produce overinflation, which will again decrease compliance. Therefore it is important to maintain an adequate, but not excessive FRC.

Indications. PEEP can cause significant haemodynamic consequences through decreasing venous return to the right heart and decreasing right ventricular function. As such, it should be judiciously used and is indicated for adults in two circumstances.

- If a PaO_2 of 60 mmHg cannot be achieved with a FiO_2 of 60%
- If the initial shunt estimation is greater than 25%

If used, PEEP is usually set with the minimal positive pressure to maintain an adequate PaO_2 with a safe FiO_2. As PEEP increases intrathoracic pressure, there can be a resulting decrease in venous return and decrease in cardiac output. A PEEP of less than 10 cmH_2O (1 kPa) is usually safe in adults if intravascular volume depletion is absent. Lower levels are used for pediatric patients. Older literature recommended routine placement of a Swan-Ganz catheter if the amount of PEEP used is greater than 10 cmH_2 for hemodynamic monitoring. More recent literature has failed to find outcome benefits with routine PA catheterisation when compared to simple central venous pressure monitoring. If cardiac output measurement is required, minimally invasive techniques, such as oesophageal doppler monitoring or arterial waveform contour monitoring may be sufficient alternatives. PEEP should be withdrawn from a patient until adequate PaO_2 can be maintained with a $FiO_2 < 40\%$. When withdrawing, it is decreased through 1–2 cmH_2O decrements while monitoring haemoglobin-oxygen saturations. Any unacceptable haemoglobin-oxygen saturation should prompt reinstitution of the last PEEP level that maintained good saturation.

Positioning

Prone (face down) positioning has been used in patients with ARDS and severe hypoxemia. It improves FRC, drainage of secretions, and ventilation-perfusion matching (efficiency of gas exchange). It may improve oxygenation in > 50% of patients, but no survival benefit has been documented.

Sedation and Paralysis

Most intubated patients receive intravenous sedation through a continuous infusion or scheduled dosing to help with anxiety or psychological stress. Sedation also helps the patient tolerate the constant irritation of the endotracheal tube in their mouth, pharynx and trachea. Without some form of sedation and analgesia, it is common for patients to "fight" the ventilator. This fighting increases work of breathing and may cause further lung injury. Daily interruption of sedation is commonly helpful to the patient for reorientation and appropriate weaning. These interruptions are frequently described as "sedation vacations" and have been shown to reduce the time patients stay on mechanical ventilation.

It is not uncommon for patients on a mechanical ventilator to be given a muscle relaxant or paralytic to aid in ventilation. These "neuromuscular blockades" prevent skeletal muscle from contracting and thereby stop all patient movement including respiratory efforts. These types of pharmaceutical agents must always be given in conjunction with sedation as the effects of the paralytics is not only uncomfortable but would cause significant psychological stress and anxiety.

Prophylaxis

- To protect against ventilator-associated pneumonia, patients' beds are often elevated to about 30°.
- Deep vein thrombosis prophylaxis with heparin or sequential compression device is important in older children and adults.
- A histamine receptor (H2) blocker or proton-pump inhibitor may be used to prevent gastrointestinal bleeding, which has been associated with mechanical ventilation

Modification of settings

In adults when 100% FiO_2 is used initially, it is easy to calculate the next FiO_2 to be used and easy to estimate the shunt fraction. The estimated shunt fraction refers to the amount of oxygen not being absorbed into the circulation. In normal physiology, gas exchange (oxygen/carbon dioxide) occurs at the level of the alveoli in the lungs. The existence of a shunt refers to any process that hinders this gas exchange, leading to wasted oxygen inspired and the flow of un-oxygenated blood back to the left heart (which ultimately supplies the rest of the body with unoxygenated blood).

When using 100% FiO_2, the degree of shunting is estimated by subtracting the measured PaO_2 (from an arterial blood gas) from 700 mmHg. For each difference of 100 mmHg, the shunt is 5%. A shunt of more than 25% should prompt a search for the cause of this hypoxemia, such as mainstem intubation or pneumothorax, and should be treated accordingly. If such complications are not present, other causes must be sought after, and PEEP should be used to treat this intrapulmonary shunt. Other such causes of a shunt include:

- Alveolar collapse from major atelectasis
- Alveolar collection of material other than gas, such as pus from pneumonia, water and protein from acute respiratory distress syndrome, water from congestive heart failure, or blood from haemorrhage

When to withdraw mechanical ventilation

Withdrawal from mechanical ventilation—also known as weaning—should not be delayed unnecessarily, nor should it be done prematurely. Patients should have their ventilation considered for withdrawal if they are able to support their own ventilation and oxygenation, and this should be assessed continuously. There are several objective parameters to look for when considering withdrawal, but there is no specific criteria that generalizes to all patients.

Trials of spontaneous breathing have been shown to accurately predict the success of spontaneous breathing. (Yang K, Tobin MJ. A prospective study of indexes predicting the outcome of weaning from mechanical ventilation. N Engl J Med 1991;324:1445–1450).

Connection to ventilators

There are various procedures and mechanical devices that provide protection against airway collapse, air leakage, and aspiration:

- Face mask - In resuscitation and for minor procedures under anaesthesia, a face mask is often sufficient to achieve a seal against air leakage. Airway patency of the unconscious patient is maintained either by manipulation of the jaw or by the use of *nasopharyngeal* or *oropharyngeal airway*. These are designed to provide a passage of air to the pharynx through the nose or mouth, respectively. Poorly fitted masks often cause nasal bridge ulcers, a problem for some patients. Face masks are also used for non-invasive ventilation in conscious patients. A full face mask does not, however, provide protection against aspiration.
- Laryngeal mask airway - The laryngeal mask airway (LMA) causes less pain and coughing than a tracheal tube. However, unlike tracheal tubes it does not seal against aspiration, making careful individualised evaluation and patient selection mandatory.
- *Tracheal intubation* is often performed for mechanical ventilation of hours to weeks duration. A tube is inserted through the nose (nasotracheal intubation) or mouth (orotracheal intubation) and advanced into the trachea. In most cases tubes with inflatable cuffs are used for protection against leakage and aspiration. Intubation with a cuffed tube is thought to provide the best protection against aspiration. Tracheal tubes inevitably cause pain and coughing. Therefore, unless a patient is unconscious or anaesthetized for other reasons, sedative drugs are usually given to provide tolerance of the tube. Other disadvantages of tracheal intubation include damage to the mucosal lining of the nasopharynx or oropharynx and subglottic stenosis.
- Esophageal obturator airway - sometimes used by emergency medical technicians and basic EMS providers not trained to intubate. It is a tube which is inserted into the esophagus, past the epiglottis. Once it is inserted, a bladder at the tip of the airway is inflated, to block ("obturate") the esophagus, and oxygen is delivered through a series of holes in the side of the tube which is then forced into the lungs.
- *Cricothyrotomy* - Patients who require emergency airway management, in whom tracheal intubation has been unsuccessful, may require an airway inserted through a surgical opening in the cricothyroid membrane. This is similar to a tracheostomy but a cricothyrotomy is reserved for emergency access.
- *Tracheostomy* - When patients require mechanical ventilation for several weeks, a tracheostomy may provide the most suitable access to the trachea. A tracheostomy is a surgically created passage into the trachea. Tracheostomy tubes are well tolerated and often do not necessitate any use of sedative drugs. Tracheostomy tubes may be inserted early during treatment in patients with pre-existing severe respiratory disease, or in any patient who is expected to be difficult to wean from mechanical ventilation, i.e., patients who have little muscular reserve.
- *Mouthpiece* - Less common interface, does not provide protection against aspiration. There are lipseal mouthpieces with flanges to help hold them in place if patient is unable.

Terminology

Terminology used in the field of mechanical ventilation and respiratory support:

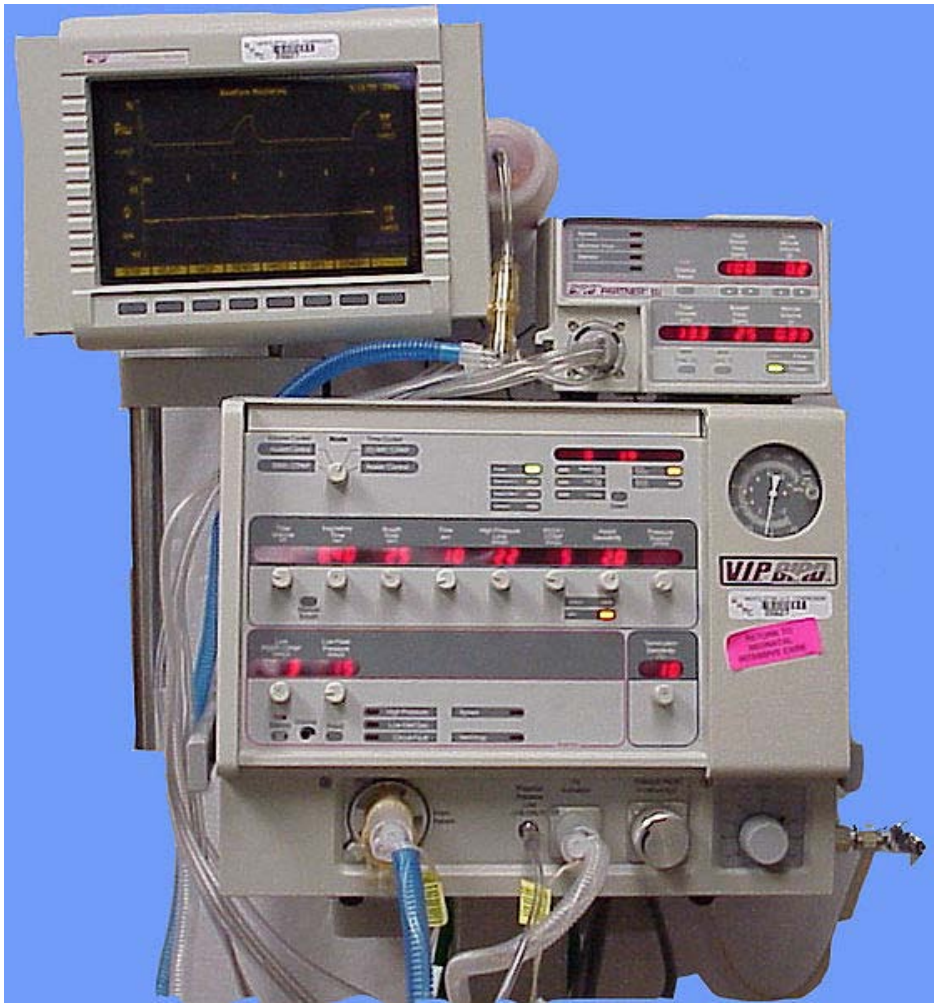
- APRV Airway pressure release ventilation

- ASB Assisted spontaneous breathing—also *ASV* = assisted spontaneous ventilation
- ASV Adaptive support ventilation—a patented technology—closed-loop mechanical respiration, a further development of MMV. Can also stand for assisted spontaneous ventilation.
- ATC Automatic tube compensation
- Automode Automode
- BCV Biphasic Cuirass Ventilation
- BIPAP Bilevel Positive Airway Pressure
- CMV Continuous mandatory ventilation
- CPAP Continuous positive airway pressure
- CPPV Continuous positive pressure ventilation
- EPAP Expiratory positive airway pressure
- HFV High frequency ventilation
    - HFFI High frequency flow interruption
    - HFJV High frequency jet ventilation
    - HFOV High frequency oscillatory ventilation
    - HFPPV High frequency positive pressure ventilation
- ILV Independent lung ventilation—separate sides positive pressure ventilation.
- IPAP Inspiratory positive airway pressure
- IPPV Intermittent positive pressure ventilation
- IRV Inversed ratio ventilation— mechanical ventilation with switched respiration phases/time rate.
- LFPPV Low frequency positive pressure ventilation
- MMV Mandatory minute volume
- NAVA Neurally Adjusted Ventilatory Assist
- NIF Negative inspiratory force—amount of force generated by a patient against a closed valve; greater than 20 cmH_2O indicates an adequately strong diaphragm.
- NIV Non-invasive ventilation
- PAP Positive airway pressure
- PAV and PAV+ Proportional assist ventilation and proportional assist ventilation plus
- *P/F* ratio Ratio of PaO_2 off an ABG and FiO_2 off the ventilator. *P/F* < 200 indicates ARDS, *P/F* < 300 indicates ALI
- PCMV (P-CMV) Pressure controlled mandatory ventilation
- PCV Pressure controlled ventilation or PC Pressure control—pressure-controlled, fully mechanical ventilation.
- PEEP Positive end-expiratory pressure
- PNPV Positive negative pressure ventilation—switching pressure mechanical ventilation
- PPS Proportional pressure support
- PRVC Pressure regulated volume controlled ventilation
- PSV Pressure Support Ventilation or PS—supported spontaneous respiration,
- RSBI Rapid shallow breathing index—ratio of breath rate divided by the tidal volume. RSBI<105 declares a patient can be extubated and maintain themselves. Also indicates patient has a good chance of staying extubated.
- (S) IMV (Synchronized) intermittent mandatory ventilation
- S-CPPV Synchronized continuous positive pressure ventilation
- S-IPPV Synchronized intermittent positive pressure ventilation
- TNI Therapy with nasal insufflation—nasal high-flow mechanical ventilation for respiration support.
- VCMV (V-CMV) Volume controlled mandatory ventilation

- VCV Volume controlled ventilation or VC, Volume Control—volume-controlled, fully mechanical ventilation.
- VS Volume Support
- ZAP Zero airway pressure—spontaneous respiration under atmospheric pressure.

Chapter 10

Medical Ventilator



The Bird VIP Infant ventilator

A **medical ventilator** may be defined as any machine designed to mechanically move breatheable air into and out of the lungs, to provide the mechanism of breathing for a patient who is physically unable to breathe, or breathing insufficiently.

While modern ventilators are generally thought of as computerized machines, patients can be ventilated indefinitely with a bag valve mask, a simple hand-operated machine. After Hurricane Katrina, dedicated staff "bagged" patients in New Orleans hospitals for days with simple bag valve masks.

Ventilators are chiefly used in intensive care medicine, home care, and emergency medicine (as standalone units) and in anesthesia (as a component of an anesthesia machine).

Function

In its simplest form, a modern positive pressure ventilator consists of a compressible air reservoir or turbine, air and oxygen supplies, a set of valves and tubes, and a disposable or reusable "patient circuit". The air reservoir is pneumatically compressed several times a minute to deliver room-air, or in most cases, an air/oxygen mixture to the patient. If a turbine is used, the turbine pushes air through the ventilator, with a flow valve adjusting pressure to meet patient-specific parameters. When overpressure is released, the patient will exhale passively due to the lungs' elasticity, the exhaled air being released usually through a one-way valve within the patient circuit called the patient manifold. The oxygen content of the inspired gas can be set from 21 percent (ambient air) to 100 percent (pure oxygen). Pressure and flow characteristics can be set mechanically or electronically.

Ventilators may also be equipped with monitoring and alarm systems for patient-related parameters (e.g. pressure, volume, and flow) and ventilator function (e.g. air leakage, power failure, mechanical failure), backup batteries, oxygen tanks, and remote control. The pneumatic system is nowadays often replaced by a computer-controlled turbopump.

Modern ventilators are electronically controlled by a small embedded system to allow exact adaptation of pressure and flow characteristics to an individual patient's needs. Fine-tuned ventilator settings also serve to make ventilation more tolerable and comfortable for the patient. In Germany, Canada, and the United States, respiratory therapists are responsible for tuning these settings while biomedical technologists are responsible for the maintenance.

The patient circuit usually consists of a set of three durable, yet lightweight plastic tubes, separated by function (e.g. inhaled air, patient pressure, exhaled air). Determined by the type of ventilation needed, the patient-end of the circuit may be either noninvasive or invasive.

Noninvasive methods, which are adequate for patients who require a ventilator only while sleeping and resting, mainly employ a nasal mask. Invasive methods require intubation, which for long-term ventilator dependence will normally be a tracheotomy cannula, as this is much more comfortable and practical for long-term care than is larynx or nasal intubation.

Life-critical system

Because the failure of a mechanical ventilation system may result in death, it is classed as a life-critical system, and precautions must be taken to ensure that mechanical ventilation systems are highly reliable. This includes their power-supply provision.

Mechanical ventilators are therefore carefully designed so that no single point of failure can endanger the patient. They usually have manual backup mechanisms to enable hand-driven respiration in the absence of power. Some systems are also equipped with compressed-gas tanks and backup batteries to provide ventilation in case of power failure or defective gas supplies, and methods to operate or call for help if their mechanisms or software fail.

Ventilation

The early history of mechanical ventilation begins with various versions of what was eventually called the iron lung, a form of noninvasive negative pressure ventilator widely used during the polio epidemics of the 20th century after the introduction of the "Drinker respirator" in 1928, and the subsequent improvements introduced by John Haven Emerson in 1931. Other forms of noninvasive ventilators, also used widely for polio patients, include Biphasic Cuirass Ventilation, the rocking bed, and rather primitive positive pressure machines.

In 1949, John Haven Emerson developed a mechanical assister for anesthesia with the cooperation of the anesthesia department at Harvard University. Mechanical ventilators began to be used increasingly in anesthesia and intensive care during the 1950s. Their development was stimulated both by the need to treat polio patients and the increasing use of muscle relaxants during anesthesia. Relaxant drugs paralyze the patient and improve operating conditions for the surgeon, but also paralyze the respiratory muscles

In the United Kingdom, the East Radcliffe and Beaver models were early examples, the later using an automotive wiper motor to drive the bellows used to inflate the lungs. Electric motors were, however, a problem in the operating theatres of that time, as their use caused an explosion hazard in the presence of flammable anesthetics such as ether and cyclopropane. In 1952, Roger Manley of the Westminster Hospital, London, developed a ventilator which was entirely gas driven, and became the most popular model used in Europe. It was an elegant design, and became a great favourite with European anesthetists for four decades, prior to the introduction of models controlled by electronics. It was independent of electrical power, and caused no explosion hazard. The original Mark I unit was developed to become the Manley Mark II in collaboration with the Blease company, who manufactured many thousands of these units. Its principle of operation was very simple, an incoming gas flow was used to lift a weighted bellows unit, which fell intermittently under gravity, forcing breathing gases into the patient's lungs. The inflation pressure could be varied by sliding the movable weight on top of the bellows. The volume of gas delivered was adjustable using a curved slider, which restricted bellows excursion. Residual pressure after the completion of expiration was also configurable, using a small weighted arm visible to the lower right of the front panel. This was a robust unit and its availability encouraged the introduction of positive pressure ventilation techniques into mainstream European anesthetic practice.

The 1955 release of Forrest Bird's "Bird Universal Medical Respirator" in the United States, changed the way mechanical ventilation was performed with the small green box becoming a familiar piece of medical equipment. The unit was sold as the Bird Mark 7 Respirator and

informally called the "Bird". It was a pneumatic device and therefore required no electrical power source to operate.

Intensive care environments around the world revolutionalized in 1971 by the introduction of the first SERVO 900 ventilator (Elema-Schönander). It was a small, silent and effective electronic ventilator, with the famous SERVO feedback system controlling what had been set and regulating delivery. For the first time, the machine could deliver the set volume in volume control ventilation.

Ventilators used under increased pressure (hyperbaric) require special precautions and few ventilators can operate under these conditions. In 1979, Sechrist Industries introduced their Model 500A ventilator which was specifically designed for use with hyperbaric chambers.

In 1991 the SERVO 300 ventilator series was introduced. The platform of the SERVO 300 series enabled treatment of all patient categories, from adult to neonate, with one single ventilator. The SERVO 300 series provided a completely new and unique gas delivery system, with rapid flow-triggering response.

A modular concept, meaning that the hospital has one ventilator model throughout the ICU department instead of a fleet with different models and brands for the different user needs, was introduced with SERVO-i in 2001. With this modular concept the ICU departments could choose the modes and options, software and hardware needed for a particular patient category.

High frequency percussive ventilation

High-frequency percussive ventilation (HFPV) began to be used in selected centres in the 1980s. It is a hybrid of conventional mechanical ventilation and high-frequency oscillatory ventilation. It has been used to salvage patients with persistent hypoxemia when on conventional mechanical ventilation or, in some cases, used as a primary modality of ventilatory support from the start.

Biphasic Cuirass Ventilation

Biphasic Cuirass Ventilation (**BCV**) is a method of ventilation which requires the patient to wear an upper body shell or cuirass, so named after the body armor worn by medieval soldiers. The ventilation is biphasic because the cuirass is attached to a pump which actively controls both the inspiratory and expiratory phases of the respiratory cycle. This method has also been described as 'Negative Pressure Ventilation' (NPV), 'External Chest Wall Oscillation' (ECWO), 'External Chest Wall Compression' (ECWC) and 'External High Frequency Oscillation' (EHFO). BCV may be considered a refinement of the iron lung ventilator. Biphasic Cuirass Ventilation was developed by the late Dr Zamir Hayek, a pioneer in the field of assisted ventilation. Some of Dr Hayek's previous inventions include the Hayek Oscillator, an early form of the technology.

Chapter 11

Cardiopulmonary Resuscitation

CPR being performed on a mannequin

Cardiopulmonary resuscitation (**CPR**) is an emergency procedure which is attempted in an effort to return life to a person in cardiac arrest. It is indicated in those who are unresponsive with no breathing or only gasps. It may be attempted both in and outside of a hospital.

CPR involves chest compressions at a rate of at least 100 per minute in an effort to create artificial circulation by manually pumping blood through the heart. In addition the rescuer may provide breaths by either exhaling into their mouth or utilizing a device that pushes air into the lungs. The process of externally providing ventilation is termed artificial respiration. Current

recommendations place emphasis on high quality chest compressions over artificial respirations and a method involving only chest compressions is recommended for untrained rescuers.

CPR alone is unlikely to restart the heart; its main purpose is to restore partial flow of oxygenated blood to the brain and heart. It may delay tissue death and extend the brief window of opportunity for a successful resuscitation without permanent brain damage. An administering of an electric shock to the heart, termed defibrillation, is usually needed to restore a viable or "perfusing" heart rhythm. Defibrillation is only effective for certain heart rhythms, namely ventricular fibrillation or pulseless ventricular tachycardia, rather than asystole or pulseless electrical activity. CPR may however induce a shockable rhythm. CPR is generally continued until the person regains return of spontaneous circulation (ROSC) or is declared dead.

Indications

CPR is indicated for any person who is unresponsive with no breathing or only gasps as breathing as it is most likely that they are in cardiac arrest. If a person still has a pulse, but is not breathing (respiratory arrest), artificial respirations are more appropriate. However, many people often have difficulty detecting a pulse and CPR may thus be used.

Methods

CPR training: CPR is being administrated while a second rescuer prepares for defibrillation

In 2010, the American Heart Association and International Liaison Committee on Resuscitation updated their CPR guidelines. The importance of high quality CPR (sufficient rate and depth without excessively ventilating) was emphasized. The order of interventions was changed for all age groups except newborns from airway, breathing, chest compressions (ABC) to chest compressions, airway, breathing (CAB). An exception to this recommendation is for those who are believed to be in a respiratory arrest (drowning, etc.).

Standard

A universal compression to ventilation ratio of 30:2 is recommended for adult and in children and infant if only a single rescuer is present. If at least 2 rescuers are present a ratio of 15:2 is preferred in children and infants. In newborns a rate of 3:1 is recommended unless a cardiac cause is known in which case a 15:2 ratio is reasonable. If an advanced airway such as an endotracheal tube or laryngeal mask airway is in placed delivery of respirations should occur without pauses in compressions at a rate of 8-10 per minute. The recommended order of interventions is chest compressions, airway, breathing or CAB in most situations. With a compression rate of at least 100 per minute in all groups. Recommended compression depth in adults and children is about 5 cm (2 inches) and in infants it is 4 cm (1.5 inches. As of 2010 the Resuscitation Council (UK) still recommends ABC for children. As it can be difficult to determine the presence or absence of a pulse the pulse check has been removed for lay providers and should not be performed for more than 10 seconds by health care providers. In adults rescuers should use two hands for the chest compressions, while in children they should use one, and with infants two fingers (index and middle fingers).

Compression only

Compression only (hands-only) CPR is a technique that involves chest compressions without artificial respiration. It is recommended as the method of choice for the untrained rescuer or those who are not proficient as it is easier to perform and instructions are easier to give over the phone. In adults with out-of-hospital cardiac arrest, compression-only CPR by the lay public has a higher success rate than standard CPR. The exceptions are cases of drownings, drug overdose, and arrest in children. Children who receive compression only CPR have the same outcomes as those who received no CPR. The method of delivering chest compressions remains the same, as does the rate (at least 100 per minute). It is hoped that the use of compression only delivery will increase the chances of the lay public delivering CPR.

Interposed abdominal compression

Interposed abdominal compressions may be beneficial in the in hospital environment. There is however no evidence of benefit pre hospital or in children.

Internal cardiac massage

Internal cardiac massage is the process of cardiac massage carried out through a surgical incision into the chest cavity. This distinguishes the process from conventional, external cardiac massage, which is carried out by compression near the sternum during cardiopulmonary resuscitation.

Effectiveness

Type of Arrest	ROSC	Survival Source
Witnessed In-Hospital Cardiac Arrest	48%	22%
Unwitnessed In-Hospital Cardiac Arrest	21%	1%
Bystander Cardiocerebral Resuscitation	40%	6%
Bystander Cardiopulmonary Resuscitation	40%	4%
No Bystander CPR (Ambulance CPR)	15%	2%
Defibrillation within 3–5 minutes	74%	30%

Used alone, CPR will result in few complete recoveries, and those who do survive often develop serious complications. Estimates vary, but many organizations stress that CPR does not "bring anyone back," it simply preserves the body for defibrillation and advanced life support. However, in the case of "non-shockable" rhythms such as Pulseless Electrical Activity (PEA), defibrillation is not indicated, and the importance of CPR rises. On average, only 5–10% of people who receive CPR survive. The purpose of CPR is not to "start" the heart, but rather to circulate oxygenated blood, and keep the brain alive until advanced care (especially defibrillation) can be initiated. As many of these patients may have a pulse that is impalpable by the layperson rescuer, the current consensus is to perform CPR on a patient who is not breathing.

Studies have shown the importance of immediate CPR followed by defibrillation within 3–5 minutes of sudden VF cardiac arrest improve survival. In cities such as Seattle where CPR training is widespread and defibrillation by EMS personnel follows quickly, the survival rate is about 30 percent. In cities such as New York, without those advantages, the survival rate is only 1–2 percent.

In most cases, there is a higher proportion of patients who achieve a Return of Spontaneous Circulation (ROSC), where their heart starts to beat on its own again, than ultimately survive to be discharged from hospital. This is due to medical staff either being ultimately unable to address the cause of the arrhythmia or cardiac arrest, or in some instances due to other co-morbidities, due to the patient being gravely ill in more than one way.

Compression-only CPR is less effective in children than in adults, as cardiac arrest in children is more likely to have a non-cardiac cause. In a 2010 prospective study of cardiac arrest in children (age 1–17), for arrests with a non-cardiac cause provision by bystanders of conventional CPR with rescue breathing yielded a favorable neurological outcome at one month more often that did compression-only CPR (OR 5.54; 95% confidence interval 2.52–16.99). For arrests with a cardiac cause in this cohort, there was no difference between the two techniques (OR 1.20; 95%

confidence interval 0.55–2.66). This is consistent with American Heart Association guidelines for parents.

Pathophysiology

CPR is used on people in cardiac arrest in order to oxygenate the blood and maintain a cardiac output to keep vital organs alive. Blood circulation and oxygenation are required to transport oxygen to the tissues. The brain may sustain damage after blood flow has been stopped for about four minutes and irreversible damage after about seven minutes. Typically if blood flow ceases for one to two hours, the cells of the body die. Because of that CPR is generally only effective if performed within seven minutes of the stoppage of blood flow. The heart also rapidly loses the ability to maintain a normal rhythm. Low body temperatures as sometimes seen in near-drownings prolong the time the brain survives. Following cardiac arrest, effective CPR enables enough oxygen to reach the brain to delay brain death, and allows the heart to remain responsive to defibrillation attempts.

Adjunct devices

While several adjunctive devices are available none other than defibrillation as of 2010 have consistently been found to be better than standard CPR for out of hospital cardiac arrest.These devices can be split in to three broad groups - timing devices, those that assist the rescuer to achieve the correct technique, especially depth and speed of compressions, and those which take over the process completely.

Timing devices

They can feature a metronome (an item carried by many ambulance crews) in order to assist the rescuer in getting the correct rate. Some units can also give timing reminders for performing compressions, breathing and changing operators.

Manual assist devices

Studies have shown that audible and visual prompting can improve the quality of CPR and prevent the decrease of compression rate and depth that naturally occurs with fatigue, and to address this potential improvement, a number of devices have been developed to help improve CPR technique.

These items can be devices to placed on top of the chest, with the rescuers hands going over the device, and a display or audio feedback giving information on depth, force or rate, or in a wearable format such as a glove. Several published evaluations show that these devices can improve the performance of chest compressions.

As well as use during actual CPR on a cardiac arrest victim, which relies on the rescuer carrying the device with them, these devices can also be used as part of training programs to improve basic skills in performing correct chest compressions.

Certain defibrillation pads are capable of performing similar function, in that they may display rate and depth of compressions. Additionally, a certain algorithm may allow them to monitor electrical activity even during CPR.

Automatic devices

There are also some automated devices available which take over the chest compressions for the rescuer. These have several advantages: they allow rescuers to focus on performing other interventions; they do not fatigue and begin to perform less effective compressions, as humans do; and they are able to perform effective compressions in limited-space environments such as air ambulances, where manual compressions are difficult. These devices use either pneumatic (high-pressure gas) or electrical power sources to drive a compressing pad on to the chest of the patient. One such device, known as the LUCAS, was developed at the University Hospital of Lund, is powered by the compressed oxygen supplies already standard in ambulances and hospitals, and has undergone numerous clinical trials, showing a marked improvement in coronary perfusion pressure and return of spontaneous circulation.

Another system called the AutoPulse is electrically powered and uses a large band around the patients chest which contracts in rhythm in order to deliver chest compressions. This is also backed by clinical studies showing increased successful return of spontaneous circulation.

Prevalence

Chance of receiving CPR

Various studies suggest that in out-of-home cardiac arrest, bystanders, lay persons or family members attempt CPR in between 14% and 45% of the time, with a median of 32%. This indicates that around a third of out-of-home arrests have a CPR attempt made on them. However, the effectiveness of this CPR is variable, and the studies suggest only around half of bystander CPR is performed correctly.

There is a clear correlation between age and the chance of CPR being commenced, with younger people being far more likely to have CPR attempted on them prior to the arrival of emergency medical services. It was also found that CPR was more commonly given by a bystander in public than when an arrest occurred in the patient's home, although health care professionals are responsible for more than half of out-of-hospital resuscitation attempts. This is supported by further research, which suggests that people with no connection to the victim are more likely to perform CPR than a member of their family. This is likely because of the shock experienced by finding a family member in need of CPR; it is easier to remain calm - and think clearly - when the person in need of CPR is a complete stranger, as in this case one will not be as frightened.

There is also a correlation between the cause of arrest and the likelihood of bystander CPR being initiated. Lay persons are most likely to give CPR to younger cardiac arrest victims in a public place when it has a medical cause; victims in arrest from trauma, exsanguination or intoxication are less likely to receive CPR.

Finally, it has been claimed that there is a higher chance of CPR being performed if the bystander is told to only perform the chest compression element of the resuscitation.

Chance of receiving CPR in time

CPR is only likely to be effective if commenced within 6 minutes after the blood flow stops, because permanent brain cell damage occurs when fresh blood infuses the cells after that time, since the cells of the brain become dormant in as little as 4–6 minutes in an oxygen deprived environment and the cells are unable to survive the reintroduction of oxygen in a traditional resuscitation. Research using cardioplegic blood infusion resulted in a 79.4% survival rate with cardiac arrest intervals of 72±43 minutes, traditional methods achieve a 15% survival rate in this scenario, by comparison. New research is currently needed to determine what role CPR, electroshock, and new advanced gradual resuscitation techniques will have with this new knowledge A notable exception is cardiac arrest occurring in conjunction with exposure to very cold temperatures. Hypothermia seems to protect by slowing down metabolic and physiologic processes, greatly decreasing the tissues' need for oxygen. There are cases where CPR, defibrillation, and advanced warming techniques have revived victims after substantial periods of hypothermia.

Society and culture

Portrayed effectiveness

CPR is often severely misrepresented in movies and television as being highly effective in resuscitating a person who is not breathing and has no circulation. A 1996 study published in the New England Journal of Medicine showed that CPR success rates in television shows was 75% for immediate circulation, and 67% survival to discharge. This gives members of the public an unrealistic expectation of a successful outcome. When educated on the actual survival rates, the proportion of patients over 60 years of age desiring CPR should they suffer a cardiac arrest drops from 41% to 22%.

Stage CPR

Chest compressions are capable of causing significant local blunt trauma, including bruising or fracture of the sternum or ribs. Performing CPR on a healthy person may or may not disrupt normal heart rhythm, but regardless the technique should not be performed on a healthy person because of the risk of trauma.

The portrayal of CPR technique on television and film often is purposely incorrect. Actors simulating the performance of CPR may bend their elbows while appearing to compress, to prevent force from reaching the chest of the actor portraying the victim. Other techniques, such as substituting a mannequin torso for the "victim" in some shots, may also be used to avoid harming actors.

Self-CPR hoax

A form of "self-CPR" termed "Cough CPR" was the subject of a hoax chain e-mail entitled "How to Survive a Heart Attack When Alone" which wrongly cited "ViaHealth Rochester General Hospital" as the source of the technique. Rochester General Hospital has denied any connection with the technique.

Rapid coughing has been used in hospitals for brief periods of cardiac arrhythmia on monitored patients. One researcher has recommended that it be taught broadly to the public.

However, “cough CPR” cannot be used outside the hospital because the first symptom of cardiac arrest is unconsciousness in which case coughing is impossible, although myocardial infarction (heart attack) may occur to give rise to the cardiac arrest, so a patient may not be immediately unconscious. Further, the vast majority of people suffering chest pain from a heart attack will not be in cardiac arrest and CPR is not needed. In these cases attempting “cough CPR” will increase the workload on the heart and may be harmful. When coughing is used on trained and monitored patients in hospitals, it has only been shown to be effective for 90 seconds.

The American Heart Association (AHA) and other resuscitation bodies do not endorse "Cough CPR", which it terms a misnomer as it is not a form of *resuscitation*. The AHA does recognize a limited legitimate use of the coughing technique: "This coughing technique to maintain blood flow during brief arrhythmias has been useful in the hospital, particularly during cardiac catheterization. In such cases the patients ECG is monitored continuously, and a physician is present."

History

Sign showing old Silvester and Holger-Nielsen methods of resuscitation

In the 19th century, Doctor H. R. Silvester described a method (The Silvester Method) of artificial respiration in which the patient is laid on their back, and their arms are raised above their head to aid inhalation and then pressed against their chest to aid exhalation. The procedure is repeated sixteen times per minute. This type of artificial respiration is occasionally seen in films made in the early part of the 20th century.

A second technique, called the Holger Neilson technique, described in the first edition of the Boy Scout Handbook in the United States in 1911, described a form of artificial respiration where the person was laid on their front, with their head to the side, resting on the palms of both hands. Upward pressure applied at the patient's elbows raised the upper body while pressure on their back forced air into the lungs, essentially the Silvester Method with the patient flipped over. This form is seen well into the 1950s (it is used in an episode of *Lassie* during the Jeff Miller era), and was often used, sometimes for comedic effect, in theatrical cartoons of the time. This method would continue to be shown, for historical purposes, side-by-side with modern CPR in the Boy Scout Handbook until its ninth edition in 1979. The technique was later banned from first-aid manuals in the UK.

However, it was not until the middle of the 20th century that the wider medical community started to recognize and promote artificial respiration combined with chest compressions as a key part of resuscitation following cardiac arrest. The combination was first seen in a 1962 training video called "The Pulse of Life" created by James Jude, Guy Knickerbocker and Peter Safar. Jude and Knickerbocker, along with William Kouwenhoven and Joseph S. Redding had recently discovered the method of external chest compressions, whereas Safar had worked with Redding and James Elam to prove the effectiveness of artificial respiration. It was at Johns Hopkins University where the technique of CPR was originally developed. The first effort at testing the technique was performed on a dog by Redding, Safar and JW Perason. Soon afterward, the technique was used to save the life of a child. Their combined findings were presented at annual Maryland Medical Society meeting on September 16, 1960 in Ocean City, and gained rapid and widespread acceptance over the following decade, helped by the video and speaking tour they undertook. Peter Safar wrote the book *ABC of resuscitation* in 1957. In the U.S., it was first promoted as a technique for the public to learn in the 1970s.

Artificial respiration was combined with chest compressions based on the assumption that active ventilation is necessary to keep circulating blood oxygenated, and the combination was accepted without comparing its effectiveness with chest compressions alone. However, research over the past decade has shown that assumption to be in error, resulting in the AHA's acknowledgment of the effectiveness of chest compressions alone.

In other animals

It is entirely feasible to perform CPR on animals, including cats and dogs. The principles and practices are virtually identical to CPR for humans. One difference is that resuscitation is usually done through the animal's nose, not the mouth. One is cautioned to only perform CPR on unconscious animals to avoid the risk of being bitten and that animals, depending on species, have a lower bone density than humans, causing bones to become weakened after CPR is performed.

Chapter 12

Dialysis

A hemodialysis machine

In medicine, **dialysis** (from Greek "dialusis", meaning dissolution, "dia", meaning through, and "lysis", meaning loosening) is primarily used to provide an artificial replacement for lost kidney function in people with renal failure. Dialysis may be used for those with an acute disturbance in kidney function (acute kidney injury, previously acute renal failure) or for those with progressive but chronically worsening kidney function–a state known as chronic kidney disease stage 5 (previously chronic renal failure or end-stage kidney disease). The latter form may develop over months or years, but in contrast to acute kidney injury is not usually reversible, and dialysis is

regarded as a "holding measure" until a renal transplant can be performed, or sometimes as the only supportive measure in those for whom a transplant would be inappropriate.

The kidneys have important roles in maintaining health. When healthy, the kidneys maintain the body's internal equilibrium of water and minerals (sodium, potassium, chloride, calcium, phosphorus, magnesium, sulfate). Those acidic metabolism end products that the body cannot get rid of via respiration are also excreted through the kidneys. The kidneys also function as a part of the endocrine system producing erythropoietin and calcitriol. Erythropoietin is involved in the production of red blood cells and calcitriol plays a role in bone formation. Dialysis is an imperfect treatment to replace kidney function because it does not correct the endocrine functions of the kidney. Dialysis treatments replace some of these functions through diffusion (waste removal) and ultrafiltration (fluid removal).

History

Dr. Willem Kolff, a Dutch physician, constructed the first working dialyzer in 1943 during the Nazi occupation of the Netherlands. Due to the scarcity of available resources, Kolff had to improvise and build the initial machine using sausage casings, beverage cans, a washing machine and various other items which were available at the time. Over the following two years, Kolff used his machine to treat 16 patients who suffered from acute kidney failure, but the results were unsuccessful. Then, in 1945, a 67-year-old woman in uremic coma regained consciousness following 11 hours of hemodialysis with the dialyzer, and lived for another seven years before dying of an unrelated condition. She was the first-ever patient successfully treated with dialysis.

Principle

Dialysis works on the principles of the diffusion of solutes and ultrafiltration of fluid across a semi-permeable membrane. Diffusion describes a property of substances in water. Substances in water tend to move from an area of high concentration to an area of low concentration. Blood flows by one side of a semi-permeable membrane, and a dialysate, or special dialysis fluid, flows by the opposite side. A semipermeable membrane is a thin layer of material that contains various sized holes, or pores. Smaller solutes and fluid pass through the membrane, but the membrane blocks the passage of larger substances (for example, red blood cells, large proteins).

The two main types of dialysis, hemodialysis and Peritoneal dialysis, remove wastes and excess water from the blood in different ways. Hemodialysis removes wastes and water by circulating blood outside the body through an external filter, called a dialyzer, that contains a semipermeable membrane. The blood flows in one direction and the dialysate flows in the opposite. The counter-current flow of the blood and dialysate maximizes the concentration gradient of solutes between the blood and dialysate, which helps to remove more urea and creatinine from the blood. The concentrations of solutes (for example potassium, phosphorus, and urea) are undesirably high in the blood, but low or absent in the dialysis solution and constant replacement of the dialysate ensures that the concentration of undesired solutes is kept low on this side of the membrane. The dialysis solution has levels of minerals like potassium and calcium that are similar to their natural concentration in healthy blood. For another solute, bicarbonate, dialysis

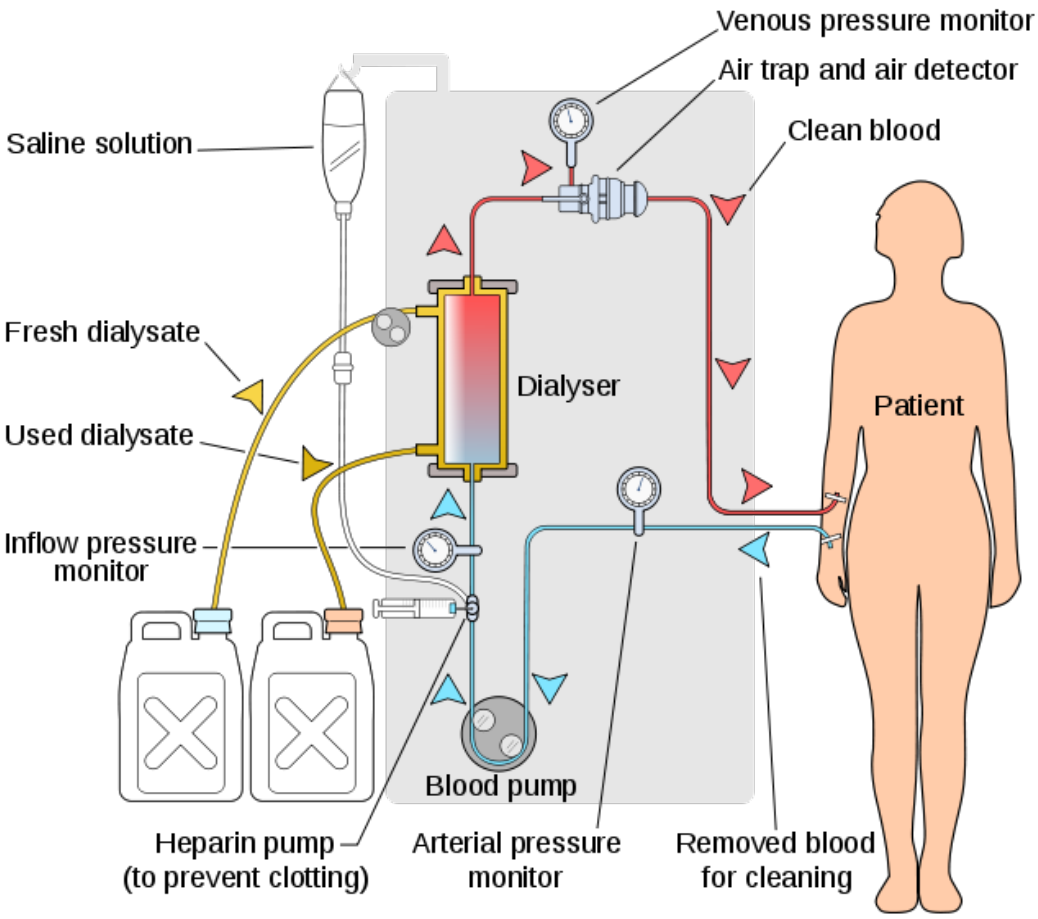
solution level is set at a slightly higher level than in normal blood, to encourage diffusion of bicarbonate into the blood, to act as a pH buffer to neutralize the metabolic acidosis that is often present in these patients. The levels of the components of dialysate are typically prescribed by a nephrologist according to the needs of the individual patient.

In peritoneal dialysis, wastes and water are removed from the blood inside the body using the *peritoneal membrane* of the peritoneum as a natural semipermeable membrane. Wastes and excess water move from the blood, across the peritoneal membrane, and into a special dialysis solution, called dialysate, in the abdominal cavity which has a composition similar to the fluid portion of blood.

Types

There are two primary and two secondary types of dialysis: hemodialysis, peritoneal dialysis, hemofiltration, hemodiafiltration, and intestinal dialysis.

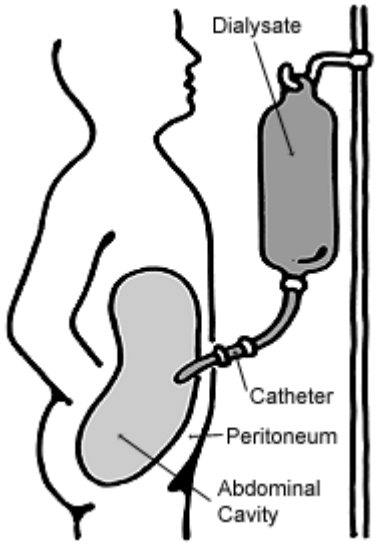
Hemodialysis



Hemodialysis schematic

In hemodialysis, the patient's blood is pumped through the blood compartment of a dialyzer, exposing it to a partially permeable membrane. The dialyzer is composed of thousands of tiny synthetic hollow fibers. The fiber wall acts as the semipermeable membrane. Blood flows through the fibers, dialysis solution flows around the outside the fibers, and water and wastes move between these two solutions. The cleansed blood is then returned via the circuit back to the body. Ultrafiltration occurs by increasing the hydrostatic pressure across the dialyzer membrane. This usually is done by applying a negative pressure to the dialysate compartment of the dialyzer. This pressure gradient causes water and dissolved solutes to move from blood to dialysate, and allows the removal of several litres of excess fluid during a typical 3 to 5 hour treatment. In the US, hemodialysis treatments are typically given in a dialysis center three times per week (due in the US to Medicare reimbursement rules); however, as of 2007 over 2,500 people in the US are dialyzing at home more frequently for various treatment lengths. Studies have demonstrated the clinical benefits of dialyzing 5 to 7 times a week, for 6 to 8 hours. This type of hemodialysis is usually called "nocturnal daily hemodialysis", which a study has shown a significant improvement in both small and large molecular weight clearance and decrease the requirement of taking phosphate binders. These frequent long treatments are often done at home while sleeping, but home dialysis is a flexible modality and schedules can be changed day to day, week to week. In general, studies have shown that both increased treatment length and frequency are clinically beneficial.

Peritoneal dialysis



Schematic diagram of peritoneal dialysis

In peritoneal dialysis, a sterile solution containing glucose is run through a tube into the peritoneal cavity, the abdominal body cavity around the intestine, where the peritoneal membrane acts as a semipermeable membrane.The peritoneal membrane or peritoneum is a layer of tissue containing blood vessels that lines and surrounds the peritoneal, or abdominal, cavity and the internal abdominal organs (stomach, spleen, liver, and intestines). The dialysate is left there for a period of time to absorb waste products, and then it is drained out through the tube

and discarded. This cycle or "exchange" is normally repeated 4-5 times during the day, (sometimes more often overnight with an automated system). Each time the dialysate fills and empties from the abdomen is called one exchange. A dwell time means that the time of dialysate stay in patient's abdominal cavity - wastes, chemicals and extra fluid move from patient's blood to the dialysate across the peritoneum. A drain process is the process after the dwell time, the dialysate full with waste products and extra fluid is drained out of patient's blood. Ultrafiltration occurs via osmosis; the dialysis solution used contains a high concentration of glucose, and the resulting osmotic pressure causes fluid to move from the blood into the dialysate. As a result, more fluid is drained than was instilled. Peritoneal dialysis is less efficient than hemodialysis, but because it is carried out for a longer period of time the net effect in terms of removal of waste products and of salt and water are similar to hemodialysis. Peritoneal dialysis is carried out at home by the patient. Although support is helpful, it is not essential. It does free patients from the routine of having to go to a dialysis clinic on a fixed schedule multiple times per week, and it can be done while travelling with a minimum of specialized equipment.

Hemofiltration

Hemofiltration is a similar treatment to hemodialysis, but it makes use of a different principle. The blood is pumped through a dialyzer or "hemofilter" as in dialysis, but no dialysate is used. A pressure gradient is applied; as a result, water moves across the very permeable membrane rapidly, "dragging" along with it many dissolved substances, importantly ones with large molecular weights, which are cleared less well by hemodialysis. Salts and water lost from the blood during this process are replaced with a "substitution fluid" that is infused into the extracorporeal circuit during the treatment. Hemodiafiltration is a term used to describe several methods of combining hemodialysis and hemofiltration in one process.

Hemodiafiltration

Hemodialfiltration is a combination of hemodialysis and hemofiltration. In theory, this technique offers the advantages of both hemodialysis and hemofiltration.

Intestinal dialysis

In intestinal dialysis, the diet is supplemented with soluble fibres such as acacia fibre, which is digested by bacteria in the colon. This bacterial growth increases the amount of nitrogen that is eliminated in fecal waste. An alternative approach utilizes the ingestion of 1 to 1.5 liters of non-absorbable solutions of polyethylene glycol or mannitol every fourth hour.

Starting indications

The decision to initiate dialysis or hemofiltration in patients with renal failure depends on several factors. These can be divided into acute or chronic indications.

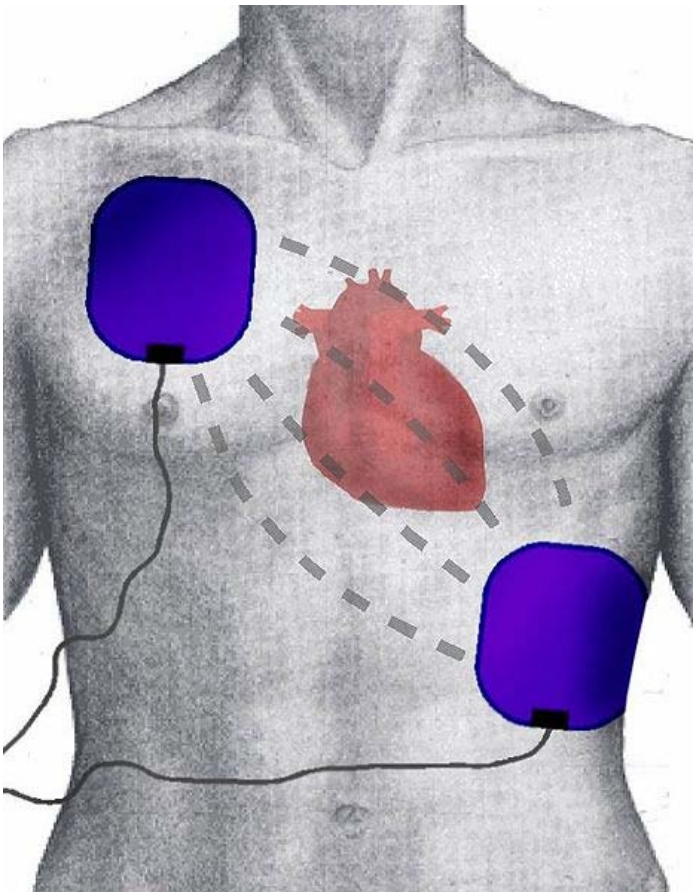
- Indications for dialysis in the patient with acute kidney injury are:
    1. Metabolic acidosis in situations where correction with sodium bicarbonate is impractical or may result in fluid overload.

2. Electrolyte abnormality, such as severe hyperkalemia, especially when combined with AKI.
3. Fluid overload not expected to respond to treatment with diuretics.
4. Complications of uremia, such as pericarditis, encephalopathy, or gastrointestinal bleeding.
5. Intoxication, that is, acute poisoning with a dialyzable substance. These substances can be represented by the mnemonic SLIME: salicylic acid, lithium, isopropanol, Magnesium-containing laxatives, and ethylene glycol.

- Chronic indications for dialysis:
    1. Symptomatic renal failure
    2. Low glomerular filtration rate (GFR) (RRT often recommended to commence at a GFR of less than 10-15 mls/min/1.73m^2). In diabetics dialysis is started earlier.
    3. Difficulty in medically controlling fluid overload, serum potassium, and/or serum phosphorus when the GFR is very low

Chapter 13

Defibrillation



View of defibrillator position and placement, using hands free electrodes

Defibrillation is the definitive treatment for the life-threatening cardiac arrhythmias, ventricular fibrillation and pulseless ventricular tachycardia. Defibrillation consists of delivering a therapeutic dose of electrical energy to the affected heart with a device called a **defibrillator**. This depolarizes a critical mass of the heart muscle, terminates the arrhythmia, and allows normal sinus rhythm to be reestablished by the body's natural pacemaker, in the sinoatrial node of the heart. Defibrillators can be external, transvenous, or implanted, depending on the type of device used or needed. Some external units, known as automated external defibrillators (AEDs),

automate the diagnosis of treatable rhythms, meaning that lay responders or bystanders are able to use them successfully with little, or in some cases no training at all.

History

Defibrillation was first demonstrated in 1899 by Jean Louis Prevost and Frederic Batelli, two physiologists from University of Geneva, Switzerland. They discovered that small electric shocks could induce ventricular fibrillation in dogs, and that larger charges would reverse the condition.

In 1933 a Dr Albert Hyman a heart specialist at the Beth Davis Hospital of New York city and a C. Henry Hyman, an electrical engineer, looking for an alternative to injecting powerful drugs directly into the heart, came up with an invention that used an electrical shock in place of drug injection. This invention was called the *Hyman Otor* where a hollow needle is used to pass an insulated wire to the heart area to deliver the electrical shock. The hollow steel needle being one end of the circuit and the insulated wire the other end. Whether the *Hyman Otor* was a success is unknown.

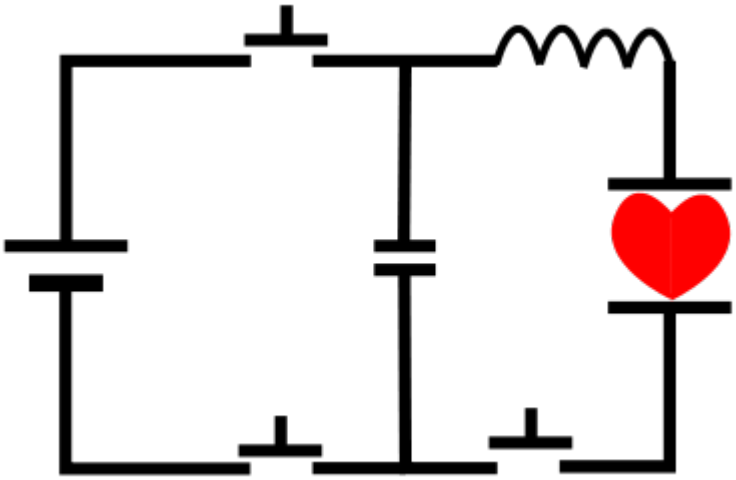
The first use on a human was in 1947 by Claude Beck, professor of surgery at Case Western Reserve University. Beck's theory was that ventricular fibrillation often occurred in hearts which were fundamentally healthy, in his terms "Hearts that are too good to die", and that there must be a way of saving them. Beck first used the technique successfully on a 14 year old boy who was being operated on for a congenital chest defect. The boy's chest was surgically opened, and manual cardiac massage was undertaken for 45 minutes until the arrival of the defibrillator. Beck used internal paddles on either side of the heart, along with procainamide, an antiarrhythmic drug, and achieved return of normal sinus rhythm.

These early defibrillators used the alternating current from a power socket, transformed from the 110-240 volts available in the line, up to between 300 and 1000 volts, to the exposed heart by way of 'paddle' type electrodes. The technique was often ineffective in reverting VF while morphological studies showed damage to the cells of the heart muscle post mortem. The nature of the AC machine with a large transformer also made these units very hard to transport, and they tended to be large units on wheels.

Closed-chest method

Until the early 1950s, defibrillation of the heart was possible only when the chest cavity was open during surgery. The technique used an alternating current from a 300 or greater volt source delivered to the sides of the exposed heart by 'paddle' electrodes where each electrode was a flat or slightly concave metal plate of about 40 mm diameter. The closed-chest defibrillator device which applied an alternating current of greater than 1000 amps, conducted by means of externally applied electrodes through the chest cage to the heart, was pioneered by Dr V. Eskin with assistance by A. Klimov in Frunze, USSR (today known as Bishkek, Kyrgyzstan) in mid 1950s.

Move to direct current



A circuit diagram showing the simplest (non-electronically controlled) defibrillator design, depending on the inductor (damping), producing a Lown, Edmark or Gurvich Waveform

In 1959 Bernard Lown commenced research into an alternative technique which involved charging of a bank of capacitors to approximately 1000 volts with an energy content of 100-200 joules then delivering the charge through an inductance such as to produce a heavily damped sinusoidal wave of finite duration (~5 milliseconds) to the heart by way of 'paddle' electrodes. The work of Lown was taken to clinical application by engineer Barouh Berkovits with his "cardioverter".

The Lown waveform, as it was known, was the standard for defibrillation until the late 1980s when numerous studies showed that a biphasic truncated waveform (BTE) was equally efficacious while requiring the delivery of lower levels of energy to produce defibrillation. A side effect was a significant reduction in weight of the machine. The BTE waveform, combined with automatic measurement of transthoracic impedance is the basis for modern defibrillators.

Portable units become available

A major breakthrough was the introduction of portable defibrillators used out of the hospital. This was pioneered in the early 1960s by Prof. Frank Pantridge in Belfast. Today portable defibrillators are among the many very important tools carried by ambulances. They are the only proven way to resuscitate a person who has had a cardiac arrest unwitnessed by EMS who is still in persistent ventricular fibrillation or ventricular tachycardia at the arrival of pre-hospital providers.

Gradual improvements in the design of defibrillators, partly based on the work developing implanted versions (see below), have led to the availability of Automated External Defibrillators. These devices can analyse the heart rhythm by themselves, diagnose the shockable rhythms, and

charge to treat. This means that no clinical skill is required in their use, allowing lay people to respond to emergencies effectively.

Change to a biphasic waveform

Until the late 1980s, external defibrillators delivered a Lown type waveform which was a heavily damped sinusoidal impulse having a mainly uniphasic characteristic. Biphasic defibrillation, alternates the direction of the pulses, completing one cycle in approximately 10 milliseconds. Biphasic defibrillation was originally developed and used for implantable cardioverter-defibrillators. When applied to external defibrillators, biphasic defibrillation significantly decreases the energy level necessary for successful defibrillation, decreasing the risk of burns and myocardial damage.

Ventricular fibrillation (VF) could be returned to normal sinus rhythm in 60% of cardiac arrest patients treated with a single shock from a monophasic defibrillator. Most biphasic defibrillators have a first shock success rate of greater than 90%.

Implantable devices

A further development in defibrillation came with the invention of the implantable device, known as an implantable cardioverter-defibrillator (or ICD). This was pioneered at Sinai Hospital in Baltimore by a team that included Stephen Heilman, Alois Langer, Jack Lattuca, Morton Mower, Michel Mirowski, and Mir Imran, with the help of industrial collaborator Intec Systems of Pittsburgh. Mirowski teamed up with Mower and Staewen, and together they commenced their research in 1969 but it was 11 years before they treated their first patient. Similar developmental work was carried out by Schuder and colleagues at the University of Missouri.

The work was commenced, despite doubts amongst leading experts in the field of arrhythmias and sudden death. There was doubt that their ideas would ever become a clinical reality. In 1962 Bernard Lown introduced the external DC defibrillator. This device applied a direct current from a discharging capacitor through the chest wall into the heart to stop heart fibrillation. In 1972, Lown stated in the journal *Circulation* - "The very rare patient who has frequent bouts of ventricular fibrillation is best treated in a coronary care unit and is better served by an effective antiarrhythmic program or surgical correction of inadequate coronary blood flow or ventricular malfunction. In fact, the implanted defibrillator system represents an imperfect solution in search of a plausible and practical application."

The problems to be overcome were the design of a system which would allow detection of ventricular fibrillation or ventricular tachycardia. Despite the lack of financial backing and grants, they persisted and the first device was implanted in February 1980 at Johns Hopkins Hospital by Dr. Levi Watkins, Jr. Modern ICDs do not require a thoracotomy and possess pacing, cardioversion, and defibrillation capabilities.

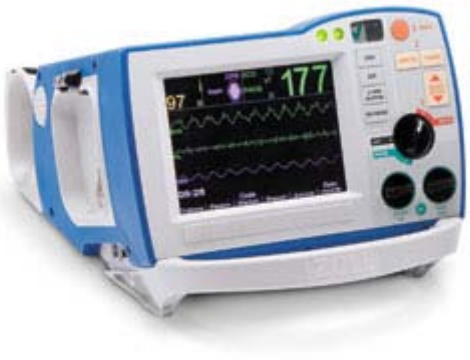
The invention of implantable units is invaluable to some regular sufferers of heart problems, although they are generally only given to those people who have already had a cardiac episode.

Types

Manual external defibrillator

External defibrillator / monitor

The units are used in conjunction with (or more often have inbuilt) electrocardiogram readers, which the healthcare provider uses to diagnose a cardiac condition (most often fibrillation or tachycardia although there are some other rhythms which can be treated by different shocks).



Manual external defibrillator monitor

The healthcare provider will then decide what charge (in joules) to use, based on proven guidelines and experience, and will deliver the shock through paddles or pads on the patient's chest. As they require detailed medical knowledge, these units are generally only found in hospitals and on some ambulances. For instance, every NHS ambulance in the United Kingdom is equipped with a manual defibrillator for use by the attending paramedics and technicians. In the United States, many advanced EMTs and all paramedics are trained to recognize lethal arrhythmias and deliver appropriate electrical therapy with a manual defibrillator when appropriate.

Manual internal defibrillator

These are the direct descendants of the work of Beck and Lown. They are virtually identical to the external version, except that the charge is delivered through internal paddles in direct contact with the heart. These are almost exclusively found in operating theatres, where the chest is likely to be open, or can be opened quickly by a surgeon.

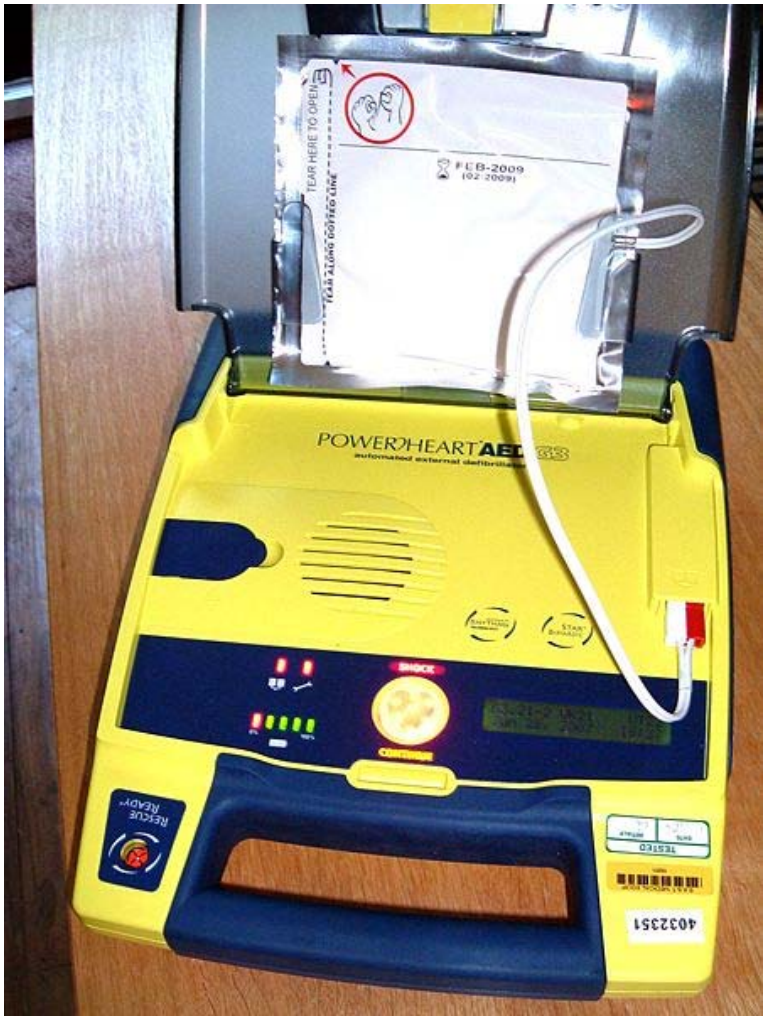
Automated external defibrillator (AED)

An AED at a railway station in Japan. The AED box has information on how to use it in Japanese, English, Chinese and Korean, and station staff are trained to use it.

These simple-to-use units are based on computer technology which is designed to analyze the heart rhythm itself, and then advise the user whether a shock is required. They are designed to be used by lay persons, who require little training to operate them correctly. They are usually limited in their interventions to delivering high joule shocks for VF (ventricular fibrillation) and VT (ventricular tachycardia) rhythms, making them generally of limited use to health professionals, who could diagnose and treat a wider range of problems with a manual or semi-automatic unit.

The automatic units also take time (generally 10–20 seconds) to diagnose the rhythm, where a professional could diagnose and treat the condition far more quickly with a manual unit. These time intervals for analysis, which require stopping chest compressions, have been shown in a number of studies to have a significant negative effect on shock success. This effect led to the recent change in the AHA defibrillation guideline (calling for two minutes of CPR after each shock without analyzing the cardiac rhythm) and some bodies recommend that AEDs should not be used when manual defibrillators and trained operators are available.

Automated external defibrillators are generally either held by trained personnel who will attend incidents, or are **public access** units which can be found in places including corporate and government offices, shopping centres, airports, restaurants, casinos, hotels, sports stadiums, schools and universities, community centers, fitness centers and health clubs.



An automated external defibrillator, open and ready for pads to be attached

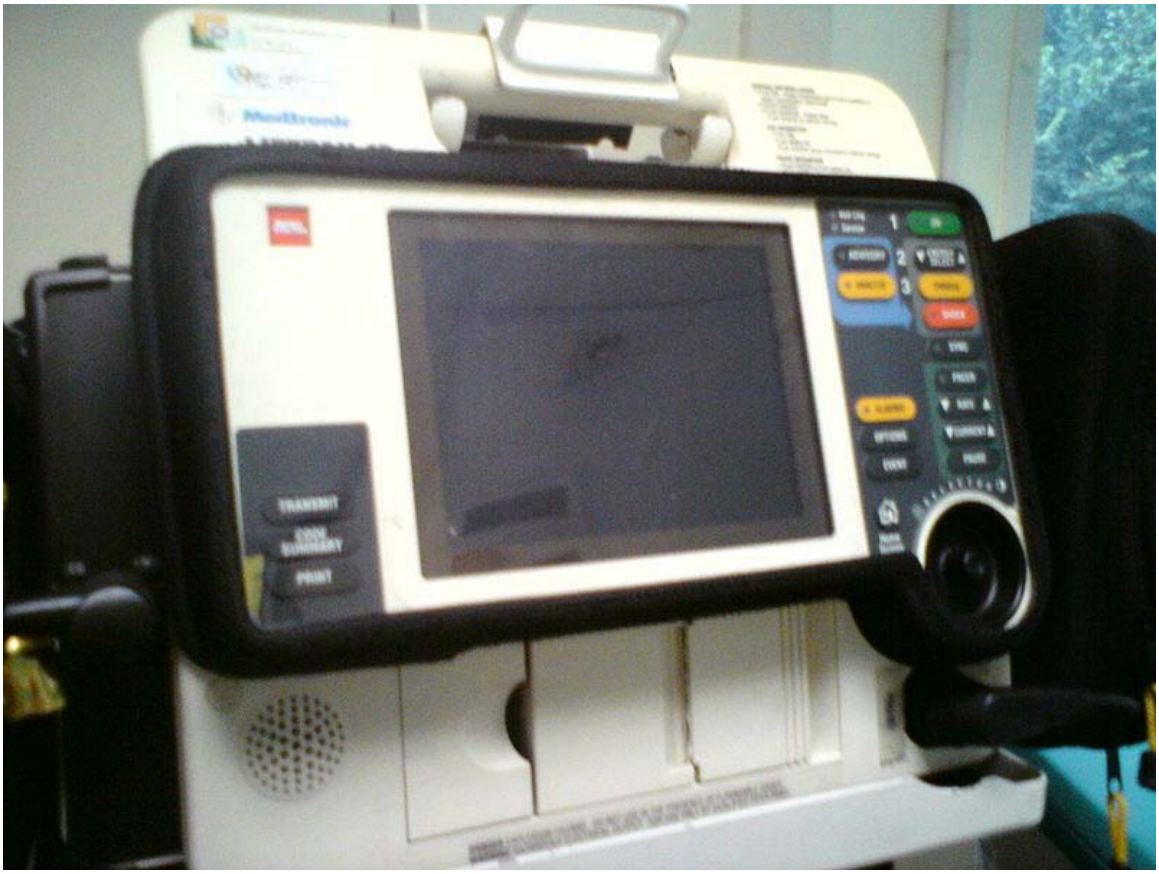
The locating of a public access AED should take in to account where large groups of people gather, and the risk category associated with these people, to ascertain whether the risk of a sudden cardiac arrest incident is high. For example, a center for teenage children is a particularly low risk category (as children very rarely enter heart rhythms such as VF (Ventricular Fibrillation) or VT (Ventricular Tachycardia), being generally young and fit, and the most common causes of pediatric cardiac arrest are respiratory arrest and trauma - where the heart is more likely to enter asystole or PEA, (where an AED is of no use). On the other hand, a large office building with a high ratio of males over 50 is a very high risk environment.

Automated-external-defibrillator

In many areas, emergency services vehicles are likely to carry AEDs. EMT-Basics in most areas are not trained in manual defibrillation, and often carry an AED instead. Some ambulances carry an AED in addition to a manual unit. In addition, some police or fire service vehicles carry an AED for first responder use. Some areas have dedicated community first responders, who are volunteers tasked with keeping an AED and taking it to any victims in their area. It is also increasingly common to find AEDs on transport such as commercial airlines and cruise ships. The presence of an AED can be a particularly decisive factor in cardiac patient survival in these scenarios, as professional medical assistance may be hours away.

In order to make them highly visible, public access AEDs often are brightly coloured, and are mounted in protective cases near the entrance of a building. When these protective cases are opened, and the defibrillator removed, some will sound a buzzer to alert nearby staff to their removal but do not necessarily summon emergency services. All trained AED operators should also know to phone for an ambulance when sending for or using an AED, as the patient will be unconscious, which always requires ambulance attendance.

Semi-automated external defibrillators



A Lifepak semi-automatic defibrillator/ECG monitor mounted in an ambulance. These units are designed for use only by healthcare professionals and are capable of measuring blood pressure and blood oxygen saturation in addition to the primary functions.

These units are a compromise between a full manual unit and an automated unit. They are mostly used by pre-hospital care professionals such as paramedics and emergency medical technicians. These units have the automated capabilities of the AED but also feature an ECG display, and a manual override, where the clinician can make their own decision, either before or instead of the computer. Some of these units are also able to act as a pacemaker if the heart rate is too slow (bradycardia) and perform other functions which require a skilled operator.

Implantable cardioverter-defibrillator (ICD)

Also known as automatic internal cardiac defibrillator (AICD). These devices are implants, similar to pacemakers (and many can also perform the pacemaking function). They constantly monitor the patient's heart rhythm, and automatically administer shocks for various life threatening arrhythmias, according to the device's programming. Many modern devices can distinguish between ventricular fibrillation, ventricular tachycardia, and more benign arrhythmias like supraventricular tachycardia and atrial fibrillation. Some devices may attempt

overdrive pacing prior to synchronised cardioversion. When the life threatening arrhythmia is ventricular fibrillation, the device is programmed to proceed immediately to an unsynchronized shock.

There are cases where the patient's ICD may fire constantly or inappropriately. This is considered a medical emergency, as it depletes the device's battery life, causes significant discomfort and anxiety to the patient, and in some cases may actually trigger life threatening arrhythmias. Some emergency medical services personnel are now equipped with a ring magnet to place over the device, which effectively disables the shock function of the device while still allowing the pacemaker to function (if the device is so equipped). If the device is shocking frequently, but appropriately, EMS personnel may administer sedation.

Wearable cardiac defibrillator

A development of the AICD is a portable external defibrillator that is worn like a vest. The unit monitors the patient 24 hours a day and will automatically deliver a biphasic shock if needed. This device is mainly indicated in patients awaiting an implantable defibrillator. Currently only one company manufactures these and they are of limited availability.

Modelling defibrillation

The efficacy of a cardiac defibrillator is highly dependent on the position of its electrodes. Most internal defibrillators are implanted in octogenarians, but a few children need the devices. Implanting defibrillators in kids is particularly difficult because children are small, will grow over time, and possess cardiac anatomy that differs from that of adults. Recently, researchers were able to create a software modeling system capable of mapping an individual’s thorax and determining the optimal position for an external or internal cardiac defibrillator.

With the help of pre-existing surgical planning applications, the software uses myocardial voltage gradients to predict the likelihood of successful defibrillation. According to the critical mass hypothesis, defibrillation is effective only if it produces a threshold voltage gradient in a large fraction of the myocardial mass. Usually, a gradient of three to five volts per centimeter is needed in 95 % of the heart. Voltage gradients of over 60 V/cm can damage tissue. The modeling software seeks to obtain safe voltage gradients above the defibrillation threshold.

Early simulations using the software suggest that small changes in electrode positioning can have large effects on defibrillation, and despite engineering hurdles that remain, the modeling system promises to help guide the placement of implanted defibrillators in children and adults.

Recent mathematical models of defibrillation are based on the bidomain model of cardiac tissue. Calculations using a realistic heart shape and fiber geometry are required to determine how cardiac tissue responds to a strong electrical shock.

Interface with the patient

The most well-known type of electrode (widely depicted in films and television) is the traditional metal paddle with an insulated (usually plastic) handle. This type must be held in place on the patient's skin while a shock or a series of shocks is delivered. Before the paddle is used, a gel must be applied to the patient's skin, in order to ensure a good connection and to minimize electrical resistance, also called chest impedance (despite the DC discharge). These are generally only found on the manual external units.

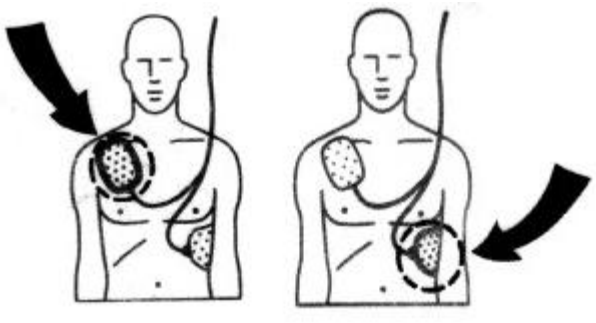
Newer types of resuscitation electrodes are designed as an adhesive pad. These are peeled off their backing and applied to the patient's chest when deemed necessary, much the same as any other sticker. These electrodes are then connected to a defibrillator. If defibrillation is required, the machine is charged, and the shock is delivered, without any need to apply any gel or to retrieve and place any paddles. These adhesive pads are found on most automated and semi-automated units, and are gradually replacing paddles entirely in non-hospital settings.

Both solid- and wet-gel adhesive electrodes are available. Solid-gel electrodes are more convenient, because there is no need to clean the patient's skin after removing the electrodes. However, the use of solid-gel electrodes presents a higher risk of burns during defibrillation, since wet-gel electrodes more evenly conduct electricity into the body.

Some adhesive electrodes are designed to be used not only for defibrillation, but also for transcutaneous pacing and synchronized electrical cardioversion.

In a hospital setting, paddles are generally preferred to pads, due to the inherent speed with which they can be placed and used. This is critical during cardiac arrest, as each second of nonperfusion means tissue loss. However, in cases in which cardiac arrest is suspected, patches placed prophalactically are superior,as they provide appropriate EKG tracing without the artifact visible from human interference with the paddles. Adhesive electrodes are also inherently safer than the paddles for the operator of the defibrillator to use, as they minimize the risk of the operator coming into physical (and thus electrical) contact with the patient as the shock is delivered, by allowing the operator to stand several feet away. Adhesive patches also require no force to remain in place and deliver the shock appropriately, whereas paddles require approximately 25 lbs of force to be applied while the shock is delivered.

Placement



Anterio-apical placement of external defibrillator electrodes (When defibrillation is unsuccessful, anterior-posterior placement is also sometimes attempted)

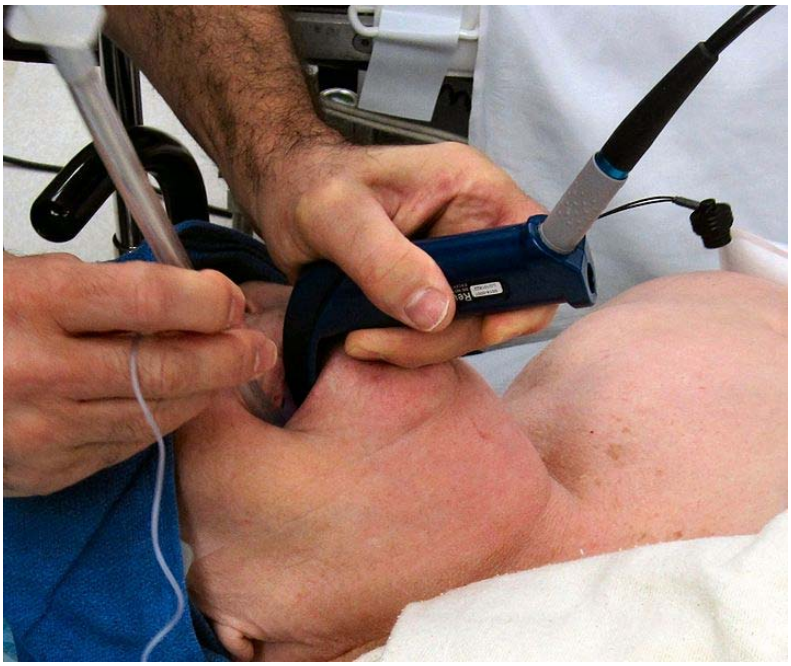
Resuscitation electrodes are placed according to one of two schemes. The anterior-posterior scheme (conf. image) is the preferred scheme for long-term electrode placement. One electrode is placed over the left precordium (the lower part of the chest, in front of the heart). The other electrode is placed on the back, behind the heart in the region between the scapula. This placement is preferred because it is best for non-invasive pacing.

The anterior-apex scheme can be used when the anterior-posterior scheme is inconvenient or unnecessary. In this scheme, the anterior electrode is placed on the right, below the clavicle. The apex electrode is applied to the left side of the patient, just below and to the left of the pectoral muscle. This scheme works well for defibrillation and cardioversion, as well as for monitoring an ECG.

Chapter 14

Tracheal Intubation

Intervention:
Tracheal intubation



laryngoscope to intubate the trachea of a morbidly obese elderly person with challenging airway anatomy

ICD-10 code:

ICD-9 code: 96.04

MeSH D007442

Other codes:

Tracheal intubation, usually simply referred to as **intubation**, is the placement of a flexible plastic tube into the trachea (windpipe) to maintain an open airway or to serve as a conduit through which to administer certain drugs. It is frequently performed in critically injured, ill or anesthetized patients to facilitate ventilation of the lungs, including mechanical ventilation, and to prevent the possibility of asphyxiation or airway obstruction. The most widely used route is orotracheal, in which an endotracheal tube is passed through the mouth and vocal apparatus into the trachea. In a nasotracheal procedure, an endotracheal tube is passed through the nose and vocal apparatus into the trachea. Other methods of intubation involve surgery and include the cricothyrotomy (used almost exclusively in emergency circumstances) and the tracheotomy, used primarily in situations where a prolonged need for airway support is anticipated.

Because it is an invasive and extremely uncomfortable medical procedure, intubation is usually performed after administration of general anesthesia and a neuromuscular-blocking drug. It can however be performed in the awake patient with local or topical anesthesia, or in an emergency without any anesthesia at all. Intubation is normally facilitated by using a conventional laryngoscope, flexible fiberoptic bronchoscope or video laryngoscope to identify the glottis, though other devices and techniques are available. After the trachea has been intubated, a balloon cuff is typically inflated near the far end of the tube to help secure it in place, to prevent leakage of respiratory gases, and to protect the tracheobronchial tree from receiving undesirable material such as stomach acid. The tube is then secured to the face or neck and connected to a T-piece, anesthesia breathing circuit, bag valve mask device, or a mechanical ventilator. Once there is no longer a need for ventilatory assistance and/or protection of the airway, the tracheal tube is removed; this is referred to as extubation of the trachea (or decannulation, in the case of a surgical airway such as a cricothyrotomy or a tracheotomy).

For centuries, tracheotomy was considered the only reliable method for intubation of the trachea. However, because only a minority of patients survived the operation, physicians undertook tracheotomy only as a last resort, on moribund patients. It was not until the late 19th century however that advances in anatomy and physiology, as well an appreciation of the germ theory of disease, had improved the outcome of this operation to the point that it could be considered an acceptable treatment option. Also at that time, advances in endoscopic instrumentation had improved to such a degree that direct laryngoscopy had become a viable means to secure the airway by the non-surgical orotracheal route. By the mid-20th century, the tracheotomy as well as endoscopy and non-surgical tracheal intubation had evolved from rarely employed procedures to becoming essential components of the practices of anesthesiology, critical care medicine, emergency medicine, gastroenterology, laryngology, pulmonology and surgery.

Tracheal intubation can be associated with minor complications such as broken teeth or lacerations of the tissues of the upper airway, or potentially fatal complications such as pulmonary aspiration of stomach contents or unrecognized intubation of the esophagus. Because of this, the potential for difficulty or complications due to the presence of unusual airway anatomy or other uncontrolled variables is carefully evaluated before undertaking tracheal intubation. Alternative strategies for securing the airway must always be readily available. The incidence of serious complications is unacceptably high when undertaken by practitioners lacking adequate training and experience.

Indications

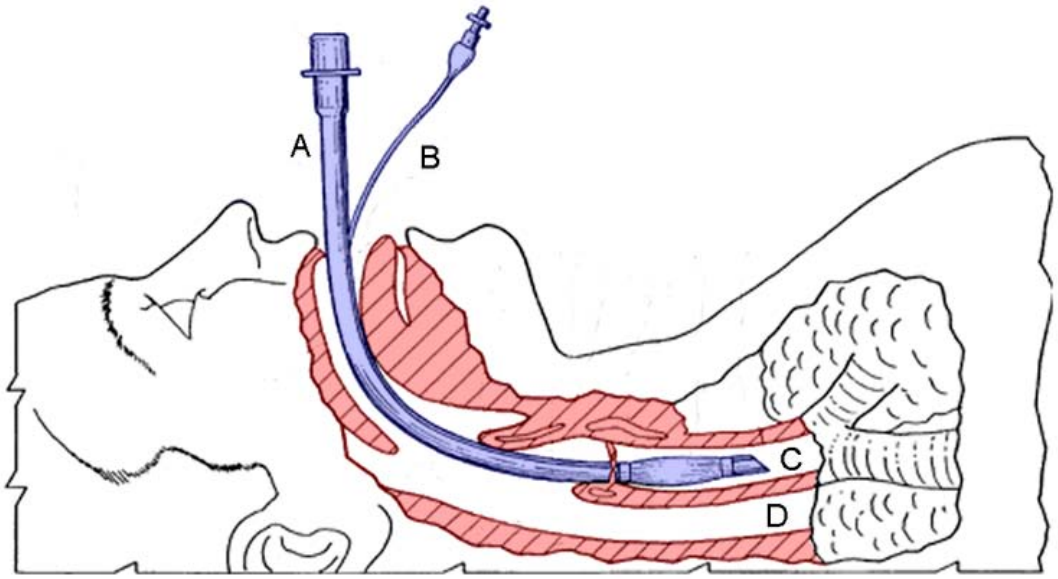


Diagram of an endotracheal tube that has been inserted into the trachea:
A - endotracheal tube (blue)
B - cuff inflation tube with pilot balloon
C - trachea
D - esophagus

Tracheal intubation is indicated in a variety of situations when illness or a medical procedure prevents a person from maintaining a clear airway, breathing, and oxygenating the blood. In these circumstances, oxygen supplementation using a simple face mask is inadequate.

Depressed level of consciousness

Perhaps the most common indication for tracheal intubation is for the placement of a conduit through which nitrous oxide or volatile anesthetics may be administered. General anesthetic agents, opioids, and neuromuscular-blocking drugs may diminish or even abolish the respiratory drive. Although it is not the only means to maintain a patent airway during general anesthesia, intubation of the trachea provides the most reliable means of oxygenation and ventilation and the greatest degree of protection against regurgitation and pulmonary aspiration.

Damage to the brain (such as from a massive stroke, non-penetrating head injury, intoxication or poisoning) may result in a depressed level of consciousness. When this becomes severe to the point of stupor or coma (defined as a score on the Glasgow Coma Scale of less than 8), dynamic collapse of the extrinsic muscles of the airway can obstruct the airway, impeding the free flow of

air into the lungs. Furthermore, protective airway reflexes such as coughing and swallowing may be diminished or absent. Tracheal intubation is often required to restore patency (the relative absence of blockage) of the airway and protect the tracheobronchial tree from pulmonary aspiration of gastric contents.

Hypoxemia

Intubation may be necessary for a patient with decreased oxygen content and oxygen saturation of the blood caused when their breathing is inadequate (hypoventilation), suspended (apnea), or when the lungs are unable to sufficiently transfer gasses to the blood. Such patients, who may be awake and alert, are typically critically ill with a multisystem disease or multiple severe injuries. Examples of such conditions include cervical spine injury, multiple rib fractures, severe pneumonia, acute respiratory distress syndrome (ARDS), or near-drowning. Specifically, intubation is considered if the arterial partial pressure of oxygen (PaO_2) is less than 60 millimeters of mercury (mm Hg) while breathing an inspired O_2 concentration (FIO_2) of 50% or greater. In patients with elevated arterial carbon dioxide, an arterial partial pressure of CO_2 ($PaCO_2$) greater than 45 mm Hg in the setting of acidemia would prompt intubation, especially if a series of measurements demonstrate a worsening respiratory acidosis. Regardless of the laboratory values, these guidelines are always interpreted in the clinical context.

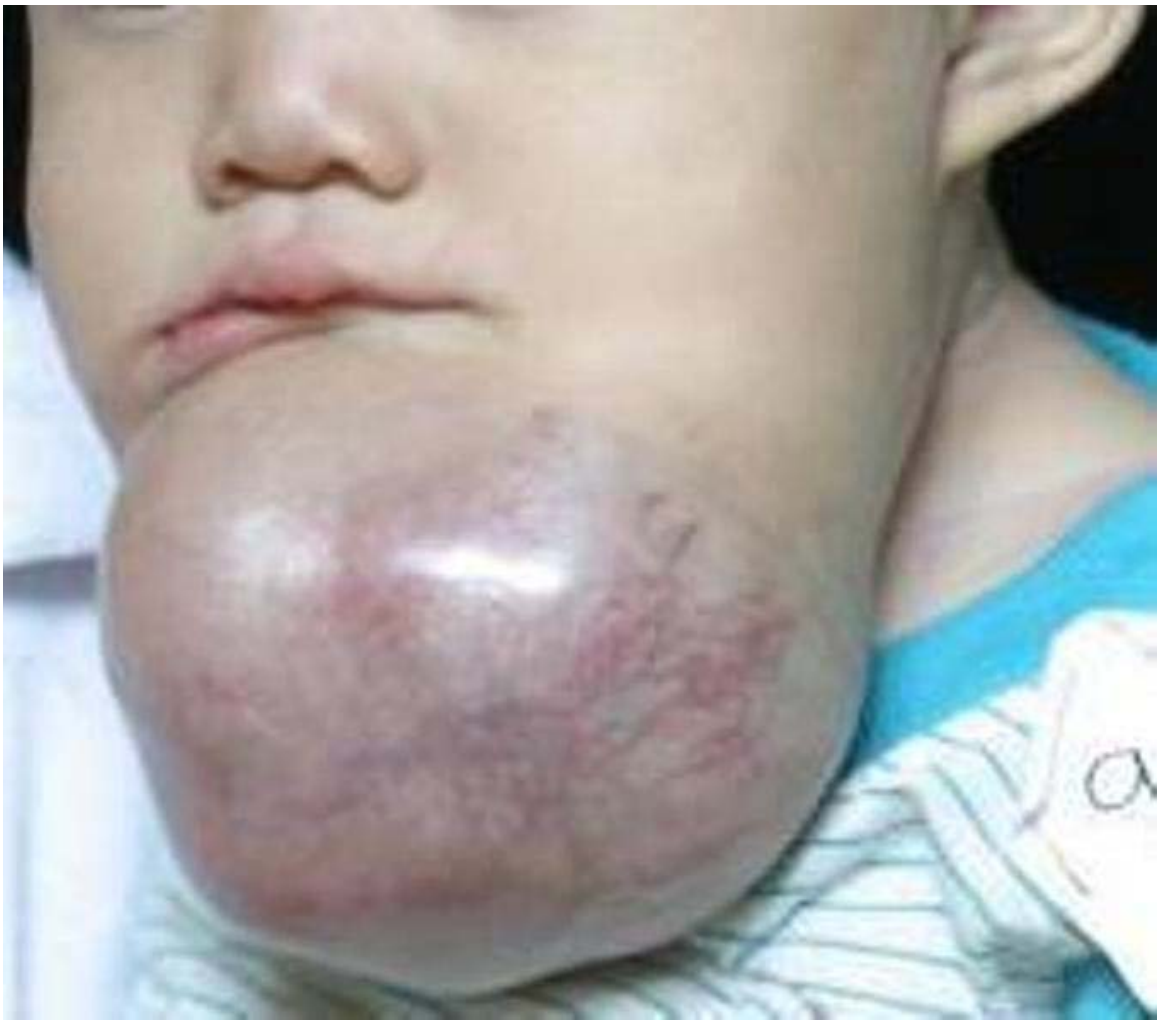
Airway obstruction

Actual or impending airway obstruction is a common indication for intubation of the trachea. Life-threatening airway obstruction may occur when a foreign body becomes lodged in the airway; this is especially common in infants and toddlers. Severe blunt or penetrating injury to the face or neck may be accompanied by swelling and an expanding hematoma, or injury to the larynx, trachea or bronchi. Airway obstruction is also common in people who have suffered smoke inhalation or burns within or near the airway. Sustained generalized seizure activity and angioedema are other common causes of life-threatening airway obstruction which may require tracheal intubation to secure the airway.

Manipulation of the airway

Diagnostic or therapeutic manipulation of the airway (such as bronchoscopy, laser therapy or stenting of the bronchi) may intermittently interfere with the ability to breathe; intubation may be necessary in such situations.

Predicting difficulty



Tracheal intubation is anticipated to be difficult in this child with a massive ameloblastoma

Tracheal intubation is not a simple procedure and the consequences of failure are grave. Therefore the patient is carefully evaluated for potential difficulty or complications beforehand. This involves taking the medical history of the patient and performing a physical examination, the results of which can be scored against one of several classification systems. The proposed surgical procedure (e.g., surgery involving the head and neck, or bariatric surgery) may lead one to anticipate difficulties with intubation. Many individuals have unusual airway anatomy, such as those who have limited movement of their neck or jaw, or those who have tumors, deep swelling due to injury or to allergy, developmental abnormalities of the jaw, or excess fatty tissue of the face and neck. Using conventional laryngoscopic techniques, intubation of the trachea can be difficult or even impossible in such patients. This is why all persons performing tracheal intubation must be familiar with alternative techniques of securing the airway. Use of the flexible fiberoptic bronchoscope and similar devices has become among the preferred techniques in the

management of such cases. However, these devices require a different skill set than that employed for conventional laryngoscopy and are expensive to purchase, maintain and repair.

When taking the patient's medical history, the subject is questioned about any significant signs or symptoms, such as difficulty in speaking or difficulty in breathing. These may suggest obstructing lesions in various locations within the upper airway, larynx, or tracheobronchial tree. A history of previous surgery (e.g., previous cervical fusion), injury, radiation therapy, or tumors involving the head, neck and upper chest can also provide clues to a potentially difficult intubation. Previous experiences with tracheal intubation, especially difficult intubation, intubation for prolonged duration (e.g., intensive care unit) or prior tracheotomy are also noted.

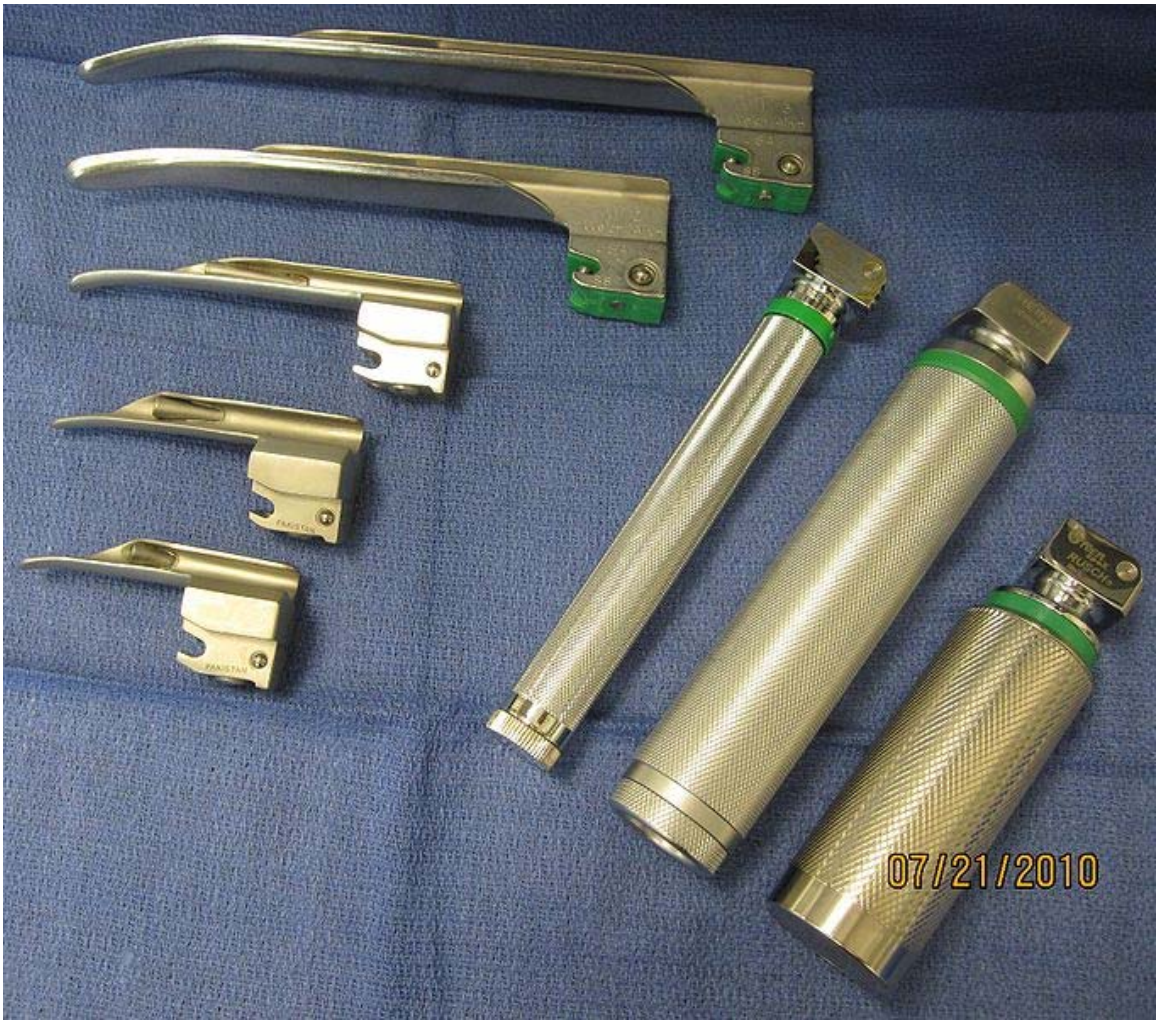
A detailed physical examination of the airway is important, particularly:

- the range of motion of the cervical spine: the subject should be able to tilt the head back and then forward so that the chin touches the chest.
- the range of motion of the jaw (the temporomandibular joint): three of the subject's fingers should be able to fit between the upper and lower incisors.
- the size and shape of the upper jaw and lower jaw, looking especially for problems such as maxillary hypoplasia (an underdeveloped upper jaw), micrognathia (an abnormally small jaw), or retrognathia (misalignment of the upper and lower jaw).
- the thyromental distance: three of the subject's fingers should be able to fit between the Adam's apple and the chin.
- the size and shape of the tongue and palate relative to the size of the mouth.
- the teeth, especially noting the presence of prominent maxillary incisors, any loose or damaged teeth, or crowns.

Many classification systems have been developed in an effort to predict difficulty of tracheal intubation, including the Cormack-Lehane grading system, the Intubation Difficulty Scale (IDS), and the Mallampati score. The Mallampati score is drawn from the observation that the size of the base of the tongue influences the difficulty of intubation. It is determined by looking at the anatomy of the mouth, and in particular the visibility of the base of palatine uvula, faucial pillars and the soft palate. Although such medical scoring systems may aid in the evaluation of patients, no single score or combination of scores can be trusted to specifically detect all and only those patients who are difficult to intubate. Furthermore, one study of experienced anesthesiologists, on the widely used Cormack–Lehane classification system, found they did not score the same patients consistently over time, and that only 25% could correctly define all four grades of the widely used Cormack–Lehane classification system. Under certain emergency circumstances (e.g., severe head trauma or suspected cervical spine injury), it may be impossible to fully utilize these the physical examination and the various classification systems to predict the difficulty of tracheal intubation. In such cases, alternative techniques of securing the airway must be readily available.

Equipment

Laryngoscopes



Laryngoscope handles with an assortment of Miller blades (large adult, small adult, child, infant and newborn)

Laryngoscope handle with an assortment of Macintosh blades (large adult, small adult, child, infant and newborn)

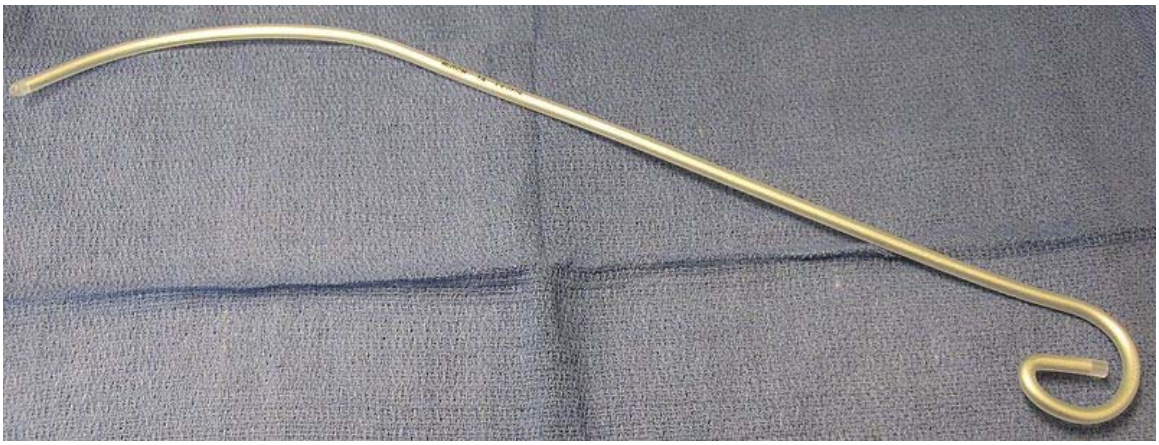
The vast majority of tracheal intubations involve the use of a viewing instrument of one type or another. The modern conventional laryngoscope consists of a handle containing batteries that power a light and a set of interchangeable blades, which are either straight or curved. This device is designed to allow the laryngoscopist to directly view the larynx. Due to the widespread availability of such devices, the technique of blind digital intubation of the trachea is rarely practiced today, although it may still be useful in certain emergency situations, such as natural or man-made disasters.

The decision to use a straight or curved laryngoscope blade depends partly on the specific anatomical features of the airway, and partly on the personal experience and preference of the

laryngoscopist. The Macintosh blade is the most widely used curved laryngoscope blade, while the Miller blade is the most popular style of straight blade. Both Miller and Macintosh laryngoscope blades are available in sizes 0 (infant) through 4 (large adult). There are many other styles of straight and curved blades, with accessories such as mirrors for enlarging the field of view and even ports for the administration of oxygen. These specialty blades are primarily designed for use by anesthetists and otolaryngologists, most commonly in the operating room.

Fiberoptic laryngoscopes have become increasingly available since the 1990s. In contrast to the conventional laryngoscope, these devices allow the laryngoscopist to indirectly view the larynx. This provides a significant advantage in situations where the operator needs to see around an acute bend in order to visualize the glottis, and deal with otherwise difficult intubations. Video laryngoscopes are specialized fiberoptic laryngoscopes that use a digital video camera sensor to allow the operator to view the glottis and larynx on a video monitor. Other "noninvasive" devices which can be employed to assist in tracheal intubation are the laryngeal mask airway (used as a conduit for endotracheal tube placement) and the AirTraq.

Stylets



An endotracheal tube stylet, useful in facilitating orotracheal intubation

An intubating stylet is a malleable metal wire designed to be inserted into the endotracheal tube to make the tube conform better to the upper airway anatomy of the specific individual. This aid is commonly used with a difficult laryngoscopy. Just as with laryngoscope blades, there are also several types of available stylets, such as the Verathon Stylet, which is specifically designed to follow the 60° blade angle of the GlideScope video laryngoscope.

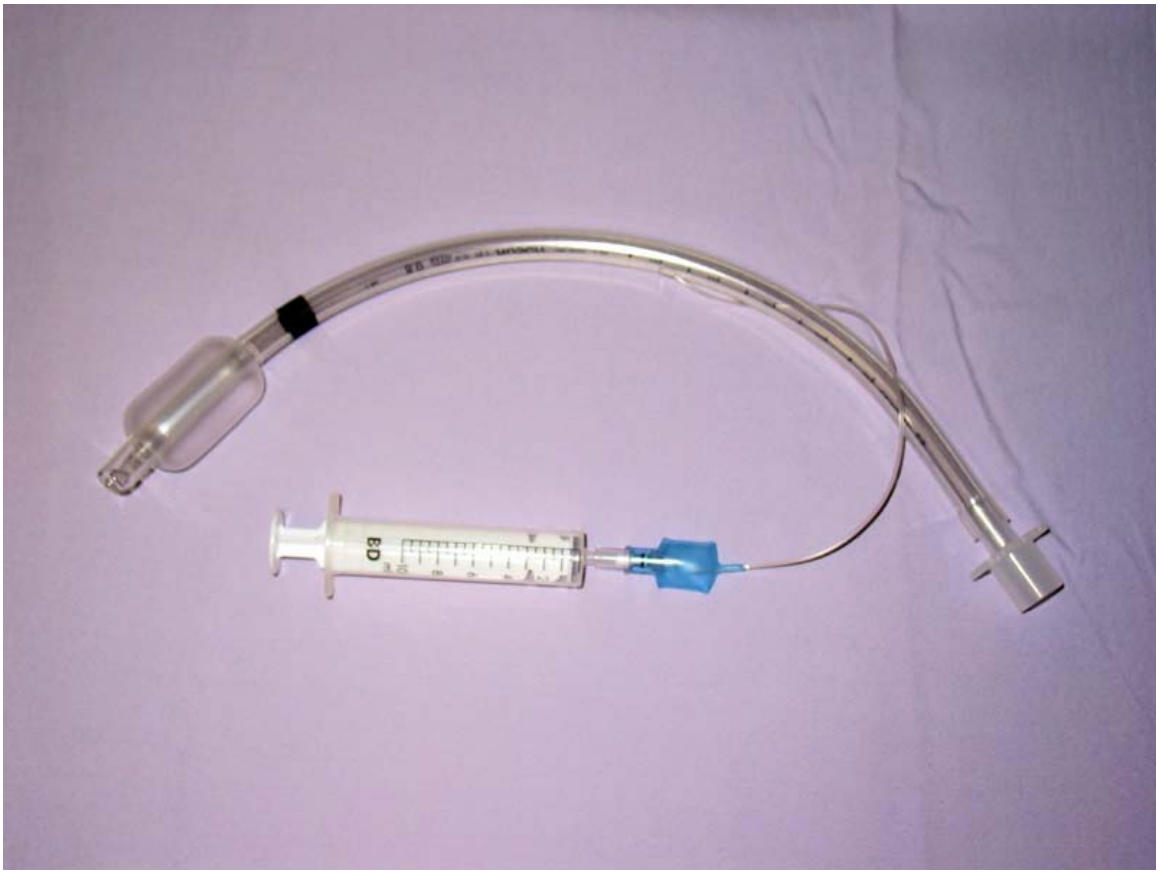
The Eschmann tracheal tube introducer (often incorrectly referred to as a "gum elastic bougie") is specialized type of stylet used to facilitate difficult intubation. This flexible device is 60 cm (24 in) in length, 15 French (5 mm diameter) with a small "hockey-stick" angle at the far end. Unlike a traditional intubating stylet, the Eschmann tracheal tube introducer is typically inserted directly into the trachea and then used as a guide over which the endotracheal tube can be passed (in a manner analogous to the Seldinger technique). As the Eschmann tracheal tube introducer is

considerably less rigid than a conventional stylet, this technique is considered to be a relatively atraumatic means of tracheal intubation.

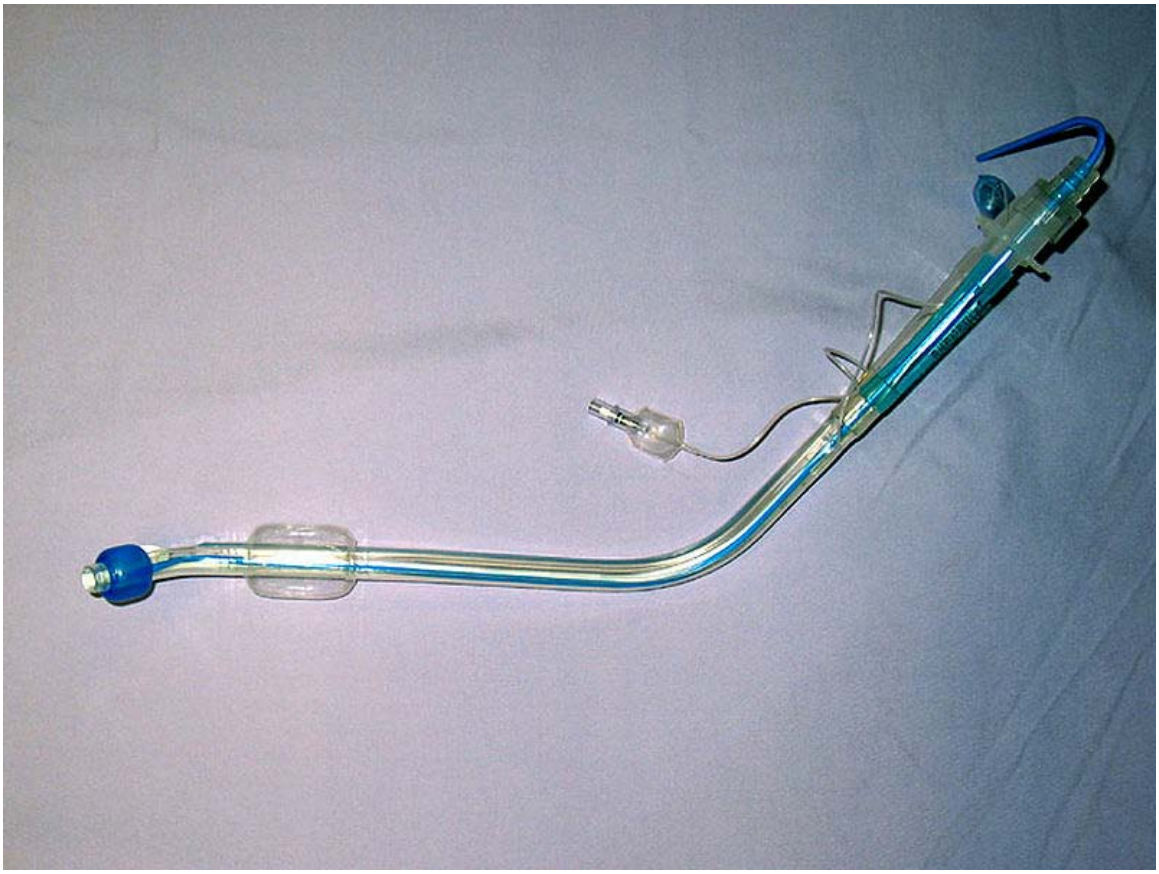
The tracheal tube exchanger is a hollow catheter, 56 to 81 cm (22.0 to 31.9 in) in length, that can be used for removal and replacement of tracheal tubes without the need for laryngoscopy. The Cook Airway Exchange Catheter (CAEC) is another example of this type of catheter; this device has a central lumen (hollow channel) through which oxygen can be administered.

The lighted stylet is a device that employs the principle of transillumination to facilitate blind orotracheal intubation (an intubation technique in which the laryngoscopist does not view the glottis).

Tracheal tubes



A cuffed endotracheal tube, constructed of polyvinyl chloride



A Carlens double-lumen endotracheal tube, used for thoracic surgical operations such as VATS lobectomy

A tracheal tube is a catheter that is inserted into the trachea for the primary purpose of establishing and maintaining a patent (open and unobstructed) airway. Tracheal tubes are frequently used for airway management in the settings of general anesthesia, critical care, mechanical ventilation and emergency medicine. Many different types of tracheal tubes are available, suited for different specific applications. An endotracheal tube is a specific type of tracheal tube that is nearly always inserted through the mouth (orotracheal) or nose (nasotracheal). It is a breathing conduit designed to be placed into the airway of critically injured, ill or anesthetized patients in order to perform mechanical positive pressure ventilation of the lungs and to prevent the possibility of aspiration or airway obstruction. The endotracheal tube has a fitting designed to be connected to a source of pressurized gas such as oxygen. At the other end is an orifice through which such gases are directed into the lungs and may also include a balloon (referred to as a cuff). The tip of the endotracheal tube is positioned above the carina (before the trachea divides to each lung) and sealed within the trachea so that the lungs can be ventilated equally. A tracheostomy tube is another type of tracheal tube; this 2–3-inch-long (51–76 mm) curved metal or plastic tube is inserted into a tracheostomy stoma or a cricothyrotomy incision.

Tracheal tubes can be used to ensure the adequate exchange of oxygen and carbon dioxide, to deliver oxygen in higher concentrations than found in air, or to administer other gases such as

helium, nitric oxide, nitrous oxide, xenon, or certain volatile anesthetic agents such as desflurane, isoflurane, or sevoflurane. They may also be used as a route for administration of certain medications such as bronchodilators, inhaled corticosteroids, and drugs used in treating cardiac arrest such as atropine, epinephrine, lidocaine and vasopressin.

Originally made from latex rubber, most modern endotracheal tubes today are constructed of polyvinyl chloride. Tubes constructed of silicone rubber, wire-reinforced silicone rubber or stainless steel are also available for special applications. For human use, tubes range in size from 2 to 10.5 mm (0.1 to 0.4 in) in internal diameter. The size is chosen based on the patient's body size, with the smaller sizes being used for infants and children. Most endotracheal tubes have an inflatable cuff to seal the tracheobronchial tree against leakage of respiratory gases and pulmonary aspiration of gastric contents, blood, secretions and other fluids. Uncuffed tubes are also available, though their use is limited mostly to children (in small children, the cricoid cartilage is the narrowest portion of the airway and usually provides an adequate seal for mechanical ventilation).

In addition to cuffed or uncuffed, preformed endotracheal tubes are also available. The oral and nasal RAE tubes (named after the inventors Ring, Adair and Elwyn) are the most widely used of the preformed tubes.

Various types of endotracheal tubes are available that have endobronchial as well as endotracheal channels (Carlens, White and Robertshaw tubes). These tubes are typically coaxial, with two separate channels and two separate openings. They incorporate an endotracheal lumen which terminates in the trachea and an endobronchial lumen, the distal tip of which is positioned 1–2 cm into the right or left mainstem bronchus. There is also the Univent tube, which has a single tracheal lumen and an integrated endobronchial blocker. These tubes enable one to ventilate both lungs, or either lung independently. Single-lung ventilation (allowing the lung on the operative side to collapse) can be useful during thoracic surgery, as it can facilitate the surgeon's view and access to other relevant structures within the thoracic cavity.

The "armored" endotracheal tubes are cuffed, wire-reinforced silicone rubber tubes. They are much more flexible than polyvinyl chloride tubes, yet they are difficult to compress or kink. This can make them useful for situations in which the trachea is anticipated to remain intubated for a prolonged duration, or if the neck is to remain flexed during surgery. Most armored tubes have a Magill curve, but preformed armored RAE tubes are also available. Another type of endotracheal tube has four small openings just above the inflatable cuff, which can be used for suction of the trachea or administration of intratracheal medications if necessary. Other tubes (such as the Bivona Fome-Cuf tube) are designed specifically for use in laser surgery in and around the airway.

Methods to confirm tube placement

No single method for confirming tracheal tube placement has been shown to be 100% reliable. Accordingly, the use of multiple methods for confirmation of correct tube placement is now widely considered to be the standard of care. Such methods include direct visualization as the tip of the tube passes through the glottis. With a properly positioned tracheal tube, equal bilateral

breath sounds will be heard upon listening to the chest with a stethoscope, and no sound upon listening to the area over the stomach. Equal bilateral rise and fall of the chest wall will be evident with ventilatory excursions. A small amount of water vapor will also be evident within the lumen of the tube with each exhalation and there will be no gastric contents in the tracheal tube at any time.

Ideally, at least one of the methods utilized for confirming tracheal tube placement will be a measuring instrument. Waveform capnography has emerged as the gold standard for the confirmation of tube placement within the trachea. Other methods relying on instruments include the use of a colorimetric end-tidal carbon dioxide detector, a self-inflating esophageal bulb, or an esophageal detection device. The distal tip of a properly positioned tracheal tube will be located in the mid-trachea, roughly 2 cm (1 in) above the bifurcation of the carina; this can be confirmed by chest x-ray. If the tracheal tube is inserted too far into the trachea, the tip will often be located within the right main bronchus, because this bronchus has a less acute angle than the left.

Special situations

Emergencies

Tracheal intubation in the emergency setting can be difficult with the fiberoptic bronchoscope due to blood, vomit, or secretions in the airway and poor patient cooperation. Because of this, patients with massive facial injury, complete upper airway obstruction, severe hypoventilation, or profuse upper airway bleeding are poor candidates for fiberoptic intubation. Fiberoptic intubation under general anesthesia typically requires two skilled individuals. Success rates of only 83–87% have been reported using fiberoptic techniques in the emergency department, with significant nasal bleeding occurring in up to 22% of patients. These drawbacks limit the use of fiberoptic bronchoscopy somewhat in urgent and emergent situations.

Personnel experienced in direct laryngoscopy are not always immediately available in certain settings that require emergency tracheal intubation. For this reason, specialized devices have been designed to act as bridges to a definitive airway. Such devices include the laryngeal mask airway, cuffed oropharyngeal airway and the esophageal-tracheal combitube (Combitube). Other devices such as rigid stylets, the lightwand (a blind technique) and indirect fiberoptic rigid stylets, such as the Bullard scope, Upsher scope and the WuScope can also be used as alternatives to direct laryngoscopy. Each of these devices have its own unique set of benefits and drawbacks, and none of them is effective under all circumstances.

Rapid-sequence induction and intubation

Rapid sequence induction and intubation (RSI) is a particular method of induction of general anesthesia, commonly employed in emergency operations and other situations where patients are assumed to have a "full stomach". The objective of RSI is to minimize the possibility of regurgitation and pulmonary aspiration of gastric contents during the induction of general anesthesia and subsequent tracheal intubation. RSI traditionally involves preoxygenating the lungs with a tightly-fitting oxygen mask, followed by the sequential administration of an

intravenous sleep-inducing agent and a rapidly-acting neuromuscular-blocking drug, before intubation of the trachea.

One important difference between RSI and routine tracheal intubation is that the practitioner does not manually assist the ventilation of the lungs after the onset of general anesthesia and cessation of breathing, until the trachea has been intubated and the cuff has been inflated. Another key feature of RSI is the application of manual pressure to the cricoid cartilage, often referred to as the "Sellick maneuver", prior to instrumentation of the airway and intubation of the trachea.

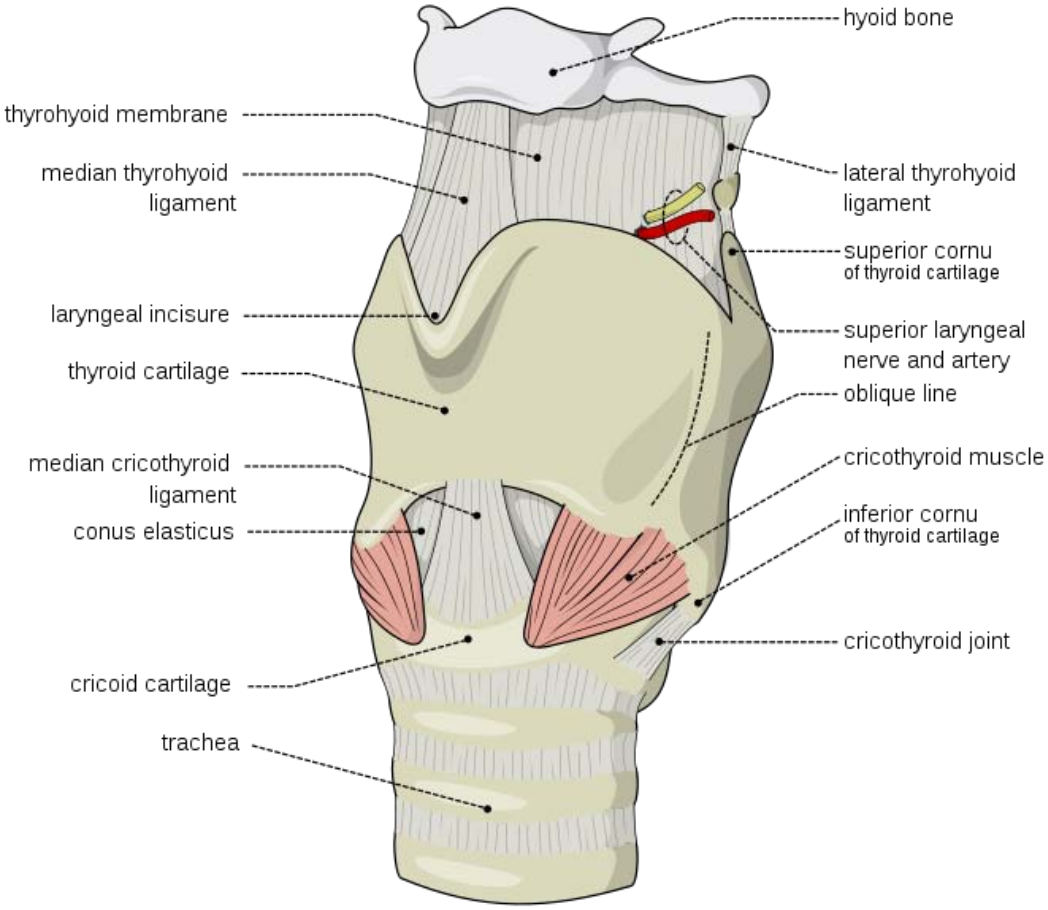
Since the introduction of RSI, there has been controversy regarding virtually every aspect of this technique, including:

- choice of induction drug, dose and method of administration.
- avoidance of manual ventilation before tracheal intubation.
- optimal position and whether the head-up, head-down, or horizontal supine position is the safest for induction of anesthesia in full-stomach patients.
- application of cricoid pressure (the Sellick maneuver).

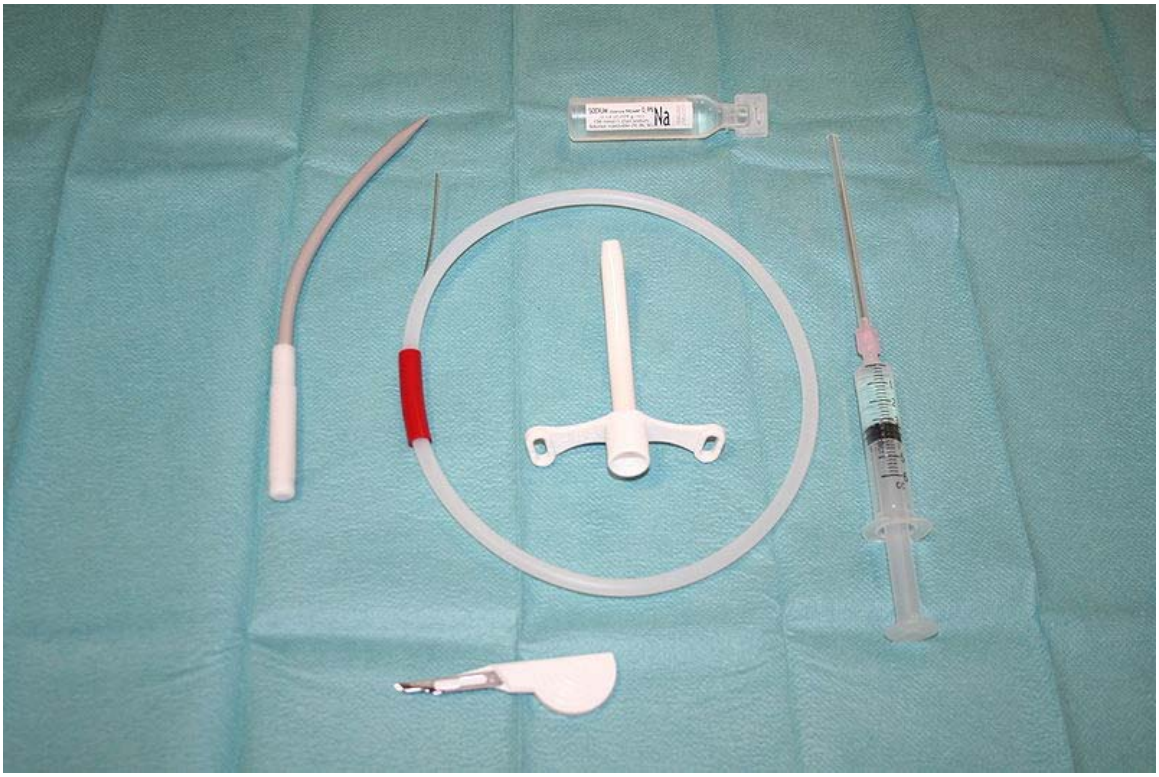
Named for British anesthetist Brian Arthur Sellick (1918–1996) who first described the procedure in 1961, the goal of the Sellick maneuver is to minimize the possibility of regurgitation and pulmonary aspiration of gastric contents, which can result in a severe and sometimes fatal chemical aspiration pneumonitis. Cricoid pressure has been widely used during RSI for nearly fifty years, despite a lack of compelling evidence to support this practice. The initial article by Sellick was based on a small sample size at a time when high tidal volumes, head-down positioning and barbiturate anesthesia were the rule. Beginning around 2000, a significant body of evidence has accumulated which questions the effectiveness of the Sellick maneuver. The application of cricoid pressure may in fact displace the esophagus laterally instead of compressing it as described by Sellick. Cricoid pressure may also compress the glottis, which can obstruct the view of the laryngoscopist and actually cause a delay in securing the airway.

The Sellick maneuver is often confused with the "BURP" (Backwards Upwards Rightwards Pressure) maneuver. While both of these involve digital pressure to the anterior aspect (front) of the laryngeal apparatus, the purpose of the latter is to improve the view of the glottis during laryngoscopy and tracheal intubation, rather than to prevent regurgitation.

Cricothyrotomy



In cricothyrotomy, the incision or puncture is made through the cricothyroid membrane in between the thyroid cartilage and the cricoid cartilage



Cricothyrotomy kit

A cricothyrotomy is an incision made through the skin and cricothyroid membrane to establish a patent airway during certain life-threatening situations, such as airway obstruction by a foreign body, angioedema, or massive facial trauma. A cricothyrotomy is nearly always performed as a last resort in cases where orotracheal and nasotracheal intubation are impossible or contraindicated. Cricothyrotomy is easier and quicker to perform than tracheotomy, does not require manipulation of the cervical spine and is associated with fewer complications.

The quickest and easiest method to perform this technique is the needle cricothyrotomy (also referred to as a percutaneous dilational cricothyrotomy), in which a large-bore (12–14 gauge) intravenous catheter is used to puncture the cricothyroid membrane. Oxygen can then be administered through this catheter via jet insufflation. However, while needle cricothyrotomy may be life-saving in extreme circumstances, this technique is only intended to be a temporizing measure until a definitive airway can be established. Needle cricothyrotomy only provides apneic oxygenation as the small diameter of an intravenous catheter allows for adequate oxygenation but not for elimination of carbon dioxide (ventilation). After one hour of apneic oxygenation through a needle cricothyrotomy, one can expect a $PaCO_2$ of greater than 250 mm Hg and an arterial pH of less than 6.72, despite an oxygen saturation of 98% or greater. A more definitive airway can be established by performing a surgical cricothyrotomy, in which a 5 to 6 mm (0.20 to 0.24 in) endotracheal tube or tracheostomy tube can be inserted through a larger incision.

Several manufacturers market prepackaged cricothyrotomy kits, which enable one to use either a wire-guided percutaneous dilational (Seldinger) technique, or the classic surgical technique to

insert a polyvinylchloride catheter through the cricothyroid membrane. The kits may be stocked in hospital emergency departments and operating suites, as well as ambulances and other selected pre-hospital settings.

Tracheotomy

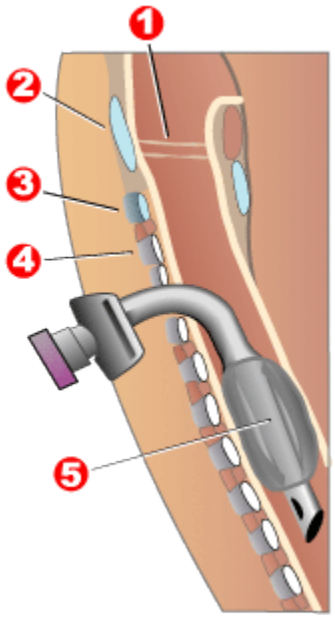


Diagram of a tracheostomy tube in the trachea:
1 - Vocal folds
2 - Thyroid cartilage
3 - Cricoid cartilage
4 - Tracheal rings
5 - Balloon cuff

Tracheotomy consists of making an incision on the front of the neck and opening a direct airway through an incision in the trachea. The resulting opening can serve independently as an airway or as a site for a tracheostomy tube to be inserted; this tube allows a person to breathe without the use of their nose or mouth. The opening may be made by a scalpel or a needle (referred to as surgical and percutaneous techniques respectively) and both techniques are widely used in current practice. In order to limit the risk of damage to the recurrent laryngeal nerves (the nerves that control the voicebox), the tracheotomy is performed as high in the trachea as possible. If only one of these nerves is damaged, the patient's voice may be impaired (dysphonia); if both of the nerves are damaged, the patient will be unable to speak (aphonia). British theoretical physicist Stephen Hawking lost his ability to speak after surgeons performed a tracheotomy in an effort to prevent recurrent pneumonia. In the acute setting, indications for tracheotomy are similar to those for cricothyrotomy. In the chronic setting, indications for tracheotomy include the need for long-term mechanical ventilation and removal of tracheal secretions (e.g., comatose patients, or extensive surgery involving the head and neck).

Children

A premature infant weighing 990 grams (35 ounces), intubated and requiring mechanical ventilation in the neonatal intensive-care unit

There are significant differences in airway anatomy and respiratory physiology between children and adults, and these are taken into careful consideration before performing tracheal intubation of any pediatric patient. The differences, which are quite significant in infants, gradually disappear as the human body approaches a mature age and body mass index.

For infants and young children, orotracheal intubation is easier than the nasotracheal route. Nasotracheal intubation carries a risk of dislodgement of adenoids and nasal bleeding. Despite the greater difficulty, nasotracheal intubation route is preferable to orotracheal intubation in

children undergoing intensive care and requiring prolonged intubation because this route allows a more secure fixation of the tube. As with adults, there are a number of devices specially designed for assistance with difficult tracheal intubation in children. Confirmation of proper position of the tracheal tube is accomplished as with adult patients.

Because the airway of a child is narrow, a small amount of glottic or tracheal swelling can produce critical obstruction. Inserting a tube that is too large relative to the diameter of the trachea can cause swelling. Conversely, inserting a tube that is too small can result in inability to achieve effective positive pressure ventilation due to retrograde escape of gas through the glottis and out the mouth and nose (often referred to as a "leak" around the tube). An excessive leak can usually be corrected by inserting a larger tube or a cuffed tube.

The tip of a correctly positioned tracheal tube will be in the mid-trachea, between the collarbones on an anteroposterior chest radiograph. The correct diameter of the tube is that which results in a small leak at a pressure of about 25 cm (10 in) of water. The appropriate inner diameter for the endotracheal tube is estimated to be roughly the same diameter as the child's little finger. The appropriate length for the endotracheal tube can be estimated by doubling the distance from the corner of the child's mouth to the ear canal. For premature infants 2.5 mm (0.10 in) internal diameter is an appropriate size for the tracheal tube. For infants of normal gestational age, 3 mm (0.12 in) internal diameter is an appropriate size. For normally nourished children 1 year of age and older, the following formulae estimate the proper diameter and depth of insertion for tracheal tubes:

- Internal diameter of tube (mm) = (patient's age in years + 16) / 4
- Appropriate depth of insertion of orotracheal tube (cm) = 12 + (patient's age in years / 2)

Complications

Tracheal intubation is generally considered the best method for airway management under a wide variety of circumstances, as it provides the most reliable means of oxygenation and ventilation and the greatest degree of protection against regurgitation and pulmonary aspiration. However, tracheal intubation requires a great deal of clinical experience to master and serious complications may result even when properly performed.

Four anatomic features must be present for orotracheal intubation to be straightforward: adequate mouth opening (full range of motion of the temporomandibular joint), sufficient pharyngeal space (determined by examining the hypopharynx), sufficient submandibular space (distance between the thyroid cartilage and the chin, the space into which the tongue must be displaced in order for the larygoscopist to view the glottis), and adequate extension of the cervical spine at the atlanto-occipital joint. If any of these variables is in any way compromised, intubation should be expected to be difficult.

Minor complications are common after laryngoscopy and insertion of an orotracheal tube. These are typically of short duration, such as sore throat, lacerations of the lips or gums or other structures within the upper airway, chipped, fractured or dislodged teeth, nasal injury, Other

complications which are common but potentially more serious include increased or irregular heartbeat, high blood pressure, elevated intracranial and introcular pressure, and bronchospasm.

More serious complications include laryngospasm, perforation of the trachea or esophagus, pulmonary aspiration of gastric contents or other foreign bodies, fracture or dislocation of the cervical spine, temporomandibular joint or arytenoid cartilages, decreased oxygen content, elevated arterial carbon dioxide, and vocal cord weakness. In addition to these complications, tracheal intubation via the nasal route carries a risk of dislodgement of adenoids and potentially severe nasal bleeding. Newer technologies such as flexible fiberoptic laryngoscopy have fared better in reducing the incidence of some of these complications, though the most frequent cause of intubation trauma remains a lack of skill on the part of the laryngoscopist.

Complications may also be severe and long-lasting or permanent, such as vocal cord damage, esophageal perforation and retropharyngeal abscess, bronchial intubation, or nerve injury. They may even be immediately life-threatening, such as laryngospasm and negative pressure pulmonary edema (fluid in the lungs), aspiration, unrecognized esophageal intubation, or accidental disconnection or dislodgement of the tracheal tube. Potentially fatal complications more often associated with prolonged intubation and/or tracheotomy include abnormal communication between the trachea and nearby structures such as the innominate artery (tracheoinnominate fistula) or esophagus (tracheoesophageal fistula). Other significant complications include airway obstruction due to loss of tracheal rigidity, ventilator-associated pneumonia and narrowing of the glottis or trachea. The cuff pressure is monitored carefully in order to avoid complications from over-inflation, many of which can be traced to excessive cuff pressure restricting the blood supply to the tracheal mucosa. A 2000 Spanish study of bedside percutaneous tracheotomy reported overall complication rates of 10–15% and procedural mortality of 0%, which is comparable to those of other series reported in the literature from the Netherlands and the United States.

Inability to secure the airway, with subsequent failure of oxygenation and ventilation is a life-threatening complication which if not immediately corrected leads to hypoxia, brain damage, cardiovascular collapse, and death. When performed improperly, the associated complications (e.g., unrecognized esophageal intubation) may be rapidly fatal. Without adequate training and experience, the incidence of such complications is unacceptably high. For example, among paramedics in several United States urban communities, unrecognized esophageal or hypopharyngeal intubation has been reported to be 6% to 25%. Among providers at the basic emergency medical technician (EMT-B) level, reported success rates for tracheal intubation are as low as 51%. In one study, nearly half of patients with misplaced tracheal tubes died in the emergency room. Because of this, recent editions of the American Heart Association's *Guidelines for Cardiopulmonary Resuscitation* have de-emphasized the role of tracheal intubation in favor of other airway management techniques such as bag-valve-mask ventilation, the laryngeal mask airway and the Combitube.

One complication—unintentional and unrecognized intubation of the esophagus—is both common (as frequent as 25% in the hands of inexperienced personnel) and likely to result in a deleterious or even fatal outcome. In such cases, oxygen is inadvertently administered to the stomach, from where it cannot be taken up by the circulatory system, instead of the lungs. If this

situation is not immediately identified and corrected, death will ensue from cerebral and cardiac anoxia.

Of 4,460 claims in the American Society of Anesthesiologists (ASA) Closed Claims Project database, 266 (approximately 6%) were for airway injury. Of these 266 cases, 87% of the injuries were temporary, 5% were permanent or disabling, and 8% resulted in death. Difficult intubation, age older than 60 years, and female gender were associated with claims for perforation of the esophagus or pharynx. Early signs of perforation were present in only 51% of perforation claims, whereas late sequelae occurred in 65%.

Alternatives

Although it offers the greatest degree of protection against regurgitation and pulmonary aspiration, tracheal intubation is not the only means to maintain a patent airway. Alternative techniques for airway management and delivery of oxygen or other breathing gases include the laryngeal mask airway, i-gel, cuffed oropharyngeal airway, CPAP mask, nasal BiPAP mask, simple face mask, and nasal cannula.

History

The earliest known depiction of a tracheotomy is found on two Egyptian tablets dating back to around 3600 BC. The 110-page Ebers Papyrus, an Egyptian medical papyrus which dates to roughly 1550 BC, also makes reference to the tracheotomy. Tracheotomy was described in the Rigveda, a Sanskrit text of ayurvedic medicine written around 2000 BC in ancient India. The Sushruta Samhita from around 400 BC is another text from the Indian subcontinent on ayurvedic medicine and surgery that mentions tracheotomy. Asclepiades of Bithynia (c. 124–40 BC) is often credited as being the first physician to perform a non-emergency tracheotomy. Galen of Pergamon (AD 129–199) clarified the anatomy of the trachea and was the first to demonstrate that the larynx generates the voice. In one of his experiments, Galen used bellows to inflate the lungs of a dead animal. Ibn Sīnā (980–1037) described the use of tracheal intubation to facilitate breathing in 1025 in his 14-volume medical encyclopedia, *The Canon of Medicine*. In the 12th century medical textbook *Al-Taisir*, Ibn Zuhr (1092–1162)—also known as Avenzoar—of Al-Andalus provided a correct description of the tracheotomy operation.

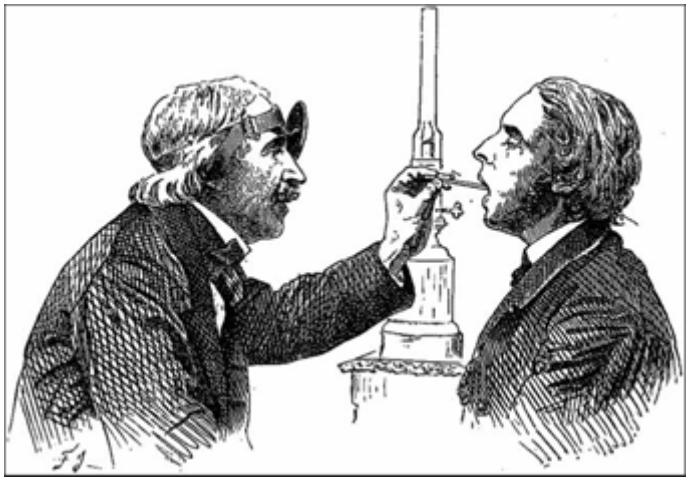
The first detailed descriptions of tracheal intubation and subsequent artificial respiration of animals were from Andreas Vesalius (1514–1564) of Brussels. In his landmark book published in 1543, *De humani corporis fabrica*, he described an experiment in which he passed a reed into the trachea of a dying animal whose thorax had been opened and maintained ventilation by blowing into the reed intermittently. Antonio Musa Brassavola (1490–1554) of Ferrara successfully treated a patient suffering from peritonsillar abscess by tracheotomy. Brassavola published his account in 1546; this operation has been identified as the first recorded successful tracheotomy, despite the many previous references to this operation. Towards the end of the 16th century, Hieronymus Fabricius (1533–1619) described a useful technique for tracheotomy in his writings, although he had never actually performed the operation himself. Fabricius was the first to introduce the idea of a tracheostomy tube. In 1620 the French surgeon Nicholas Habicot

(1550–1624) published a report of four successful tracheotomies. In 1714, anatomist Georg Detharding (1671–1747) of the University of Rostock performed a tracheotomy on a drowning victim.

Despite the many recorded instances of its use since antiquity, it was not until the early 19th century that the tracheotomy finally began to be recognized as a legitimate means of treating severe airway obstruction. In 1852, French physician Armand Trousseau (1801–1867) presented a series of 169 tracheotomies to the Académie Impériale de Médecine. 158 of these were performed for the treatment of croup, and 11 were performed for "chronic maladies of the larynx". Between 1830 and 1855, more than 350 tracheotomies were performed in Paris, most of them at the Hôpital des Enfants Malades, a public hospital, with an overall survival rate of only 20–25%. This compares with 58% of the 24 patients in Trousseau's private practice, who fared better due to greater postoperative care.

In 1871, the German surgeon Friedrich Trendelenburg (1844–1924) published a paper describing the first successful elective human tracheotomy to be performed for the purpose of administration of general anesthesia. In 1888, Sir Morell Mackenzie (1837–1892) published a book discussing the indications for tracheotomy. In the early 20th century, tracheotomy became a life-saving treatment for patients afflicted with paralytic poliomyelitis who required mechanical ventilation. In 1909, Philadelphia laryngologist Chevalier Jackson (1865–1958) described a technique for tracheotomy that is used to this day.

Laryngoscopy and non-surgical techniques



The laryngoscopy. From García, 1884

In 1854, a Spanish singing teacher named Manuel García (1805–1906) became the first man to view the functioning glottis in a living human. In 1858, French pediatrician Eugène Bouchut (1818–1891) developed a new technique for non-surgical orotracheal intubation to bypass laryngeal obstruction resulting from a diphtheria-related pseudomembrane. In 1880, Scottish surgeon William Macewen (1848–1924) reported on his use of orotracheal intubation as an alternative to tracheotomy to allow a patient with glottic edema to breathe, as well as in the setting of general anesthesia with chloroform. In 1895, Alfred Kirstein (1863–1922) of Berlin

first described direct visualization of the vocal cords, using an esophagoscope he had modified for this purpose; he called this device an autoscope.

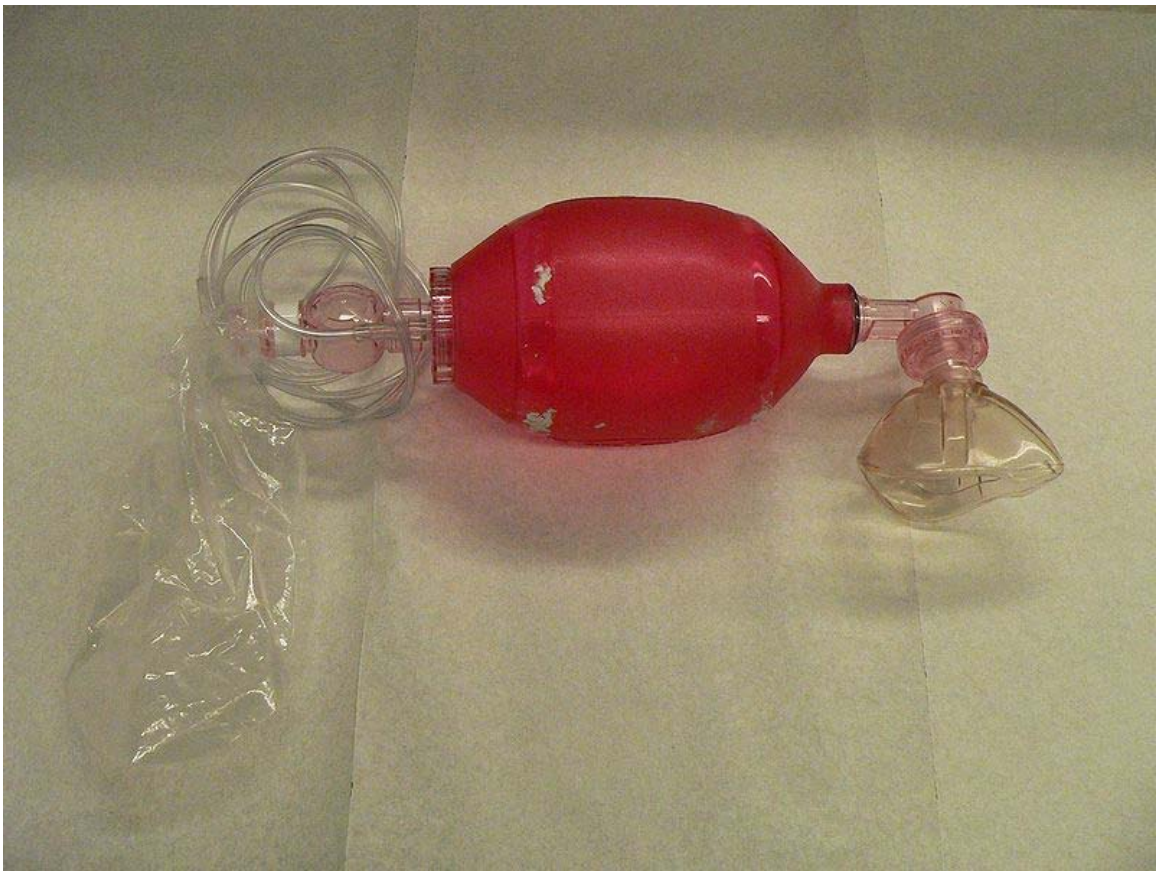
In 1913, Chevalier Jackson was the first to report a high rate of success for the use of direct laryngoscopy as a means to intubate the trachea. Jackson introduced a new laryngoscope blade that incorporated a component that the operator could slide out to allow room for passage of an endotracheal tube or bronchoscope. Also in 1913, New York surgeon Henry H. Janeway (1873–1921) published results he had achieved using a laryngoscope he had recently developed. Another pioneer in this field was Sir Ivan Whiteside Magill (1888–1986), who developed the technique of awake blind nasotracheal intubation, the Magill forceps, the Magill laryngoscope blade, and several apparati for the administration of volatile anesthetic agents. The Magill curve of an endotracheal tube is also named for Magill. Sir Robert Reynolds Macintosh (1897–1989) introduced a curved laryngoscope blade in 1943; the Macintosh blade remains to this day the most widely used laryngoscope blade for orotracheal intubation.

Between 1945 and 1952, optical engineers built upon the earlier work of Rudolph Schindler (1888–1968), developing the first gastrocamera. In 1964, optical fiber technology was applied to one of these early gastrocameras to produce the first flexible fiberoptic endoscope. Initially used in upper GI endoscopy, this device was first used for laryngoscopy and tracheal intubation by Peter Murphy, an English anesthetist, in 1967. The concept of using a stylet for replacing or exchanging orotracheal tubes was introduced by Finucane and Kupshik in 1978, using a central venous catheter.

By the mid-1980s, the flexible fiberoptic bronchoscope had become an indispensable instrument within the pulmonology and anesthesia communities. The digital revolution of the 21st century has brought newer technology to the art and science of tracheal intubation. Several manufacturers have developed video laryngoscopes which employ digital technology such as the CMOS active pixel sensor (CMOS APS) to generate a view of the glottis so that the trachea may be intubated.

Chapter 15

Bag Valve Mask



A disposable BVM Resuscitator

A **bag valve mask** (also known as a **BVM** or **Ambu bag**) is a hand-held device used to provide positive pressure ventilation to a patient who is not breathing or who is breathing inadequately. The device is a normal part of a resuscitation kit for trained professionals, such as ambulance crew. The BVM is frequently used in hospitals, and is an essential part of a crash cart. The device is used extensively in the operating room to ventilate an anaesthetised patient in the minutes before a mechanical ventilator is attached. The device is self-filling with air, although additional oxygen (O_2) can be added.

Use of the BVM to ventilate a patient is frequently called "**bagging**" the patient. Bagging is regularly necessary in medical emergencies when the patient's breathing is insufficient (respiratory failure) or has ceased completely (respiratory arrest). The BVM resuscitator is used in order to manually provide mechanical ventilation in preference to mouth-to-mouth resuscitation (either direct or through an adjunct such as a pocket mask).

Components

The Ambu Resuscitator bag or BVM, this version shows is a hybrid MkIII body, Mark IV head and with an old obsolete latex inflatable seal on the mask. The part labelled 1 is a flexible mask designed to seal to the patient's face, and the part labelled 3 is a self-filling bag, i.e. re-fills as an action of the elastic re-coil of the bag after compression.

The BVM consists of a flexible air chamber, about the size of a football ball, attached to a face mask via a shutter valve. When the air chamber or "bag" is squeezed, the device forces air through into the patient's lungs; when the bag is released, it self-inflates, drawing in ambient air or a low pressure oxygen flow supplied from a regulated cylinder, while the patient's lungs deflate to the air through the one way valve.

Bag and valve combinations can also be attached to an alternate airway adjunct, such as an endotracheal tube or laryngeal mask airway. Often a small HME filter (Heat & Moisture exchanger, or humidifying / bacterial filter) is used.

A bag valve mask can be used without being attached to an oxygen tank to provide air to the patient, often called "room air" in the U.S. Supplemental oxygen increases the partial pressure of oxygen inhaled, helping to increase perfusion in the patient.

Most devices also have a reservoir which can fill with oxygen while the patient is exhaling (a process which happens passively), in order to increase the amount of oxygen that can be delivered to the patient to nearly 100%.

Bag valve masks come in different sizes to fit infants, children, and adults.

Most types of the device are disposable and therefore single use, while others are designed to be cleaned and reused.

Method of operation

The BVM directs the gas inside it via a one-way valve when compressed by a rescuer; the gas is then delivered through a mask and into the patient's trachea, bronchus and into the lungs. In order to be effective, a bag valve mask must deliver between 500 and 800 milliliters of air to the patient's lungs, but if oxygen is provided through the tubing and if the patient's chest rises with each inhalation (indicating that adequate amounts of air are reaching the lungs), 400 to 600 ml may still be adequate. Squeezing the bag once every 5 seconds for an adult or once every 3 seconds for an infant or child provides an adequate respiratory rate (12 respirations per minute in an adult and 20 per minute in a child or infant).

Professional rescuers are taught to ensure that the mask portion of the BVM is properly sealed around the patient's face (that is, to ensure proper "mask seal"); otherwise, air escapes from the mask and is not pushed into the lungs. In order to maintain this protocol, some protocols use a method of ventilation involving two rescuers: one rescuer to hold the mask to the patient's face with both hands and ensure a mask seal, while the other squeezes the bag. However, as most ambulances have only two members of crew, the other crew member is likely to be doing compressions in the case of CPR, or may be performing other interventions such as defibrillation or cannulation. In this case, or if no other options are available, the BVM can also be operated by a single rescuer who holds the mask to the patient's face with one hand, in the anaesthetists grip, and squeezes the bag with the other.

When using a BVM, as with other methods of positive pressure ventilation, there is a risk of over-inflating the lungs. This can lead to pressure damage to the lungs themselves, and can also cause air to enter the stomach, causing gastric distention which can make it more difficult to inflate the lungs and which can cause the patient to vomit. This can be avoided by care on behalf of the rescuer. Alternatively, some models of BVM (usually Paediatric) are fitted with a valve which prevents over inflation, by venting the pressure when a pre-set pressure is reached. Nevertheless, cricoid pressure should be applied whenever possible until the patient is intubated or until ventilations have ceased.

An endotracheal tube (ETT) can be inserted by a trained practitioner and can substitute for the mask portion of the BVM. This provides a more secure fit and is easier to manage during

emergency transport, since the ET tube is sealed with an inflatable cuff in the trachea, so that any regurgitation is less likely to enter the lungs. Such material can severely damage the lung tissue, and in the absence of an ET tube, could choke the patient by obstructing the airway. Inhalation of stomach contents can be fatal; the after effects can cause Mendelson's syndrome or aspiration pneumonia.

Some rescuers may also choose to use a different form of resuscitation adjunt, such as an oropharyngeal airway or Laryngeal mask airway, which would be inserted and then used with the BVM.

In a hospital, long-term mechanical ventilation is provided by using more complex devices such as an intensive care ventilator, rather than by a BVM, which requires at least one person to operate it constantly.

A flow-restricted, oxygen-powered ventilation device (FROPVD) is similar to a BVM in that oxygen is pushed through a mask into the patient's lungs, but unlike a BVM, in the FROPVD the pressure needed to push air into the patient's lungs is generated by oxygen via a pressure regulator from a cylinder rather than by squeezing a bag.

Ambu bag

One proprietary brand of a self-inflating BVM resuscitator is called the Ambu bag. The concept for the original Ambu bag was developed in 1953 by the German engineer, Dr. Holger Hesse, and his partner, Danish anaesthetist Henning Ruben. In 1956, the world's first non-electric, self-inflating resuscitator was ready for production by their company, Ambu A/S, which still produces a wide range of single-patient and multi-use resuscitators. The Ambu name has become an example of a Genericized trademark, as all manual bag resuscitators in medical settings are now often referred to generically as "Ambu bags," even though Ambu brand resuscitator bags are still produced and other companies are not allowed to use the Ambu trademark.