The Historical Evolution of Burn Surgery

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December 6th, 2010

Submitted for the 2010 Howard A. Graney Competition for

Undergraduate Writing in the History of Surgery

***Graphic Source:** Google Images, citation number 25.

Introduction

A blue sky, disguised by clouds of smoke riddled with arrows of fire paints the backdrop as the French forces attempt to withhold the Romans near the city of Genoa[5]. The violence and bloodshed offers new lessons and unanticipated challenges for the physicians and surgeons who scour the battlefield. With the advent of gunpowder and artillery, medieval warfare has transformed into a hellish scene with sounds of pounding cannons and screaming soldiers scorched to death from the blaze; bled to death from the bullet. What is a young barber-surgeon to do, but apply the standard of care of his day--that of scalding-hot oil!

> *"From the same wretched shop and magazine of cruelty, come all sorts of mines, countermines, pots of fire, trains, fiery arrows, lances, crossbows, barrels, balls of fire, burning faggots, and all such fiery engines and inventions. Closely stuffed with fuel and matter for fire, and cast by the defenders upon the bodies and tents of their assailants, they easily catch fire by the violence of their motion. They are certainly the most miserable and pernicious kind of invention, by which we often see a thousand unsuspecting men blown up with a mine by the force of gunpowder. At other times, in the very heat of the conflict you may see the stoutest soldiers seized upon by fiery engines, to burn in their harnesses, no waters being sufficiently powerful to restrain and quench the raging and wasting violence of such fire cruelly spreading over the body and bowels.*
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> *This oyle hath a wonderful force to assuage pain to bring the wound to suppuration and cause the falling away of the eschar…put of this a sufficient quality into the wound; for this being applied indifferent hot…which is the true manner of curing these kinds of wounds according to Hippocrates."*
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> *~Ambroise Pare, Father of Modern Surgery*[1,2,3]

Since the discovery of the first flame, the exothermic combustion reactions of oxygen and carbon have exposed human flesh to significant destruction and disfigurement in the form of burns. Writings about the treatment of burns predate Galen and Hippocrates, with the *Ebers Papyrus* (1534 B.C.E.). It described a five-day treatment regimen that included incantations, emersion in mud, and concoctions consisting of cow dung, bees wax, ram's horn and barley porridge with a resin-soaked dressing of the tree shrub acacia with red ochre, and copper.[3] One thousand years later, Hippocrates advised the application of melted skin of swine mixed with a resin of bitumen (asphalt).[4] The approach to burns with various salves and seemingly putrid concoctions varied by region, and different treatments (albeit similar in concept) emerged from Greek, Egyptian, and Chinese physicians of the time. By the mid-16th Century during the peak of the Roman Empire, prominent healers of the day had expanded upon the Hippocratic repertoire for burns. Paracelsus, who studied botany among other disciplines, advocated for the use of a salve of fat from wild hogs and bears soaked in red wine, with roasted earthworms, and moss that grew on the skull of a dead man[4]. Soon this logic shifted. Gun powder was the one pivotal development that not only changed the face of warfare, but that of war wounds. As the Roman Empire declined during the Italian Wars, most Renaissance physicians turned to applying boiling-hot oil for the acute management of burns and wounds from gunpowder and other "fiery engines" of destruction[1].

Anatomy of a Burn

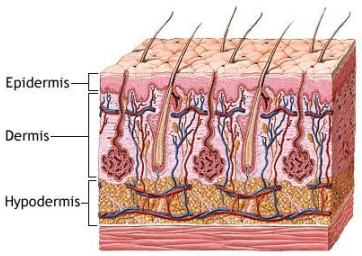
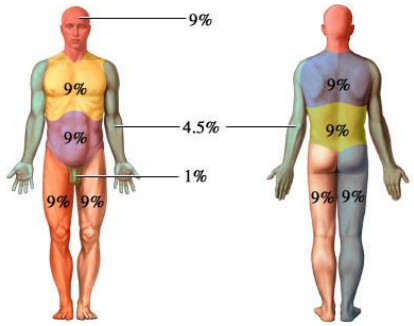


Diagram of Human Skin[24]

Human integument, or skin, is considered the largest organ in the body. It consists of a superficial (epidermis) and deep (dermis) layer. Human skin has many functions vital to life, but by far its most important role is to serve as a protective barrier effectively shielding us from the elements and from microbes that would otherwise compromise our survival. It also serves to regulate body temperature and synthesize Vitamin D, which is required for many physiological processes. Burns vary in severity according to the depth of tissues affected and type of burn (e.g., fire, chemical, electrical). The deeper the burn (and greater surface area covered), the more extensive the damage to internal organs and tissues. Burns elicit compensatory inflammatory responses within the body, which can further compromise tissues and organ function. The most widely used categorical system for burns was developed by a German physician, Wilhelm Fabry, in 1607.[3] This system, still widely used today, consists of three degrees of severity with the first degree considered a superficial burn with only minimal destruction to the epidermis (e.g., sun burn). Second degree burns involve the epidermis and part or all of the dermis layers, whereas third-degree burns penetrate deep into the dermis and can reach connective tissue, muscle or bone. Second and third degree burns are more deleterious since they result in the destruction of capillary beds and nerves that lie in the dermis and deeper tissues.

Burn severity is also determined by a rough percentage of total body surface area (TBSA) exposed. Methods for estimating TBSA have been developed recently, with the Rule of Nines being the most popular method applied in an acute setting. For an adult, TBSA percentages break down as follows: head and arms, 9%; anterior and posterior torso and each leg, 18%; palm of each hand and perineum, 1%.[6,7,8] Finally, burns can be described by three zones: the zone of coagulation (tissue necrosis), zone of stasis and edema (decreased blood-flow and capillary leakage), and the zone of hyperemia (where blood-flow increases).[6,78] Thus, one always must be aware that a superficial-looking burn might be more severe depending on this zone criteria. Heat is transferred differently through tissues depending on the source of the burn (i.e., flame, electrical, chemical); this can alter the body's response to a burn.



Rule of Nines for estimating TBSA[24]

Acute complications of burns include hypovolemic shock (a.k.a., "burn shock") due to fluid loss, mostly plasma; compartment syndrome due to excessive fluid escape and edema compressing the vasculature; multi-organ failure due to under perfusion and inflammatory mediators; and smoke-inhalation injury leading to

respiratory collapse.[6,7] Chronic complications include recurrent infections (most common culprits: *Staphylococcus, Streptococcus,* Gram negative bacteria, anaerobes, and antibiotic resistant bacteria); decreased mobility due to skin contractures and stiffening joints; hypertrophy of scar tissue and disfigurement; decreased bone and muscle mass due to catabolism (increased energy demand and concurrent catecholamine release).[6,7] These complications are the same today as they were thousands of years ago; what has changed is our approach to burn care and advances in surgical management.

The physical destruction of tissues brought on by burn exposure, followed in turn with the onslaught of inflammatory mediators as the body responds to the trauma has been aptly described as a "riot in the body".[3] The body's reaction to a burn is often as violent as the offending agent. Dr. George T. Pack, a prominent 1930s pathologist who authored a seminal medical handbook on burns, eloquently commented that "of all the accidental injuries to which the human body is exposed, burns are responsible for pain of the most agonizing character and suffering of a most protracted course."[4] The consequent psychosocial issues, post-traumatic stress, and emotional concerns about body-image are complex and significant for the patient.[8] Historically (as is current practice), a surgeon was the primary caregiver responsible for coordinating the treatment plan of burn patients. Extraordinary care must be taken to stabilize each burn patient, monitor and dress their wounds, replace fluids, and prevent infection or burn shock from developing. Additionally, surgeons have had the unique opportunity throughout history to care for patients injured and burned during wartime. Indeed, many of the developments in burn surgery can be attributed to lessons learned from the battlefield and improvements made by those practicing surgeons.

Historical Evolution of Burn Surgery: Of Wars and Barber-Surgeons

Medieval Burn Surgery

The medieval era provides one with a convenient starting point for the study of burn surgery, its history and its impact on modern-day practices. During the Italian Wars and Wars of Religion of the 16th century, a humble, relatively unknown French barber-surgeon by the name of Ambroise Pare rose to the forefront of surgical care for his innovative approach to wound care for war victims, particularly those injured by artillery or from related burns. Pare was born in 1510 in the town of Laval near Normandy, France. Son of a cabinet-maker, he lacked the family lineage of educated physicians and the financial

Portrait of Ambroise Pare, the Gentle Surgeon[24]

means to attend prestigious colleges.[1] Barber-surgeons at the time were regarded as the least skilled and knowledgeable of the health professionals. They mainly assisted the medical elite, who passed the time pondering medical questions dressed in their long robes, and writing their treatises in Greek or Latin. Pare did not know these languages. He could not afford tuition or the fees necessary for licensure as a barber-surgeon, but joined the ranks of the French military regardless.[1] His surgical skill and ability to write descriptively in conversational French earned him recognition among his colleagues.

> *"One of the Marshalls' [of Montejan] kitchen boys fell by chance into a caldron of oyle being almost boiling hot; I being called to dresse him were…to use refridgerating medicines commonly used in this café: there was present by chance a certain old country woman, who hearing that I desired medicines for a burn persuaded me at the first dressing, that I should lay raw onions with a little salt; for so I should hinder the breaking out of blisters or pustules, as she had found by certain and frequent experience. Wherefore I thought good to try the force of her Medicine upon this greasy scullion. I the next day found those places of his body whereto the onions lay, to be free from blisters, but the other parts which they had not touched to be all blistered"*
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> *~Ambroise Pare, Father of Modern Surgery (On burns)*[2]

Although initially a follower of traditional medical standards and surgical practices, Pare chose to deviate from Hippocratic and contemporary methods for burn treatment. Wounds from gun powder were thought to be poisoned or impure, and boiling-hot oil was applied as a means of cleansing prior to healing or removal of the eschar (Greek: *scab*). Recognizing the agony of patients who received the oil for their burns, Pare decided to experiment with gentler modes of treatment. No one knows for certain what or who inspired him to pursue other treatment modalities. However, he began to notice impressive results with the patients who received less invasive emollient salves with compressive dressings for their burn wounds.[1] Their pain was better managed, and each appeared to be recovering faster than those receiving the standard hot oil regimen. Derided by his elitist medical contemporaries, Pare ignored the ridicule and continued his observations with astute, detailed writings. He soon entertained increasing numbers of followers who, along with other notable progressives such as Andreas Vesalius (father of anatomy), would go onto make significant contributions to medicine and surgery. Earning a reputation as the gentle surgeon, his teachings and volumes of texts inspired others to pursue the discipline, which enhanced the status and respect afforded to surgeons. The works of Ambroise Pare, who is often cited as the father of modern surgery, has thus forever altered the discipline of surgery and approach to wounds and burns.[1,3]

Surgery in an Age of Science

With advances in the study of anatomy resulting from the works of Andreas Vesalius and Giovanni Morgagni, surgical techniques improved leading to better outcomes.[1] The scientific revolution was fully underway by the 18th century. It was not enough to study the human form and employ surgical procedures; the time had come for experimentation, careful comparison of interventions, and reporting the findings of research to be adopted by the medical community. John Hunter, a Scottish-

born surgeon advanced the science and objectivity behind the practice of surgery. Dr. Hunter purchased land in the countryside where he performed experiments on a diverse range of animals.[1] His "research farm" as it became known, lead to significant discoveries from comparative anatomy and physiology.

The trend caught on, and by the dawn of the 19th century, a Harvard physician by the name of Jacob Bigelow was fast at work conducting experiments on rabbits to compare burn treatments. Dr. Bigelow taught botany and *Materia Medica* (modern-day pharmacology) while at Harvard, and grew interested in burn care. The treatment of burns continued to vary depending on the perspective of the doctor who was charged with caring for a burn victim. This concerned Dr. Bigelow, who later commented that "many practitioners, instead of resorting to general remedies of inflammation, have placed their reliance on the supposed powers of a specific remedy".[9] He conducted a study on rabbits that compared two popular treatments for burns, adding a stimulant such as turpentine versus immersing the burn in a vat of ice water. It is arguably one of the first attempts at conducting a controlled study comparing the effectiveness of burn treatments. The results were published in the first issue of the *New England Journal of Medicine* in 1812. Ahead of its time, the research of Dr. Bigelow was an early indication of evidence-based medicine in the context of burn care.

Across the Atlantic, one could find many more rich examples of advances in the science of surgery. The Napoleonic Wars were well underway. New methods of warfare again challenged military surgeons. In his *Memoirs of Military Surgery and Campaigns of the French Army*, Napoleon's chief surgeon wrote extensively on the treatment of burns. His name was Dominique-Jean Larrey. Of all of Dr. Larrey's contributions to combat surgery, the most recognized is certainly his invention of the ambulance.[10,25] The concept of an ambulance had been around for centuries, but Dr. Larrey was the first to officially study how it could work. Recognizing that casualty transport from the frontlines through thousands of soldiers was markedly inadequate, he developed a system known as the "flying ambulance." It consisted of a division of 113 men with 12 light and 4 heavy transport carriages that could be deployed on command to bring severely wounded soldiers back to a central medical post.[10,25] This change afforded surgeons an opportunity to save more lives and to treat severe burn wounds that otherwise would have gone uninspected and perhaps become infected on the battlefield. Like Jacob Bigelow, Larrey recognized the paucity of effective treatments for burns. He commented in his memoirs on burns that current concepts were poorly understood. He favored a wax-based paste known as cerate to cover the burn until

> *"Of the injurious effects of cold ammoniated water, vinegar and water, vegeto-mineral water, and of a solution of opium in ice-water, mentioned in some modern works and used by many practitioners for severe burns, I have long been convinced, and I am persuaded, that this description of wounds would not be so frequently attended with fatal consequences, were the treatment of them better understood."*
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> *~D.J. Larrey, Napoleon's Surgeon (On burns)*

suppuration (establishment of pus), but also indicated that honey could be substituted.[10]

At the same time that Dr. Larrey was advising Napoleon's generals on better combat medicine strategies, a young boy from a poor family began to befriend soldiers within the French cavalry. During his youth, the boy witnessed hundreds of wounded soldiers and was fascinated by their injuries and the skill of the surgeons who attended to them. Encouraged by his mentors he soon left to study medicine and surgery in Paris, rising to the status of Chief Surgeon of the most prestigious hospital in France at the time, the Hotel Dieu.[11] His name was Guillaume Dupuytren, a man who would later become known as the father of modern plastic surgery.[11, 12] Dupuytren is most frequently associated with the textbook physical finding known as a "Dupuytren contracture." However, his contributions extend far beyond his observations in orthopedics.

Portrait of Guillaume Dupuytren, Father of Plastic Surgery[24]

He was the first person to recognize the skin tension lines, leading to the use of the word "contracture." With regards to burns, contractures describe the process of wound healing around joints that results in increased rigidity and reduced mobility.[11, 8] And he expanded on the previous classification scheme for burns, dividing them into six degrees of severity according to: erythema of skin; vesication; destruction of the cuticle; destruction of the entire integument; encroachment on muscles; and disorganization and charring of the tissue.[4,11] While this scheme was not adopted as commonly as Fabry's burn classification, it still assisted surgeons by providing an expanded frame of reference for burns. It prompted a renewed interest in burn treatments and the study of burn physiology. Dupuytren later went on to develop his own surgical burn treatments, which included a critical new procedure known as wound debridement.[11] Debridement is defined as "the removal of foreign material and dead or damaged tissue, especially in a wound."[13] He would also use silver nitrate, emollients, and cerate similar to D.J. Larrey's burn treatment followed by application of a breathable compressive dressing.[11] The genius of this shift in treatment of burns lies in the use of debridement, silver nitrate, and compressive dressings, all of which reduce the chance of infection, promote healing, and improve rehabilitation.[3,7,8] Variations of these treatments remain in use today, nearly 200 years after Dupuytren's time.

By the end of the 19th century, medical and surgical approaches to burn care began to make their way into textbooks and reference books. There was yet to be a standard approach to burns, and in fact this standardization has only come about within the last 20 years. However, physicians of the time within various disciplines strived for consistency despite the lack of innovation in burn management since the days of Dupuytren. The U.S. Civil War, like countless wars throughout history,

provided other opportunities for surgeons to approach the burn patient. Infection at the wound site continued to be the most common cause of death for those who survived beyond the acute period. It was during the Civil War that surgeons increasingly recognized the utility of amputation to prevent the complications of infection from traumatic wounds of the limbs, including severe burns. The popularity of amputation and other more invasive surgeries gained traction following advances in general anesthesia, pioneered by Sir Humphry Davy who wrote extensively on the use of nitrous oxide and related anesthetics.[1] These procedures, while life-saving, meant life-long disability for the patient.

Albeit unbeknownst to the attending physicians of the time, it seems logical that burn survivors of late 1800s avoided complications of infections as a direct result of the toxic or acidic combinations of ointments used in their wound dressings. As the treatment of burns extended in scope of practice to include physicians in the growing specialty of dermatology, approaches to burn care continued to diversify. George Thomas, a prominent dermatologist who taught medicine at the College of Physicians and Surgeons in New York, published one of the first reference handbooks on dermatology to discuss the treatment of burns.[14] Published in 1906, the *Ready Reference Handbook of Diseases of the Skin* received much attention. It describes several treatment options for burns, including the application of a cocaine solution with "equal parts of linseed oil and lime-water, to which may be added 5% of carbolic acid, absorbent cotton being soaked with the oil laid over the burn and covered with impermeable rubber tissue."[14] The handbook goes on to recommend another option consisting of painting a varnish of linseed oil, wax, and salicylic acid and powered bicarbonate sodium, with blisters requiring opening with picric acid.[14] The addition of cocaine or salicylic acid presumably helped with pain. Yet the use of carbolic acid (a benzene derivative) and picric acid (used in explosives) which have both been classified as highly toxic and carcinogenic, would by today's standards be considered barbaric. In reading of the treatments, one may come to the conclusion that burn care had regressed to the times of Paracelsus. As with the countless advances in surgical practice beforehand, two World Wars (and a host of significant medical discoveries) became the driving force behind the modern surgical care of burns.

A World at War

World Wars I & II, and the discovery of sulfa drugs and antibiotics such as penicillin, drastically changed the medical and surgical approach to burns. Advances came with better understanding of wound dressings, physiology of burns and effects of inflammation, and new approaches to reconstructive surgery. In *The Treatment of War Wounds* published in 1917 by W.W. Keen as a military report, burns were cited as the most common injury experienced by soldiers like nothing that had been seen before.[15] The report described the works of American and British military surgeons who were making strides in improving dressings for burns, and

development of a field manual for medics in the acute management of burns.[15] Lieutenant-Colonel A. J. Hull, of the British Arm, developed and patented "No. 7 Paraffin," which was reportedly superior to earlier wax-based ointments, as it contained resorcinol (an ingredient in dye, benzene derivative), eucalyptus oil, olive oil, paraffin molle (petroleum-based mixture), and paraffin durum (solid paraffin mixture).[15] Dr. Hull describes his treatment protocol in the report, which includes No. 7 Paraffin as either a spray or to be brushed gently with a "camel's-hair brush" followed by a cotton-wool dressing.[15] There is specific mention of aseptic technique and hand-washing is emphasized; both adding to the effectiveness of the treatment through reducing exposure to infectious microbes. The new emphasis on hand-washing in the early part of the 20th century can be attributed to the groundbreaking theories touted by Louis Pasteur and Joseph Lister in the mid-1800s.[1] The incorporation of aseptic techniques among military surgeons in both World Wars undoubtedly contributed to the reduced mortality and morbidity of soldiers who underwent surgical procedures and burn treatments.

The first successful skin transplantation procedure using autologous skin grafts (grafts harvested from the patient) occurred during World War I under the direction of Dr. Harold Gillies, a surgeon with the Aldershot Burn Unit (present-day Cambridge Military Hospital), UK.[3] Dr. Gillies's early work on skin transplantation set the stage for future advances in reconstructive surgery for burn victims that we utilize today. In later years, his work would inspire the development of techniques for excising burns, harvesting skin from donor sites using a manual and electric-powered dermatomes, as well as concepts related to the use of cadaveric skin grafts and meshed skin grafts.[3,6,8] But the skin grafts were unfortunately not yet in-vogue during the World Wars, and by the 1930s treatments still utilized cold-water immersions, paraffin dressings, and a process known as "tanning."[4] Tanning, or the use of tannic acid (an astringent ingredient used in dyes for 'tanning' of leather and other textiles) was developed by Edward Clark Davidson, a physician from Michigan, who promoted the use of tannic acid as a "sealant" following a thorough debridement of the burn wound.[3]

The practice caught on with domestic and military physicians alike, until Robert Aldrich of Johns Hopkins developed a different sealant with reportedly milder effects on the wounded tissue. It became known as the "triple-dye" method, due to the incorporation of the dye known as Gentian violet (a coal-tar derivative), which had previously been used for microscopic slide preparation.[3] The triple-dye method was touted by Dr. Aldrich as an improvement on the tanning method since it could both seal the wound (like the tannic acid) and have the added advantage of killing gram positive bacteria, such as *Staphylococcus aureus*, one of the most common infectious agents to complicate burns.[3] Physicians knew that one of the worst threats to a burn victim (aside from the possibility of dying from the burn itself) was the

complications resulting from inflammation and infection. There was not a lot being done to address inflammation, but the idea to "seal" a wound or prevent bacterial growth with chemicals was certainly a rationale for maintaining tanning and triple-dyes for burn care.

During World Wars I & II, the U.S. military responded to the increased need to research combat medicine (including the treatment of burns) and infused funds into their many military academies and institutes. This culminated in 1943 with the establishment of Surgical Research Unit, now called the U.S. Army Institute for Surgical Research (USAISR).[16] Located originally in Staten Island, New York it was moved to Fort Sam Houston, Texas in 1947 and went on to house the country's largest burn unit and thermal injury research facility with a staff of over 300 physicians, surgeons, and allied health professionals committed to burn care.[16] As the Army's primary burn unit, in 1949 it transitioned to headquarters for the Army's central Medical Research and Development Command, and served as the model for burn units throughout the country.[16] Today it remains a top authority on burn surgery and research, and is housed in the Brooke Army Medical Center in Houston. The timing of the U.S. military's commitment to burn treatment could not have been better, as a fire tragedy in Boston toward the end of the war would again change the face of burn care. And while a great deal of the modern-day advances in burns can and should be credited to the work of war surgeons throughout history, the infamous 1942 fire at the Coconut Grove Club in Boston paved the way for some of the most innovative approaches to burn care developed by brilliant academicians on the domestic front.

A Fire at the Coconut Grove Club

In November of 1942, the Coconut Gove Club in Boston, Massachusetts was filled beyond its capacity. Over a thousand people managed to crowd into the two-story nightclub. The popularity of the club attracted civilians and soldiers alike—those on leave from military service or others about to ship out.[3] And on November 28th, it brought in several hundred others on Thanksgiving holiday break, as well as energetic football fans on their way from a shut-out game between Holy Cross and Boston College.[3] As the name of the club suggests, the tropical theme provided a nice indoor escape from the snow and wind of the Boston winter. And while the paper and fabric decorations appeared lovely to the dancing masses, they covered the entire building, fire-exits and all. One match, lit by wait staff to help them change a light-bulb set the room ablaze.[3] A stampede of patrons crowded the main entrance, which eventually jammed the revolving doors. Hundreds of people were trapped in the club as a result of poor fire-escape protocols and limited exits, and suffocated from what would later be described as smoke-inhalation injury[3]. The Boston Fire Department promptly responded to the call and had the flames out within the hour, but it was too late. Approximately 300 people died at the scene, with the total death toll reaching almost 500 people. It was described as a particularly grotesque scene, and the worst domestic fire tragedy since the 1906 fire in San Francisco.[3]

Coconut Grove Nightclub Fire, 1942[24]

Within hours, Boston City Hospital and Massachusetts General Hospital received an exodus of burn victims who made it out of the club struggling to stay alive.[3] Surgeons from the U.S. military with expertise in burns, the American Red Cross, and the Nurses Aides Corps were called in to assist with the response. Physicians and surgeons from nearby Harvard University also came to assist the overwhelmed staff at Mass General and Boston City Hospitals. One recent graduate of Harvard was a burn and trauma resident at Boston City Hospital known as Stanley Levenson.[3] He had completed extensive research on wound care and the effects of vitamin C for burn treatments, but was beginning his first year of the surgery residency. The evening of the Coconut Grove fire, Dr. Levenson was joined by another young surgeon named Charles Davidson. Both of them were assigned to work with the attending physician, Dr. Maxwell Finland, a Harvard-trained infectious disease specialist.[3] The three doctors had their work cut out for them as the wards began filling with suffering burn victims.

It was not until well after the end of the World Wars did research begin to shift once more away from tanning and triple-dye treatments for burn patients. Fresh out of medical school, Levenson and Davidson were aware of recent research by Drs. Sumner Koch and Harvey Allen out of Cook County Medical Center in Chicago, Illinois. The Chicago physicians had gone away from the tannic acid and triple-dye method, instead favoring a bulky, "greasy" dressing consisting of petroleum jelly with significantly better outcomes in the wounds of their burn patients.[3] The two young doctors decided to utilize this new Allen-Koch method, which had recently been adopted at other nearby hospitals, including Mass General. When push came to shove, the Allen-Koch method was not used uniformly on all burn patients from the Coconut Grove fire, and out of necessity methods of tanning and triple-dyes predominated. Through their triage and management of the Coconut Grove burn victims, and through observations of the outcomes of these patients, the three physicians collaborated with physicians at Mass General on several key research studies and publications that revolutionized our modern-day understanding of burns. Indeed, one of these studies validated the Allen-Koch method of burn wound dressing as superior to tanning and triple-dye treatments.[3] Two additional landmark studies by Dr. Levenson and his colleagues resulted in a major shift in treating burn patients.

The first study by Levenson described in detail the concept of smoke-inhalation injury.[3] Damage to the respiratory system was a known complication of burns, particularly with those exposed to flame burns. Yet until his investigation of the topic, the damage was suspected to result only indirectly from toxins or particulate matter released by certain other burned materials during a fire. While partially correct, Levenson's studies debunked this myth by revealing how the epithelial

lining of the respiratory tract is directly injured and sloughed off as a result of inspiration of super-heated air in combination with the smoke itself.[3] Smoke (which contains various destructive and lethal chemicals including carbon monoxide, hydrogen cyanide, and hydrochloric acid among others) facilitates respiratory depression and loss of consciousness due to lack of oxygen. Those that survive a fire, but sustained smoke-inhalation injuries are at an increased risk for complications including infectious conditions like pneumonia.[3] These findings prompted the development of smoke detectors, and supported public policies and implementation of a variety of other public health safety measures.

The other study by Dr. Levenson documented a simple, yet extremely critical observation about severely burned patients: they lose fluids (mainly plasma) at rates that threaten their lives and stifle any hope of recovery unless replaced. In the 1930s, a Yale-trained physician by the name of Frank Underhill was the first to characterize a condition he called "burn shock," which is essentially an extreme form of hypovolemic shock (marked depletion of fluids and blood volumes).[3] The mechanism of burn shock is complex, but is thought to result from a combination of a loss of blood volume from capillary leakage and release of inflammatory mediators. The loss of volume results in decreased blood pressure to and tissues do not receive enough oxygen. It can also lead to a condition known as disseminated intravascular coagulation, as the blood thickens from reduced plasma and increased stasis within vessels. Clots form throughout the vasculature with the generation of emboli that can lodge in the heart, brain, lungs or elsewhere causing immediate death.

Dr. Levenson had heard of Underhill's work and had himself seen the consequences of inadequate fluids in burn patients. There had been an over-emphasis on the burn *wounds*, while ignoring basic physiological needs. His recommendation that above all, burn patients must receive adequate fluid resuscitation has since saved thousands of lives.[3] As a result of this early research, a protocol for fluid resuscitation is now in place known as the Parkland formula. Developed by Charles Baxter in the 1960s while treating burn patients at Parkland Memorial Hospital in Dallas, Texas, it consists of 4 mL of lactated Ringer's solution per kg of patient's body weight times the percentage of TBSA burned.[3,7] Fluid replacement has since become of highest priority for acute management of burns, following stabilization of airway and breathing.

The Aftermath of Coconut Grove

Several lessons were learned from the tragic fire at Coconut Grove. In addition to new theories to explain smoke inhalation injury which advanced our prevention efforts, as well as new therapies that included fluid replacement for burn victims, Dr. Levenson and his colleagues at Boston City Hospital learned that the

current delivery of medical care for mass burn casualties was in dire need of revision. They were not alone. The newly established U.S. Army Institute of Surgical Research and their team of expert burn specialists were eager to learn from this experience. And for the first time in history, there was a new weapon in the burn surgeon's arsenal: antibiotics. Penicillin being the most famous "magic-bullet" antibiotic, these drugs helped reduce complications from infections of burn wounds and deaths declined substantially[3]. After the discovery of antibiotics, topical dressing for burns also improved (e.g., Bacitracin and Silver Sulfadiazine ointments). With the Allen-Koch method revised to include the new antimicrobials as part of the burn dressing, the protocols calling for tannic acid or triple-dye treatments fell from practice and became something of the past.[3,17]

Collaborations flourished, and the research and progress in burn surgery followed suit. Building upon the work of Levenson and others who recalled the Coconut Grove experience, Colonel John A. Moncrief, a burn surgeon with the Brooke Army Medical Center, conducted a series of studies comparing fluid replacement interventions for burn victims. In particular, Dr. Moncrief was interested in the effects of vasoactive pharmaceuticals used in conjunction with fluid replacement regimens, to help modulate the body's systemic response to burn injury.[18] Furthermore, he wanted to know more about the complications of burns, and the hemodynamic responses of the body that leads to hypovolemic or "burn shock". Moncrief published several key studies on these topics, helping to catalogue the types of burns and their complications.[18,19] His research advanced the military's own protocols for management of burns, and researchers began entirely new investigations into the physiology of shock and the various pharmacologic interventions to reverse these processes in critical burn patients.

One of Dr. Moncrief's younger contemporaries, Basil A. Pruitt, soon gained his own appreciation for burn surgery research. Dr. Pruitt received his medical degree from Harvard in 1948 and in fact completed his internship at Boston City Hospital only years after Coconut Grove. In 1962, he entered a residency in general surgery at Brooke General Hospital where he developed an interest in burn surgery, presumably from interactions with Moncrief. Pruitt soon picked up where his mentor had left off focusing on studies that evaluated the body's release of endogenous catecholamines and other inflammatory mediators.[20] In 1974, he published a paper in the *Annals of Surgery*, which was among the first to describe the central role of catecholamines in mediating a heightened metabolic response following a burn injury.[20] He taught these concepts to hundreds of medical students, residents, and burn surgeons over the past 30 years. To this day, Dr. Pruitt maintains a faculty appointment in the Department of Surgery at the University of Texas Health Science Center in San Antonio, Texas.

New Bugs, New Wars, New Challenges

In the United States today, 1.5 million patients per year suffer from burns that require treatment, with half of these resulting from flame burns.[6,7] Approximately 5,500 people die annually from burns, with most deaths (75%) occurring prior to reaching the hospital.[6,7] The most common cause of death for the remaining cases continues to be infection, which has complicated burn care for centuries. Yet the infections that lead to death are often the result of antibiotic resistance, with the biggest threat being methicillin-resistant *Staphylococcus aureus* (MRSA).[21] The same Gram positive bacteria that complicated burns for the patients of Ambroise Pare and John Hunter has managed to survive and evolve over the centuries into a superior form that is increasingly difficult to eradicate with modern antibiotics. Gram negative (mostly *Pseudomonas* and *Acinetobacter*) and anaerobic bacteria have also developed multi-drug resistance, as well as resistant molds and yeasts such as *Aspergillus* and *Candida*, which are especially difficult to treat in immune-compromised patients or those with chronic diseases who suffer from severe burns.[21]

The wars in Iraq and Afghanistan have presented new challenges to the treatment of burns. The U.S. Army Institute of Surgical Research Burn Center at Brooke Army Medical Center has enhanced its operations since the days of Moncrief and Pruitt. During the Vietnam War, the Army utilized its Burn Flight Team for improved evacuation of burn victims so they could be cared for at top-rate burn treatment centers far from the battlefield.[16] In 1998, the Burn Flight Team underwent another transition to the Special Medical Augmentation Response Team (SMART), which has a mission to provide "world-class medical augmentation in burn and trauma triage, resuscitation, treatment, and evacuation."[16] In recent wars, the rescue missions undertaken by the SMART Burn Flight Team give new meaning to the term "flying ambulance," a significant improvement on the concept as originally envisioned by Napoleon's surgeon. In fact, a recent study published in the *Annals of Surgery* reported no difference in the health outcomes between civilian burn patients and soldiers who sustained combat burns who underwent evacuation from the battlefield to distant military burn centers.[22] In other words, despite the delays in transport, soldiers suffering from combat burns are receiving the highest level of critical care for burns in the field and in the air and fare equally as well as civilian patients with nearby medical facilities.[22]

New wars and conflicts also mean new challenges for physicians and surgeons as they continue to tweak their approach to burns. While flame burns remain the most common type of burn sustained, so-called "acid assault burns" have increased in numbers through many parts of the developing world and especially in areas of conflict.[23] The victims (usually women) are targeted by terrorists who aim to disfigure and disgrace by scarring the flesh of the face with toxic chemicals, such as

hydrochloric acid. Removing the offending chemicals from the tissue through careful debridement is often followed by a series of reconstructive surgeries.[23] Yet this assumes that the patient, a helpless victim of an assault, can afford the expense of treatment and surgeries, a luxury that is often beyond the reach of most victims. In recent years, plastic surgeons that have expertise in the reconstructive surgeries for severe burns have volunteered their expertise on global health expeditions. They help reverse disfigurement from the scarring and thus facilitate the long healing process for victims of acid assault burns. The post-traumatic stress from such an incident can be significant for the victim, and there is an increasing recognition of the need to address psychosocial issues in burn patients regardless of the source of the burn.[8]

Modern Burn Unit and Beyond

In the U.S. today, there has been a transformation in the approach to burn treatment. Just as in the days of Pare, a surgeon is the team leader for the management of burn care, but the emphasis has shifted to the word *team* as opposed to *surgeon*. Present-day burn units are multi-disciplinary in nature, consisting of trauma or plastic surgeons, intensivists, hospitalists, nursing, dieticians, psychiatrists or psychologists, physical and occupational therapists, social workers, and pharmacists.[8] The surgeon still plays the central role in decisions that impact the patient's care. But today's burn surgeon integrates his practice with many other skilled practitioners to assure the best quality of care for each patient. It was recognized after the Coconut Grove fire in Boston in the 1940s that a multidisciplinary approach to burn treatment was indicated over the fragmented standard of care of the day. After 60 years of burn surgery research, this approach is finally being successfully implemented across the country. During World War II, a patient with burns of 40% of total body surface area (TBSA) had a 1 in 2 chance of death; today it has risen to 80%.[7] Put another way, in 1945 if a person had burns covering 40% of their body they would have a 50/50 chance of survival; in 2010 a person's chances of survival would be the same (50/50) as in 1945, but could sustain burns up to 80% of their body!

Advances continue to be made in many fields that hold relevance for burn care. Emphasis on fluid replacement is still paramount, but the recommendations now call for prompt attention to nutritional support since the metabolic demands on the body are increased during recovery from burns.[7] Physical therapy is also encouraged as soon as the patient can begin the regimens safely. Early excision of severe burns via tangential excision has become the standard of care.[6,7,8] Interestingly, recent meta-analyses of randomized, controlled trials of burn patients that compared early wound excision interventions with those of simple dressings followed by later skin grafting showed a reduced overall mortality rate for patients who received the early excisions.[6] Early excision prepares the wound for reconstructive procedures involving various skin grafts; it improves the odds that the skin graft will "take" and not be rejected by the underlying tissue. When a burn patient is received in the

emergency room, a stepwise protocol is implemented. Following emergency stabilization of burn victims, fluid resuscitation, and an initial evaluation for TBSA and degree of burn severity, patients receive a secondary evaluation. Modern-day algorithms for burn care recommend that patients with 10% or greater TBSA be referred to surgical specialists and certified burn centers for further evaluation.[6,7] From here, surgeons can employ a number of advanced techniques for burn reconstruction and rehabilitation.

Skin grafts from cadavers (homografts) can be utilized as a temporary means of maintaining the viability of underlying tissue following burn excision.[8] Engraftment of a split-thickness (includes epidermis and upper- to mid-dermis) autograft can take 5 days, whereas full-thickness grafts (epidermis and full dermis layers) take closer to 10 days to complete engraftment.[7,8] Full-thickness grafts are usually reserved for fitting over joints and other areas of tension and movement that require a more durable graft.[8] Additionally, a technique known as "meshing" can be utilized by the surgeon who will make lengthwise slits in the skin graft that open into a mesh-like pattern to cover larger burn wounds. The spaces in the graft will gradually fill as the keratinocytes (skin cells) migrate towards the center of each space.[8] Engraftment can also be enhanced with chemically treated grafts that contain silicone or collagen, and can be sealed with the assistance of fibrin glue.[6,8] The graft is then dressed with petroleum gauze with antibiotic or silver-based ointment to prevent infection.[6]

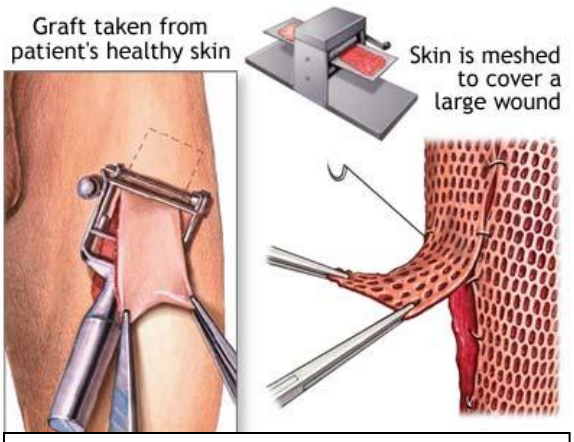

Diagram depicting skin grafts and "meshing" to cover burn wounds.[24]

The key to success of the graft is dependent on a number of factors, but a healthy blood supply to the skin graft is arguably the most critical. For patients with extensive burns and limited sites for donor skin to be harvested, an implantable device known as a "tissue expander" can be placed under healthy skin until additional skin grows to accommodate the device. When the device is removed, the surgeon can harvest the skin "flap" and use it for engraftment at another site.[8] New therapies are continually being developed, including epidermal sprays, synthetic skin substitutes, and cultured skin autografts. While these therapies have not been approved by the U.S. Food and Drug Administration, they are being used and experimented with throughout Europe.[6,7,8] These therapies hold promise for the future of burn surgery.

Conclusion

Modern-day burn surgery and medical care owes its success to the surgical pioneers throughout history who sought after improved methods with each and every patient. Great surgeons like Pare, Hunter, Larrey, and Dupuytren all recognized aspects of treating patients that would save lives and improve the quality of care received. Each generation of physicians built upon the foundations solidified by their heroic predecessors. Sometimes the foundation of knowledge was faulty, and a courageous few would see to it to remove the weak cinder-blocks of the status quo and replace them with stronger, more scientifically sound versions. Wars and other tragedies, such as the Coconut Grove fire taught us many pearls of wisdom about wound care and management of burns. Research centers were established and numerous textbooks were published on the subject, which has greatly advanced our understanding. We have gone from boiled bear fat, boiling-oil, and moss from a dead man's skull to antibiotics, compressive dressings, and skin transplants. We are even seeing human skin being grown in Petri dishes! The medical and surgical discoveries for burns have greatly reduced the burden of morbidity and mortality for burn victims compared to centuries past. And with a new model of multidisciplinary, team-based, integrated care for burn patients, one is only left to wonder what the next discovery will be for burns of gunshot, flame, and all such "fiery engines".

~RJF

Acknowledgments

I would like to thank Lindsey MacAllister, MA, an archivist at the Des Moines University Library's Kendall Reed Rare Book Room for the generous time she spent with me as I searched some of the primary literature used for this paper (including an original work by Ambroise Pare from the 16th century). Thank you, Lindsey, for your initial guidance, insight, and patience as I researched this topic.

Thanks also to Dr. Reed for some of his suggestions for U.S. Army references related to burn surgery (see: Moncrief and Pruitt with Brooke Army Medical Center). They were helpful, and I am most grateful!

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