Escape from a Greater Affliction: The Historical Evolution of Amputation

"Sometimes the extremities become gangrenous…you must cut off that limb as far as the disease has spread, so that the patient may escape death or greater affliction, greater than the loss of the limb."

--Albucasis, c. A.D. 1000[1]

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February 3, 2012

Submission to 2012 Howard A. Graney Competition

for Undergraduate Writing in the History of Surgery

Amputation of an ischemic appendage is one of the oldest and most serious surgical operations. Often portrayed as gruesome, it exists as a necessary procedure for survival, especially during times of war. *Amputatio*, first mentioned in Roman texts, refers to the criminal punishment of cutting off one's hands.[3] Reflecting a more surgical meaning, the Latin noun from the verb *amputare*, meaning to cut off or cut away, was derived from *amb*, about and *putare*, to prune or lop.[2] From the original Latin term *membrum*, a limb, and the Old French term *desmembrer,* evolved the English term "dismember" which described surgical amputation prior to the 17th century. *Amputatio*, or amputation, was not linked to limb excision by surgeons until the 17th century.[3,4]

Performed since ancient times, surgical amputation remains one of the oldest surgical specialties. Although warranted to save lives in ancient times, amputation rarely resulted in the desired outcome. Many patients undergoing an amputation would often succumb to massive hemorrhage and septic shock.[5] To combat the extraordinarily high complication rates, surgeons relied on speed and technique to improve outcomes and minimize pain. War served as a catalyst for surgical innovation in the field of amputation. However, the high mortality of amputation would not decrease until the advent of aseptic technique and general anesthesia in the mid-nineteenth century.[3,4,5]

Cultural views regarding amputation have their roots in traditional beliefs as well as taboos and religious convictions, all of which influenced the evolution of amputation.[3] Anthropological evidence credits the earliest amputations to cave paintings uncovered in present-day Spain, France, and New Mexico nearly 36,000 years ago.[7] These paintings are thought to suggest the practice of self-mutilation to appease gods during religious ceremonies.[7] Likewise, Peruvian votives featuring amputees have been found in South America.[8, 13] In many cultures, amputation served as retribution for a judicial punishment. In Arabic culture, a foot was removed for laziness, both arms for rebellion and a hand for theft.[8,9] Amputation also held a place in characterization of religious deities. Ancient gods such as Tezcatlitoca, the Aztec god of creation and vengeance, was a right foot amputee.[8,13] New Hah, a Celtic Irish god, was portrayed with a four fingered silver prosthesis due to a previous left arm amputation.[7,9] In cultures who embraced amputation, prosthetics filled the functional, cosmetic, and psychosocial void often left behind. Depictions of amputation and prosthetics in ancient times through myths, legends, and artwork demonstrate remarkably similar attributes to those used today.

Amenhotep II's Great Toe[14]

In the advent of traumatic injuries, some societies viewed dismemberment as the last resort to save a

life, whereas others viewed death as a noble alternative to mutilation.[3,4,18] In ancient Egypt, amputation was feared more than death and thought to affect the amputee in the afterlife. One of the earliest examples stems from ancient Egypt in the reign of Amenhotep II in the 15th century B.C. Mummified remains clearly reveal a prosthesis manufactured from leather and wood to replace an amputated right great toe which was necessary to serve him well in the afterlife.[4,9,14] Usmah, a 12th century Arabic writer, documented a rare amputation involving a Lebanese physician and crusading knight. After treating the knight for a leg ulcer with poultice, the physician asked his patient if he preferred to "live with one leg or die with two?" Instinctively, he replied "one leg." After beckoning the axeman, the physician laid the leg on a block of wood. With two blows of the axe, the limb was amputated although, unfortunately, it was reported the knight later died of hemorrhage.[14]

Although medicine has changed significantly since the time of Hippocrates, the causes of limb ischemia, necrosis and trauma have changed little. Classically, limb ischemia stemmed from frostbite, plague, toxins, ergot, benign or malignant tumors, and nutrition or vitamin deficiencies. Today, the most common cause of degenerative arterial disease is due to diabetes mellitus. From ancient times until today, surgical amputation remains a necessary means of life preservation after non-surgical approaches have been exhausted.[9]

The Advent of Amputation

The earliest human remains with signs of amputation, dated circa 4900 B.C., were found in the Neolithic site of Buthiers-Boulancourt near Paris, France. The remains were of older male lacking bones in the left forearm, wrist, and hand. Analysis of the possible site of amputation indicated a clear oblique section through the medial and lateral epicondyle consistent with the flint tools available at the time. Further examination revealed no sign of inflammation, suggesting a surgical, rather than a traumatic etiology. Measurements of cortical thickness indicate that he not only survived the amputation but lived for months or years afterward.[11] The Rig-Veda, an ancient Indian poem composed between 3500 and 1800 B.C., serves as the oldest written account of amputation. According to the Sanskrit narrative, Queen Vishpla was wounded in battle, only to have her leg amputated, fitted with a prosthetic and courageously returned to battle a short time later.[3,5]

In ancient Greece, "surgery" was derived from the Greek word for "hard work." Amputation or "hard work" entailed the manual application of ointments, dressings and bandages to counter suppuration and unpleasant odor. The limb was treated with the hope that gangrenous or necrotic tissue would slough off at the demarcation line with living tissues therefore, allowing spontaneous wound healing.[3,4,12]

Hippocrates of Cos, a Greek physician practicing around 460 to 380 B.C., recommended amputation for the treatment of gangrene. Removal of ischemic tissue was best performed distal to the necrotic demarcation at the point in time where it was fairly dead and had completely lost sensation. To control hemorrhage, he advocated the use of cautery and vascular ligatures. Contemporaries of Hippocrates were also familiar with cautery, as well as the tourniquet, surgical drains, and the need for surgical cleanliness and antisepsis with wine and vinegar.[3,4,5,12]

'…even when a portion of the thigh comes away, or of the arm, both bones and flesh, but less as in this case; and when the forearm and leg drop off, the patients readily recover.' [17]

~Hippocrates, 4th century B.C.

Many other surgeons of the time were torn between an expectorant approach and surgical amputation. The hesitation to perform surgical amputation may have been partly attributed to medical professionalism of the time. Circa 1900 B.C., King Hamurabi of Babylon codified and inscribed the laws of the land onto the pillar of the main temple. Regarding physicians, he justified the loss of a patient equal to sacrifice of the physician's very own hand.[3,4,5]

'If a physician shall make a severe wound with an operating knife and kill a patient or destroy an eye, his hand shall be cut off. [3,4,5]

~Code of Hamurabi

In contrast, amputation was embraced by allies and foes alike during ancient Greek and Roman warfare. According to Herodotus of Halicarnassus, in 484 B.C. a Persian soldier escaped imprisonment by cutting off his own leg. After replacing it with a wooden prosthesis, he was able to travel 30 miles to Tregea where he was captured by Zaccynthius and promptly decapitated.[14] This account was validated in 1858 with the discovery of a copper and wood leg in Capri, Italy dated to 300 BC, consistent with prosthetic design of that time.[14] In 218 B.C., Roman general Marcus Sergius, who led his legion against Carthage in the second Punic War sustained 23 injuries including

amputation of his right hand. He fought four times with only a left hand until a prosthesis was fashioned which allowed him hold a shield. Despite his spryness in battle, he was denied the chance to become a priest as that occupation inevitably required the use of both hands.[3]

The Evolution of Amputation

In the 1st century A.D., Celsus, a Roman encyclopedist, advocated circular surgical amputation through healthy tissue proximal to the area of ischemia. His writings document ligation of vessels, proximal division of bone in order to allow a "flap" of skin to cover the stump, and packing the wound with lint soaked in vinegar. As with Celsus, Roman surgeons of the time had a wide array of forceps, scalpels and saws to operate with. The instruments, dated to 79 A.D., were later found in the volcanic remains of Pompeii. Although many patients continued to die intraoperatively, he surmised that amputation was safe enough considering there were no other remedies to treat ischemic limbs.[2,4,5,12,22]

'It does not matter, however, whether the remedy is safe enough, since it is the only one. Therefore, between the sound and diseased part, the flesh is to be cut through with a scalpel down to the bone…it is better that some of the sound part be cut away than any of the diseased part should be left behind.'

~Celsus[15]

An Arabic contemporary of Celsus, Albucasis, employed amputation in the treatment of congenital malformations such as polydactyly and gangrene secondary to poisonous reptile and spider bites. Instead of only proximal tourniquet placement, he applied tourniquets proximal and distal to the site of transection to tense the soft tissue which was then protected by linen dressings to avoid saw injury.[1,10] He also pioneered the double suture which is still used today for high tension closures.[15] Similarly, renowned ancient surgeon Sushruta Samhita (circa 100-800 A.D.) considered amputation in the treatment of infected thorns and poisonous inoculations embedded in the hands and feet of his patients, often dismembering the limb as high as the wrist and ankles.[3] In extreme trauma situations, such as crushed or mangled limbs, he was known to amputate as well.[15,22]

A paradigm shift began with Archigenes of Apemea, a Roman medical author and practitioner in 1st-2nd century A.D. Due to loss of its natural connection to the body; Archigenes felt that any appendage fraught with sepsis or cancer should be removed surgically. Along with the support of Heliodorus, surgeons began performing more elective amputations for ulcers, tumors, injuries, and deformity instead of operating only to avert imminent septic shock.[5,12] If a patient was deemed strong and had the power to cope, he was placed in a position where the instrument could easily make a circular incision. A tight circumferential bandage was

tied proximal to the amputation site to prevent hemorrhage.[12] In hopes of decreasing post operative pain and potential metastasis, nerves were removed from the periphery of the amputation site followed by complete amputation of the limb.[16] Similar to his Roman predecessors, Archigenes advocated vessel ligation but also the use of cold water to control arterial bleeding through vasoconstriction.[3,4,7] His approach fostered the practice of utilizing vascular embolization to control tumor blood supply. After suturing the incision closed, a cataplasm of leek, bread, salt and other astringent ingredients was applied to the wound followed by 2 to 3 days of post-operative antisepsis against inflammation.[3,16] In instances of massive hemorrhage, the use of cautery was drawn upon, although due to the high instance of post-operative complications Archigenes strongly advised against its use.

A harsh critic of Archigenes, Galen sought to burn the "roots of the tumor" with cautery which proved to be incredibly dangerous.[16] Despite high rates of complication and mortality, it served as the modern day precursor to thermal ablation. In fear of post-operative metastasis, Galen regarded ligation as a key step in amputation as well. Pre-operatively, Galen treated his patients with "purgative medicaments" to thin their blood.[14,16] Despite his prolific writings and deep convictions regarding amputation of cancer stricken limbs, Galen continued to champion the expectorant approach in the treatment of the traumatic amputation.[3,16]

Just as amputation began the transition from an art to medical science, its progress was stifled by the Catholic Church. Between 1130 and 1247, "*Ecclesia abhorret a sanguine,*" a decree by the church prohibiting bleeding served as a discredit to surgery and surgeons. With the support of priests and university trainees lost, surgery was placed in the hands of empirics and barber surgeons. In the hands of barber surgeons, whose title stems from their dexterity and skill with razors, patient care and surgical skill deteriorated and what procedures remained in practice involved minor wound surgery and venesection.[3] Due to the feudal system of the Dark Ages, Europe was effectively divided into isolated kingdoms which further impeded innovation and dissemination of surgical knowledge.[3,9]

Gunpowder and Lead

In the 14th century, the scientific and literary stagnancy of the Dark Ages had passed. Surgical innovation slowly progressed although many technical advances from Hippocratic, Roman, and Greek times were either forgotten or abandoned. This regression produced devastating casualties with the advent of firearms and the use of gunpowder near Crecy, France in 1346 which would quickly spread throughout Europe.[3,5,7,16] It would be over 100 years later until amputation was routinely employed to treat battlefield wounds involving gunpowder.[3,4,12]

In the 15th century, surgeons became more specialized and left difficult and physically exerting operations, such as amputation to the "rough, uncouth and uneducated" barber surgeons who had served as the sole surgeons during the Dark Ages. As a result, innovation involving instrumentation and technique ran rampant.[4,12] Despite innovations in amputation technique, the incredibly high rates of complications involving amputation haunted the conscience of many surgeons of the time.[17]

'...it is more honest for the physician that it falls spontaneously than to amputate it. For if one amputates there is always some rancor or regret, and thoughts by the patient that the limb might have survived."

~Guy de Chauliac [19]

With the 16th century, came a slow, yet hard fought battle to overcome barbaric practices which had exponentially increased complications from amputations for centuries. In 1517, Hans von Gersdorff published *Feldtbuch der Wundt-Artzney* or the Field-Book of Wound Surgery. Gersdorff advocated, similar to Albucasis a mere 1500 years earlier, placing tourniquets proximal and distal to the amputation site a few finger breadths apart. To control bleeding, a styptic containing egg white was advised. If that did not work, cauterizing could be employed or warm, not boiling, oil. Gersdorff dressed the stumps with a cow or pig bladder to aid in wound healing.[5,12,18]

Inspired by the work of Gersdorff, Ambrose Paré sought to challenge barbaric surgical practices of the time. Before attending medical school, Paré spent many years as a barber surgeon apprentice and then a surgeon in the French military.[4,5] On the battlefield, he performed countless amputations including those above and below the knee, above the wrist, and the first description of an elbow disarticulation. Yet, different from his predecessors, his pride could be found in his meticulous analysis of patient outcomes regarding different approaches and sites.[4,12]

Paré challenged the practice of hot iron cautery and boiling oil in his renowned work *La Méthode de Traicter les Playes Faictes par Hacquebutes et aultres bastons á feu* or Method of Treating Wounds.[3,4,18] Although he cited the usefulness of hot iron cautery on necrotic tissue, he was adamant it had no place in the treatment of hemorrhage from living tissue. On living tissue, it proved to be incredibly painful and often resulted in the development of an eschar which would slough off and inevitably introduce secondary hemorrhage and an incurable ulcer.[18] Instead, he championed a return of vessel ligation to control hemorrhage.[4,5,12] Paré also supported use of tourniquet placement proximal to the amputation site, his reasoning being three-fold: proper vessel ligation, induction of distal numbness, and the ability to pull the skin and soft tissue proximal to facilitate bone transaction and ensure proper

stump coverage.[4] To ensure efficiency, Paré fashioned a spring loaded artery forceps or "crow's beak" forceps to occlude vessels while applying the ligature, known today as the hemostat. When ligating larger arteries, he recommended the use a needle and thread to puncture the skin, passing around the vessel and back through the skin again to be tightened over a linen pad to prevent skin necrosis. This approach ensured a secure ligation while facilitating easy removal in the event of post-operative infection.[3,4]

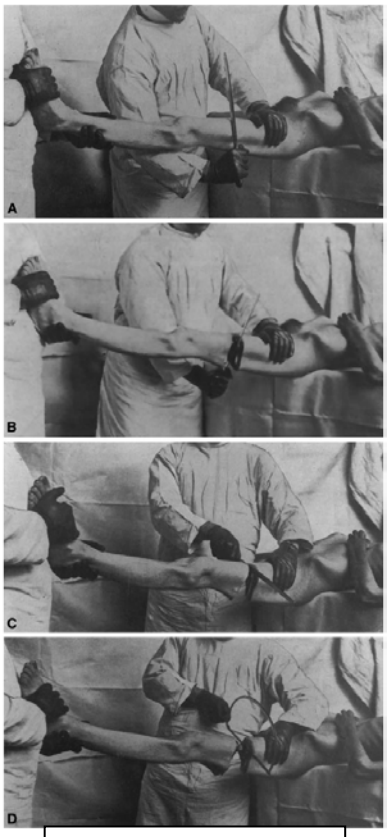
In selecting the appropriate surgical approach for each of his patients, his first and foremost goal was survival, closely followed by the ability to fashion a stump suitable for use with a prosthetic device, even if it meant removing more tissue than necessary. Holding deep convictions for the necessity of his patients to have the ability to function post-operatively he designed many prosthetics himself for both upper and lower limbs.[3,4,12] One of Pare's most famous 'Le Petit Lorrain,' was a mechanical hand operated by catches and springs that was worn into battle by a French army captain. His above knee prosthetics consisted of a kneeling peg and prosthetic foot which featured a fixed equines position, locking knee and suspension harness which are still used today.[2,3,5,14,18] Paré was the first to characterize and sought, although unsuccessfully, to prevent the phenomenon of "phantom pain."[3,4,5,12] Through his diligent efforts, Paré not only revolutionized amputation practices of his time but also set a solid foundation for the field of vascular surgery.

Utilization of Petit's Tourniquet[3]

Shortly after the re-introduction of the ligature by Paré, William Harvey's discovery of the circulatory system in 1616 set the stage for further development and use of the tourniquet. Although many were fashioned, Jean Louis Petit's tourniquet in 1718 stood the test of time.[18] Designed as a screw tourniquet, it enabled the surgeon to control pressure by minor adjustments of the screw. Proving much more effective than relying on the fingers of an assistant to provide ligation, Petit's screw tourniquet also allowed surgeons to view any bleeding vessels that may remain without re-applying the tourniquet.[2,3,4,18] Now that surgeons could adequately control hemorrhage, the blood loss resulting from amputation decreased drastically.

In the 16th and 17th centuries surgeons favored the "one stage circular cut," an approach entertained by Celsus centuries earlier. After positioning the patient and applying a tourniquet, the surgeon approached the compromised appendage from the lateral side. The knife was then directed around the medial side facing the lateral side of the thigh with the knife handle at the top

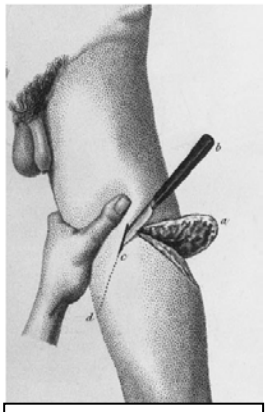
and knife point at the bottom. Positioned with the knife between his thumb and forefinger of the left hand, the cut is began at the lateral side of the thigh and then extended to the medial side, throughout which the position of the arm changes. To complete the soft tissue amputation, the knife must be "thrown" to cut the dorsal side. Holding the knife point firmly, the right hand rotates about the knife handle with the thumb turning the back of the amputating knife and the forefinger turning the knife edge. Often, the operation began with the surgeon on their knees and completed standing up. A curved knife was most efficient in transecting the skin, muscles and bone of the thigh so it detached at the same level. Although this approach allowed easy identification of vessels and nerves, constructing a stump proved to be a challenge and the healing process often fraught with high rates of post-operative complications.[2,3,4,5,18]



"One Stage Circular Cut"[2]

In 1718, Petit attempted to remedy the high complication rate by employing the "two stage circular cut." First, he transected the skin and subcutaneous tissue two fingerbreadths distal to the planned level of amputation. Pulling the skin and subcutaneous tissue cranial, he cut the muscles more proximal. Subsequently, he sawed the bone at the same level as the muscles. Popular with the contemporaries of his time, the "two stage circular cut" was championed by German physician and surgeon Lorenz Heister (1683-1758), the Royal Austrian army doctor Johann Junczovsky and Prussian general surgeon of the army Johann Nepomuk Rust (1775-1840) within their respective surgical textbooks.[3]

To avoid the need for high tension closures and subsequent complications, James Yonge revealed the "flap" approach to amputation in 1679 as noted in *A new Way of Amputation, and a speedier convenient Method of curing Stumps, than that commonly practiced*.[2,3] Instead of performing a circular cut, Yonge constructed a long flap of skin and fascia to cover bone ends, divided the musculature in a circular fashion, which accommodated a drain and allowed closure with four or five sutures without tension. By using turpentine as a wound dressing, the method was claimed to heal stumps within three weeks.[3,12] According to Yonge, the method devised came from "a very ingenious brother of ours," Mr. C. Lowdham of Exeter, who left no personal record of the operation.[2]



Alanson's approach to remedy the "sugar-loaf" deformity[5]

Although the newer approaches provided a means for covering the stump, many patients continued to suffer from unhealed stumps with protruding femoral shafts, referred to as the "sugar-loaf" deformity. In 1779, Edward Alanson of Liverpool invented the "triple incision" approach in attempt to remedy the sugar-loaf deformity. Alanson incised the skin as usual, allowing it to retract and subsequently advanced the incision obliquely proximal dividing the subcutaneous tissue and muscles. To complete, the bone was transected and soft tissue brought distal to surround and protect the femoral shaft at its apex.[3,5,12]

Military Medicine: Forever Changed

Often political turmoil and scientific advances follow a similar vein. Dominique Jean Larrey's service to Napoleon and France proved no different. Initially a naval doctor, recurrent bouts of seasickness convinced Larrey to pursue different medical endeavors. While broadening his anatomical and surgical skills, Larrey became deeply disturbed by the political situation and the fate of his fellow people of France.

This fervor compelled Larrey to publicly express his political concerns on July 14, 1789 when he led 1500 medical students to the storming of the Bastille. Three years later, France found itself in war. Larrey was assigned as a divisional *Chirurgien-en-Chef* or Surgeon-Major in the Army of the Rhine, this appointment would forever change Larrey's career and the history of military medicine.

On the frontlines, Larrey witnessed with shock the low value attributed to soldiers by high ranking officers of the army. Not only were they treated as dispensable entities, but the wounded lost their humanity and were largely ignored. Viewed not as suffering individuals but problematic units which slowed progression of the army, measures for the salvage of injured soldiers were non-existent. Driven by the virtues of compassion and morality, the unjustified death of even one soldier who could be saved was unacceptable in Larrey's eyes.

When a soldier was injured during combat, military practice of the time was to leave the soldier on the battlefield until the end of the engagement. Battles often raged on for hours, and the lucky injured soldier would be collected by his comrades and taken to a distant medical facility. If the army with which he served was defeated, he inevitably was abandoned and, in most cases, slaughtered by enemy troops without mercy.

'This misfortune induced me to propose…the plan of an ambulance, calculated to follow the advanced guard in the same manner as the flying artillery. My proposition was accepted, and I was authorized to construct a carriage, which I called the "Flying Ambulance."' [28]

~Baron Larrey

Not only did Larrey advocate timely medical care but the medical officers carried portable surgical instruments, field dressings, and some medications on their saddles as well as in the carriages. The concept of *triage*, unknown in warfare prior to the 19th century stemmed from Larrey's fortitude towards the common soldier.[3,28]Encompassing virtues of a true military surgeon, Larrey obeyed the rules of both medicine and humanity. He often collected enemy soldiers who had been injured by French cannons and weapons then medically treated them to the same caliber as his own countrymen. During his 18 year service to Napoleon, Larrey forged ahead in 25 campaigns, 60 battles and more than 400 engagements.[28] Through this, Larrey honed his skills of wound management and amputation. With his antidote for pain being alcohol, his technique had to be extremely quick and accurate. In a catastrophic retreat from the Russians after the battle of Borodino, it is said that Larrey performed 200 amputations within 24 hours without resting for a moment. In lieu of transporting injured soldiers directly to the hospital which delayed surgery and increased the risk of septic shock, Larrey advocated for early amputation and care to reduce suffering, morbidity and mortality.

Not only was the essence of time a factor, Larrey performed complete debridement to provide a good stump. This practice served to avoid infection which plagued many amputates post-operatively as well as ensured satisfactory mobility of the limb. To dull the excruciating pain of amputation, Larrey attempted refrigeration of the compromised limb. Larrey pioneered amputation at the hip joint, an operation which very few of his contemporaries or predecessors would employ due to its incredibly high mortality rate, as well as delayed primary closure. Larrey's astute and virtuous character fostered a gamut of unprecedented contributions to the surgical and medical world. As a "mere surgeon," Larrey was denied his wish to rest among marshals, generals, and soldiers; but his burial at the Pére Lachaise cemetery attracted thousands of mourners.[28]

Advent of Anesthetics and Aseptic Technique

In 1846, sulphuric ether was first used by Morton and Warren at the Massachusetts General Hospital.[27] The used of anesthetics spread rapidly and fully embraced by the surgical field. Operations that were once hastened to lessen the amount of pain inflicted on the patient were of the past. Anesthetics not only allowed time for thought and technical improvement during surgery as well as the incorporation of basic aseptic technique.[4,5,27]

Until the late 1800s, the extensive "putrification and suppuration" of war wounds compelled surgeons to perform high rates of amputation. Although the post operative period often proved to be fatal, the pathophysiological theory of the time warranted its practice. According to the "spontaneous generation theory," wound infection was attributed to toxins released by dying tissues.[22] A surgeon himself, Lister became extremely concerned about the high mortality rate associated with amputation. Through caring for his patients, he realized that mortality was much higher post-operatively in those who were treated in hospitals compared to those treated at home.[20] Lister hypothesized that the septicemia and putrification process he witnessed on a daily basis closely resembled the fermentation process described by Louis Pasteur in the 1860's. Convinced that invisible living particles were responsible for the putrification of wounds, he began surgically debriding his amputees' limbs and cleansing them with carbolic acid. Although his first attempts failed, he was eventually able to drop his mortality rate from 45% to 15%.[21] Despite his evidence based approach, the surgical world was slow to adopt Lister's aseptic technique.

'The nurse fetched a drain from a neighboring ward. Deprés took the drain immersed in carbolic acid, put it on the floor, rolled it under his foot and then placed it in the wound.' [3]

~Terrillon, 1892

A Nation at War

As Lister was waging a battle against putrification, the United States was facing a battle of its own—The Civil War. The incredibly high incidence of amputations during the Civil War compared to any other war before, or since, is intricately related to the firearms of the time. Muskets were rifled instead of smoothbored as in Napoleonic times. Rifled muskets fired lead bullets with relative power and accuracy up to a half mile away. Although lead bullets traveled slow, once they hit flesh the bullet would flatten out and carry bits of clothing and skin into the wound which served as a prime breeding ground for infection. To combat septic shock, amputation was employed and served as the most common major operation during the Civil War.[18] Unfortunately, the Civil

War occurred before Lister's aseptic technique was accepted and much less incorporated into standard surgical technique. Accounts by William Keen, a Union Army surgeon, suggested that it was seven times safer to fight through all three days of Gettysburg rather than undergo an amputation.[22]

'As long as he is deadly pale, the pulse small and thread, the surface cold, and the thirst, restlessness, and jactitation excessive, it is obvious that recourse to the knife must be wholly out of question.'[23]

~Gross, 1861

Although many Civil War surgeons were labeled as "butchers," the wounded soldiers hemodynamic stability and wherewithal was taken into account. Samuel D. Gross, a Civil War surgeon, advised against amputation in cases of septic shock.[23] According to fellow surgeon, Dunlap Pearce Penhallow, the chief signs and symptoms of septic shock and collapse where hemorrhage, pain, nature of wounds, exposure or exhaustion, transportation, and sepsis.[24] As the battle raged on around them, wounded soldiers would have to persevere in hopes of making it to the field hospital in a relatively stable condition. A half hour prior to amputation, ¼ grain of morphia and 1/100 grain of atropine was given subcutaneously[23]. The roots of main nerves were often numbed with a weak solution of cocaine or novocaine. During the operation, the soldier was kept warm by blankets while under anesthesia. Although operations were to be performed quickly, a saline adrenaline injection and oxygen was administered if signs of cardiovascular collapse occurred. Following the amputation, patients were placed in a warm bed and closely monitored. At the sign of septic shock, the foot of the bed was elevated about 8 inches and warm rectal saline was administered at the rate of 10 drops per minute.[24]

Roughly a decade later, Theodore Billroth was one of the few to heed Lister's recommendations while serving as a military surgeon during the Franco-Prussian War. While performing amputations he not only utilized aseptic technique to treat erysipelas but worked meticulously for proper hemostasis and soft tissue approximation. Instead of suturing amputation stumps closed, he championed open drainage and healing by secondary intention. Using this approach, it is reported that Billroth followed almost 100 patients and noted only one case of gangrene.[22,25]

The World at War

Although time had marched on, soldiers of the 20th century faced many of the same obstacles that plagued those before them. Similar to accounts of Larrey's winter campaign in East Prussia centuries earlier, in World War I, soldiers exposed to the elements suffered from a myriad of ailments which nearly crippled entire armies.[3,28] The art of static warfare placed soldiers' nearly

immobile in muddy, flooded trenches for days on end without change of wet socks or boots. Distal ischemia secondary to vasospasm and lymphedema forced their skin to break down and served as a welcoming path for infection. Significant numbers were disabled by gangrene and many spent the winter of 1914-1915 recovering from amputation.[3] Before the next winter, preventive measures prevailed and only a few men were forced to sacrifice their limbs. By wearing larger boots, regular powdering and drying of the feet, and duty limited to 36 hour shifts the incidence of trench foot was greatly reduced.[3]

Although the rate of amputation in World War I was much less the Civil War, gunpowder and lead remained a force to be reckoned with. In the Civil War, 90% of firearm wounds were caused by bullets and the rest by shells. At the turn of the 20th century, particularly in World War I, this ratio was reversed.[27] The highly explosive shell, which, when it penetrates skin disintegrated into a spray of shrapnel that took the destruction of appendages to a new level. In response to the mass casualties, General Norman Kirk carefully reviewed the surgical approaches behind amputation of the time. Many old techniques were discarded, new innovations developed, and the surgical approach of amputation as a whole was simplified for the sake of increasing functionality and decreasing complication rates.[27] Through General Kirk's efforts, incredible strides were made in the field of amputation.

Prior to the World War II, many post-operative complications once fought by surgeons were conquered. In 1928, Alexander Fleming discovered Penicillin which was manufactured in massive quantities by the 1940s. In 1938, the antibiotic drug class, sulfonamides, became available.[4,18] With hemorrhage, pain, and infection under control, new weapons and firearms designed to inflict increasingly brutal wounds would further challenge the practice of amputation.

Based on his experience salvaging limbs in World War I, in 1943, General Kirk established five amputee centers at army hospitals in preparation for treating wounded soldiers.[27] Within the amputee centers were physicians, therapists, nurses, and prosthetists responsible for performing revision surgery, prosthetic fitting, and physical therapy. With World War II in full swing, two more army hospitals were added within a year to handle the overflow of wounded veterans.[26,27]

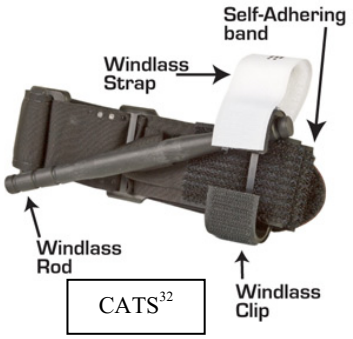
Despite the strides made in the approaches to amputation, more often than not, stumps continued to be plagued with ischemia and other complications. In 1952, Dr. Felix Mondry sought to improve amputation by employing a myoplastic approach. During the amputation, muscle groups were transected accordingly to their natural tension and stitched together carefully to

equalize tension and ensure an adequate blood supply.[4] As a result, amputation transitioned from the most gruesome, traumatic surgery imaginable to a life saving operation focused on regaining patient independence.[6,27]

During the Korean War, medicine embraced the necessity of resuscitation and witnessed a subsequent drop in the mortality rate of severely injured soldiers. Pioneered by Alexis Carrel in the early 1900s, blood vessel repair became a common practice in during the Korean War.[4,30] Microscopic studies revealed that injury of the intimal layer of arteries were often more severe than the adventitial layer.[29] As a result, during amputations visibly damaged arteries were ligated more proximal than originally had been done to decrease potential post-operative vascular complications. When vessels were repaired properly, amputation rates were slashed from 50% in World War II to 10% during the Korean War.[30]

A Revival: Iraq and Afghanistan

Although history has taught us much about amputation, it remains an ever evolving field in modern day warfare. Military casualties in Iraq and Afghanistan have greatly influenced clinical implications of amputation as we know it today. To prevent massive hemorrhage, the Combat Application Tourniquet System or CATS, fashioned similar to Petit's tourniquet centuries ago, is used on the battlefield. CATS enables a wounded soldier to apply and tighten the windlass rod with one hand to his own compromised limb. Applied correctly, CATS tourniquets save many lives.[31,32] Heroic measures undertaken by surgeons to conserve the limb often result in more harm than good to the patient, even potentially risking death. Complete transection of any major blood vessels, nerves, or extensive soft tissue loss is an absolute contraindication to limb salvage.[30]



CATS[32]

Even today, the challenges overcome by the surgeons who have performed amputations throughout the ages are unparalleled. Despite the imminent risk of hemorrhage and septic shock they pushed on, whether it be proved to be fruitful or in vain. From Hippocratic times until today, the surgical approach to amputation has changed little. An exponential decrease in mortality for an operation once fraught with complications was due to the development of the tourniquet, proper vessel ligation and repair, and anesthesia. As the history of surgery progressed, the evolution of amputation has allowed many to escape from a greater affliction.

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